Economic Valuation of Biodiversity and Ecosystem Services

Delhi School of Economics

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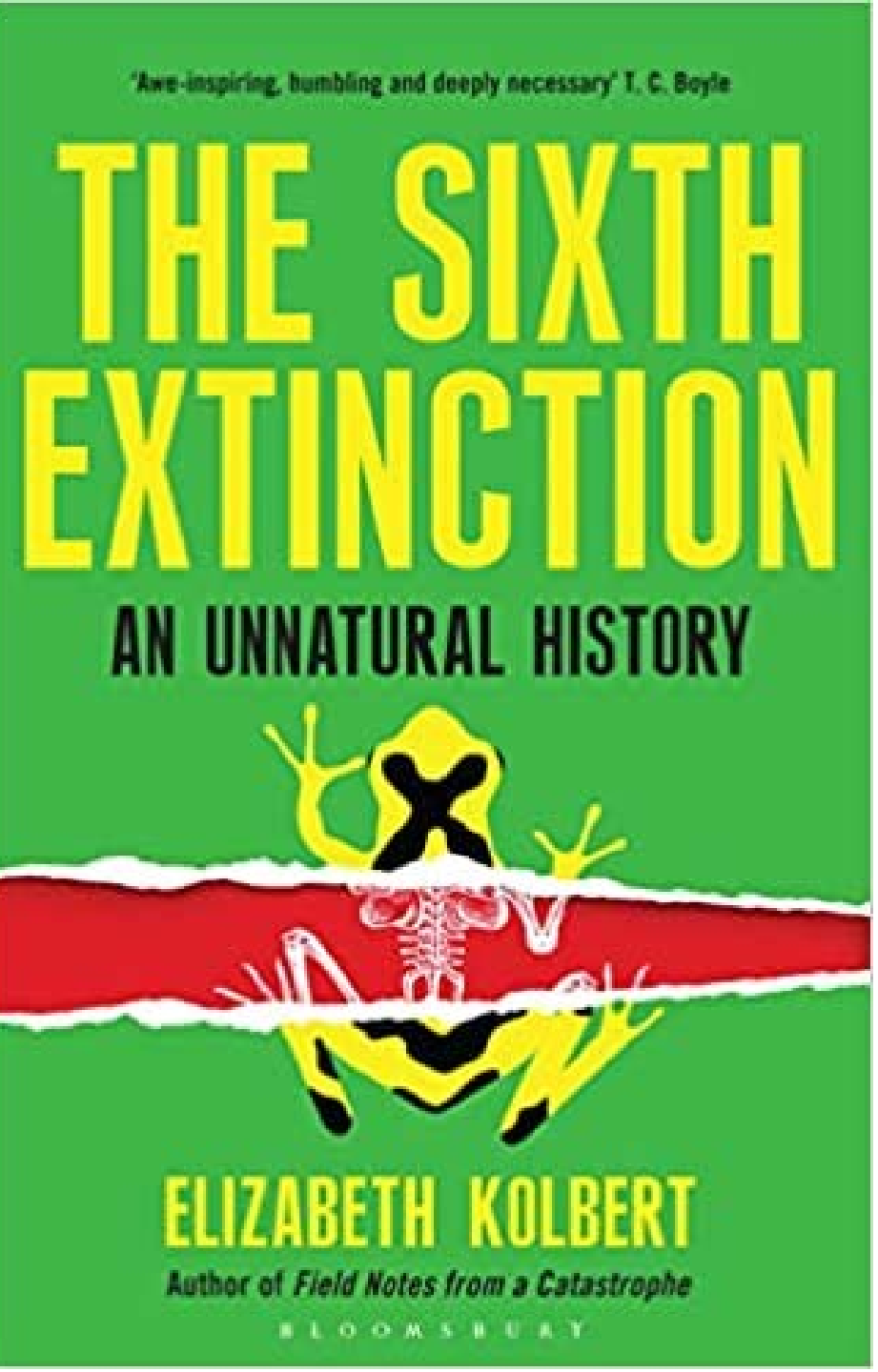
Economic Valuation of Biodiversity and Ecosystem Services

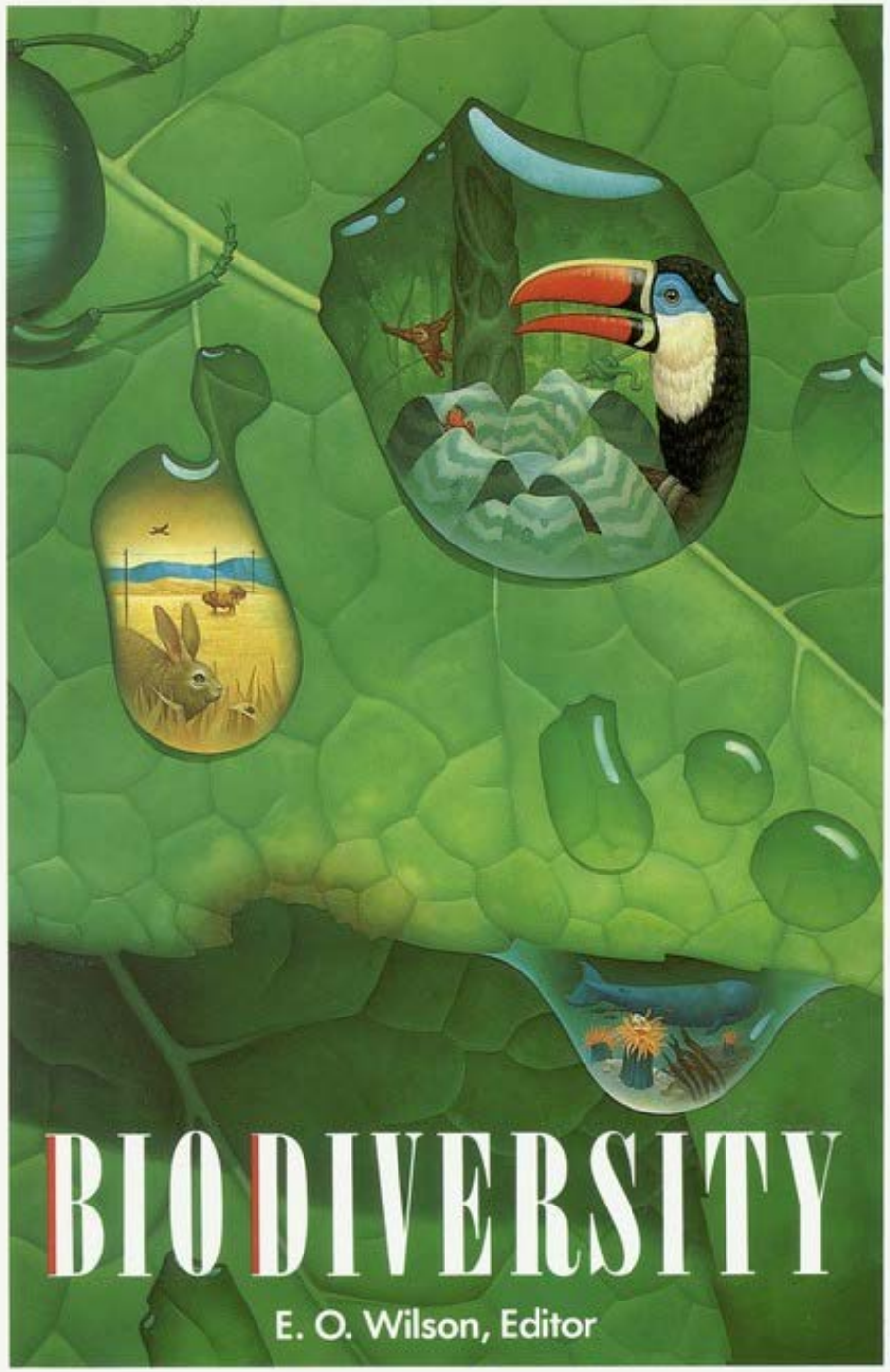
Important recent reviews, e. g.,

World Bank report (2021)

Report prepared for the UK Government by Sir Partha Dasgupta (2021)



- "'Biodiversity' is what you get when you take 'logical' out of 'Biological Diversity."
- Supposedly E. O. Wilson was concerned that "Biodiversity" sounded "too glitzy"
- But a compact expression was needed to encapsulate a serious concern



Some other prominent contributions (*very incomplete!*)

- World Bank *Changing Wealth of Nations* reports
- UK *National Ecosystem Assessment* (2011, 2014)
- *TEEB* (2012)
- *Millennium Ecosystem Assessment* (2005)
- Pearce and Moran (1994)
- Recent surveys:
  - Hanley and Perrings (2019)
  - Paul, et al. (2020)
  - Binder, et al., (2017)
- Data sets, platforms, computational models, etc.: ARIES, InVEST, EVRI, etc.

There has been a lot written on biodiversity and ecosystem service valuation

- Googling terms like “Economic Value of Ecosystem Services” and “Economic Value of Biodiversity” yields close to half a million hits.
- Since 2018 Google Scholar lists over 1,000 papers for the former, over 500 for the latter.
- Related search strings (e. g., “Ecosystem Service Valuation”) give comparable totals
  - These terms are not necessarily inclusive; I did exact-match searches
  - Few of my papers, for example, come up, save when cited by others.

Since I can't survey and summarize the entire genre, what *should* I try to do in these talks?

"*Despite increasing calls for considering valuation in policy decisions, scientific documentation shows less than 5% of published valuation studies report uptake in policy decisions*"

Pascual, *et al*., 2022.

Why?

- "Less than one-third of all studies provided a sound basis for their conclusions." (Seppelt, *et al*., 2011)
- A majority of 381 peer-reviewed studies relating water to ecosystem services "failed to adequately link changes in environmental conditions to human well-being, instead stopping at the point of suggesting that one was connected to the other." (Brauman 2015)
- More than half of 28 papers surveyed at random from the EVRI database used replacement cost or did not consider *marginal* values (Blomqvist and Simpson 2018)
- I fear the situation hasn't improved markedly since the above surveys.
- Benefit transfers may be perpetuating problematic estimates

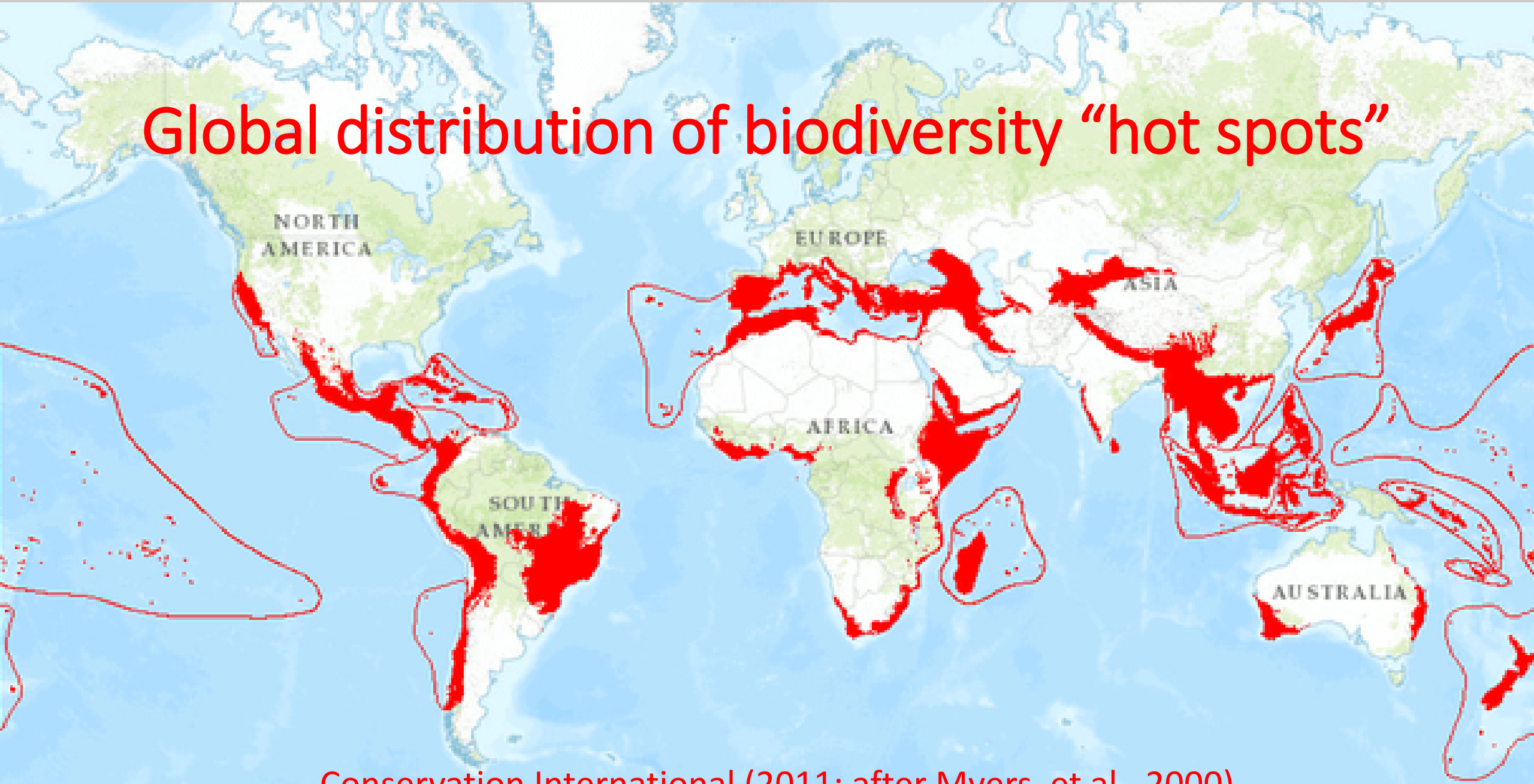
Biologically diverse natural habitats *are*, at *many times*, and *in many places,* "worth more alive than dead"

- But in others they may not be . . .
- Or the values they provide to broad communities may not cover the opportunity costs of the smaller groups that bear them.
- A few observations:
  - The existence of externalities does not necessarily imply severe misallocation.
  - The diamonds and water paradox explains a great deal.
  - "Paradoxes of efficiency": when diverse natural ecosystems may be most valuable when "a little goes a long way".

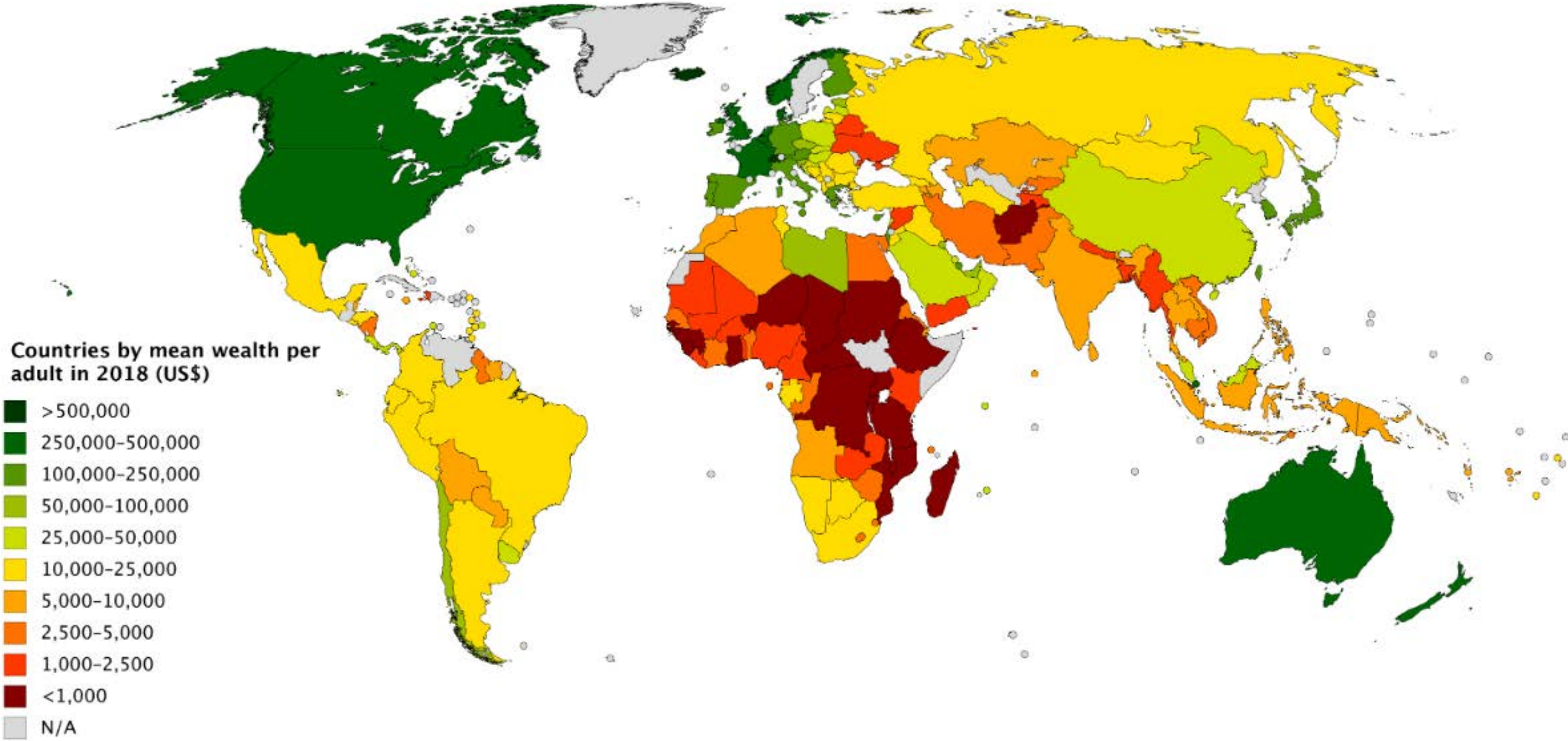
Why undertake a critical review of biodiversity and ecosystem service valuation?

1. When we *can* make a strong argument that conservation will yield benefits to landowners and communities, we *should*
   – This is just the fundamental argument for benefit-cost analysis.
   – If we can extend consensus on best practices, we can make compelling arguments stronger.
2. When values are more difficult to quantify, we might appeal to broader societal decision-making processes.
3. The above two considerations may have important implications for the organization of lanscapes.
4. We also have moral obligations.

Global distribution of biodiversity “hot spots”



Conservation International (2011; after Myers, et al., 2000)


Countries by mean wealth per adult in 2018 (US$)
>500,000
250,000–500,000
100,000–250,000
50,000–100,000
25,000–50,000
10,000–25,000
5,000–10,000
2,500–5,000
1,000–2,500
<1,000
N/A

Nature for nature's sake resonates only with the already converted . . . the billion humans living in rural poverty remain unwilling or unable to move. We need these people as partners in conservation, and ecosystem-service approaches provide a means of motivating and enabling them.

Armsworth, *et al.*, 2007

Arguments to "motivate[*e*] and enable[*e*] . . .the billion humans living in rural poverty" must make economic sense.

- Should we provide the best information we can to overcome externalities and increase well-being? *Of course we should!*
- Should we put more of the burden of conservation on already poor communities if we cannot substantiate the benefits they will receive? *Of course we should <u>not</u>!*
- The fact that externalities may exist does not necessarily mean that landscapes should be dramatically reorganized.
- The largest externalities may be *global*, rather than *local*, in scope, and so call for *global* redistribution.

Outline of these lectures

I. Overview of *how* biodiversity and ecosystem services affect human welfare – and hence, of how their *economic values* might be estimated.
II. Examples of modeling and estimation of some representative values.
III. Consideration of values:
   - Of complementary (or not?) ecosystem services
   - In growth and macroeconomic models
   - Benefit transfer
   - Under fundamental uncertainty.

Some things I will largely leave out:

- Stated preference valuation; *reasons will be given shortly.*
- Ecological footprints, replacement cost (as distinct from *avoided* cost) estimates, etc.; largely incompatible with decision-making under constrained optimization.
- Fine points of terminology between ecosystem services, nature's benefits to people, nature-based solutions, etc.
  - By and large, society makes choices about how much to pollute, how many and what kind of organisms to harvest, how much habitat to preserve, etc.
  - The key question is "What are the consequences of these choices for welfare?"

A few final introductory remarks:

- Let me err on the side of including more material at the expense, perhaps, of explaining it in less detail; I may skip over some things in the interest of time.
- I'll address *clarifying* questions, but will try to avoid extensive digressions.
- I am going to generally presume we're in agreement on deep philosophical issues (anthropocentric perspective, etc.)
- I will be very happy to talk after for as long as you like!


What are biodiversity and ecosystem services, and how do they affect welfare?

Defining biodiversity

- Numbers of different types of alleles, organisms, biomes
- Relative abundance, with less equal distributions generally deemed less desirable (at least when driven by human actions).
- Species count is often used as operational measure.
- In making policy choices we generally contemplate actions that affect the diversity (in either sense) or “naturalness” of ecosystems.

How does biodiversity affect well-being?

- Intrinsic concern about the survival of other forms and/or assemblages of life; they may affect utility directly.
- Harvest of natural products
- Biodiversity may give rise to valuable new products.
- Naturally diverse ecosystems may enhance the productivity of, or regulate, managed systems
  - E. g. pollinators fertilize crops.
  - Forests on coasts or rivers prevent erosion and treat wastes.

“Existence Values” and Separability

Suppose utility is of the form

$$U(\beta, \boldsymbol{x})$$

where β is a measure of bioddiversity, $\boldsymbol{x}$ is a vector of purchased consumption goods with price vector $\boldsymbol{p}$, and income is M.

If β is not allocated in any market, effects of a change on market demands might be captured in the relationships

$$\frac{MU_i}{MU_j} = \frac{p_i}{p_j} \;\; \forall\, i, j \;\text{ and }\; \boldsymbol{p}'\boldsymbol{x} = M$$

Separability and estimation

Ergo, if $\frac{MU_i}{MU_j}$ is independent of β at all prices (if the utility function is *separable*), we can't recover estimates of the value of β from market data

If utility is *not* separable, we *can* use market data to estimate biodiversity values:

- Weak complementarity in travel cost models, for example
- Production, profit, and cost functions and hedonic pricing

But if utility is not separable, we may have a "hopeless case" [Freeman 1979]

- If the MRS between any two market goods is unaffected by β, we can't use *revealed preference* methods for valuation.
- What could we do?
- Expenditure function

$$e(\boldsymbol{p}, \beta, u) \equiv \min_{\boldsymbol{x}} \boldsymbol{p}'\boldsymbol{x} \text{ s.t. } U(\boldsymbol{x}, \beta) \geq u$$

- The derivative $\partial e / \partial \beta$ measures marginal willingness to pay for β

How would you estimate this in practice?

Ask people!

- “How much money would I have to give you to make you as well off as you are now if there were fewer tigers in the world?” or
- “How much would you give me to save more of the world’s tigers?”

Various other approaches are often taken;

- e. g., “Choice experiments”
- “If given the choice between having fewer tigers in the world and paying ₹500 less per month for electricity/food/forest products which would you choose?”

Why I'm not going to say much more about "stated preference" methods in these talks

- It's a topic worthy of hours of analysis on its own.
- I remain troubled by "the Popperian question": what evidence would falsify an SP result?
- SP studies purport to tell us what measures people would vote to enact to protect biodiversity.
  - Much of the economic literature has focused on whether instrumental arguments might prove more persuasive, given that people, by and large, are *not* voting to protect biodiversity.

Production functions

- When biodiversity enhances productivity the benefit will be the implied factor price.
- Simple example: "Robinson Crusoe" produces goods for his own benefit

$$U[f(L,\beta),\bar{L} - L]$$

- He'll labor in production until the value of his marginal product is equal to the marginal value of leisure:

$$MU_x \cdot MP_L - MU_L = 0$$

Familiar expression:

$$\frac{MU_x}{MU_L} \cdot MP_L = \frac{p_x}{p_L} \cdot MP_L \iff w = p \cdot MP_L$$

So

$$MU_x \cdot MP_\beta + (MU_x \cdot MP_L - MU_L)\frac{dL}{d\beta} = MU_x \cdot MP_\beta$$

is the “factor price” of nonmarket input β

This generalizes to market interactions with any number of inputs

$$\pi(p, \boldsymbol{w}, \beta) = \max_{\boldsymbol{x}} pf(\boldsymbol{x}, \beta) - \boldsymbol{w}'\boldsymbol{x}$$

So

$$\frac{\partial \pi}{\partial \beta} = p\frac{\partial f}{\partial \beta} + [pf_{\boldsymbol{x}\prime} - \boldsymbol{w}']\frac{d\boldsymbol{x}}{d\beta} = p\frac{\partial f}{\partial \beta}$$

We could, then, use this production function approach to estimate values.

Alternatively dual (cost) function approach leads to *avoided cost* estimation.

A complication: we don't often affect *biodiversity* directly

Causes of biodiversity loss/changes in relative abundance:

- Overharvesting
- Competition/predation/infection by introduced organisms
- Chemical pollution
- Climate change
- Habitat loss

Habitat loss has often been implicated as the most important driver of biodiversity loss, although climate change is becoming more important, and they are linked by importance of migratory corridors.

Implication for economic analysis: chain-rule effects

Suppose, for example, that

- Habitat area determines species diversity;
- Species diversity determines the provision of a valuable input
- The input contributes to the production of a marketed product.

Then the value of the marginal product of *habitat area* in the production of marketed products is

Price of output	X	*MP* of input in production of output	X	*MP* of species diversity in production of input	X	*MP* of habitat in production of species diversity

An example:
How does the preservation of pollinator habitat affect the value of pollination services?

- Preservation of pollinator habitat leads to increased abundance of pollinators (*. . . or does it?*)
- Increased abundance of pollinators leads to increase in pollination services
- Increase in seed set increases harvest
- Increase in harvest increases revenue

Or, if that's not clear . . .

Pollination in the InVEST module

Sharpe, et al., 2020

Total crop yield on farm *f*

$$YT(f) = 1 - \nu(f)\left(1 - \sum_{x \in X(f)} PYT(x)/|X(f)|\right)$$

The half-saturation constant for farm *f* at pixel *x*

Total pollinator-dependent yield

$$PYT(x) = \min(mp(f(x)) + FP(x), 1)$$

$$FP(x) = \frac{PAT(x, j(f(x)))(1 - h(f(x)))}{h(f(x))(1 - PAT(x, j(f(x)))) + PAT(x, j(f(x)))}$$

Proportion of pollination needs met by managed pollinators available at pixel *x* within farm polygon *f*.

$$PAT(x, j) = \sum_{s \in S} PA(x, s, j)$$

$$PA(x, s, j) = \left(\frac{RA(l(x), j)fa(s, j)}{FR(x, s)}\right) \frac{\sum_{x' \in X} PS(x', s)\exp(-D(x, x')/\alpha_s)}{\exp(-D(x, x')/\alpha_s)}$$

Index of relative abundance of floral resources on landcover *j* during season *j*,

relative foraging activity for pollinator species during season .

The distance between pixels *x* and *x'*

Expected foraging distance for pollinato

$$FR(x, s) = \frac{\sum_{x' \in X} \exp(-D(x, x')/\alpha_s) \sum_{j \in J} RA(l(x'), j)fa(s, j)}{\sum_{x' \in X} \exp(-D(x, x')/\alpha_s)}$$

$$PS(x, s) = FR(x, s)HN(x, s)sa(s)$$

$$HN(x, s) = \max_{n \in N}(N(l(x), n)ns(s, n))$$

Nesting suitability preference for species *s* in nesting type *n*.

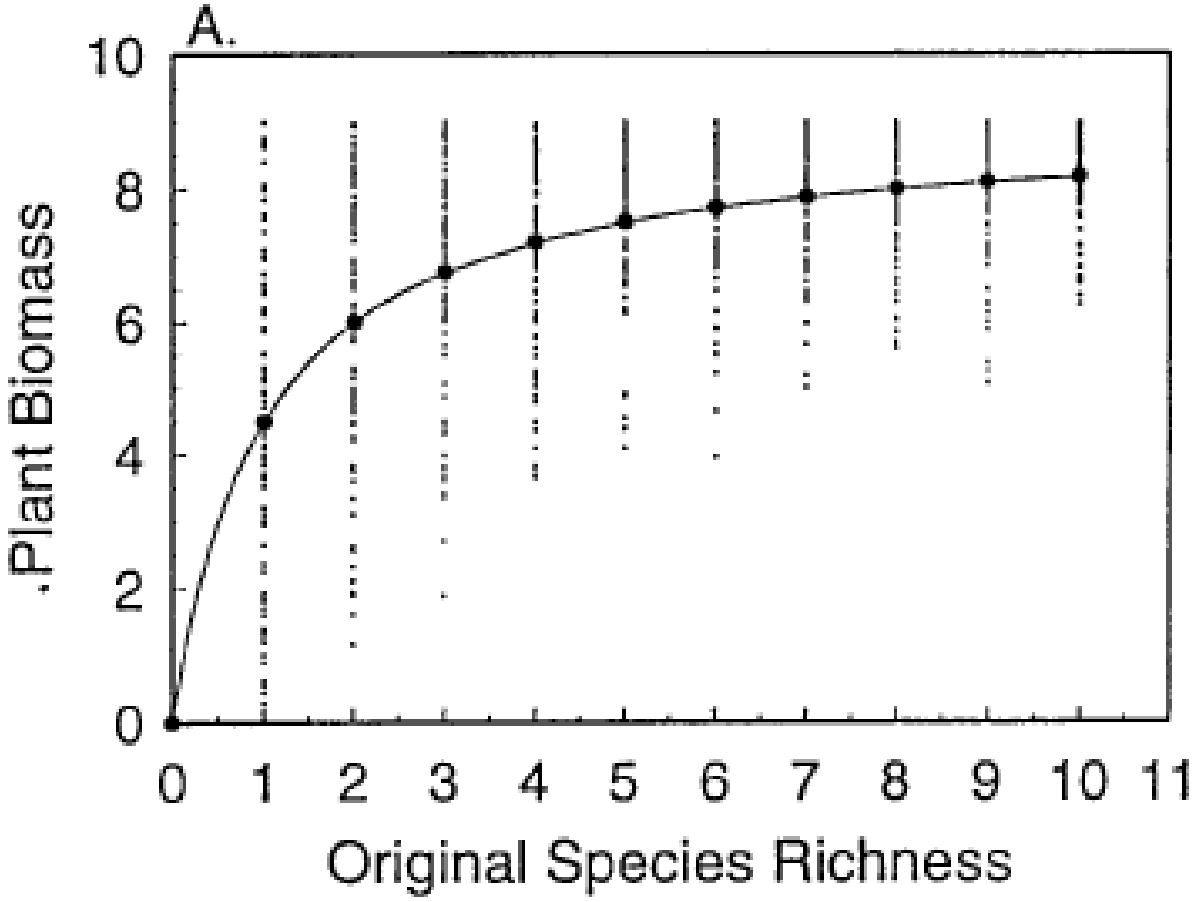
nesting substrate index for landcover type *l* for substrate type *n*

Variables in the model

Appendix: Table of Variables

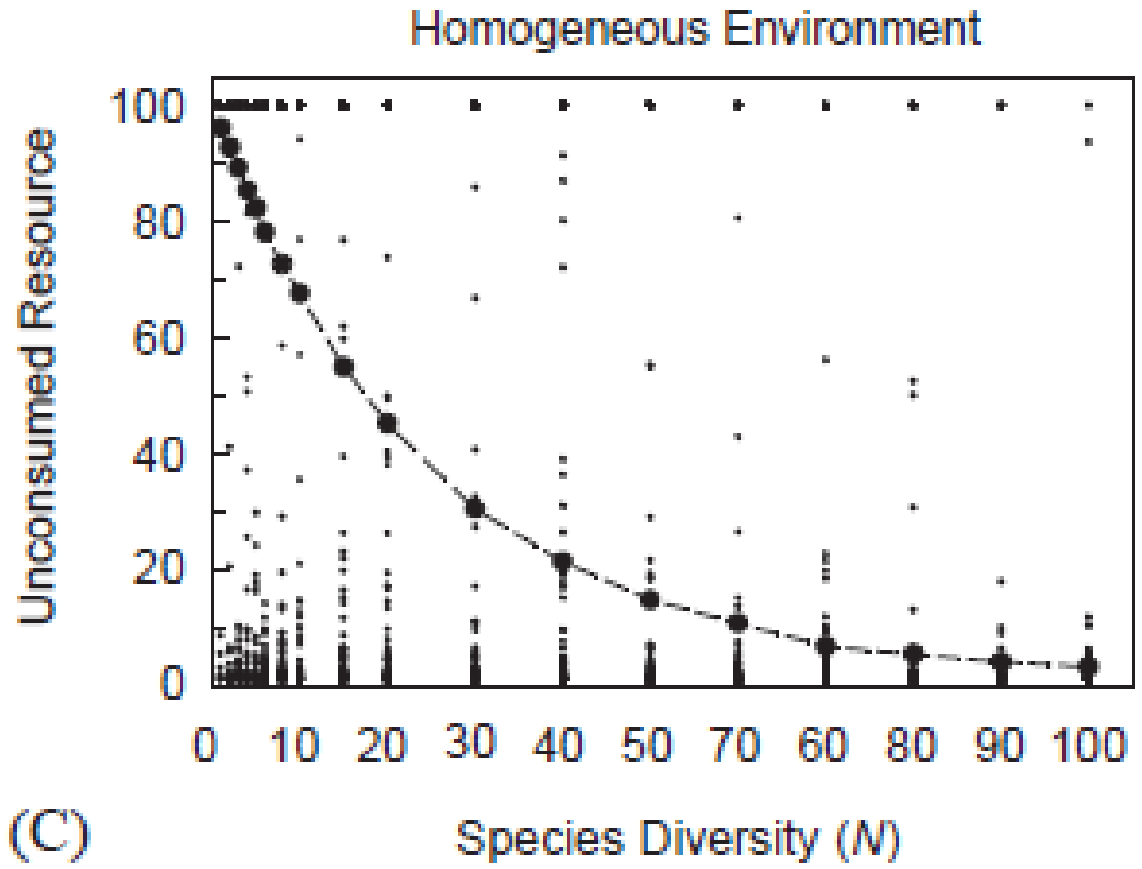
- x - a pixel coordinate.
- X - set of all pixels in the landcover map.
- $f(x)$ - farm at pixel x.
- F - set of all pixels that are located in farms.
- s - bee species.
- n - nesting type (ground, cavity).
- N - set of all nesting types.
- j - season (fall, spring, etc).
- J - set of all seasons (ex: (fall, spring)).
- $fj(f, x)$ - active pollination season for farm f at pixel x.
- α_s - mean foraging distance for species s.
- $ns(s, n)$ - nesting suitability preference for species s in nesting type n.
- $HN(x, s)$ - habitat nesting suitability at pixel x for species s [0.0, 1.0].
- $N(l, n)$ - the nesting suitable index for landcover type l for suitable type n in the range $[0.0, 1.0]$.
- $RA(l, j)$ - index of relative abundance of floral resources on landcover type l during season j. $[0.0, 1.0]$
- $fa(s, j)$ - relative foraging activity for species s during season j.
- $FR(x, s)$ - accessible floral resources index at pixel x for species s.
- $D(x, x')$ - euclidean distance between the centroid of pixel x and x'.
- $PS(x, s)$ - pollinator supply index at pixel x for species s.
- $PA(x, s, j)$ - pollinator abundance at pixel x for species s.
- $PAT(x, j)$ - total on-farm pollinator abundance at pixel x in season j accounting for all species
- $FP(x)$ - the potential contribution of on-farm pollinator abundance to pollinator-dependent crop yield at a farm pixel during the season in which pollination is needed for that farm.
- $mp(f)$ - abundance of managed pollinators on farm f relative to the recommended stocking rate.
- $h(f)$ - half saturation coefficient for farm f.
- $PYT(x)$ - total pollinator-attributable yield at pixel x for season j, accounting for wild and managed pollinators.
- $PYW(x)$ - wild-pollinator-attributable yield at pixel x for season j.
- $sa(s)$ - relative species abundance index for species s.
- $YT(f)$ - average farm yield for farm parcel f accounting for pollinator dependency of crop.
- $YW(f)$ - proportion of average farm yield for farm parcel f attributable to wild pollinators, accounting for pollinator dependency of crop.
- $\nu(f)$ - proportion of crop yield dependent on pollination.

How is diversity related to function? Ecological examples



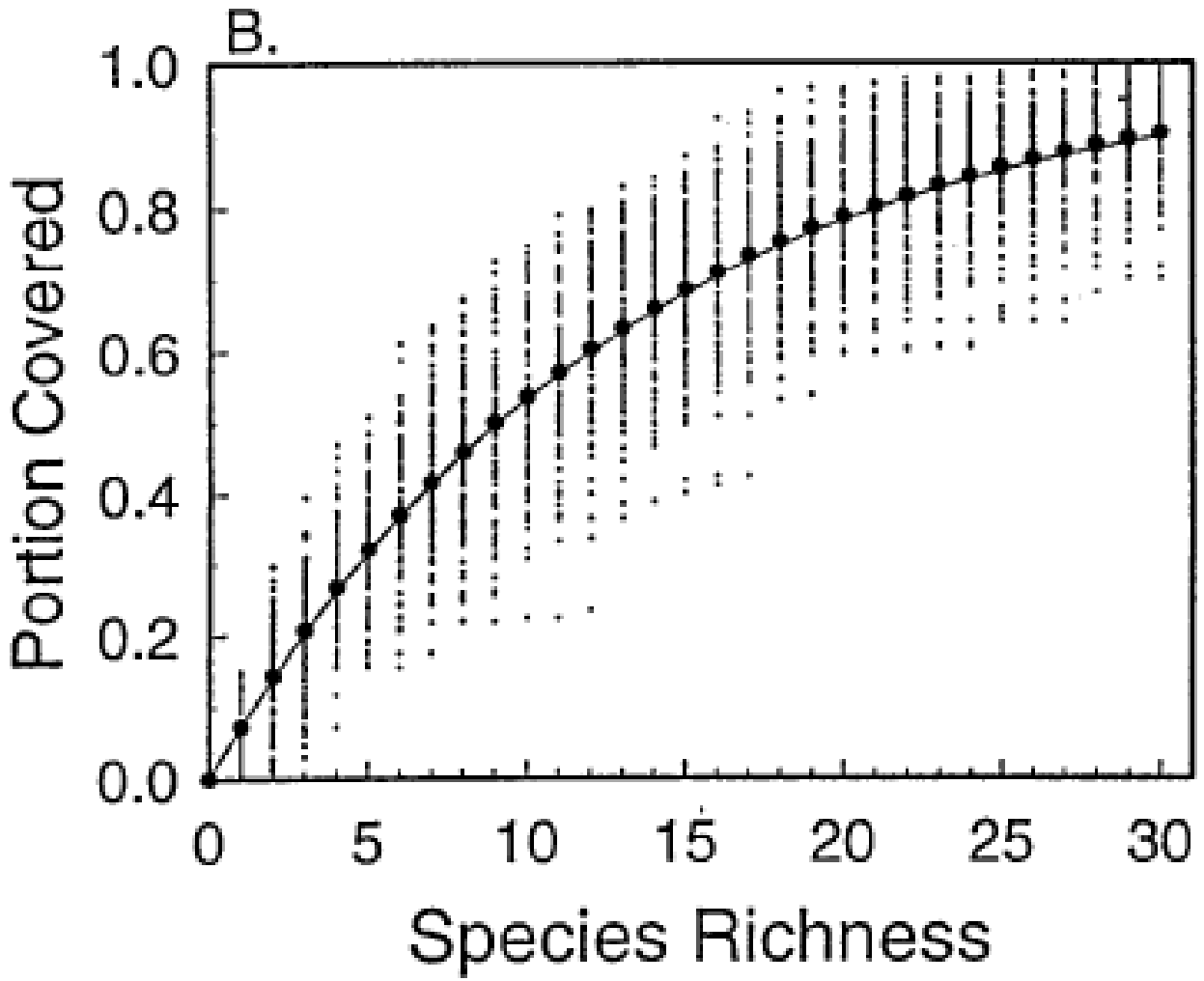
Plant biomass should increase with species richness (Tilman, Lehman, and Thomson, 1997)

Diversity and Function



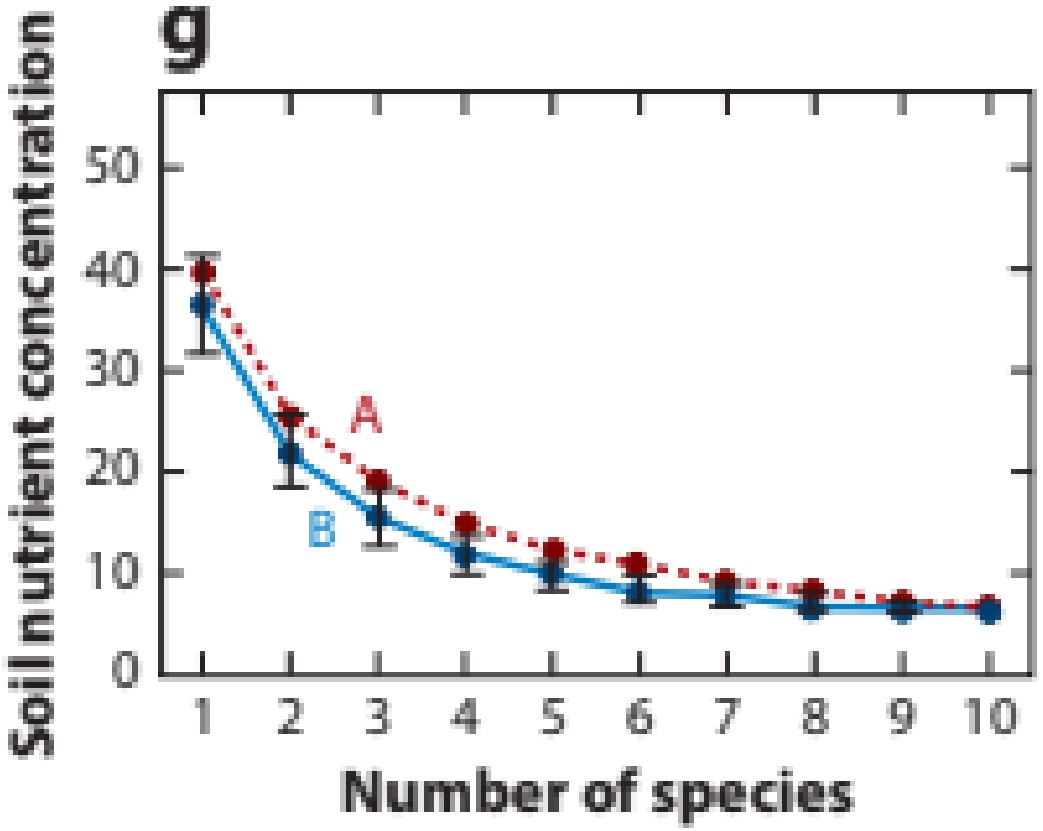
Free resources should decline with species richness (Tilman, Polasky, and Lehman, 2005)

Diversity and Function



Occupation of potential habitat should increase with species richness (Tilman, Lehman, and Thomson, 1997)

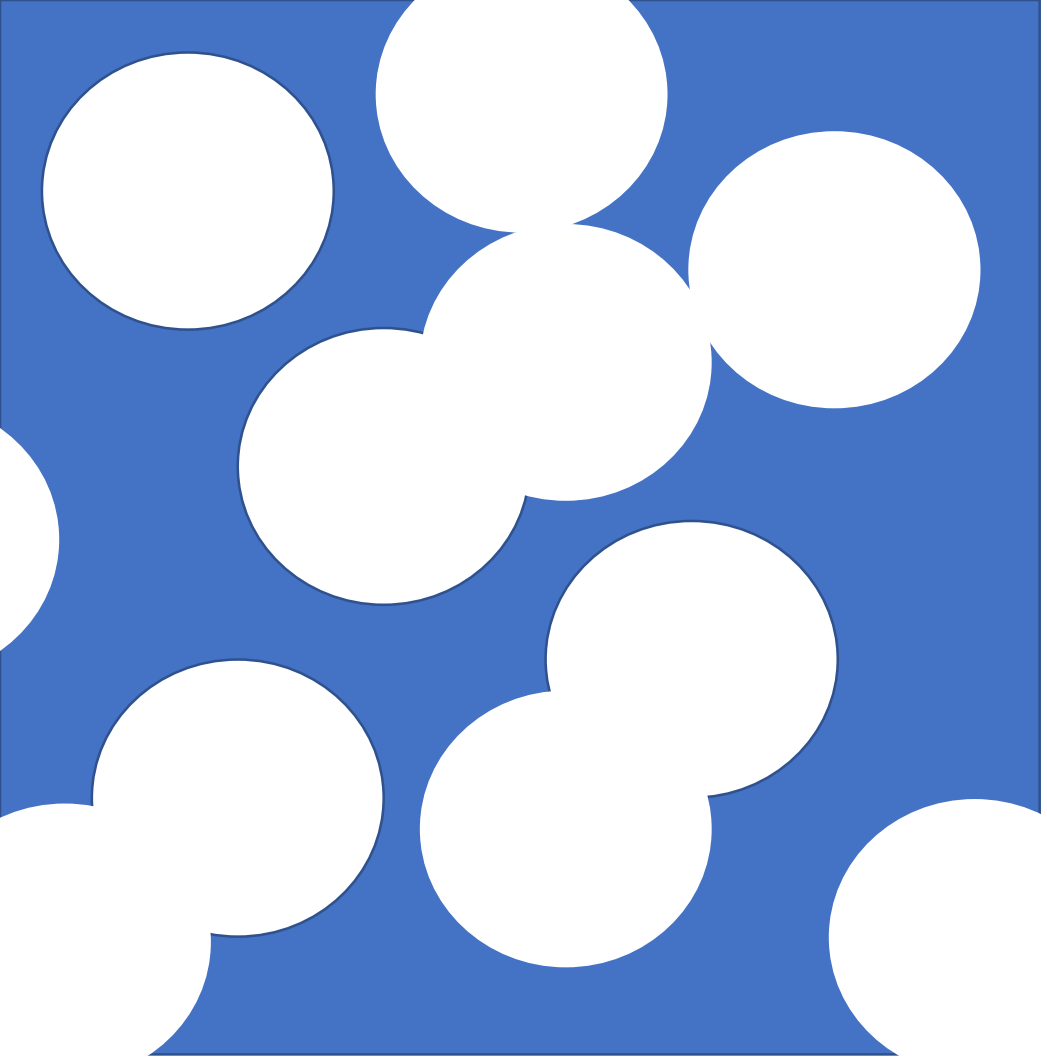
Diversity and Function



Soil nutrient concentrations decline with species richness (Tilman, Isbell, and Cowles, 2014)

Factors emphasized in ecological literature

- The more diversity there is, the more likely it is that the “best” species will prevail
  - Each of N species could be treated as a Bernoulli trial with probability of “success” p; the probability of at least one success is then $1 - (1-p)^N$
  - This generalizes to thinking of each species as a random draw and the expectation of the “best” as being that of the greatest order statistic.
- More diversity gives greater “coverage”



Tilman's "snowballs on the side of a barn".

- Sides of square represent range of conditions (e. g., temperature and precipitation)
- Center of each circle represents most preferred combination for each species, radius range under which it can function,
- If sides are of length W and circles are each of radius one, the area expected *not* to be covered will be

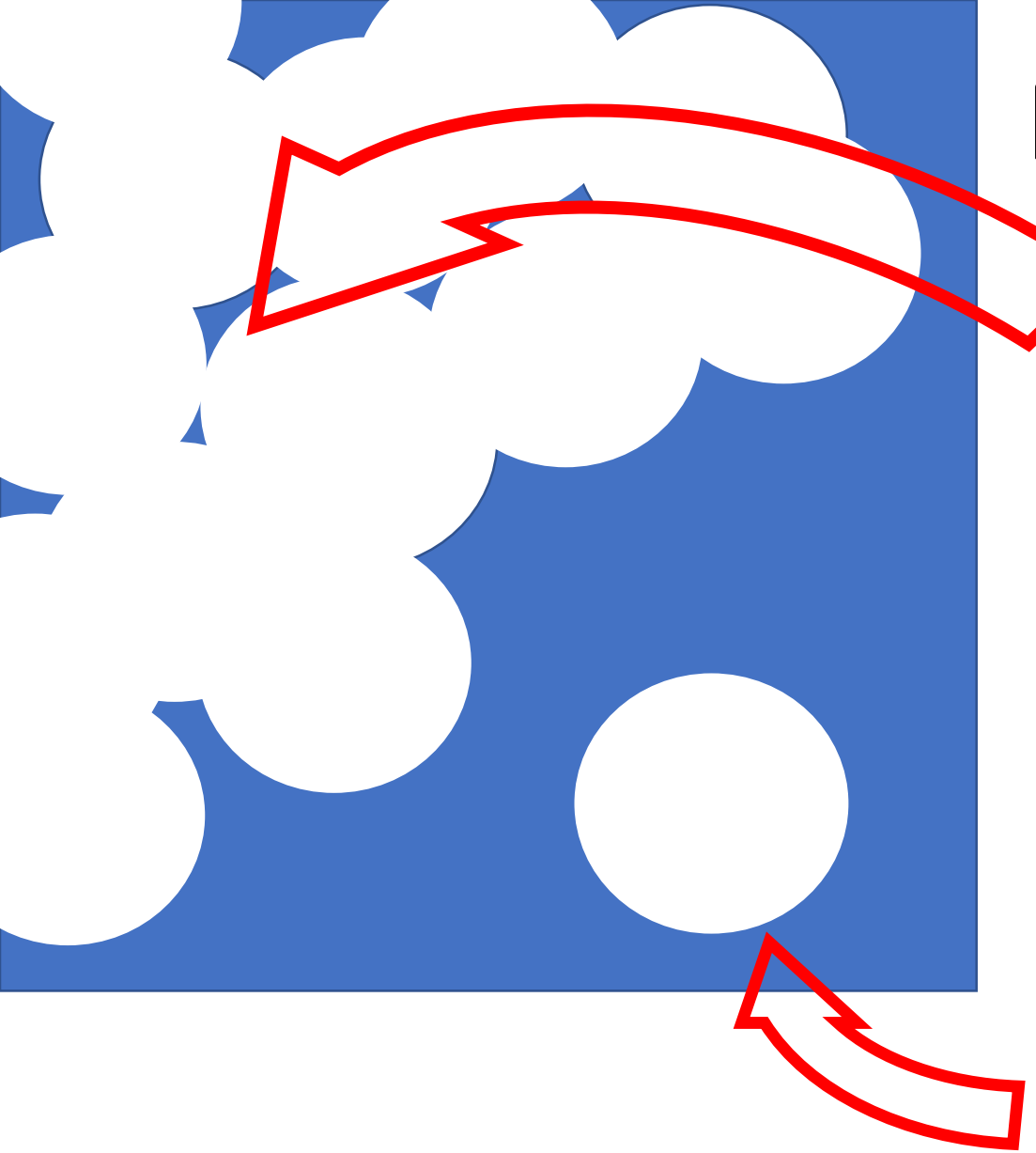
$$\left(1 - \frac{\pi}{W^2 + 4W + \pi}\right)^N$$

Example: Temperature and precipitation vary, and under some conditions some species take up soil nutrients and under others different species do.

Diversity affects function *in the same way here* as in the "looking for the best" scenario.

Diversity and portfolio theory

- The more species there are, the more insurance we may have against adverse states of the world.
- In nature some species may survive because they reemerge and thrive under unusual conditions (e. g., early successional species that emerge after fires).
- In managed systems we may want to maintain some species for “insurance”
- Basic principle of finance: we will accept lower expected rate of return on assets that pay off when others do not (Weitzman 1992 on diversity measures).



Revisiting the “snowballs”

If most of the “snowballs” tend to land in the upper left

We might place a high value on a “snowball” that lands in the lower right.

In ecological terms, we’d want the species that “pays off” under conditions that the others don’t.

Complementarity

- Examples of “finding the best,” “covering the space,” and “filling the portfolio” don’t really illustrate *complementarity*.
- The ecological literature emphasizes *overyielding* (“whole greater than sum of parts”).
- In economics we have examples of CES functions, Dixit-Stiglitz model, etc.
- This is the subject of many anecdotes (e. g., plant/pollinator mutualisms).

Application: Simpson, Sedjo, and Reid (1996)

MERCK

INBio
Instituto Nacional de Biodiversidad

Application: Simpson, Sedjo, and Reid (1996)

- There was great enthusiasm for "bioprospecting" in the early 1990s.
- Biodiversity as input into stochastic production.
- Suppose it costs c to test a species for its efficacy in providing a potential pharmaceutical product.
- Let R be the payoff in the event of a discovery
- Suppose p is the probability that any species chosen at random provides the desired product
- Then the value of having a collection of N species to test is

$$V = \frac{pR - c}{p}[1 - (1 - p)^N]$$

A useful approximation (it will come up repeatedly)

If p is small,

$$(1-p)^N = \left(\left[\frac{1/p-1}{1/p}\right]^{1/p}\right)^{pN}$$

$$\lim_{p\to 0}\left(\frac{1/p-1}{1/p}\right)^{1/p} = 1/e$$

So for small p, $(1-p)^N \approx e^{-pN}$

Value of marginal species is

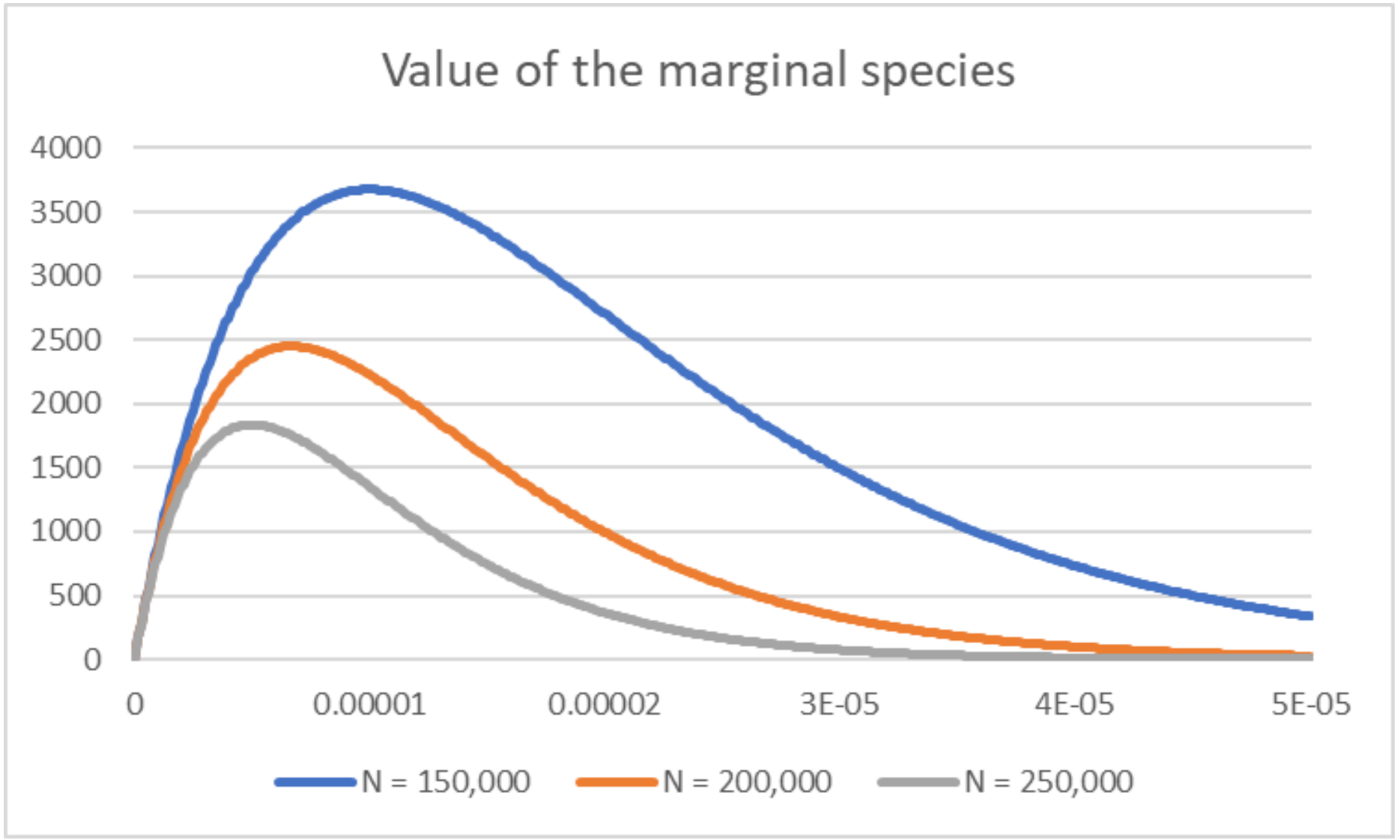
$$(pR - c) \cdot e^{-pN}$$

Expected payoff from testing an N + 1st species

Probability that a discovery is not made among the first N species tested

If p is small, $pR - c$ vanishes

If p is *not* small, e^{-pN} vanishes if *N* is large



R = $ 1 billion

c = $10

SSR (1996) results

Using the approximation,

$$V = \frac{pR - c}{p}[1 - e^{-pN}]$$

The value of the marginal species is approximately

$$\frac{\partial V}{\partial N} = v = (pR - c)e^{-pN}$$

An upper bound can be found by setting the derivative with respect to p to zero:

$$Re^{-pN} - N(pR - c)e^{-pN} = 0$$

Implies

$$p^* = \frac{R+Nc}{NR} \text{ and } v^* = \frac{R-c}{N} e^{-\frac{R+Nc}{Nc}}$$

SSR (1996) results

We used data on

- The costs of pharmaceutical research,
- The value of new products, and
- The expected pace of new product demands
- We added an admittedly *ad hoc* assumption on return on investment in pharmaceutical research

*Upper bound on v*alue of marginal species: USD 10,000 (in 1995).

Relating a *biodiversity* value to an *ecosystem*

- Assume number of species in a habitat of size A_i is determined by island biogeographic relationship (MacArthur and Wilson 1967)

$$S_i = \alpha_i A_i^{\beta}$$

- Implies

$$\frac{\partial S_i}{\partial A_i} = \beta S_i$$

- That, in turn, implied values for preserving a hectare of land in each of 18 “hotspots” of endemic species diversity.
- They varied from about USD 0.20 to USD 20.
- This was far lower than the opportunity cost of land.

Some subsequent events

- Rausser and Small (2000) revisited our figures and argued that prior information made values 1,000 times higher in some spots, *but zero in others*.
- Costello and Ward (2007) revisited R&S, found that different parameter choices was driving results, and concurred with us that “marginal land values from bioprospecting are far too small to provide plausible conservation incentives.”

In the meantime, back in the real world . . .

Researchers continued to cite and dispute [SSR, R&S, C&W, etc.], *and the academic-industrial complex went on spinning out research on bioprospecting and genetic resources.*

But an interesting thing was happening in the real world while we academic scribblers were squabbling amongst ourselves:

Nothing.

Simpson (2020)

Bioprospecting has not taken off

- The INBio-Merck deal lapsed
- Large payments have not been recorded elsewhere
- The history of bioprospecting supports the economic proposition that new research leads are not scarce.

A BITTER PILL

March 9, 2012 | Ecological Health, Green Business | 10 Comment

The modern medicine chest is packed with stories of lifesaving drugs ingeniously drawn from unlikely species. So why haven't drug companies—or conservationists— been able to cash in on nature's pharmacy?

It seemed like the beginning of a new era in drug discovery, international development, and habitat preservation alike.

It was also too good to be true. In 2008, Merck quietly abandoned its search for new drugs from the natural world, shifting its attention to synthetic compounds and vaccines instead. Then [*in 2011*], as if to mark the anniversary of its Costa Rican folly, the company gave away its entire library of natural compounds—100,000 extracts representing 60 percent of all known plant genera, ready to be screened for the next big miracle drug.

Some takeaways from the bioprospecting episode

Bioprospecting was touted as win-win-win proposition:

- New medicines for the world
- Higher incomes in the tropics
- More conservation of imperiled rainforests

It wasn't.

Bioprospecting didn't bring in the money advocates hoped it would.

Could the millions spent have done more for conservation? For development?

Did the *perception* of value – even in the absence of tangible evidence – still motivate conservation?

What if someday we do desperately need new products?

Other valuation examples

- For each topic I'll consider (an) important paper(s)on biodiversity/ ecosystem service valuation.
- Examples will be:
  - Forests and water treatment costs (Vincent, *et al*., 2016)
  - Pollination (Ricketts, et al., 2004; Ricketts and Lonsdorf 2013)
  - Coastal protection (Das and Crépin 2013; Barbier, et al., 2008)
  - Recreational values (Adamowicz and Naidoo 2005)
- Examples chosen because
  - These issues have drawn a lot of attention
  - These studies illustrate thoughtful approaches

Examples (continued)

- .Papers take different empirical approaches:
  - Econometric (Vincent, et al., Adamowicz and Naidoo)
  - Field experiments and simulation (Ricketts and Lonsdorf)
  - Modeling and calibration (Das and Crépin)
- Why different methods were required or adopted
- Most of these examples share some common elements
  - (Approximately) exponentially declining marginal values
  - Marginal value is a single-peaked function of an “effectiveness” parameter
  - A “paradox of efficiency” arises.