Session II:
Examples and methods of estimation

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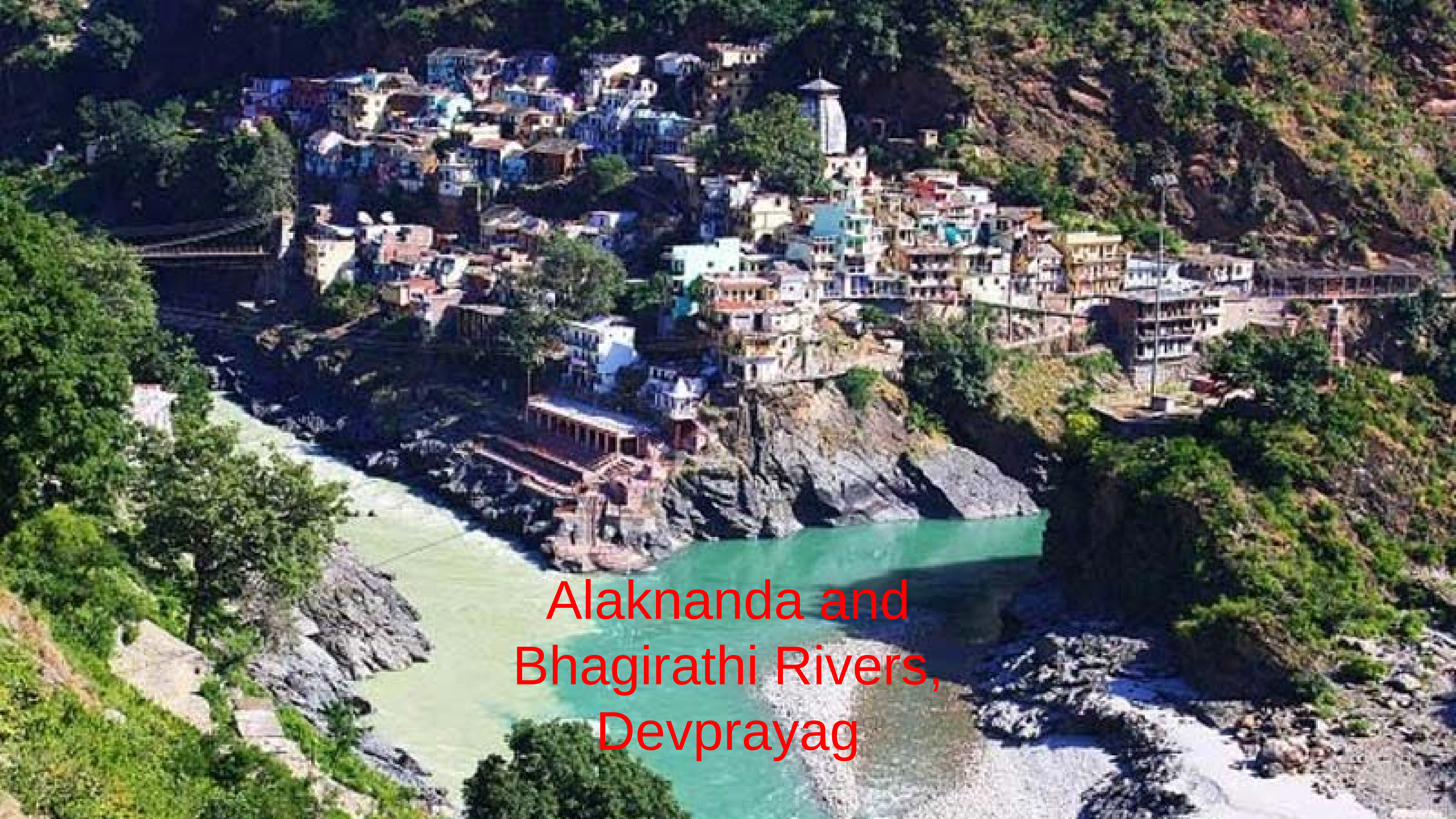
The last session was mostly about “why” to estimate values of natural ecosystms; This session will be about “how”

- Last time I gave the example of “bioprospecting”
- I calibrated a simple theoretical model to estimate a bound on marginal values
- In other settings econometric approaches might be used
  - There will be challenges in estimation, though
  - Which approach is better when?
  - How detailed should models be?

Diverse natural ecosystems for pollution treatment

- Seminal studies of natural systems for retention of nutrients, sediment, and wastes; e. g.,
  - Dixon, *et al*., 1994 on sedimentation of reservoirs.
  - Breaux, *et al.,* 1995 on food processing wastes (Louisiana, USA)
  - Emerton, *et al*., 1999 on urban wastewater treatment (Kampala, Uganda)

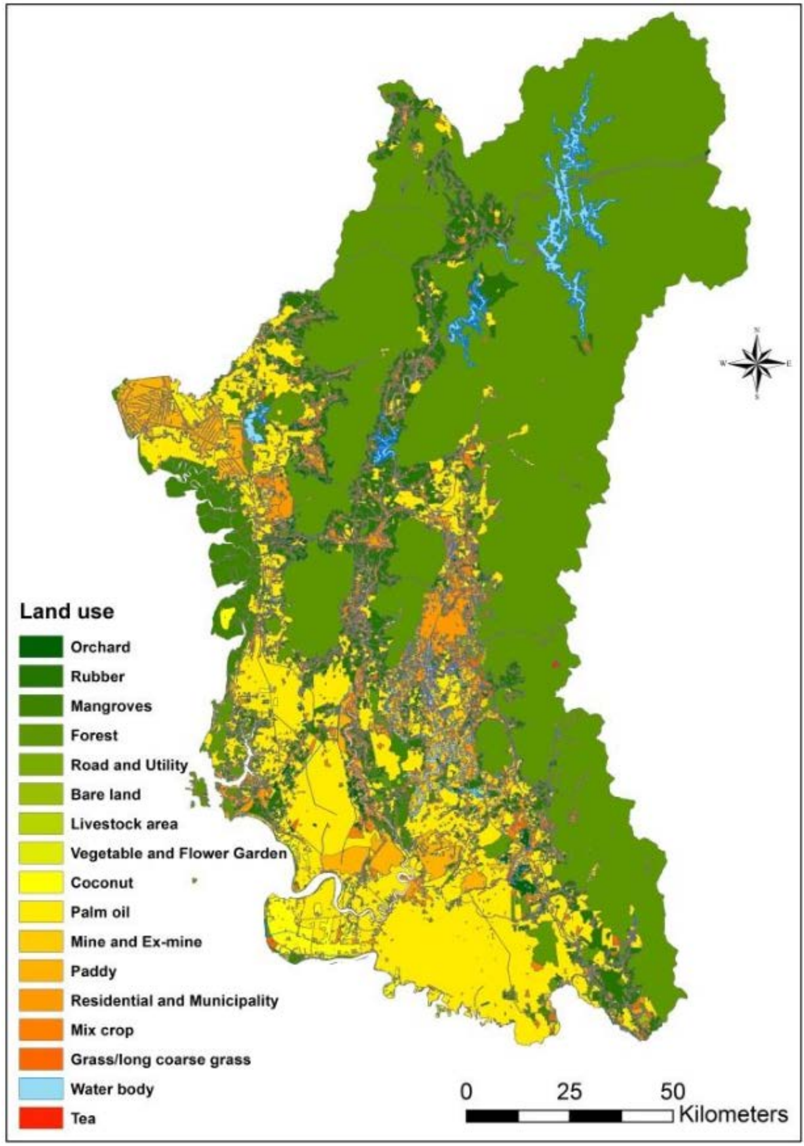

Alaknanda and
Bhagirathi Rivers,
Devprayag

Evidence from natural science

- "Paired watershed studies" document effects of land cover on water flow and materials transported (Brown, et al., 2005).
- Numerous studies document effects of riparian buffers on nutrient and other pollution flows (Mayer, et al., 2007; Mander 2008).
- These studies often adopt exponential decay as a conceptual depiction and/or empirical model of pollution treatment (we'll come back to this).

An econometric study: Vincent, *et al.*, 2016

- Considered water treatment costs in Malaysia.
- Treatment costs increase with sediment concentration in the water.
- Vincent, *et al.*, related costs to area of forest cover maintained in basins above treated waters.
- They had an extensive panel data set, so time- and basin-invariant factors could be cancelled out.



Procedure and results

Vincent, et al., estimate

$$\ln C_{it} \;=\; \beta \ln\left(\frac{A_{it}}{A_{it}+F_{it}}\right) + \boldsymbol{X}'_{it}\boldsymbol{\gamma} + f.e. + \varepsilon_{it}$$

Where

- C_{it} is treatment costs at plant in basin i at time $t;$
- F_{it} is forest cover in basin i at time t;
- A_i is the area of basin i;
- $\boldsymbol{X}$ is a vector of other explanatory variables, $\boldsymbol{\gamma}$ is corresponding vector of parameter values;
- $f.e.$ are basin- and time-specific fixed effects;
- ε_{it} is a disturbance term.

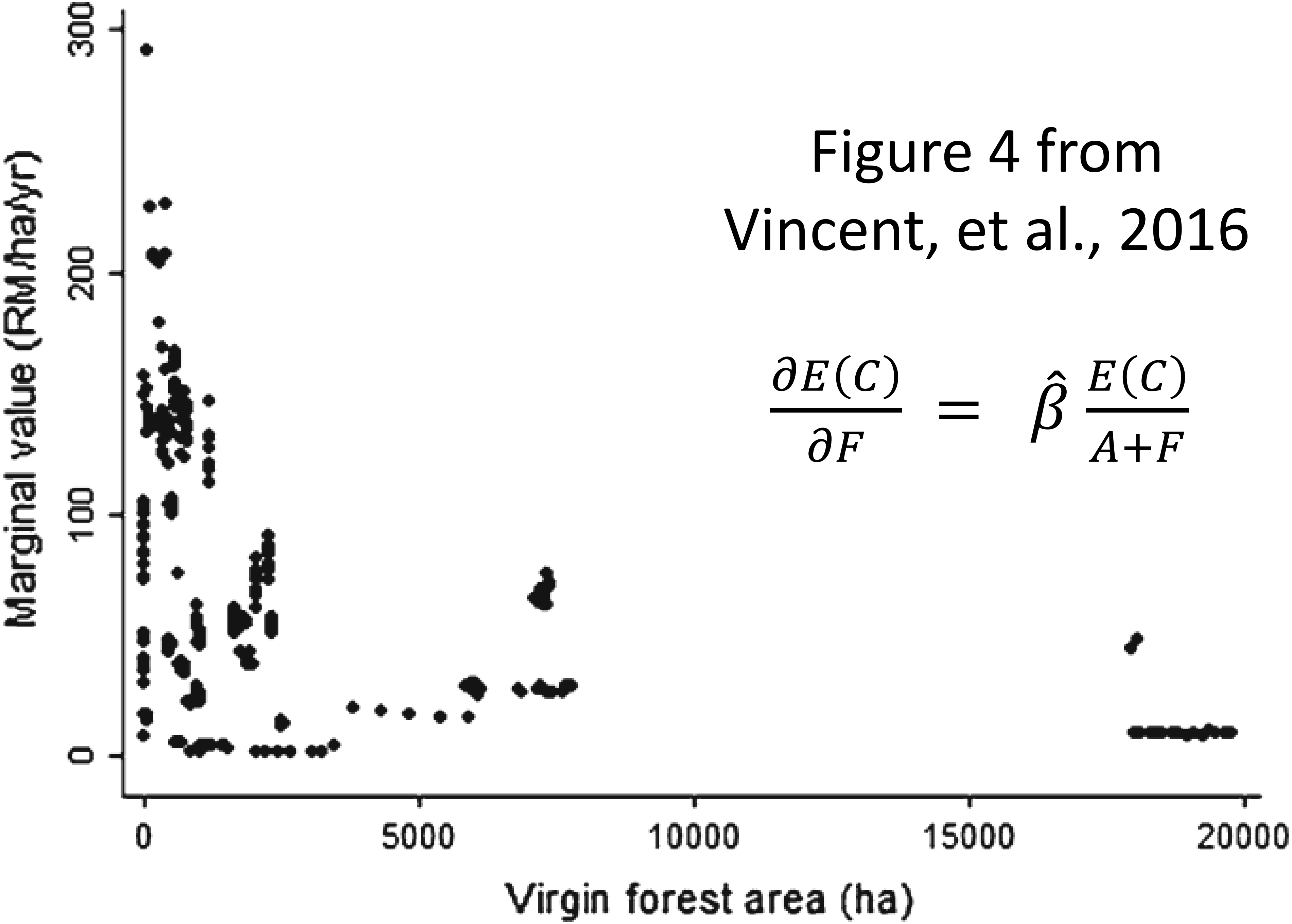


Figure 4 from
Vincent, et al., 2016

$$\frac{\partial E(C)}{\partial F} = \hat{\beta}\,\frac{E(C)}{A+F}$$

Endogeneity concerns

- Vincent, et al., instrumented the volume of water treated with 2-month lag
  - Might treatment plant operators try to reduce costs of treating restricting quantities when flows are high?
  - The IV was probably not required *in this instance*.
- More generally, concerns arise when land *use* and land *value* may be simultaneously determined (Irwin and Bockstael 2001)
- Can we find adequate instruments or natural experiments?

"The existing econometric literature investigating the effect of conservation on nearby development has not fully examined, nor found a solution to, the endogeneity of land conservation." (Zipp, *et al*., 2017)

An analogous question:
Are protected areas really protecting anything?

- Andam, et al. (2008) wanted to know if:
  - Declaring habitats as “protected” prevented them from being converted when the potential earnings from development were high; or
  - Parcels were designated for “protection” when it wasn’t really needed .
- Their matching study showed that nominal protected status didn’t have a strong effect.

Conclusions and concerns

Vincent, *et al*., find statistically significant benefits (avoided costs) to increased forest cover.

However, forest value for water treatment was “very small compared to producer surpluses for competing land uses”.

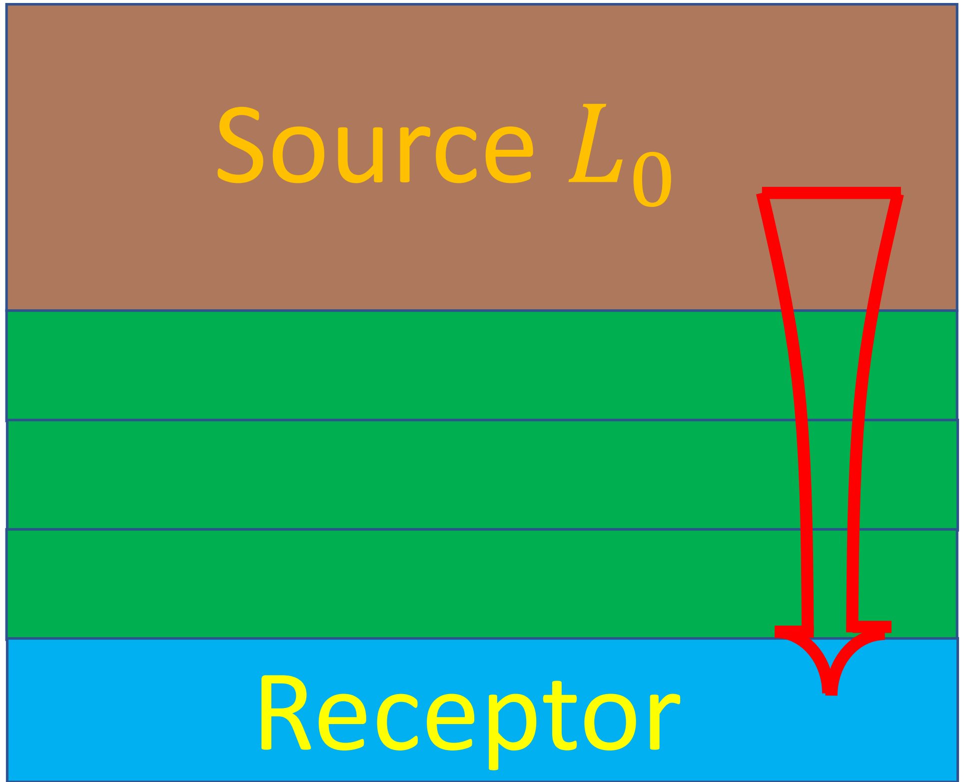
Vincent, *et al*., argue that

- Measured benefits may have been underestimated due to attenuation bias; and
- unmeasured benefits of other services might be substantial.

A schematic model of water treatment services

- Recall the remark a few slides back: empirical natural science studies often substantiate that water treatment exhibits an "exponential decay" property.

- This might arise in an intuitive way
- A flow of pollution L_0 is emitted from a source
- A fraction ρ is filtered out over every meter of "riparian buffer" traversed.
- $\Delta L = \rho L \implies L_W = L_0 e^{-\rho W}$ in limit of small steps, with W the width of the buffer



Avoided cost

- Suppose that the cost of treating water to a specified standard is $C(L_0 e^{-\rho W})$
  - For simplicity, suppose that riparian buffer of width W is maintained along a stream of unit length; and
  - The pollution load per linear meter of the stream is the same
- The marginal value of an extra meter of buffer width along the entire stream would be

$$C' \cdot \rho L_0 e^{-\rho W}$$

Example (Simpson 2017)

- Applied the simple model just sketched to treatment of nutrient pollution (largely *N* runoff from fertilizer and animal wastes) in Chesapeake Bay watershed.
- Removal rates ~ 1 – 3% m^{-1}.
- Stream density ~ 2.2 km · km^{-2}
- Land values ~ USD 12,000 ha^{-1}
- *N* loading ~ 28 kg $ha^{-1} \cdot yr^{-1}$.
- Avoided treatment cost ~ USD 35 kg^{-1}.

Findings

- Generous riparian buffers may be justified
  - At 2% removal rate, buffers of 75 m on each side of streams would be optimal.
  - Buffers would retain ~ 80% of nutrients, *but*
  - Buffers would cover more than 1/3 of basin, so much of effect would be from reduction of initial load.
  - Even at 10% (consistent with findings of *H*. Simpson, *et al.* 2013 for Texas), 35 m buffers would be optimal, but "paradox of efficiency" arises.
- Agricultural and input use in the US (and elsewhere) are greatly distorted, so it might be interesting to see if farmers would reduce nutrient applications before reducing crop areas.

That was a simple model;
do we need much more complex ones?

A small snippet of the InVEST Nutrient and Sediment Module documentation (Sharpe, et al., 2020)

$$LS_i = S_i \frac{(A_{i-in} + D^2)^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot x_i^m \cdot (22.13)^m} \tag{45}$$

where

- S_i is the slope factor for grid cell i calculated as a function of slope radians θ

$$S = \begin{cases} 10.8 \cdot \sin(\theta) + 0.03, & \text{where } \theta < 9\% \\ 16.8 \cdot \sin(\theta) - 0.50, & \text{where } \theta \geq 9\% \end{cases}$$

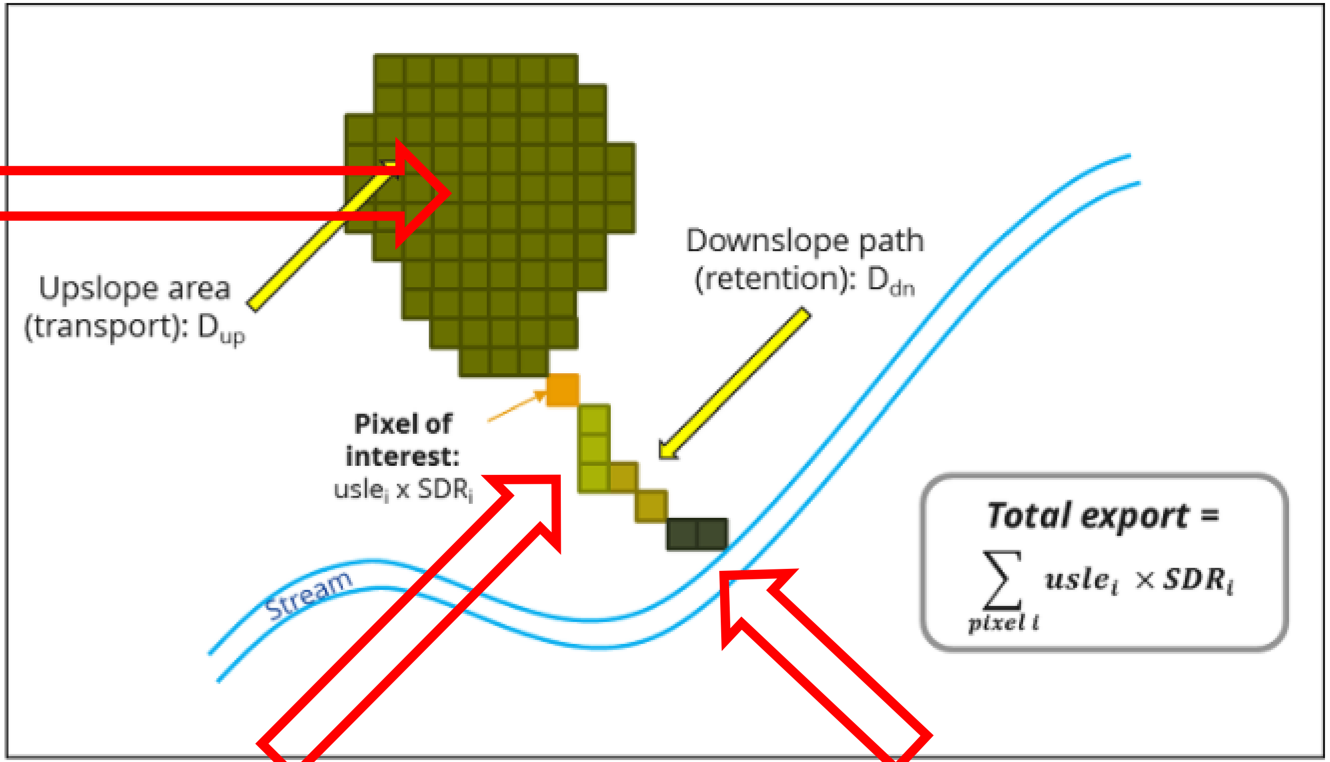
- A_{i-in} is the contributing area (m^2) at the inlet of a grid cell which is computed from the Multiple-Flow Direction method
- D is the grid cell linear dimension (m)
- x_i is the mean of aspect weighted by proportional outflow from grid cell i determined by a Multiple-Flow Direction algorithm. It is calculated by

$$x_i = \sum_{d \in \{0,7\}} x_d \cdot P_i(d)$$

  where $x_d = |\sin \alpha(d)| + |\cos \alpha(d)|$, $\alpha(d)$ is the radian angle for direction d, and $P_i(d)$ is the proportion of total outflow at cell i in direction d.
- m is the RUSLE length exponent factor.

The models are complicated, but the underlying structure is relatively simple

Land use and input application generate gross load



Fraction of load may be retained by vegetation

The value of load reduction may be estimated by aquatic damage or avoided treatment cost.

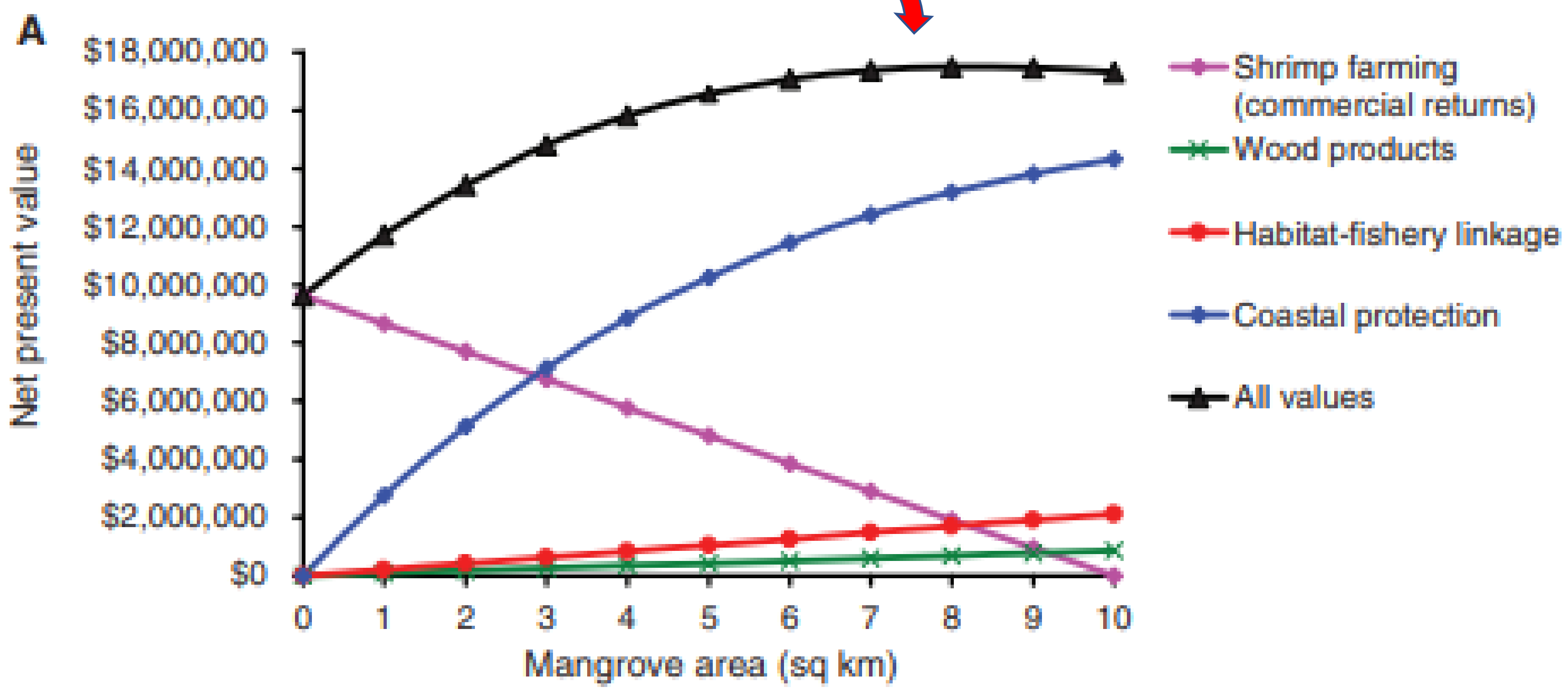
Coastal Protection

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)

While mangroves provide valuable services, the farther inland, the higher the opportunity cost relative to the benefit



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 η 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 ρ: $D = gV^{\rho}$

Combining . . . .

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

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

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

Pollination

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.

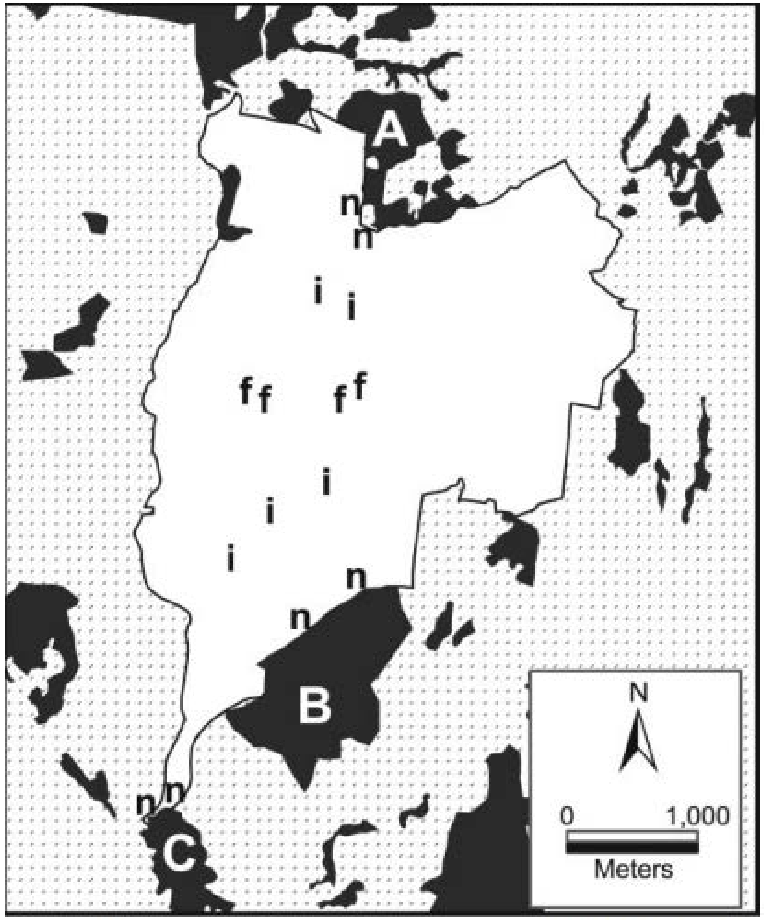
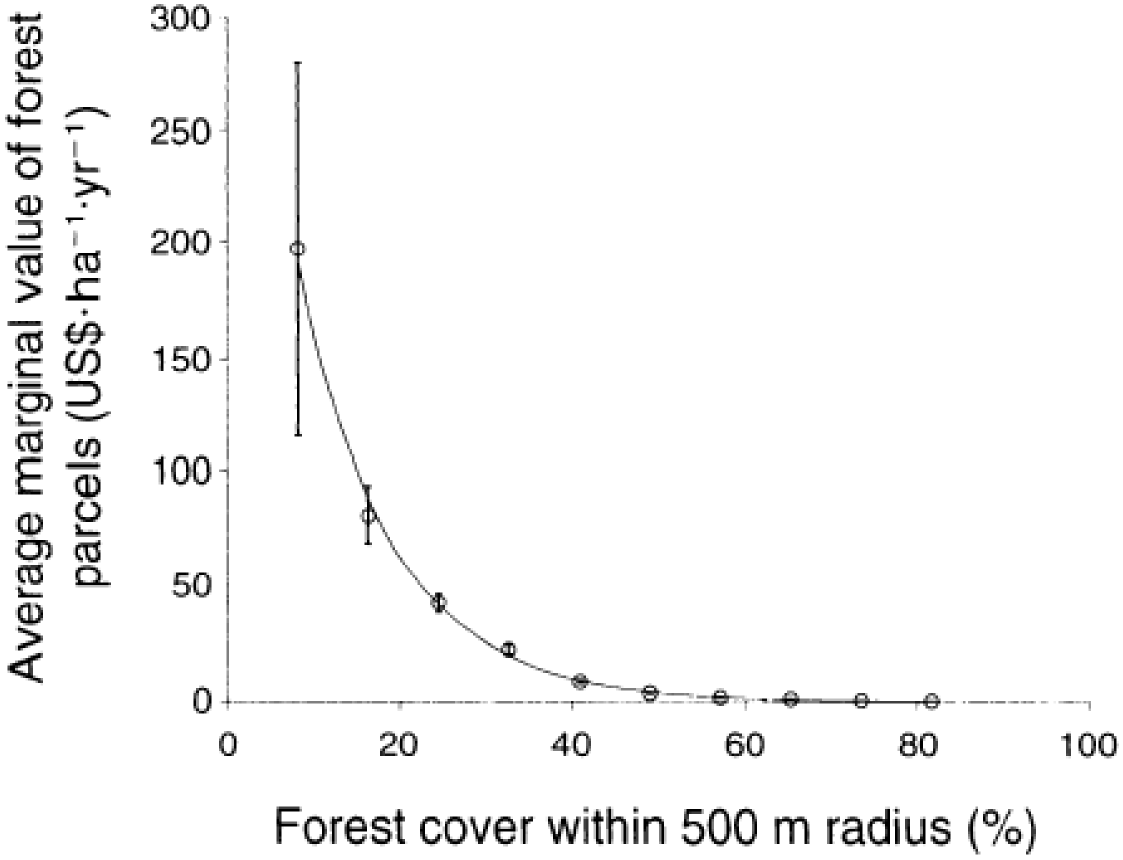


Fig. 1. Map of study area and sites. Finca Santa Fe (1,065 ha) is in white; stippled area is a mix of coffee, pasture, and sugar cane; black areas are forests. The three focal forest patches are labeled A (46 ha), B (111 ha), and C (34 ha). Study sites are labeled n, i, and f for near, intermediate, and far distance classes.

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;
- α and β 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 Φ flowers.
- Each of B bees can visit – and hence, potentially pollinate – ϕ flowers.
- The probability that any particular bee will visit any particular flower is, then, ϕ/Φ .
- 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

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

- 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^{-1})
- 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 $1/8^{th}$ of total potential acreage.

How much does more complexity buy us? 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

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

$$FP(x) = \frac{PAT(x, j(f(x)))(1 - h(f(x)))}{h(f(x))(1 - 2PAT(x, j(f(x))) + PAT(x, j(f(x))}$$

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 l during season j,

relative foraging activity for pollinator species during season .

The distance between pixels x and x'

Expected foraging distance for pollinatc

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

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

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

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 substrate index for landcover type l for substrate 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 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 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.

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 nature tourism

Recreational demand is often modeled as analogous to new-product search; would-be visitors “search” for their utility-maximizing choice.

Expected utility

Suppose individual i chooses the best option, j, from among N alternatives defined by attributes $\boldsymbol{x}_{ij}$, and their expected utility is

$$E(U) = \ln \sum_{j=1}^{N} e^{u(\boldsymbol{x}_{ij})}$$

If the k^{th} component of $\boldsymbol{x}_{ij}$ is a measure of the biota endemic to site j that partially determines its appeal to individual i; then

$$\frac{\partial E(U)}{\partial x_{ijk}} = \frac{e^{u(\boldsymbol{x}_{ij})}}{\sum_{j=1}^{N} e^{u(\boldsymbol{x}_{ij})}} \frac{\partial u(\boldsymbol{x}_{ij})}{\partial x_{ijk}}$$

That was a "backwards explanation" of the multinomial logit model

$$\frac{\partial E(U)}{\partial x_{ijk}} = P_{ij} \cdot \frac{\partial u(\boldsymbol{x}_{ij})}{\partial x_{ijk}}$$

Probability individual i visits site j

Increased enjoyment individual i experiences on visiting site j when attribute k varies

This is just the envelope theorem: if P_{ij} is chosen optimally, the traveler will gain no expected utility through changing sites.

Naidoo and Adamowicz (2005)

- Random-parameter logit model of site selection among destinations in Uganda and other options
- Varied likelihood of bird sightings as a result of changes in PA management.
- N&A use SP survey results because the "logistics of [*an RP*] approach would be extremely challenging".
- WTP for park admission increases in bird diversity; but
- Maximized park admission revenues would still be "significantly lower than extractive management schemes" and "show that biodiversity conservation does have *modest* potential to contribute economically to sustainable development" [*emphasis added*].