# Session III: More examples and aggregating values

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# **Coastal Protection**



#### **Coastal Protection**

- There has been great interest in maintaining coastal forests (largely mangroves in the tropics)
- Provide storm protection, as well as nursery grounds for fisheries (Barbier and Strand 1998).
- Climate change makes services of coastal ecosystems both more valuable and more vulnerable.
- Diminishing returns are likely to be important in coastal protection.

#### Interior optimum (Barbier, et al., 2008)



#### Will econometric studies be accurate?

- Costanza, et al. (2008) regressed storm damage in the US on areas of coastal habitat preserved.
- Found significant values but, in many cases, not enough to offset the opportunity costs of forgone near-shore land use.
- Is habitat maintenance exogenous?
  - The value of avoided damages would be greater the more valuable are properties at risk; but
  - Coastal vegetation is more likely to be reduced the higher are the opportunities costs of forgone conversion (especially with externalities).

#### Some good examples from India

- Well known study by Das and Vincent (2009) demonstrates how coastal ecosystems saved lives in the 1999 cyclone.
- Follow-up work by Das and Crépin (2013)
  - Provides further economic detail on the value of coastal protection
  - Nicely links natural science and economic models.
- How do mangroves (and other natural vegetation) "work"?
  - Diminish both wave (storm surge and tsunami) and wind damage.
  - Das and Crépin consider both, but in interest of simplicity I'll focus on waves
  - Wave energy is proportional to the square of wave height
  - Wave heights are reduced/energy dissipated over vegetated area traversed.

### Interpretation of Das and Crépin

Damage depends on the velocity of waves hitting structures and extent of inland intrusion;

Velocity depends on wave height;

Wave height depends on

- Width of vegetation traversed between open water and structures
- Distance between structures and coastal forest (assumed fixed)

Assume

- Height declines exponentially at rate  $\eta$  per unit width of vegetation:  $H = H_0 e^{-\eta m}$
- Velocity is proportional to the square root of height:  $V = k\sqrt{H}$
- Damage increases in velocity to the power  $\rho: D = gV^{\rho}$

#### Combining . . .

$$D = g \big[ k (H_0 e^{-\eta m})^{1/2} \big]^{\rho}$$

or

$$D = Ke^{-Rm}$$

Where *K* subsumes all the constants and  $R = -\eta \rho/2$ The form is familiar, and

$$\frac{\partial D}{\partial m} = -RKe^{-Rm}$$

#### Findings and some further thoughts

- Das and Crépin calibrate findings with observed costs of repair, extent of damage, attenuation of waves, etc. [*NB: Das and Crépin consider both wind and wave damage*]
- Estimated protective value of coastal mangroves as 1999 USD 177/ha
  The figure is not insignificant, but land values were estimate at about USD 3800/ha at the time.
- Another dimension of analysis:
  - A critical parameter I subsumed is the intensity of the storm  $(H_0)$ ; how much damage would an <u>un</u>attenuated storm do?

## Das and Crépin estimate avoided damage given intensity of storms

- To derive an expected NPV of coastal ecosystems maintained to prevent storm damage, we would need to consider the distribution of storms.
- Let
  - -D(S,m) be the damage done to some set of structures by a storm of intensity S when they are protected by a coastal forest of width m;
  - -f(S) be the pdf of storm intensity
- Then if both the damage function and the distribution of storm intensity were the same over time then the NPV of the protection afforded by a width *m* would be

$$\int_{\Sigma} D(S,m)f(S) \, dS \Big/ \delta$$





# Polination

and the second second

#### Pollination

- Commonly cited example of ecosystem service (Armsworth, et al., 2007; Johnson, et al., 2021).
- Areas of adjacent habitat are believed to provide nesting and alternative foraging for pollinators that enhance crop yields.
- The value of pollination services may be limited, though.
  - While many varieties of crops benefit from insect pollination, most of the value of production comes from crops that do not require insect pollination (Ghazoul 2005).
  - "crop production would decline by around 5% in higher income countries, and 8% at low-to-middle incomes if pollinator insects vanished." (Ritchie 2021; emphasis added)

#### Pollination and *marginal* value

- One sometimes encounters statistics such as that "x% of the y crop was pollinated by species z; therefore the value of species z is x% of the value of y."
- No, it isn't.
- If there are sufficient numbers of other pollinators (or alternative means of pollination) the value of species z could be essentially zero.
- If a pollinator of species z didn't land on a flower, one of another species might have.

Measuring the value of the marginal pollinator and hectare of habitat

• Ricketts, et al., (2004) did a clever study in Costa Rica measuring quantity and quality of coffee production in areas located closer to remnant patches of forest relative to those more distant.



Measuring the value of the marginal pollinator and hectare of habitat

Found that values were higher in areas closer to pollinators.

But:

- Increased value of production may not have covered the opportunity cost of land clearing; and
- The *Finca Santa Fe* coffee plantation was subsequently uprooted to plant pineapple; pineapple does not require insect pollination.





#### Ricketts and Lonsdorf (2013)

R&L calibrated models that relate

- Pollinator numbers to habitat condition;
- Pollinator numbers to visits to particularly farms/plants;
- Pollinator visits to crop yields; and
- Then relate the enhanced value of yields back to the forest areas supporting the pollinators.



### Sources of diminishing returns

- The number of pollinators *emerging from* habitats retained for their protection will increase less-than-proportionately with habitat extent
- Ricketts and Lonsdorf assume yield, Y, is a concave function of pollinator abundance, P

$$\frac{Y_0 - Y}{Y_0} = \alpha \frac{\beta}{P + \beta}$$

Where

- $Y_0$  is potential maximum yield;
- $-\alpha$  and  $\beta$  are parameters calibrated from data.
- "Yield gap" closes as the number of pollinators increases

## A simple model of pollination (Simpson 2019)

- A field is planted with  $\Phi$  flowers.
- Each of *B* bees can visit and hence, potentially pollinate  $\phi$  flowers.
- $\bullet$  The probability that any particular bee will visit any particular flower is, then,  $\phi/\Phi$  .
- The probability that any particular bee will *not* visit any particular flower is  $1 \phi/\Phi$ .
- So the probability that *at least one* bee will visit a flower is

$$1 - \left(1 - \frac{\phi}{\Phi}\right)^B \approx 1 - e^{-\phi B/\Phi}$$

#### The value of the "marginal pollinator"

• If a fertilized ovum is worth *P* and it costs *c* to cultivate each flower, farm profit will be

$$\pi = P(1 - e^{-\phi B/\Phi})\Phi - c\Phi$$

• Differentiating with respect to the number of pollinators,

$$\frac{\partial \pi}{\partial B} = P\phi e^{-\phi B/\Phi}$$

- Intuition is again straightforward; the value of the "marginal pollinator" is
  - The value of a fertilized flower  $\Rightarrow$  potential fruit; times
  - The number of flowers the pollinator may visit; times
  - The probability the flowers it will visit would not be fertilized by another pollinator.

#### Results

- Another "paradox of efficiency" may arise: if pollinators are very prolific, it may not require many to meet crop needs.
- How much land might be set aside for native pollinator habitat for the California almond crop *if natives can compete with apis mellifera*?
- Land devoted to California almond growing is expensive (> USD 25,000 ha<sup>-1</sup>)
- In my 2019 paper I argued that the *largest* fraction of farm area farmers would devote to pollinator habitat would be on the order of 1/8<sup>th</sup> of total potential acreage.

#### How much does more complexity buy us? Pollination in the InVEST module Sharpe, et al., 2020



type / for substrate type n

#### Variables in the model

#### Appendix: Table of Variables

- z 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.
- n nealing type (ground, cavity).
- N set of all neating types.
- j season (fail, spring, etc).
- J set of all seasons (ex: {fail, spring}).
- fj(f, z) active pollination season for farm f at pixel z.
- α<sub>4</sub> mean foreging distance for species s.
- ns(s, n) nesting suitability preference for species s in nesting type n.
- HN(x, x) habital reading suitability at pixel x for species x [0.0, 1.0].
- N(l, n) the nexting substrate index for landcover type l for substrate type n in the range [0.0, 1.0].
- RA(I, j) index of relative abundance of floral resources on landcover type I during season j. [0.0, 1.0]
- fa(s, j) relative foraging activity for species # during season j.
- FR(x, x) accessible floral resources index at pixel x for species x.
- D(x, x') euclidean distance between the centroid of pixel x and x'
- PS(x, s) polinator supply index at pixel x for species s.
- PA(x, s, j) pollinator abundance at pixel s 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 polinator abundance to polinator-dependent crop yield at a farm pixel during the season in which polination is needed for that farm.
- mp(f) abundance of managed polinators on farm f relative to the recommended stocking rate.
- h(f) half saturation coefficient for farm f.
- PYT(x) total polinator-attributable yield at pixel x for season j, accounting for wild and managed polinatora.
- PYW(x) wild-polinator-attributable yield at pixel x for season j.
- As(a) relative species abundance index for species a.
- 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.
- P(f) proportion of crop yield dependent on pollination



## Apis mellifera

VS

## Osmia lignaria



- Some farmers have tried to establish Blue Orchard Bees (*Osmia lignaria*) as alternative pollinators of California almonds.
- The farmers proposed to accomplish this by:
  - Selectively propagating species of wildflowers on which the BOB depends.
  - Sterilizing the soil in the intended BOB habitat to eliminate organisms that might compete with, eat, or infect the flowers raised as BOB fodder;
  - Excluding mice and toads that might prey on the BOB
  - Caging in the areas in which BOB were propagated with netting to keep the BOB in and other insects out.
- This wouldn't be preserving wild habitat to provide pollinators to farms so much as domesticating and farming wild pollinators.

Biodiversity and Ecosystem Service Values in "Green Accounts" and "Genuine Wealth"

- Weitzman (1976): Properly measured national income (utility from current consumption + net investment) indicated the equivalent constant level of utility that could be enjoyed in perpertuity
- Hartwick (1977): If well-being is sustained perpetually, the value of net investment cannot be negative
  - Converse does not necessarily hold).
  - Sustainability and substitutability: the forms of capital that are being lost cannot be irreplaceable (if they were, their price would be unbounded)
- Dasgupta and Maler (2000; cf. Pearce et al., 1996): Genuine wealth (aggregate of net investment) measures intertemporal well-being.
- But to do accounting we must know prices and quantities!

#### Contents of the Dasgupta Review (2021)

#### Contents

Foreword Preface Part I - Foundations Chapter 0 How We Got to Where We Are 0.1 Economic History Since Year 0 0.2 Economic Growth and Sustainable Development 1.3 Historical Success and Failures 1.4 Understanding Humanity's Cont Nature as an Asset 1.0 Portfolio Management Classification of Capital Good 2 Rates of Return and Arbitrage Con 3 Public Asset Management and the Wealth/Wel 1.4 Two Types of Comparison 1.5 The Earth System and Economic Growth 1.6 Total vs. Marginal Values 8 Anthropocentric Value of Biodiversity Biodiversity and Ecosystem Servio 2.1 Biodiversity in Ecosystems 2.2 Primary Producers Ecosystems do not Maximise NPR Ecosystem Goods and Services: Classification Invisibility and Silence of Regulating and Mai servation vs. Pollution 7 Ecosystem Productivity and Resilience 8 Biodiversity and Ecosystem Productivity/Resilience 9 Modularity as a Spatial Feature of Ecosystems 10 Biodiversity and Ecosystem Productivity: Summar Annex 2.1 Community Structure Annex 2.2 Measuring Biodiversity Chapter 3 **Biospheric Disruptions** 3.1 Fragmentation as Disturbance 3.2 Stability Regimes 3.3 History Dependence 3.4 Conservation Ecology and Tipping Point Annex 3.2 Tipping Points Annex 3.3 Hysteresis and Irreversibilities in Lake nnex 3.5 Morals Human Impact on the Biosphere 4.1 Depreciating the Biosphere 4.2 Demand and Supply 4.3 The Impact Inequality 5 The Impact Equation 6 Technology and Institution 4.8 Core of the Review The Bounded Global Economy 4\*.1 Substitutes and Complements 4\*.2 Modelling the Global Economy 4\*.3 Contemporary Models of Econ Risk and Uncertainty 5.1 Portfolio Choice under Uncertain .2 Independent vs. Correlated Risks i.3 Reducing Risks and the Losses from Risks i.4 When to Stop Business-as-Usual i.5 The Value of Keeping Options Open nnex 5.1 Fat Talk and Unbounded Utilitie Laws and Norms as Social Institutions .1 Societal Trust and Economic Progress 6.1 Social missi and commune requests
 6.2 The idea of Trust
 6.3 The Basis of Trust, 1
 6.4 The Basis of Trust, 2
 6.5 Social Capital act the Basis of Societal Coherence
 6.6 Social Capital and Identity
 6.7 The Primary of Integrity Human Institutions and Ecological Systems, 1: Unidirectional Externalities and Regulatory Policie 7.1 Property Rights and Wealth Distribution 2 Externalities and Rights 3 Taxing and Subsidising Externalities

7.4 Quantity Restrictions 7.5 Markets for Externalities 7.6 Payment for Ecosystem Services 203 Part II – Extensions Chapter 8 Human Institutions and Ecological Systems, 2: Common Chapter 14 Distribution and Sustainability Pool Resources 14.1 Global Variation in Demand and Supply 8.1 Open Access Resources 14.2 Distribution of Humanity's Demand 8.2 Common Pool Resources (CPR 4.3 Distribution of the Biosphere's Suppl 4.4 Interactions Between the Biosphere a 8.3 CPRs and the Poor World Chapter 15 Trade and the Biosphere 8.4 Fragility of CPRs 8 5 Property Rights to Land 15.1 Trade and the Impact Equation 15.2 Trade Expansion and Pressures on the Biosphere 15.3 Enhancing Trade Practices and Policies to Suppo 8.6 Property Rights and Manage Annex 8.1 Estimating Subsidies Chapter 16 Demand for Provisioning Services and Its Consequence 219 Chapter 8\* Management of CPRs: A Formal Model 16.1 Current Harvest of Provisioning Services and Future Prospect 16.2 Trade-Offs Between Provisioning and Regulating Services 16.3 Technology to Increase Efficiency in Our Use of the Biosphy 8\*.1 A Timeless World 8\*.2 Mutual Enforcement of Optim Chapter 17 Manaping Nature-Related Financial Risk and Uncertaint 8".3 Privatising the CPR 7.1 Nature-Related Financial Risks 8\*.4 Extensions 17.2 Uncertainty and Short-Termism 17.3 Assessing Nature-Related Final Chapter 9 Human Institutions and Ecological Systems, 3: Consumption Chapter 18 Conservation of Nature Practices and Reproductive Behaviour 18.1 Ecosystem Assets 18.2 How Much Ecosystem Stack Do We Need? 18.3 What Kind ef Stock Do We Need? 18.4 How Can We Improve and Increase Our Sn 18.5 Conservation Planning and Evaluation 9.1 Socially Embedded Consumption Preferences 9.2 Consumption Practices 9.3 Induced Behavioural Change 9.4 Factors that Slow Fertility Transition 9.5 Socially Embedded Reproductive Behaviou Chapter 19 Restoration of Nature 9.6 Importance of Investment in Family Planning and Recorductive Health 19.1 The Role of Ecosystem Restr 9.7 Unmet Need, Desired Family Size, and the UN's Sustainable Developm 19.2 Rewilding 19.3 Nature-Based Solutions Annex 9.1 Socially Embedded Preferences for Cons 19.4 Sustainable Production Landscapes and Sea Chapter 10 Well-Being Across the Generations 9.5 Invasive Non-Native Species 9.6 Bringing Natural Capital into Spatial Planning 10.1 Classical Utilitarianism Chapter 20 Finance for Sustainable Engagement with Nature 0.2 Utilitarian Reasoning behind the Veil of Ignoranc 20.1 Public Finance 10.3 Discounting Future Generation 20.2 Private Finance 10.4 Intuitionism and Pragmatism 10.5 Discounting in Arbitrary Futu 10.6 Directives on Discounting 10.7 Social Rates of Return on 0.8 Accounting Prices 10.9 Should Environmental Projects be Eva 10.10 The Idea of Investment Annex 10.1 A Simple Exercise in Optimum Savi Annex 10.2 Uncertainty and Declining Discount Rates Part III - The Road Ahead The Content of Well-Being: Empirics 11.1 Objective Measures of Well-Being Chapter 21 Options for Change 1.2 Measuring Well-Reing by Asking People 21.1 Address the Imbalance Bets Increase Nature's Supply nts of Well-Being 21.2 Changing Our Measures of Economic Progra 21.3 Transforming Our Institutions and System Appendia Acronyms ctivity as Accounting Price Glossary 5 Nature's Existence Value and Intrinsic Worth: Sarrey References lature's Intrinsic Worth: Moral Standing Advnowledgement 3.9 Total Factor Productivity Growth 3.10 Growth in GDP and Inclusive Wealt 3.11 Net Present Values 13.12 Inclusive Wealth and th 13 Lower Discount Rates for 3.14 Optimum Development 13.16 Internal Rate of Return nex 13.2 Saving the Blue Whal Annex 13.3 The Significance of GD Accounting Prices and Inclusive Wealth Chapter 13\* 13° 1 The Model 1\*.2 The Optimisation Problem Inclusive Wealth and the Long Run

A 609 page tome on the *Economics of Biodiversity* emphasizing the importance of assigning appropriate prices to natural assets devotes only 13 pages to "How to do it"?

Chapter 12 Valuing Biodiversity 301 12.1 Estimating Accounting Prices: General Observations 302 12.2 Stated Preference for Public Goods 304 12.3 Revealed Preference for Amenities 305 12.4 Productivity as Accounting Price 306 12.5 Human Health 307 12.6 Nature's Existence Value and Intrinsic Worth: Sacredness 309 12.7 Nature's Intrinsic Worth: Moral Standing 310

# Where should benefit estimates for accounting come from?

- While there are thousands of existing studies, there may be millions of things to be valued.
- Ecosystem service values may be *highly* nonlinear and vary with
  - Size, configuration, and condition of the area supplying ecosystem services.
  - Proximity of *beneficiaries* of services to systems *providing* them: farms to pollinators, cities to storm protection, sources and receptors to waste treatment.
  - Linear extrapolation can be wildly inaccurate in some instances
  - The major exception may be carbon storage, but other ecosystem service values should not be extrapolated in the same way.



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO,"

#### Figures like these reflect some *extremely* heroic assumptions! Source: Bateman, *et al.*, 2013

Change in agricultural values (FGM £/ha/yr) Gain > 200 Gain 50 to 200 Gain < 50 No change Loss < 50 Loss 50 to 200 Loss > 200

Change in GHG	emis
values (£/ha/yr)	
> 60	
41 to 60	
21 to 40	
1 to 20	
0 to -19	
-20 to -39	
-40 to -59	
< -59	

sion

Change in recreation value (£'000/5km cell/yr) Gain > 1000 Gain 500 to 1000 Gain 100 to 500 Gain 10 to 100 Loss 10 to Gain 10 Loss 10 to 100 Loss 100 to 500 Loss 500 to 1000 Loss > 1000 Change in urban greenspace values (£/household/yr) Gain > £400 Gain £200 to £400 Gain £100 to £199 Gain £50 to £99 Gain £49 to Lass £50 Lass £51 to £400 Loss £401 to £900 Loss £901 to £2000 Biodiversity index: Change in general bird diversity (%) > 1.5% 0% < -1.5% 0 250 500 FIGURE 9. PREDICTED VALUE OF ALL FOREST ECOSYSTEM SERVICES, PER HECTARE PER YEAR, IN 2013 U.S. DOLLARS. THE SERVICES CONSIDERED INCLUDE RECREATION, HABITAT AND SPECIES PROTECTION, NWFPS, AND WATER SERVICES. MAPPED USING DATA ON 782,636 GRID CELLS, EACH 10 KM BY 10 KM IN SIZE

# And these even more so!

Siikimäki, et al., 2015

They assigned a value to more than half of the land on earth!

One day Alice came to a fork in the road and saw a Cheshire cat in a tree. "Which road do I take ?" She asked. "Where do you want to go?" was his response. "I don't know," Alice responded. "Then said the cat, "it doesn't matter."

# A final thought

Back to *why* are we valuing biodiversity and ecosystem services?

- To carefully allocate parcels between conservation or direct use?
- If so, have we thought about what sort of landscape we want?
- Is valuation just "an eye-opening metaphor intended to awaken society to think more deeply about the importance of nature" (Norgaard 2010), or do we really want to be guided by the implications?