

Cost-Effective Species Conservation:

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Global species conservation and habitat protection

- Spending by top 8 conservation NGOs totaled more than \$2 billion in 2002
- Conservation priorities traditionally set by simple, biology-based systems:
 - Species richness
 - Hotspots (richness + threats)
- Up until ~10 years ago, economic costs rarely considered in setting priorities
- Even today, economic values rarely considered (although “ecological goods & services” attempting to fill that gap)

Cost-Effective Conservation

- In the past 10 years or so, increasing attention to conservation as an “economic” activity
- Conservation biologists use a *cost-effectiveness* framework to analyze conservation expenditures. Important issues have included
 - Metrics for effectiveness
 - Data for effectiveness metrics and costs
- Goal: Improve “efficiency” of conservation actions given a budget constraint, but don’t ask whether that budget should be larger or smaller (i.e., no benefit-cost analysis)

Cost-effectiveness analysis for species conservation

- General problem: Allocate a global conservation budget, C , across a set of n ecoregions
 - Budget is spent on habitat protection (km^2), $\{A_i\}$
 - Maximize the total (global) number of species conserved, S :

$$\sum_{i=1}^n c_i A_i \leq C \quad \text{and} \quad S = \sum_{i=1}^n s_i A_i$$

Cost-effectiveness analysis for species conservation

➤ Specific forms for $C(\cdot)$ and $S(\cdot)$:

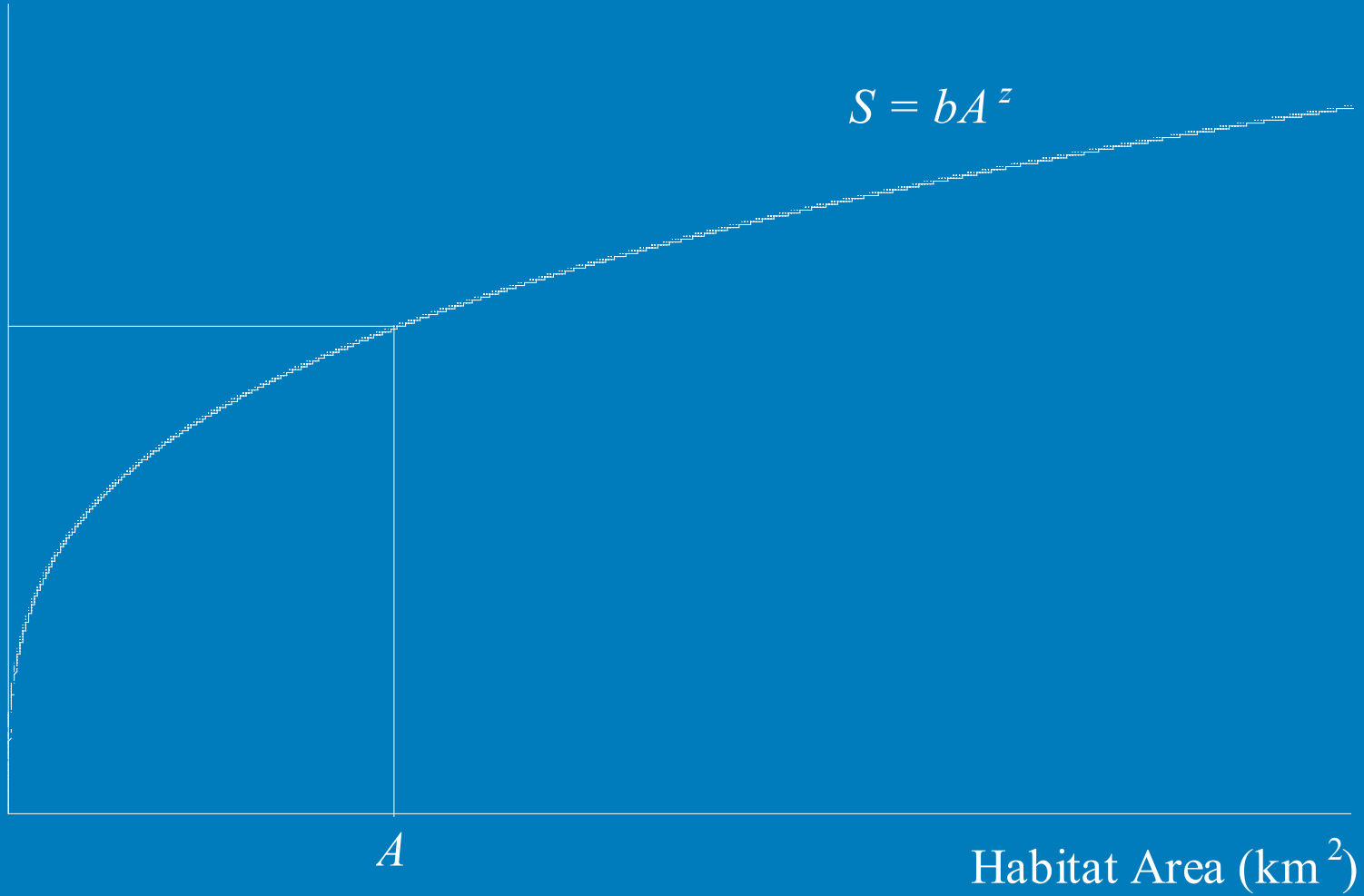
- $C = \sum c_i A_i$, where c_i = cost (per km²) of habitat protection in ecoregion i .
- $S = \sum S_i$, sum of species conserved in ecoregion i (each ecoregion has *unique* set of species)
- $S_i = b_i A_i^z$, species-area function for ecoregion i

Species-area function

- Species-area function relates habitat area to number of species extant in that area
- Long known to be an empirical relation, works particularly well for islands and species of terrestrial flora and fauna
- $S = bA^z$ most common functional form, with $z = 0.2 - 0.4$
- This relation has been applied to *global* extinctions by considering species endemic to particular areas and projecting species extinctions as a result of habitat loss in those areas.
- Hoekstra et al. (2007) have also used the species-area function in examining cost-effectiveness of conservation (and I steal data from their paper)

Species Conserved

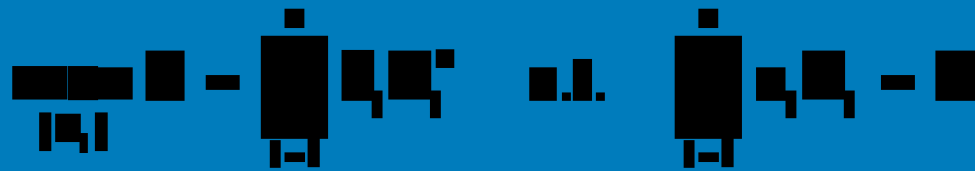
S



A

Habitat Area (km^2)

Cost-effective species conservation: Basic model



S = global number of species conserved;

A_i = area (km²) of habitat protected in ecoregion i

z_i, b_i = parameters of the species-area function for ecoregion i

c_i = cost per km² of habitat protection in ecoregion i , and

C = global conservation budget

Cost-effective species conservation: Basic model and results

$$S = \sum_i A_i^z \quad C = \sum_i c_i A_i$$

Additive separability of $S(\cdot)$ and $C(\cdot)$ makes algebraic solutions possible for A_i^* , w_i^* (share of ecoregion i in total area of habitat protection), and e_i^* (share of ecoregion i habitat protection expenditures in total conservation budget):

$$A_i^* = \frac{b_i}{c_i} \frac{1}{\sum_j \frac{b_j}{c_j}} \quad w_i^* = \frac{b_i}{c_i} / \sum_j \frac{b_j}{c_j} \quad e_i^* = \frac{b_i}{c_i} / \sum_j \frac{b_j}{c_j}$$

where $\theta_i = b_i / c_i$ and $\gamma = 1/(1-z)$

Cost-effective species conservation: Basic model and results

- $\theta_i \Rightarrow$ “Priorities” for relative habitat protection shares

$$\theta_i = \frac{c_i}{\sum_j c_j} = \frac{c_i}{C} \quad \text{where } C = \sum_j c_j$$

- Lagrange multiplier, λ , has simple but important interpretation:

$$\lambda = \frac{\partial \text{Species}}{\partial \text{Budget}}$$

- $\lambda =$ “shadow value” of conservation budget in conserving species (species/\$)

Cost-effective species conservation: Additional habitat constraints

➤ Legacy conservation areas

- Current protected areas can be treated as a set of *minimum* habitat area constraints:

$$\{A_i^0\} \Rightarrow A_i \geq A_i^0$$

➤ Geographic limits on habitat protection

- Limits on available habitat can be treated as a set of *maximum* habitat area constraints:

$$\{A_i^{max}\} \Rightarrow A_i \leq A_i^{max}$$

- ## ➤ Add either or both to Lagrangian and maximize subject to full set of constraints

Cost-effective species conservation: Applications

- Cost-effectiveness and conservation priorities – are there simple rules of thumb to guide conservation?
- Legacy conservation and conservation priorities – how does the existence of such areas change priorities?
- “Representative” conservation:

The Nature Conservancy has set the most ambitious goal in the organization’s history: to work with others to ensure, by 2015, the effective conservation of places that represent at least 10 percent of every major habitat type on Earth.
- **Habitat protection v. habitat restoration**

Ecoregional data for applications

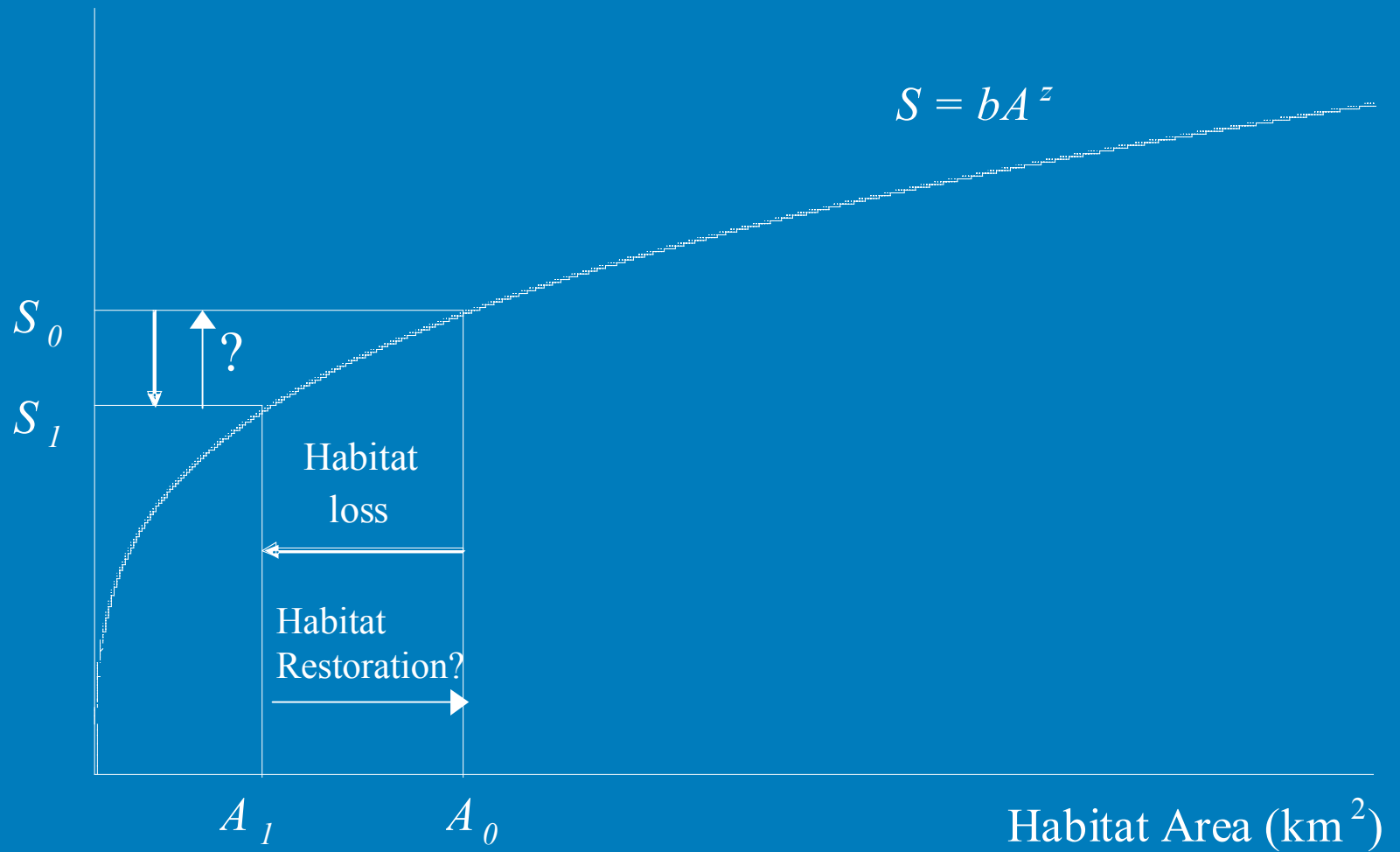
- Data from Hoekstra *et al.* (2007) on species-area parameters and conservation costs for 6 ecoregions used to illustrate applications

Ecoregion	b_i	c_i	z	Maximum Area
Southwest Amazon moist forests	147	\$940	0.3	726,678
Sichuan Basin evergreen broadleaf forests	95	\$1,488		9,913
Peninsular Malaysian rain forests	207	\$3,883		69,036
Veracruz montane forests	210	\$4,353		2,684
Central African mangroves	9	\$1,029		24,830
Mitchell grass downs	18	\$2,332		449,308

Habitat protection and restoration

- The species-area function is most often used to predict species extinctions caused by habitat loss.
- Because an increase in habitat area does not have the power to bring species back from extinction, does this make the species-area curve a "one-way" relation?

Species Conserved



Habitat protection and restoration

➤ Not necessarily:

Models of habitat loss suggest that the process produces an “extinction debt,” a pool of species that will eventually go extinct unless the habitat is repaired or restored. . . . Restoration of the habitat before these extinctions occur may provide an important means of allowing a significant number of species to recover. (Dobson et al., 1997)

Habitat protection and restoration

- Assume that habitat is constrained in ecoregion 1:

$$\sum_{i=1}^n x_i - \sum_{i=1}^n a_i x_i \leq b_1 \quad \text{s.t.} \quad \sum_{i=1}^n a_i x_i - \sum_{i=1}^n c_i x_i \leq A_1 - \sum_{i=1}^n c_i x_i$$

$$x_i - \sum_{i=1}^n a_i x_i \leq b_i \quad \text{s.t.} \quad \sum_{i=1}^n a_i x_i - \sum_{i=1}^n c_i x_i \leq A_1 - \sum_{i=1}^n c_i x_i$$

- Let the maximal number of species obtained from the solution to this problem be:

$$S^* = S^*(b_i, c_i, z, C, A_1^{max}) = S^*(C, A_1^{max})$$

Habitat protection and restoration

- Consider the first-order condition for ecoregion 1:

$$\frac{\partial U_1}{\partial H_1} = \alpha_1 H_1^{\alpha_1 - 1} - \beta_1 H_1 - \lambda_1$$

- If the habitat constraint is binding, then we have

$$\alpha_1 H_1^{\alpha_1 - 1} - \beta_1 H_1 = \lambda_1$$

Species

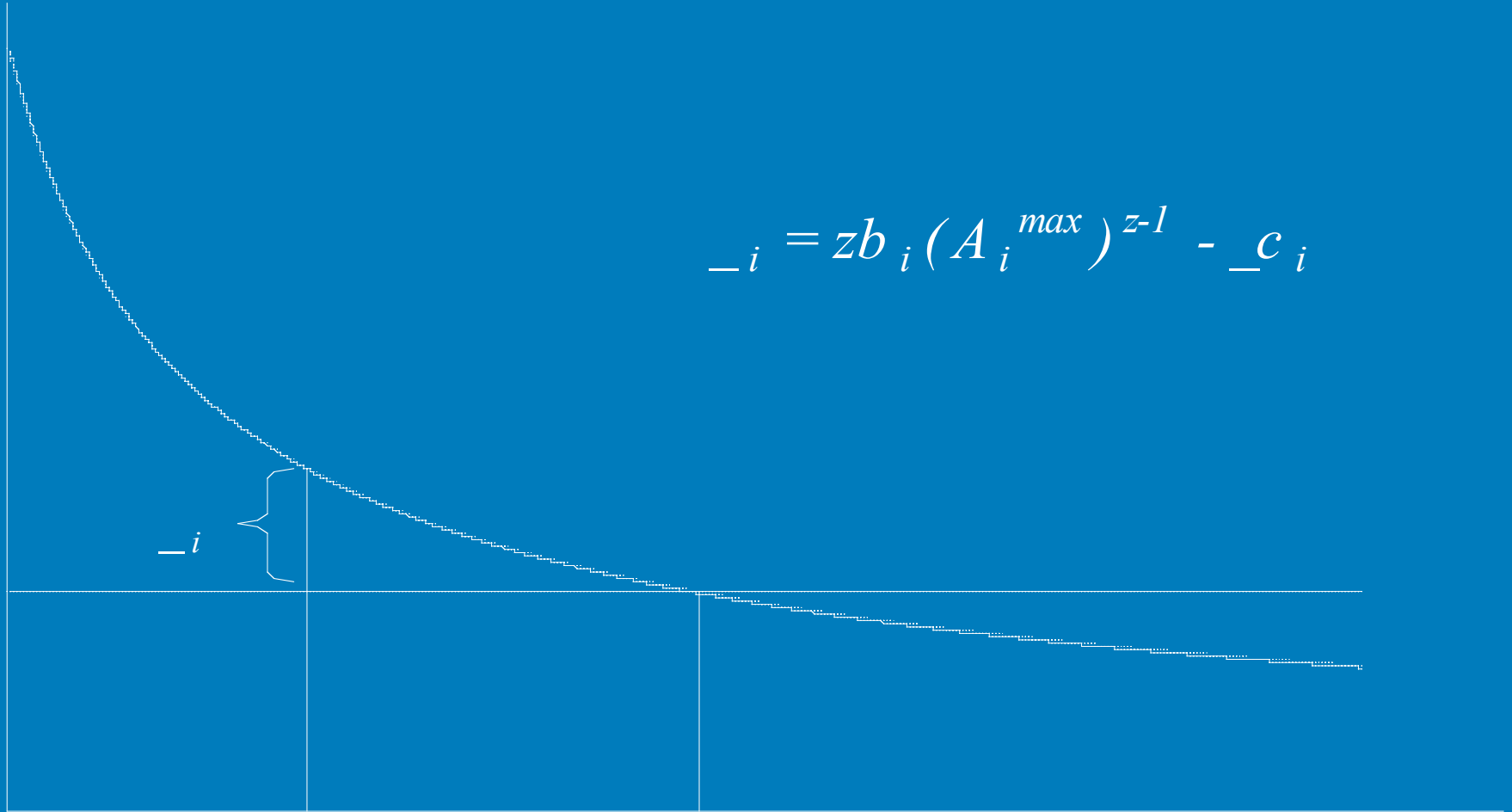
$$S_i = zb_i(A_i^{max})^{z-1} - c_i$$

S_i

A_i^{max}

A_i^*

Habitat Protection (km²)



Habitat protection and restoration

- As was the case for λ , δ_1 has an important interpretation:

$$\frac{\partial \text{MB}}{\partial H_1} = \frac{\partial \text{MB}}{\partial H_2} = \dots = \delta_1$$

- $\delta_1 = \text{MB of relaxing maximum habitat constraint}$
= MB of habitat restoration (in species)
- Suppose
 - Habitat can be restored in ecoregion 1 at a cost of r_1 per km^2
 - Restoration funding must come out of the conservation budget
- What is the “optimal” amount of habitat restoration?

Habitat protection and restoration

➤ Let

- C_0 = Conservation budget (protection, C_P , + restoration, C_R)
- A_I^0 = Initial maximum area for ecoregion 1
- A_I^R = Restored habitat in ecoregion 1

➤ Then,

- $A_I^{max} = A_I^0 + A_I^R$
- $C_P = C_0 - C_R = C_0 - r_I A_I^R$

Habitat protection and restoration

- Substitute these expressions into S^* :

$$S^* = S^*(C_P, A_1^{max}) = S^*(C_0 - r_1 A_1^R, A_1^0 + A_1^R)$$

and solve a new optimization problem:

$$\max_{A_1^R} S^*(C_0 - r_1 A_1^R, A_1^0 + A_1^R)$$

Habitat protection and restoration

- First-order condition:

$$\frac{p_1' \cdot H_1}{p_2 \cdot H_2} = \frac{p_1' \cdot H_1^*}{p_2 \cdot H_2^*} = 1$$

- Substitute from original maximization:

$$p_1 \cdot H_1 = p_2 \cdot H_2$$

$$p_1 \cdot H_1^* = p_2 \cdot H_2^* = p_1 \cdot H_1 = p_2 \cdot H_2$$

Species conserved

$$MB_R = -I$$

$$MC_R = -r I$$

$A_1^{R^*}$

Habitat restored (km²)



Species conserved

Effect of budget increase ($C_1 \rightarrow C_2$) on $A_1^{R^*}$

$MB_R(C_1)$

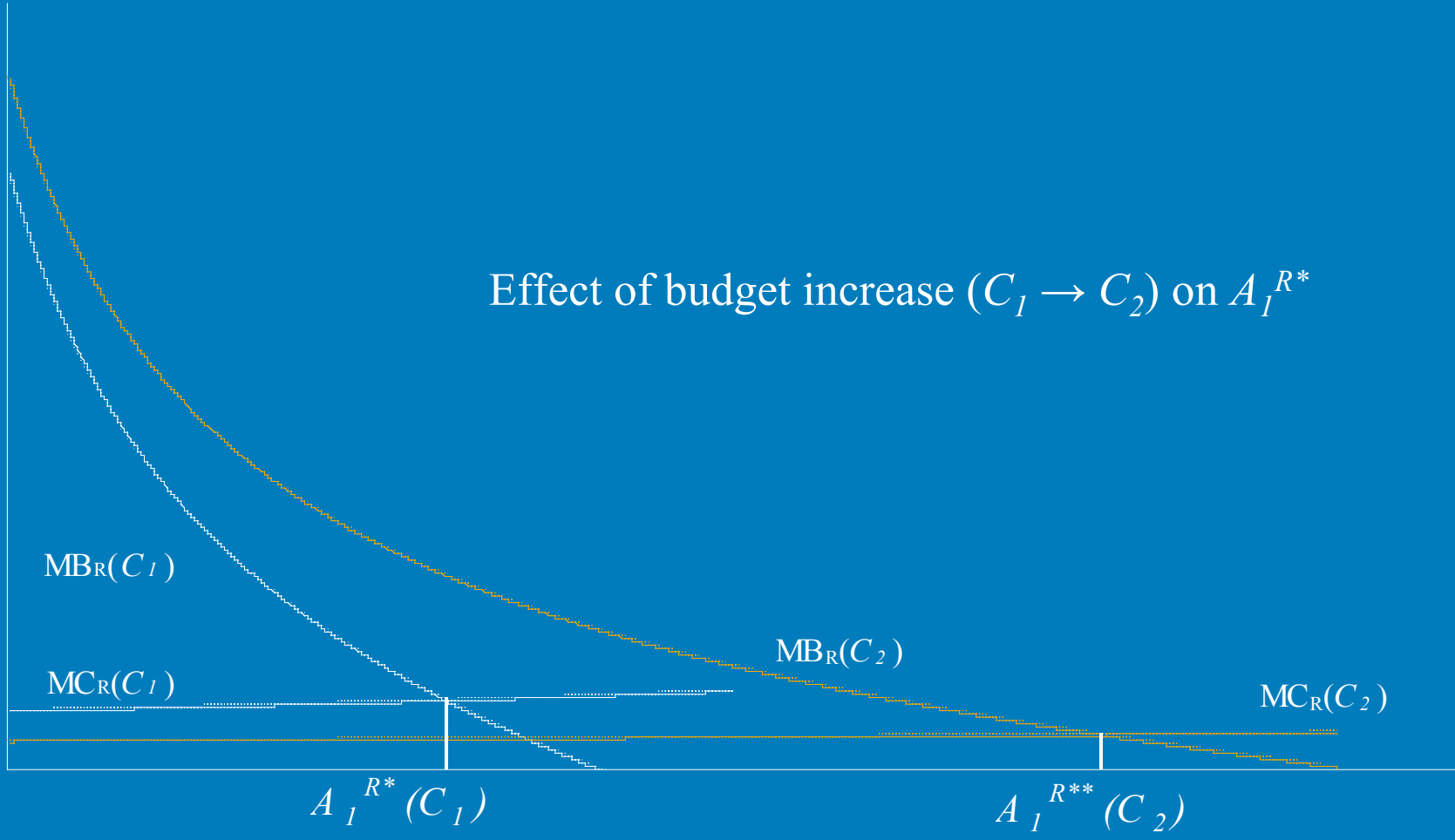
$MC_R(C_1)$

$MB_R(C_2)$

$MC_R(C_2)$

$A_1^{R^*}(C_1)$

$A_1^{R^{**}}(C_2)$



From CEA to BCA?

- Invert the model and you get one-half of a standard BCA:

$$V(x_1, x_2, \dots, x_n) = V(x_1, x_2, \dots, x_n) - V(x_1, x_2, \dots, x_n)$$

$$= V(x_1, x_2, \dots, x_n) - V(x_1, x_2, \dots, x_n) = \text{Value of biological good}$$

- Still need a function that captures the value/WTP for the appropriate biological metric
 - Valuations for species – about 40 – 50 studies exist, only 10-20% of which are acceptable
 - Ecological values holds out some hope, but data are worse
 - “Biodiversity”?

The Value of Biodiversity: Bird feeders and Deer feeders

"Well, I suppose I would associate [biodiversity] with just looking out in the backyard, you know, looking at the bird feeders and the deer feeders and ferns and the elms and the oaks making a place interesting, making it um I don't know, ecologically uh balanced is what I think about. In fact, this morning I saw a mother [deer] and two fawns out here. It was wonderful, and the hummingbirds were flying at the feeder at the same time, so here I'm looking at all these beautiful, wonderful things that make me feel just great, it's a spiritual connection to me."

- Heberlein, Wilson, Bishop, and Schaeffer (2005)