The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2022-15

Workshop on Theoretical Ecology and Global Change

2 - 18 March 2009

Food Web Collapse and the decline of ecosystem services

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Food web collapse and the decline of ecosystem services

Andy Dobson

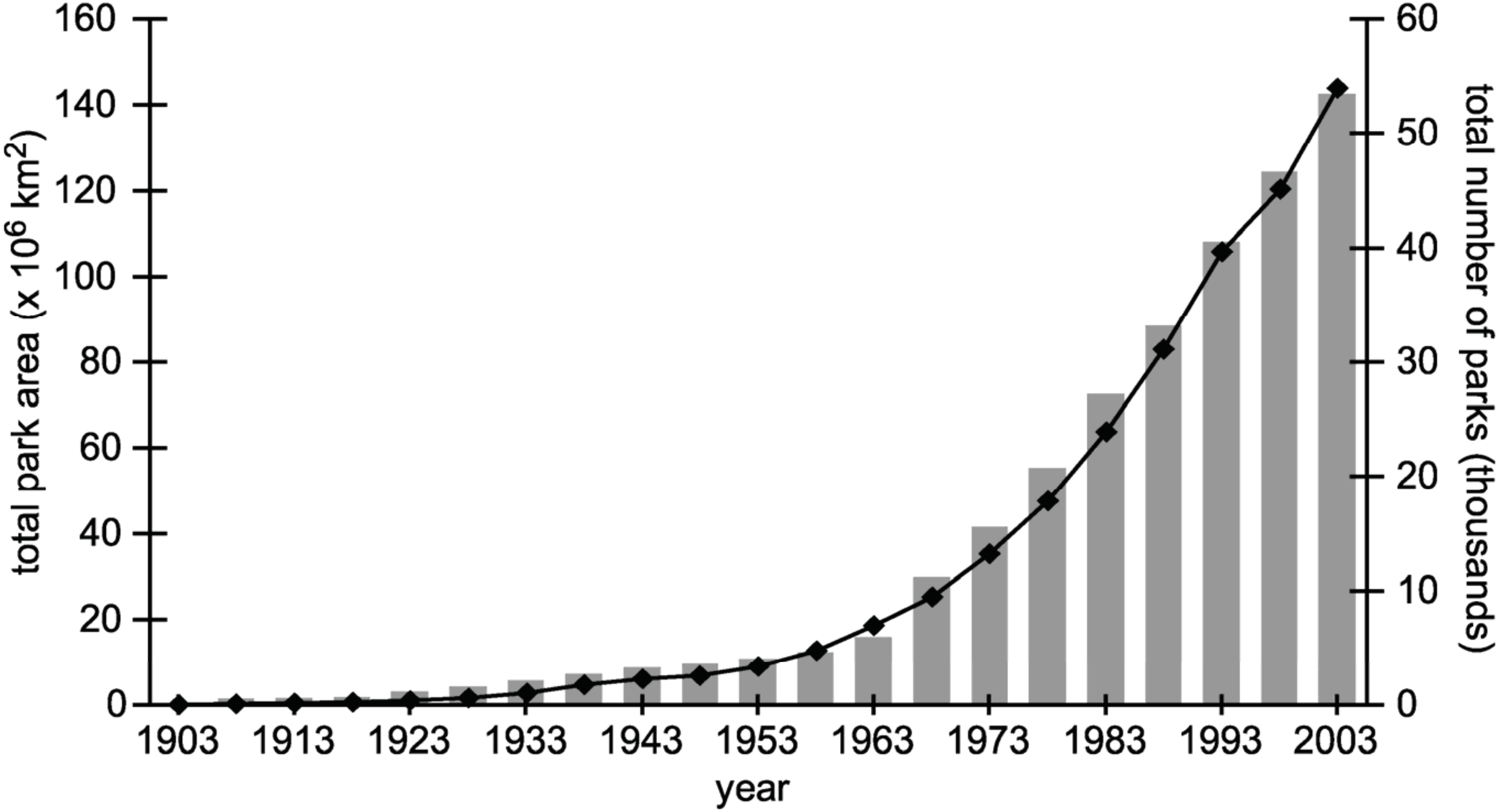
Principal collaborators

- David Wilcove
- Will Turner
- Walter Jetz
- Jon-Paul Rodriguez
- Mark Roberts
- MA Scenarios Team

Brief Outline

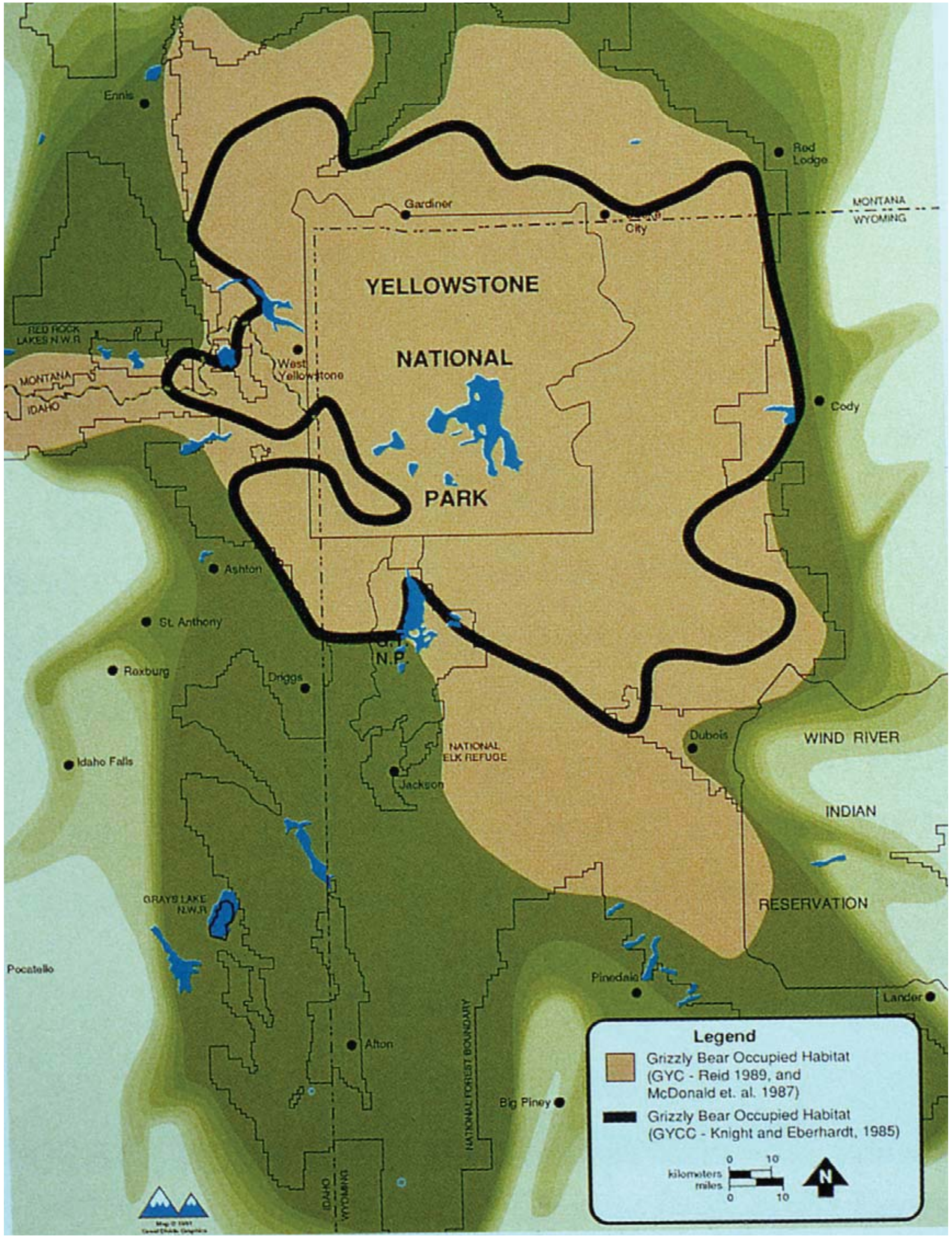
- Population Viability Analysis
- Future threats to birds
- Identifying sites to protect
- Ecosystem Services & habitat loss
- Dynamics of habitat loss
- Trophic collapse and ecosystem services

Global Nature Reserves



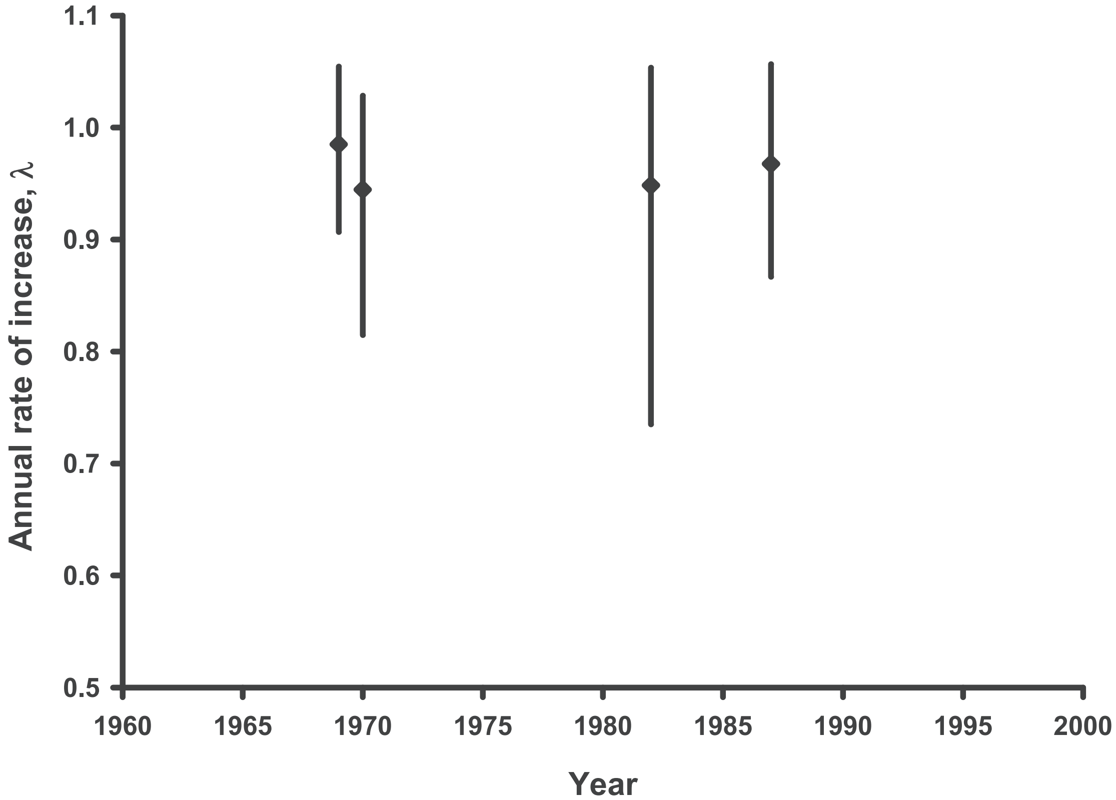

"FOR THE BENEFIT AND
ENJOYMENT OF THE PEOPLE"

Do these parks protect biodiversity?

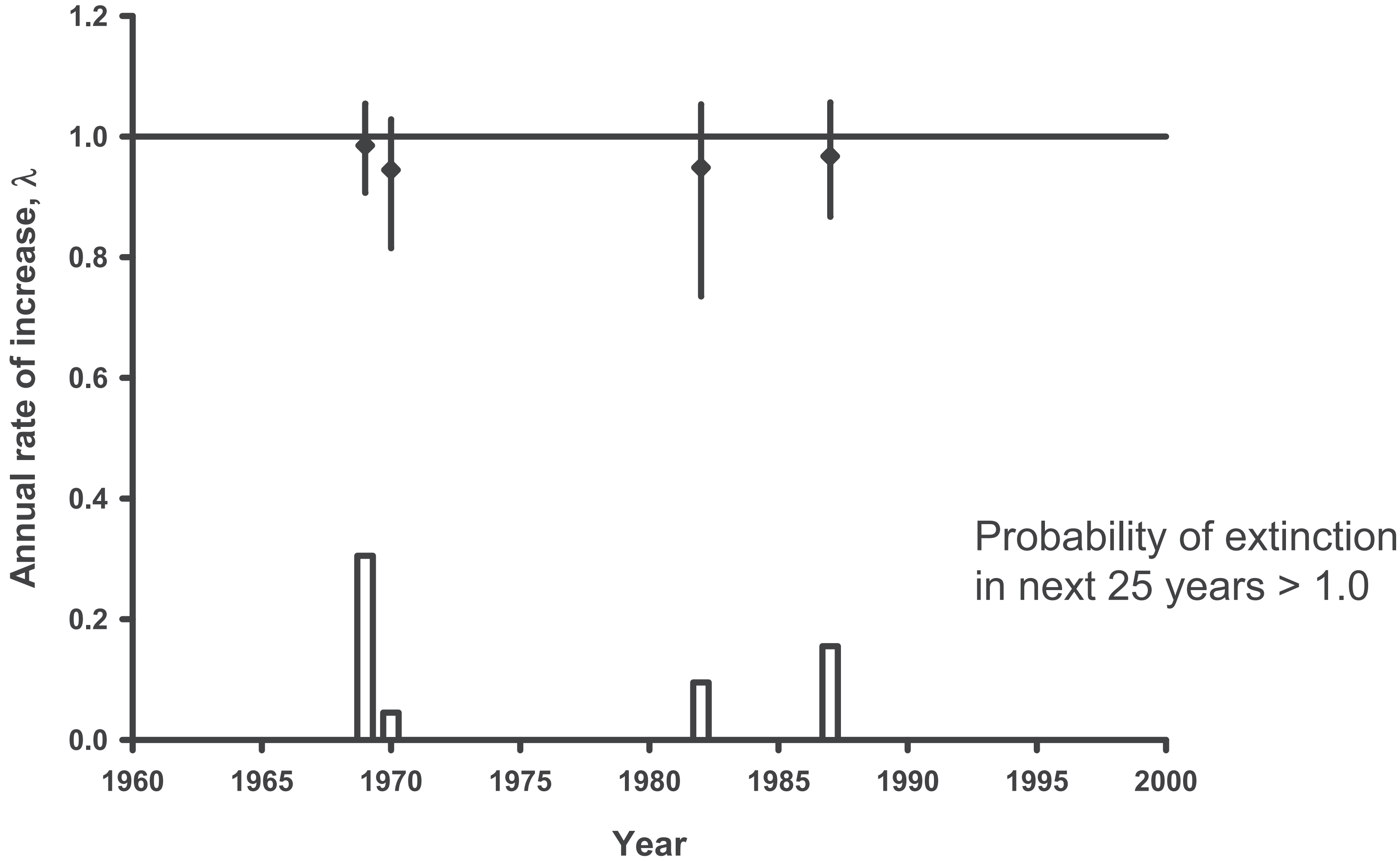


Ennis
Red Lodge
Gardiner
City
MONTANA
WYOMING
YELLOWSTONE
NATIONAL
PARK
RED ROCK LAKES N.W.R
MONTANA
IDAHO
West Yellowstone
Cody
Ashton
St. Anthony
Rexburg
Driggs
N.P.
NATIONAL ELK REFUGE
Jackson
Dubois
WIND RIVER
INDIAN
RESERVATION
Idaho Falls
GRAYS LAKE N.W.R.
Pocatello
Pinedale
Lander
Afton
Big Piney
NATIONAL FOREST BOUNDARY
IDAHO
WYOMING
Legend
Grizzly Bear Occupied Habitat (GYC - Reid 1989, and McDonald et. al. 1987)
Grizzly Bear Occupied Habitat (GYCC - Knight and Eberhardt, 1985)
kilometers 0 10
miles 0 10
N

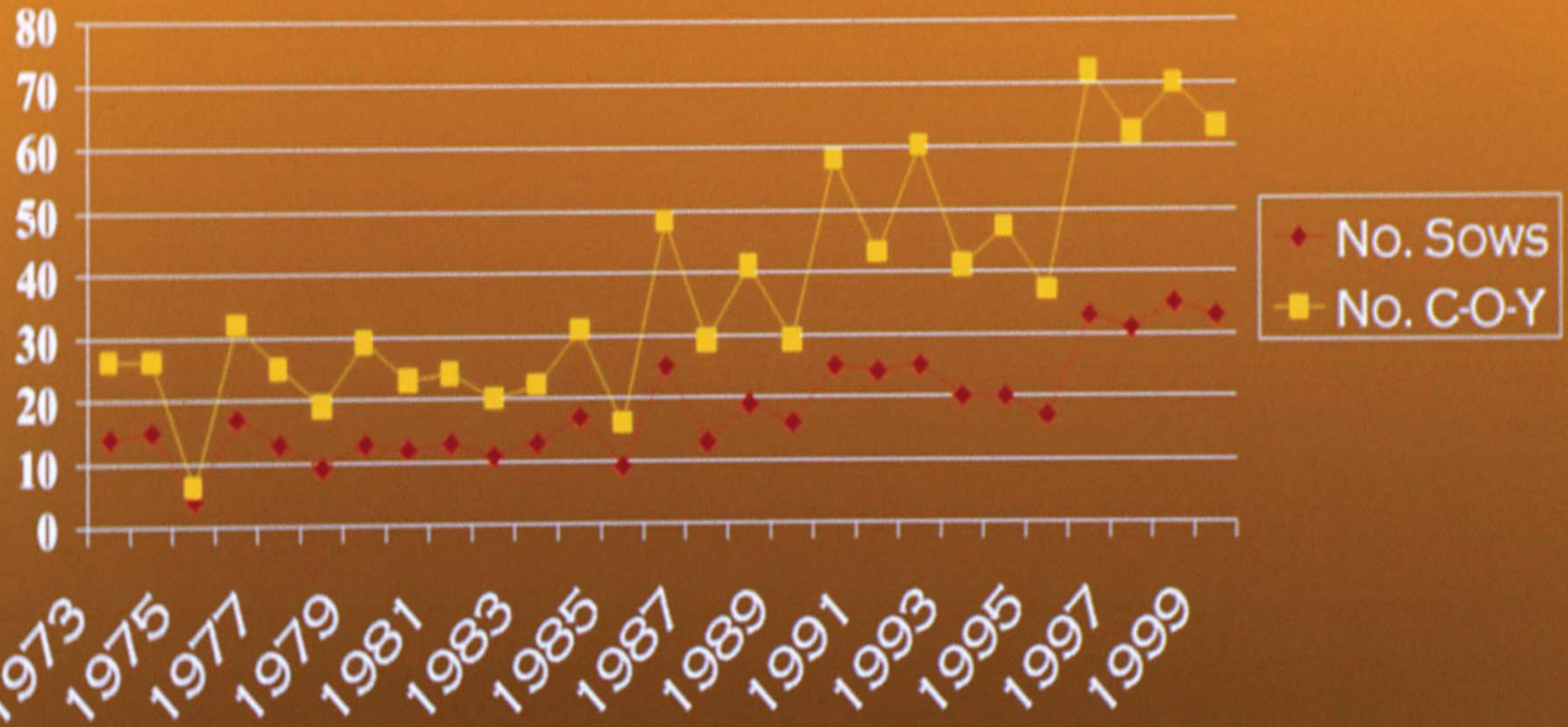
PVA's for Yellowstone Grizzly's



PVA for Yellowstone grizzly bears

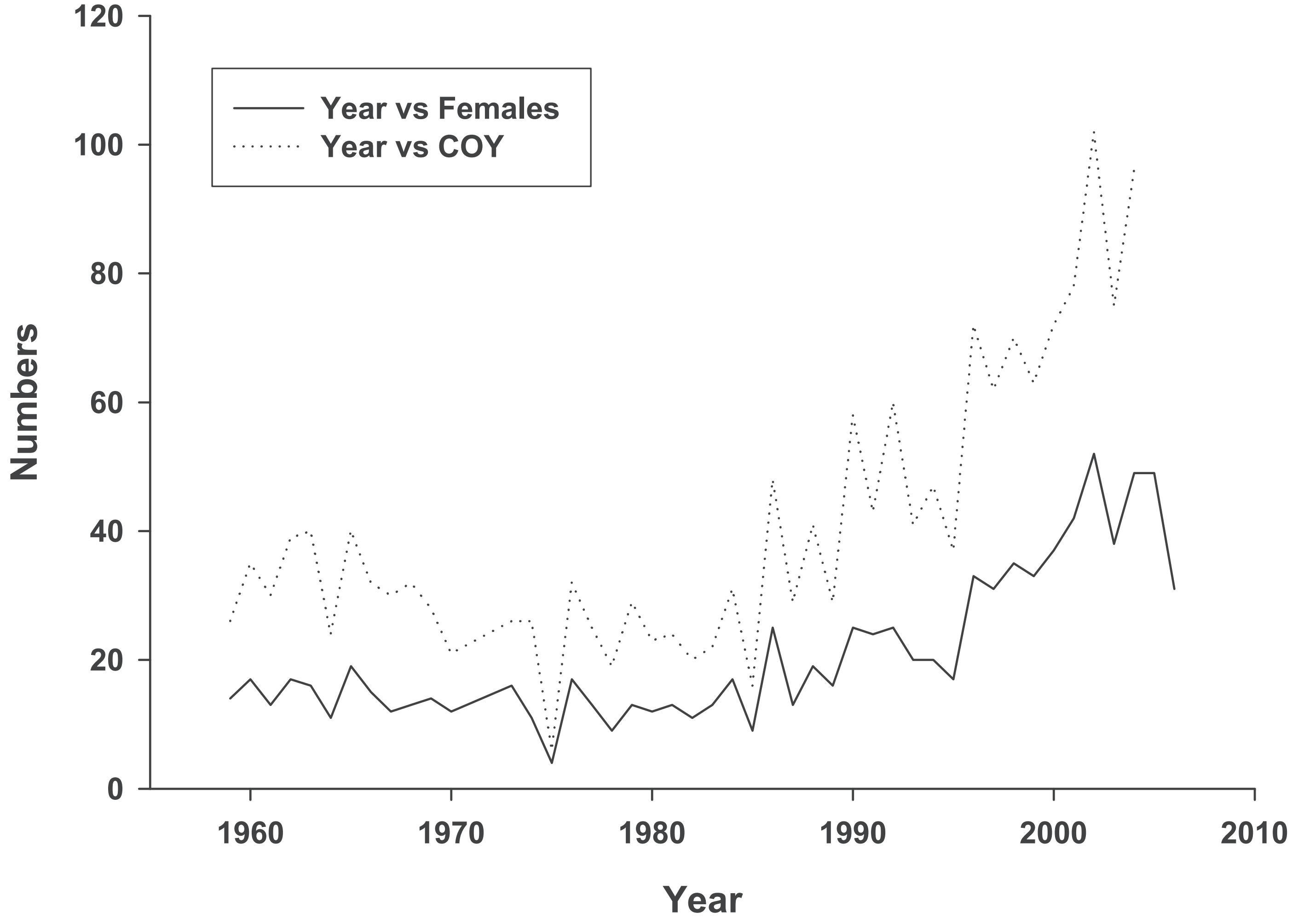


Grizzly Bear Reproduction Greater Yellowstone Area 1973-1999

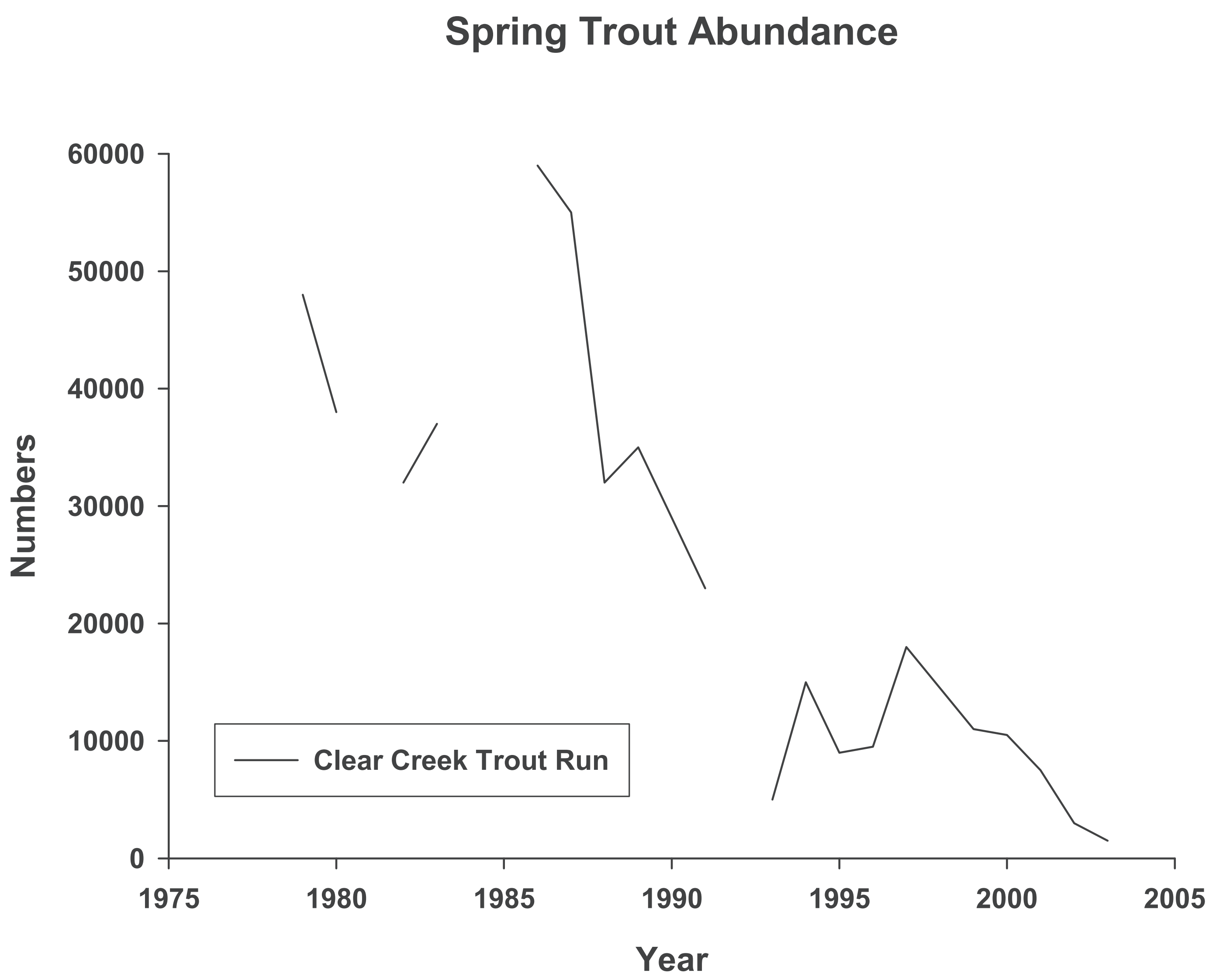


Source: 1999 Annual Report of the Interagency Grizzly Bear Study Team

Observed females with cubs



Resources for grizzlies



Future PVA : Detailed stochastic demographic model..with “peer-reviewed” data ?

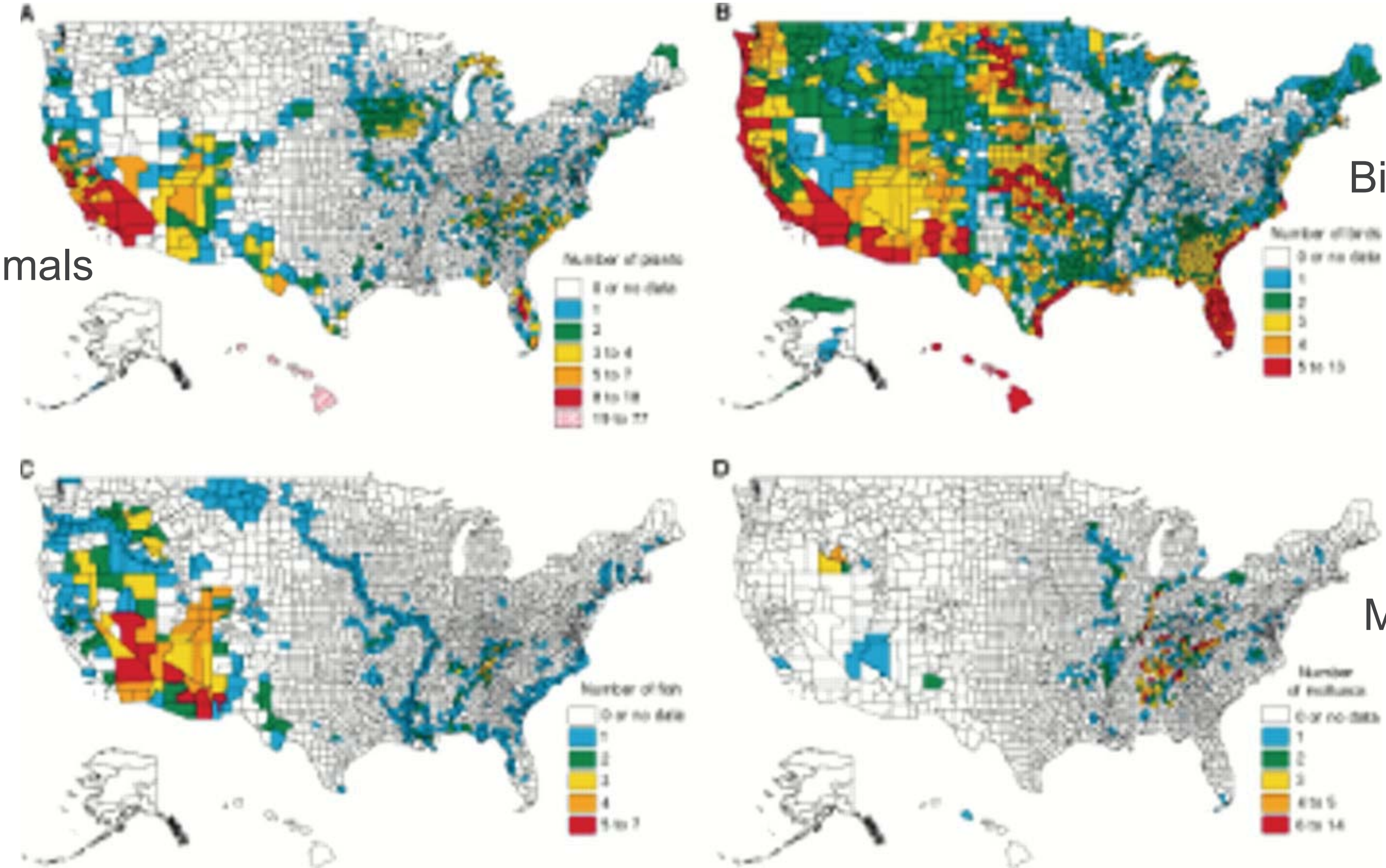
Or : More phenomological bear / habitat / resource model ?

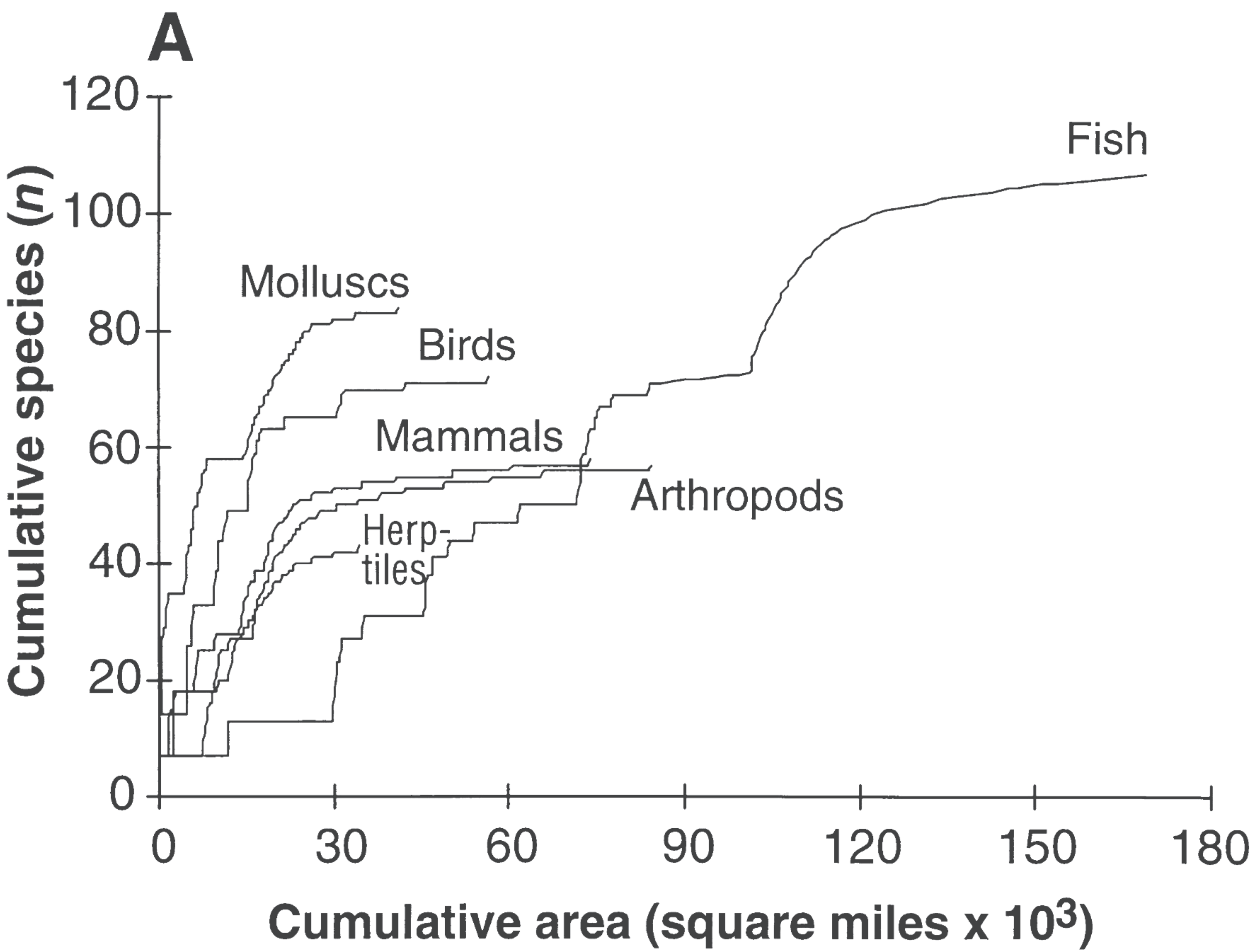
What determines where we put new nature reserves?

Criteria for establishing and expanding reserve systems

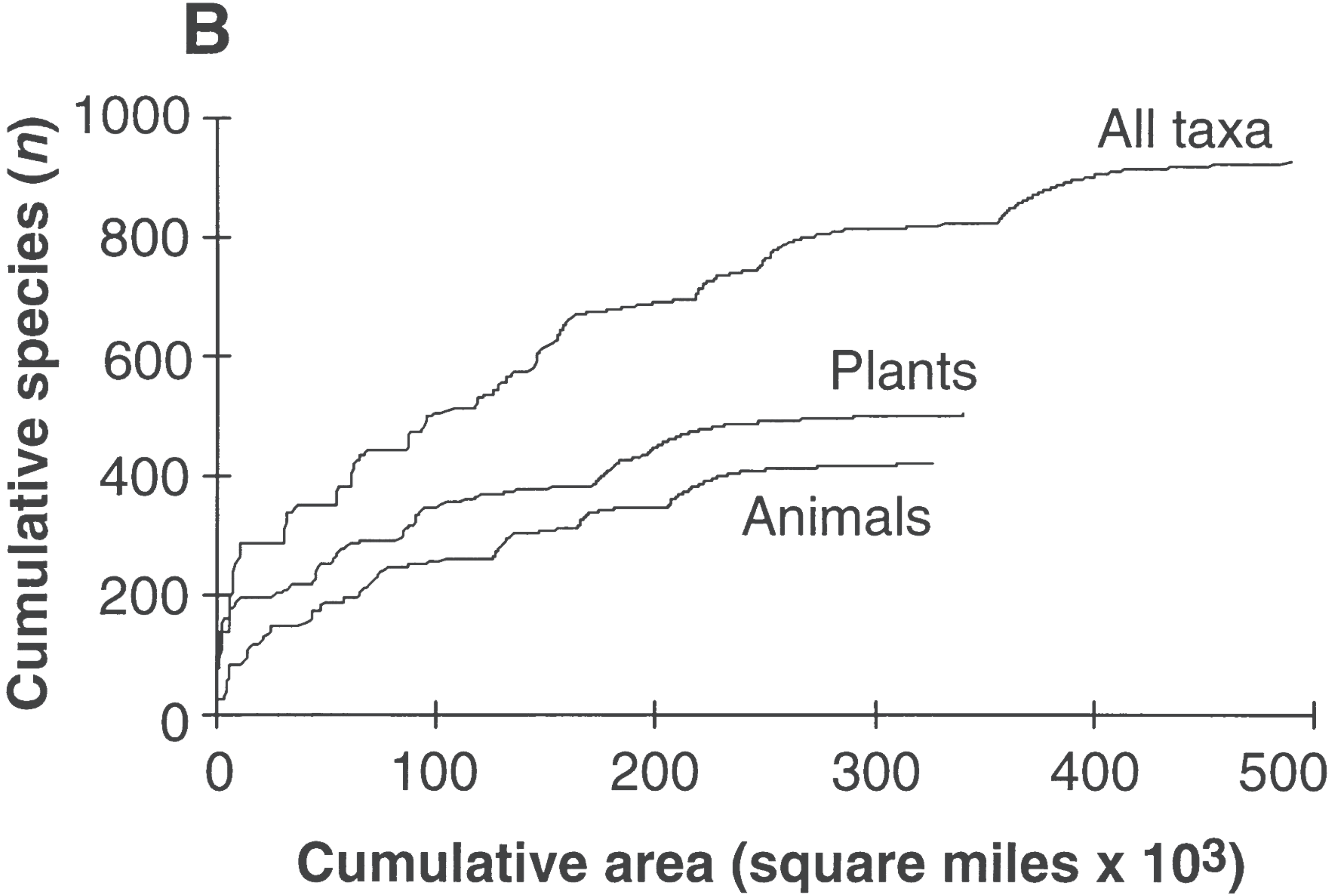
- Spatial distribution of species that need to be conserved
- Cost and availability of land
- Present and future threats
- Selection algorithms focus on different criteria – can we develop ones that ‘optimize’ across present and future threats?

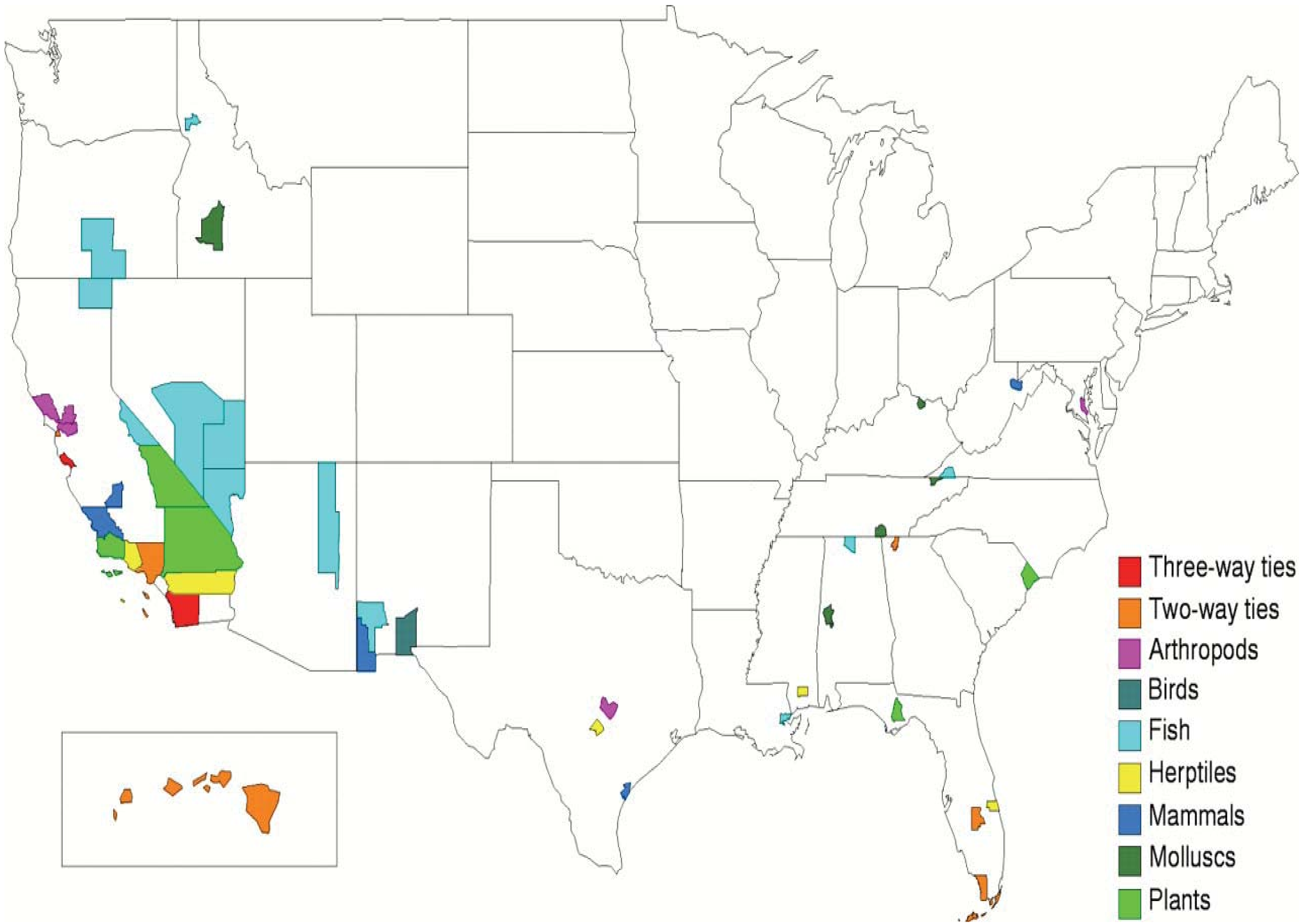
Geographical distribution of Endangered species in the US




A
Cumulative species (n)
120
100
80
60
40
20
0
Fish
Molluscs
Birds
Mammals
Arthropods
Herp-
tiles
0
30
60
90
120
150
180
Cumulative area (square miles x 10^3)

What is minimal area required to protect at least one population of all currently listed US Endangered Species?



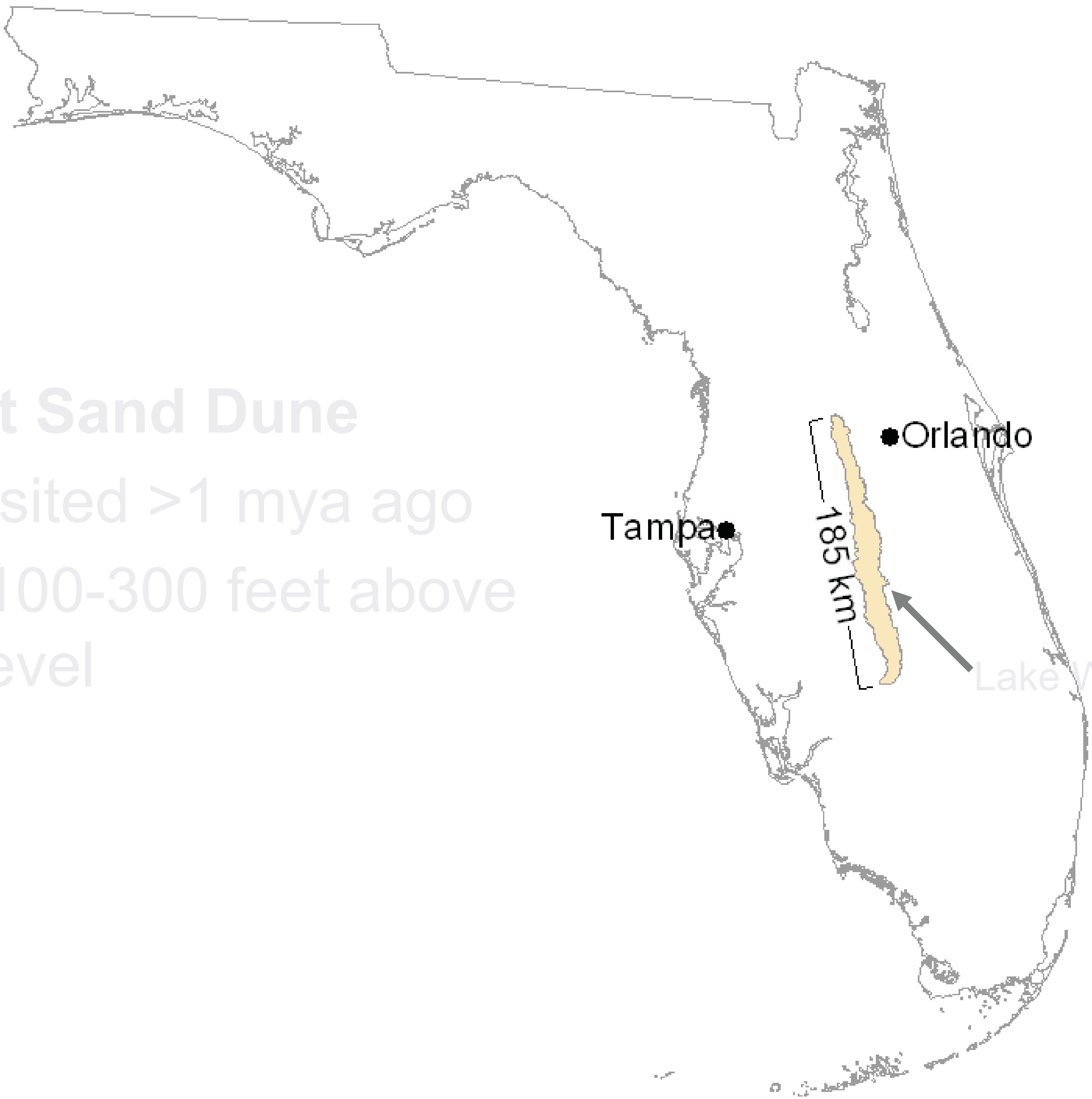


Three-way ties
Two-way ties
Arthropods
Birds
Fish
Herptiles
Mammals
Molluscs
Plants

Florida scrub jay

Ancient Sand Dune

- Deposited >1 mya ago
- now 100-300 feet above sea level



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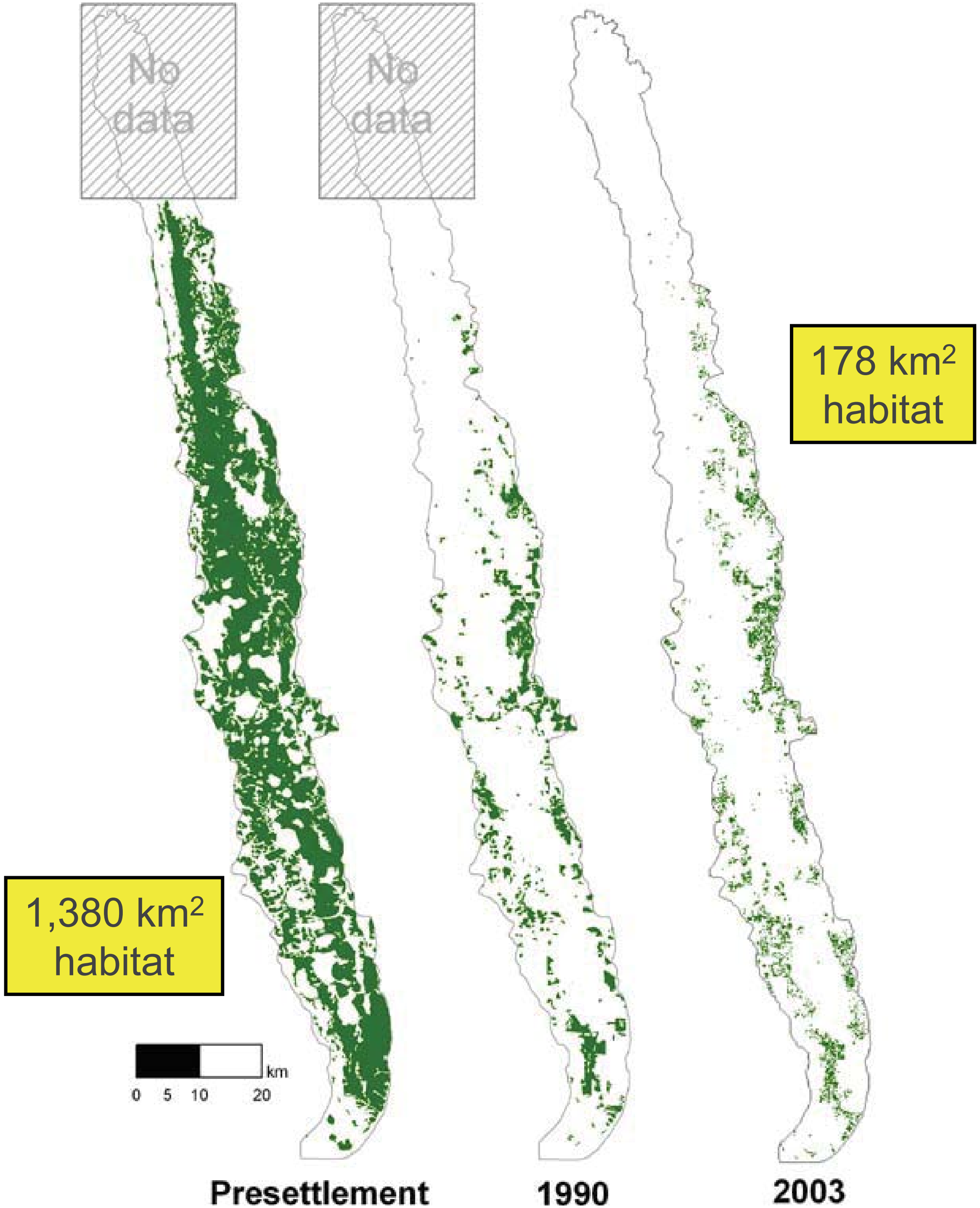
© R. Bowman


No data
No data
178 km²
habitat
1,380 km²
habitat
0 5 10 20
km
Presettlement
1990
2003

Species

© S. Telford

Quantifying future threats: The MA Scenarios

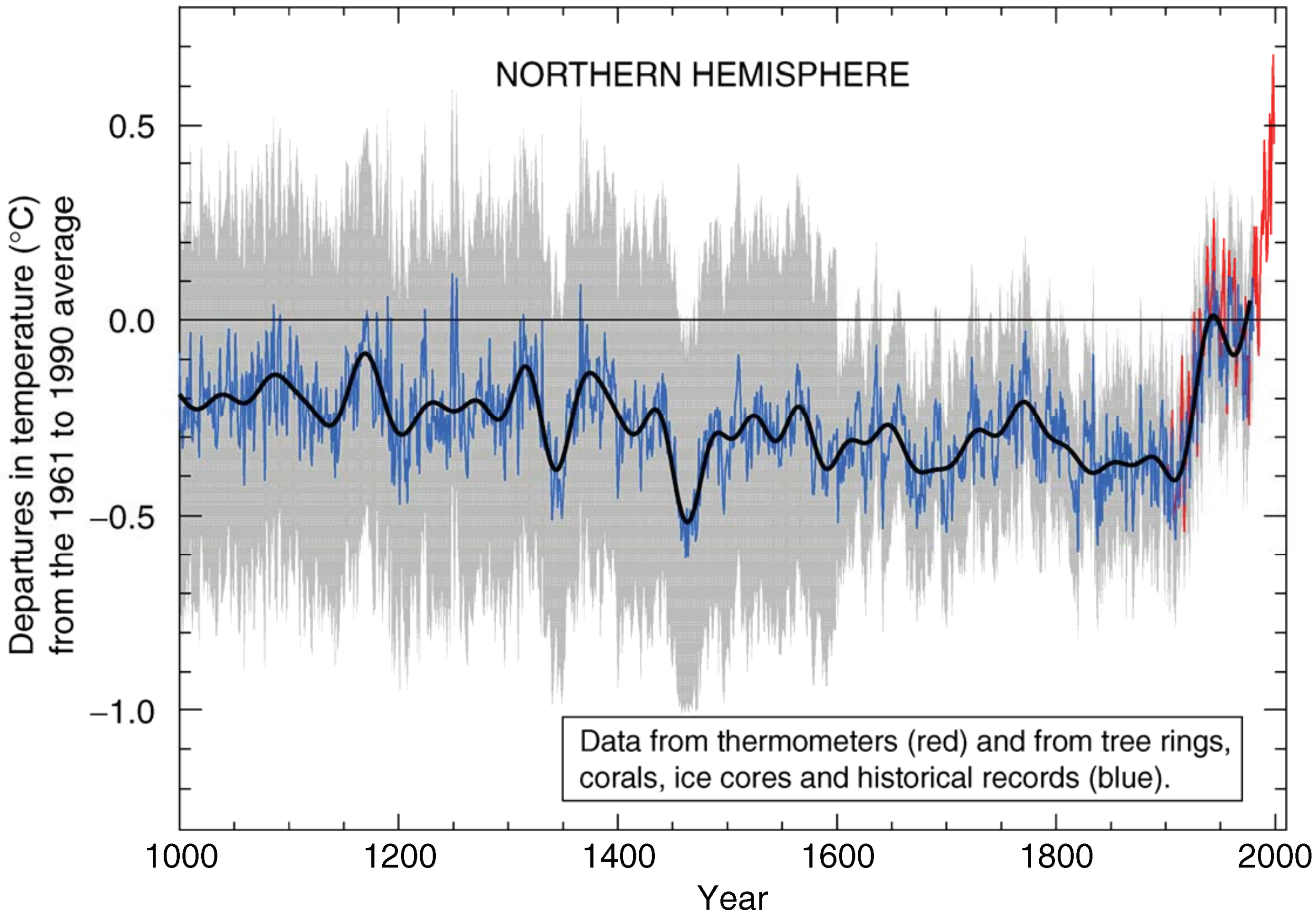
- Use a range of climate and human population growth projections to examine possible futures
- Climate change is based on the IGPCC projections
- Human population based on a range of economic projections that assume different responses to environment

Future land-use and climate change and extinction risk in birds

Walter Jetz
Biological Sciences
University of California San Diego

David S. Wilcove
Andy P. Dobson
Ecology, Evolutionary Biology
Princeton Univeristy

Observed climate change



Observed change in annual mean temperature

The impact on species?

The impact on species?

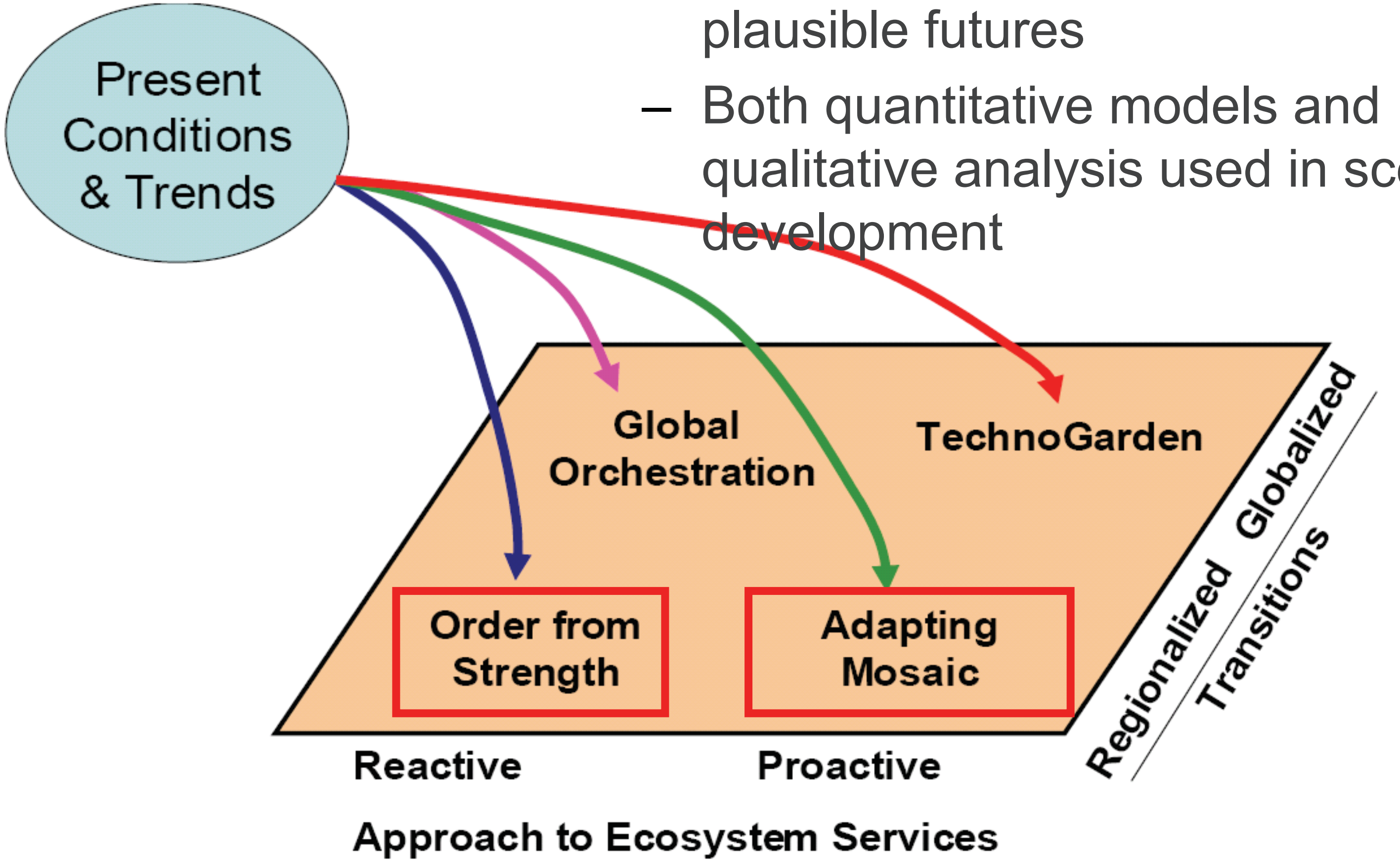
(following Thomas et al., Nature 2004)

The Millennium Ecosystem Assessment

4 Scenarios

about the future of the world

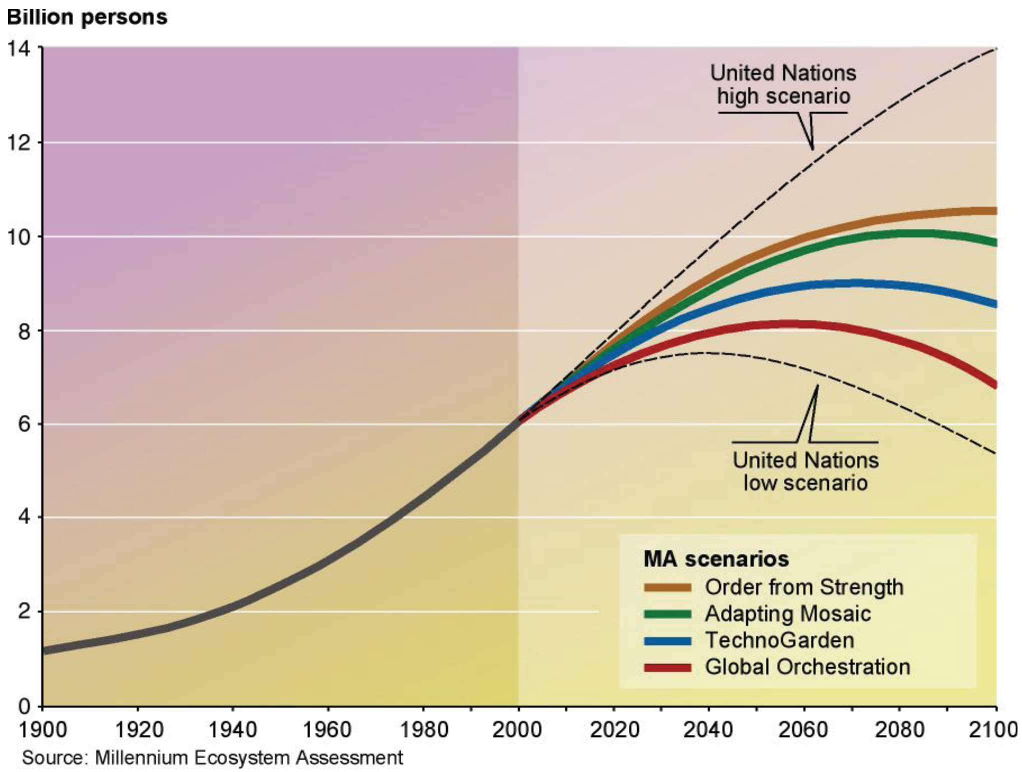
- Not predictions – scenarios are plausible futures
- Both quantitative models and qualitative analysis used in scenario development



Source: Millennium Ecosystem Assessment

Changes in indirect drivers

- In MA Scenarios:
  - Population projected to grow to 8–10 billion in 2050
  - Per capita income projected to increase two- to fourfold



Source: Millennium Ecosystem Assessment

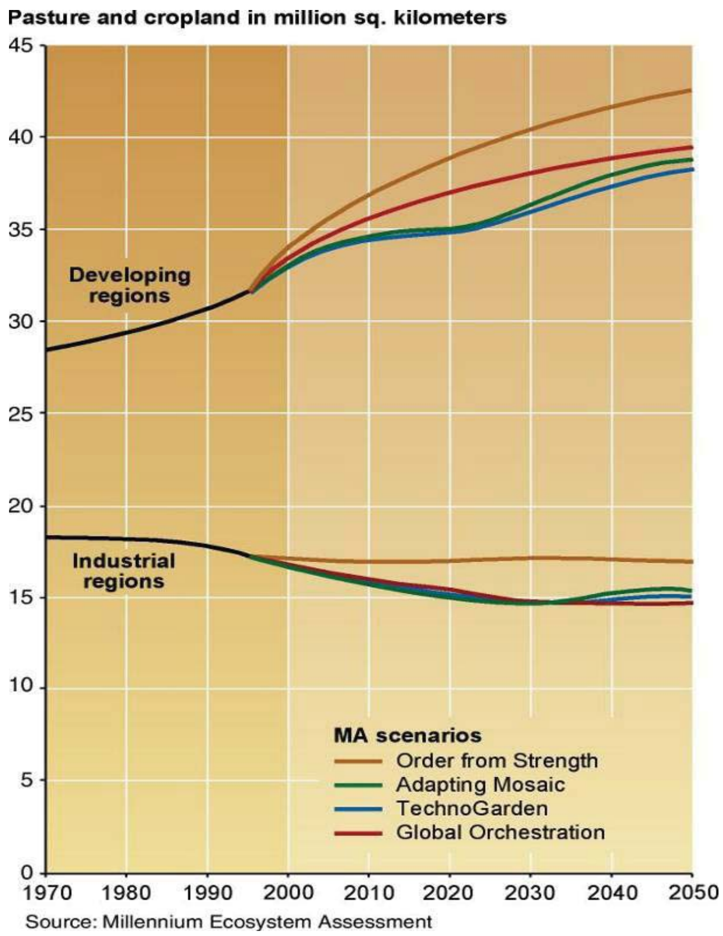
Changes in indirect drivers

Table 9.11. Kyoto Greenhouse Gas Emissions in 1995 and Assumptions for 2050in MA Scenarios (IMAGE 2.2)

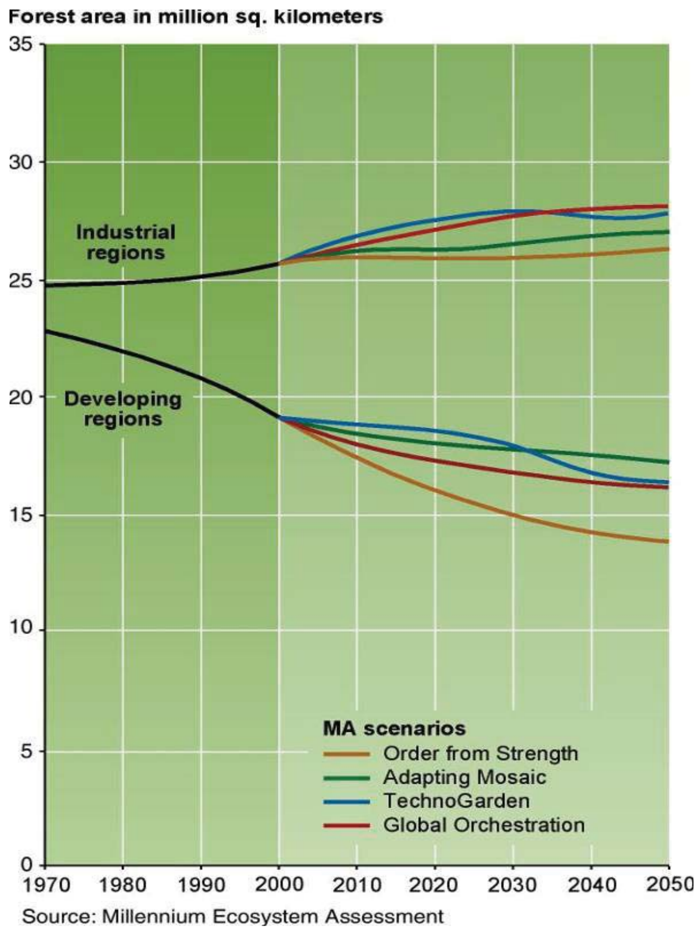
Greenhouse Gas	Emissions in 1995	Global Orchestration	Order from Strength	Adapting Mosaic	Techno-Garden
		(emissions in GtC-equivalent[a])			
CO_2	7.3	20.1	15.4	13.3	4.7
CH_4	1.8	3.7	3.3	3.2	1.6
N_2O	0.7	1.1	1.1	0.9	0.6
Other GHG	0.0	0.7	0.5	0.6	0.2
		(percent)			
OECD and former Soviet Union as share of total emissions	48	30	34	29	22

[a] GtC-equivalent emissions are the contribution of different greenhouse gases expressed in tons of carbon based on 100-year global warming potentials.

Changes in direct drivers

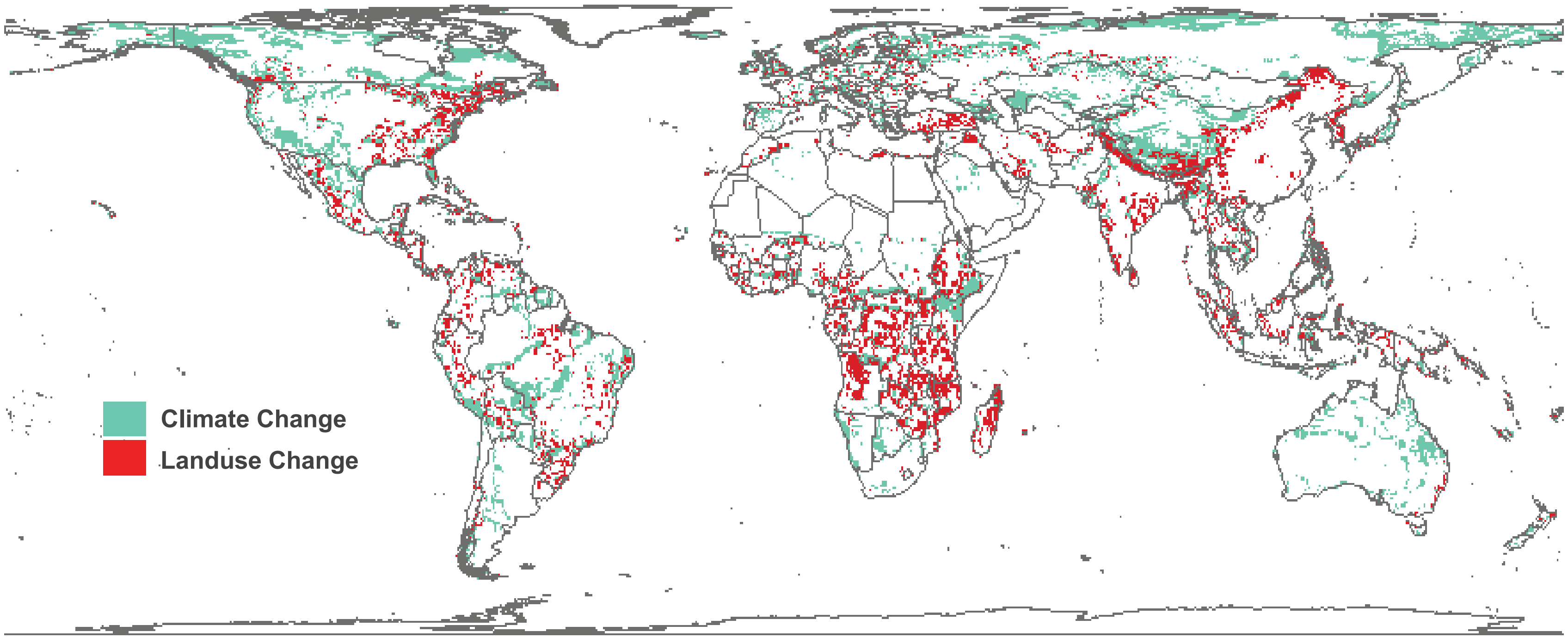


Crop Land



Forest Area

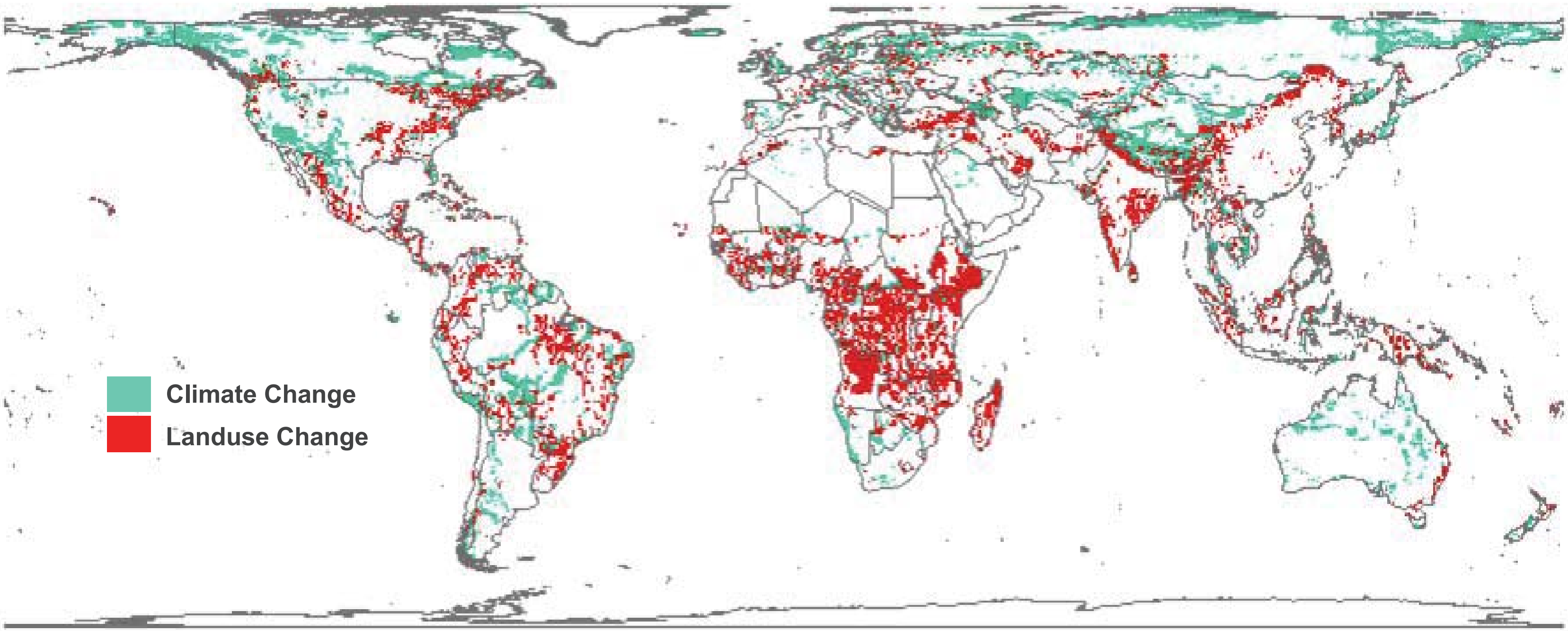
Climate and Land-use Change: The Global Patttern



Adapting Mosaic 2100

Model: Image 2.2
(Strengers et al 2005)

Climate and Land-use Change: The Global Patttern

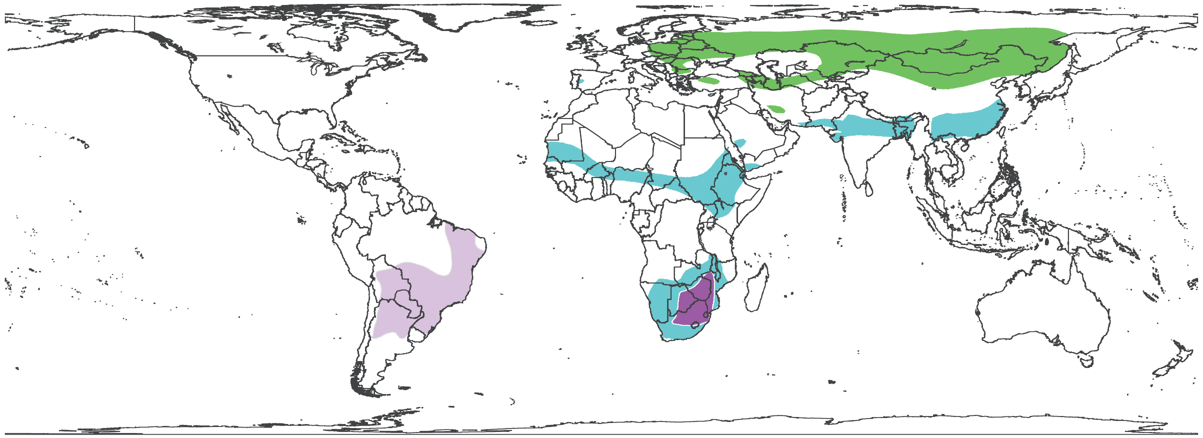


Order from Strength, 2100

Model: Image 2.2
(Strengers et al 2005)

?

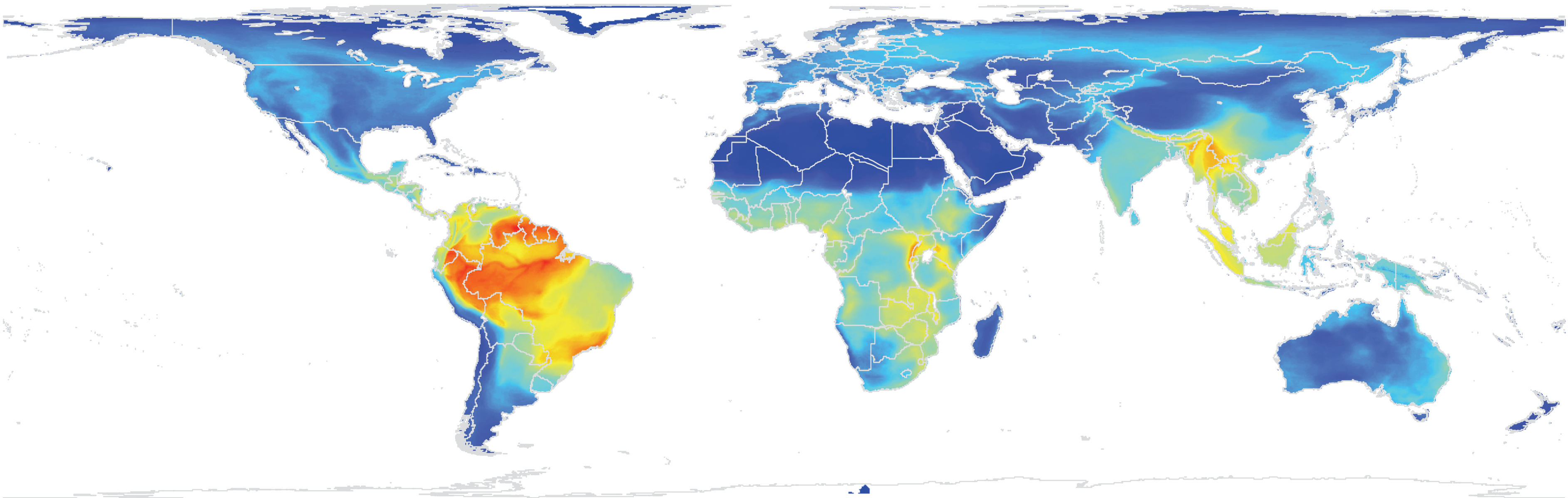
A global distribution database



- Distribution ranges of all 9,754 species, geo-registered to known projection
- Following analysis:
  - polygon ranges resampled to 0.5° grid (259,200 quadrats)
  - 11,418,435 quadrat records
  - Excluded 838 freshwater, marine and pelagic species
  - Breeding ranges only

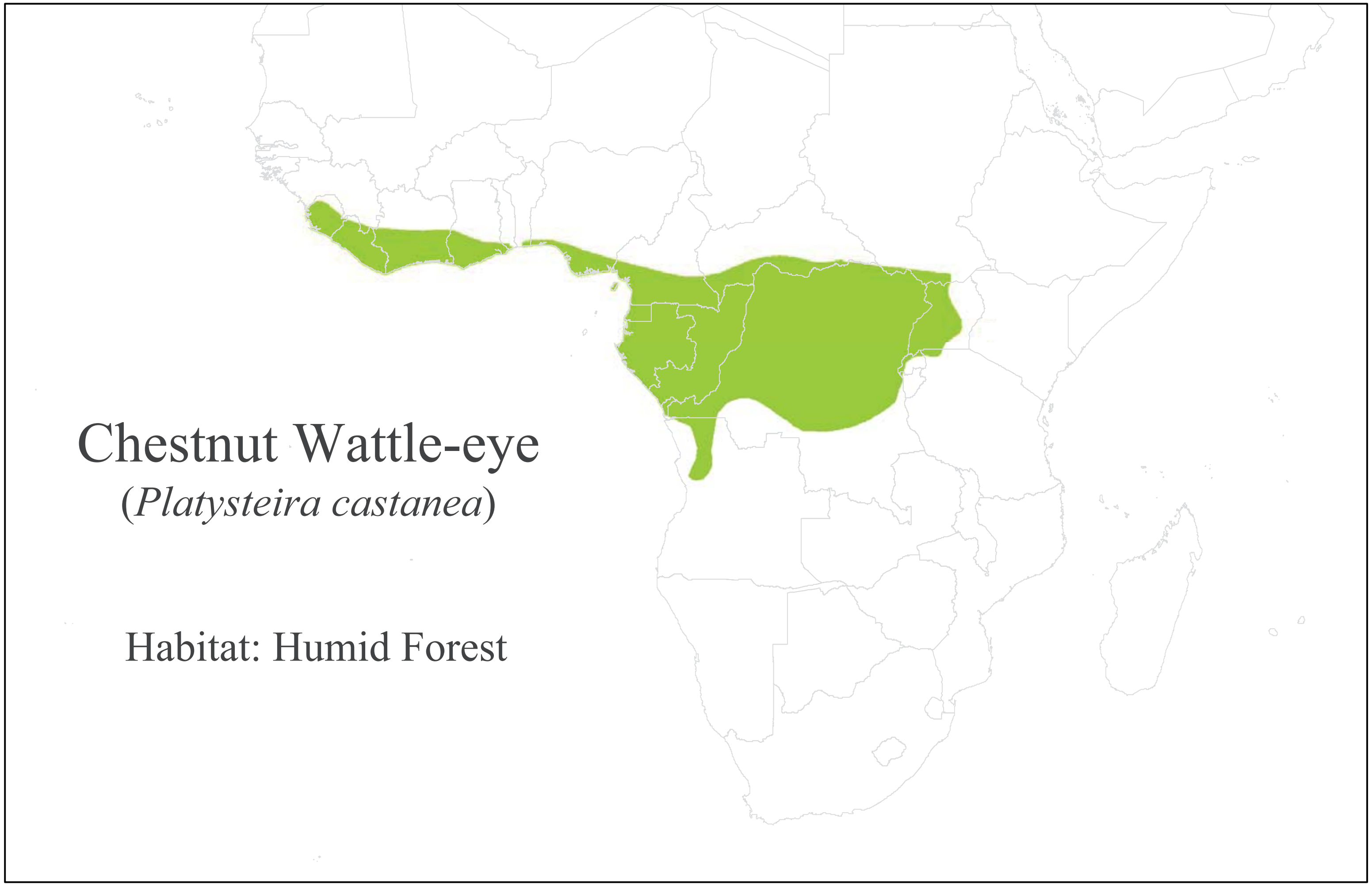
The geographic pattern

All Aves

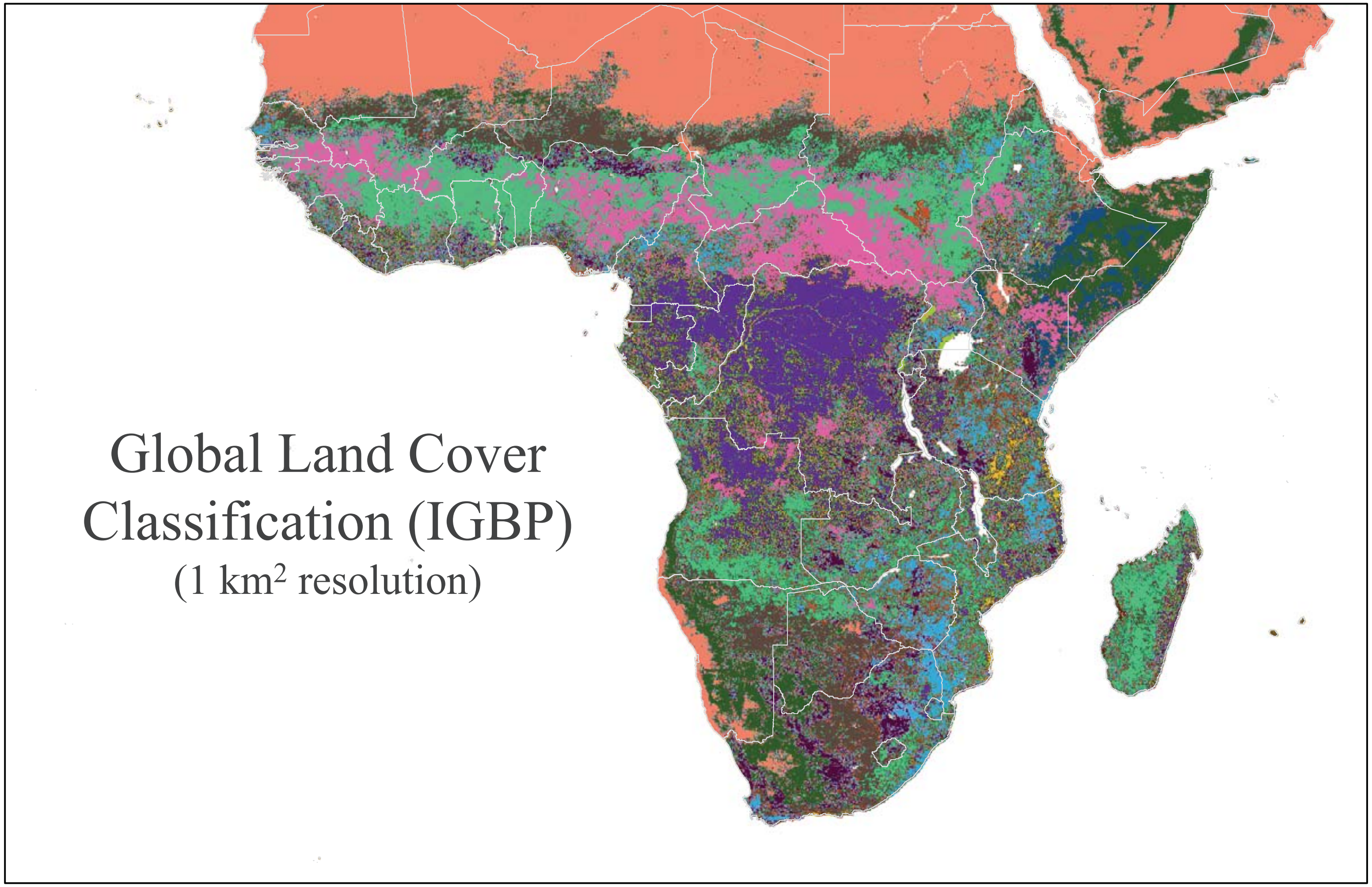


Families with over 50% pelagic or freshwater species excluded
1-523 species per 5km pixel

From extent of occurrence
to estimate of area of occupancy …

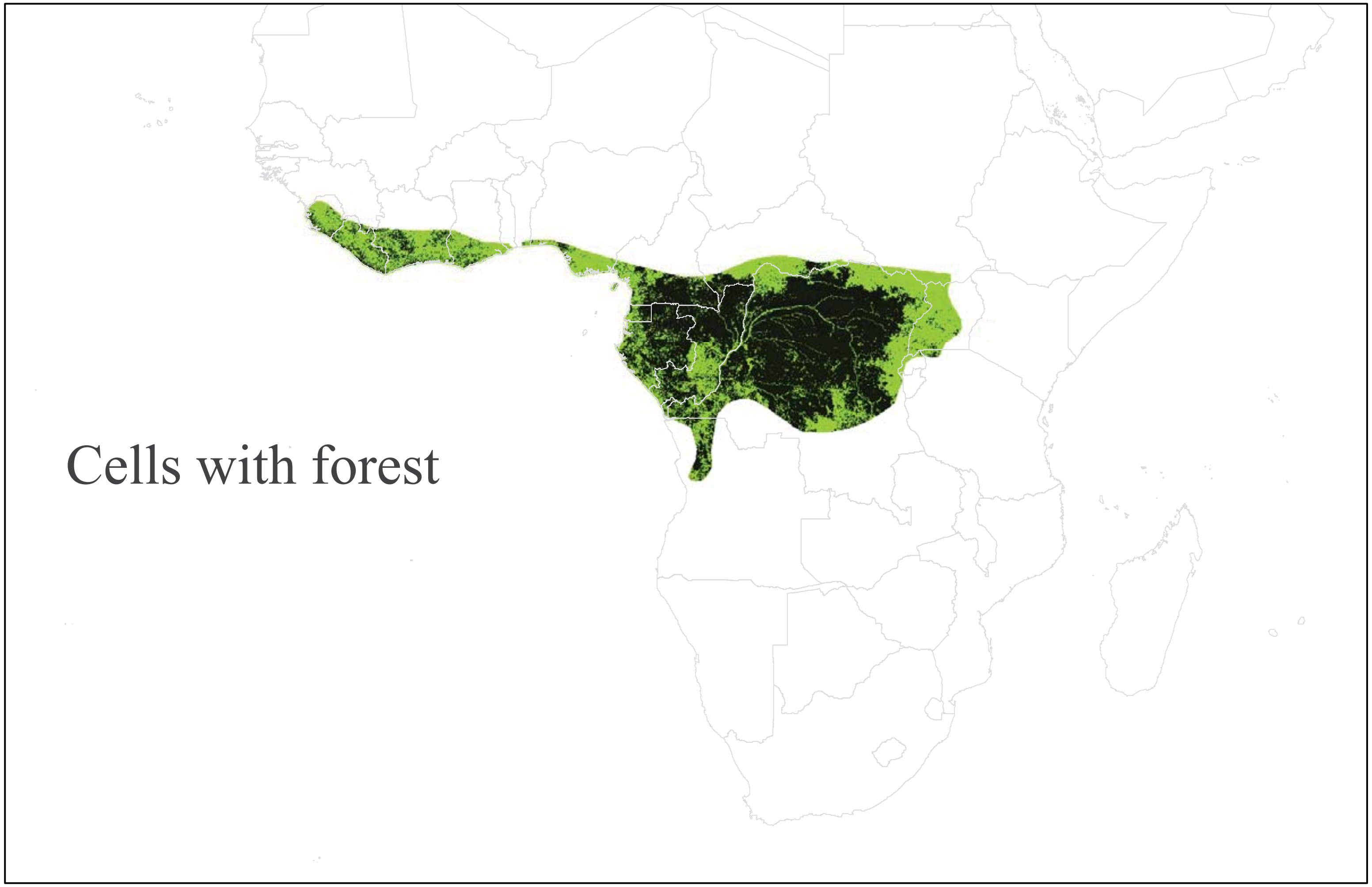


From extent of occurrence
to estimate of area of occupancy …

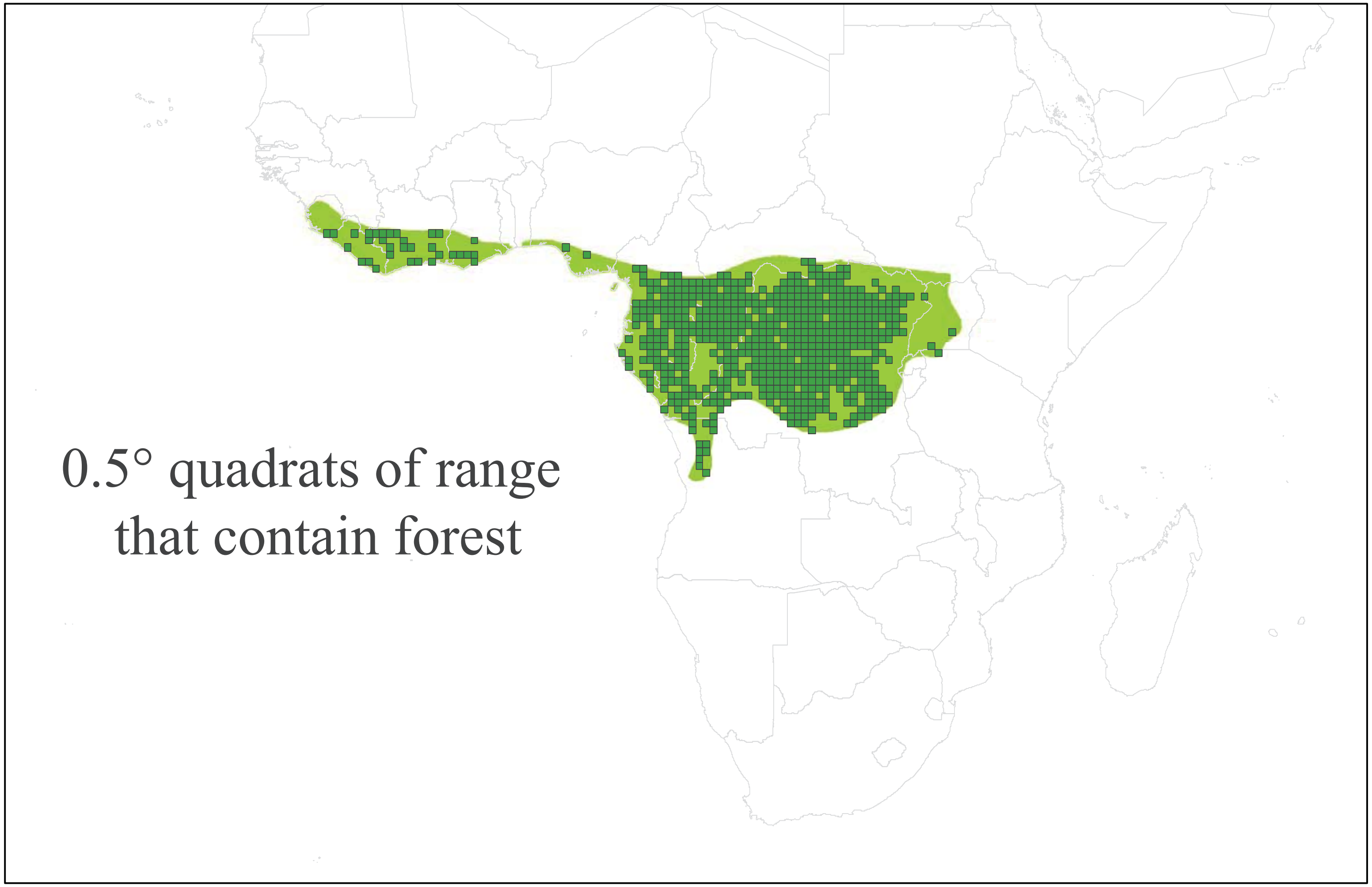


Global Land Cover
Classification (IGBP)
(1 km^2 resolution)

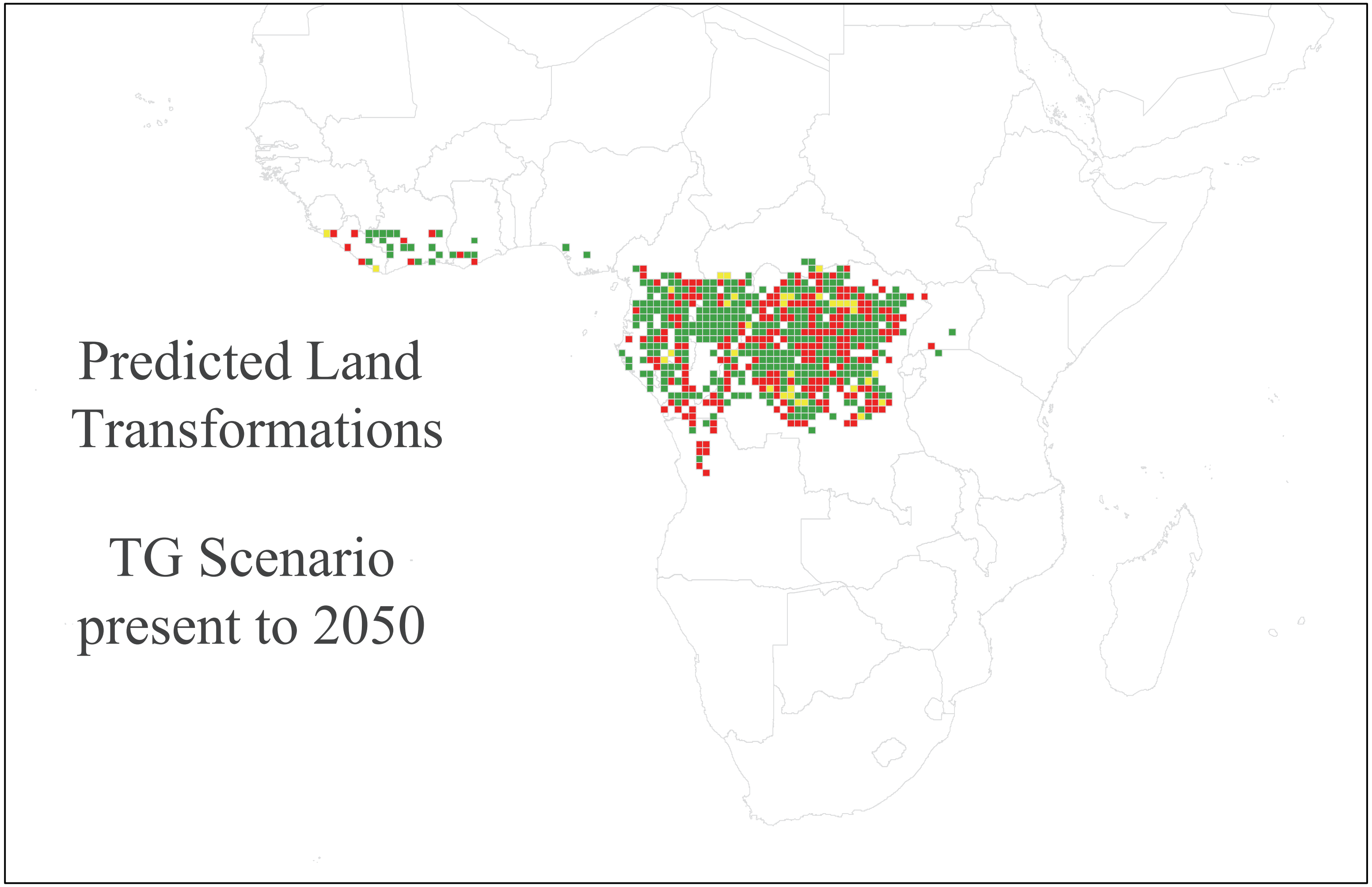
From extent of occurrence
to estimate of area of occupancy …



From extent of occurrence
to estimate of area of occupancy …



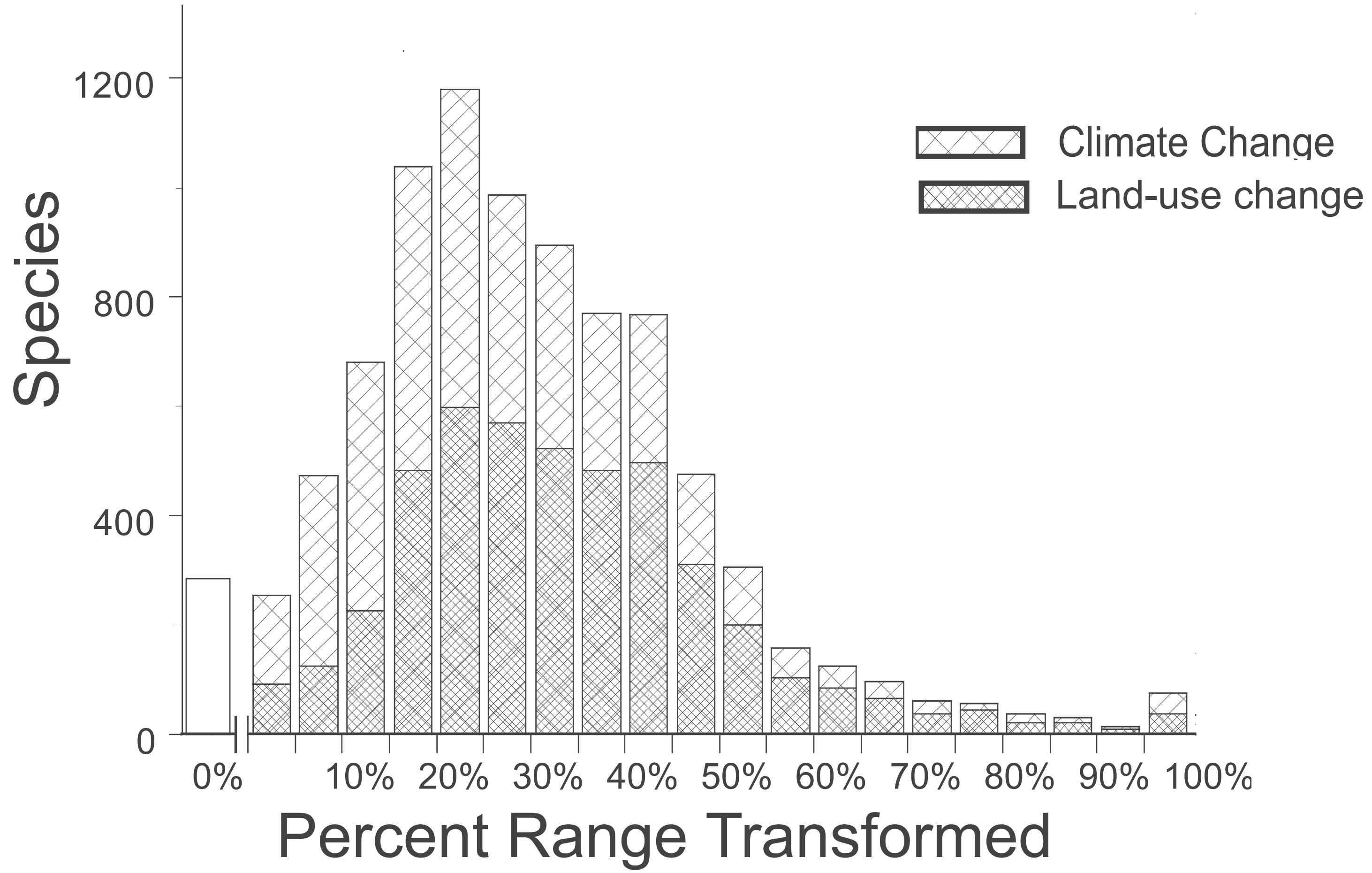
From estimate of area of occupancy
to estimate of area lost …



Environmental Change: The Pattern

	IPCC	Year	Climate		LandCover		
			CO_2	ΔT	Clim.	Hab.	
TechnoGarden	**B1**	***2050***	4.7	*1.6°*	*11%*	*8%*	Madonna's World
		2100		*1.9°*	*15%*	*10%*	
Adapting Mosaic	**B2**	***2050***	13	*1.9°*	*11%*	*7%*	Marley's World
		2100		*3.0°*	*16%*	*9%*	
Global Orchestration	**A1**	***2050***	20	*2.1°*	*11%*	*9%*	MaNonna's World
		2100		*3.4°*	*17%*	*13%*	
Order from Strength	**A2**	***2050***	15	*1.8°*	*10%*	*10%*	Maradona's World
		2100		*3.2°*	*14%*	*14%*	

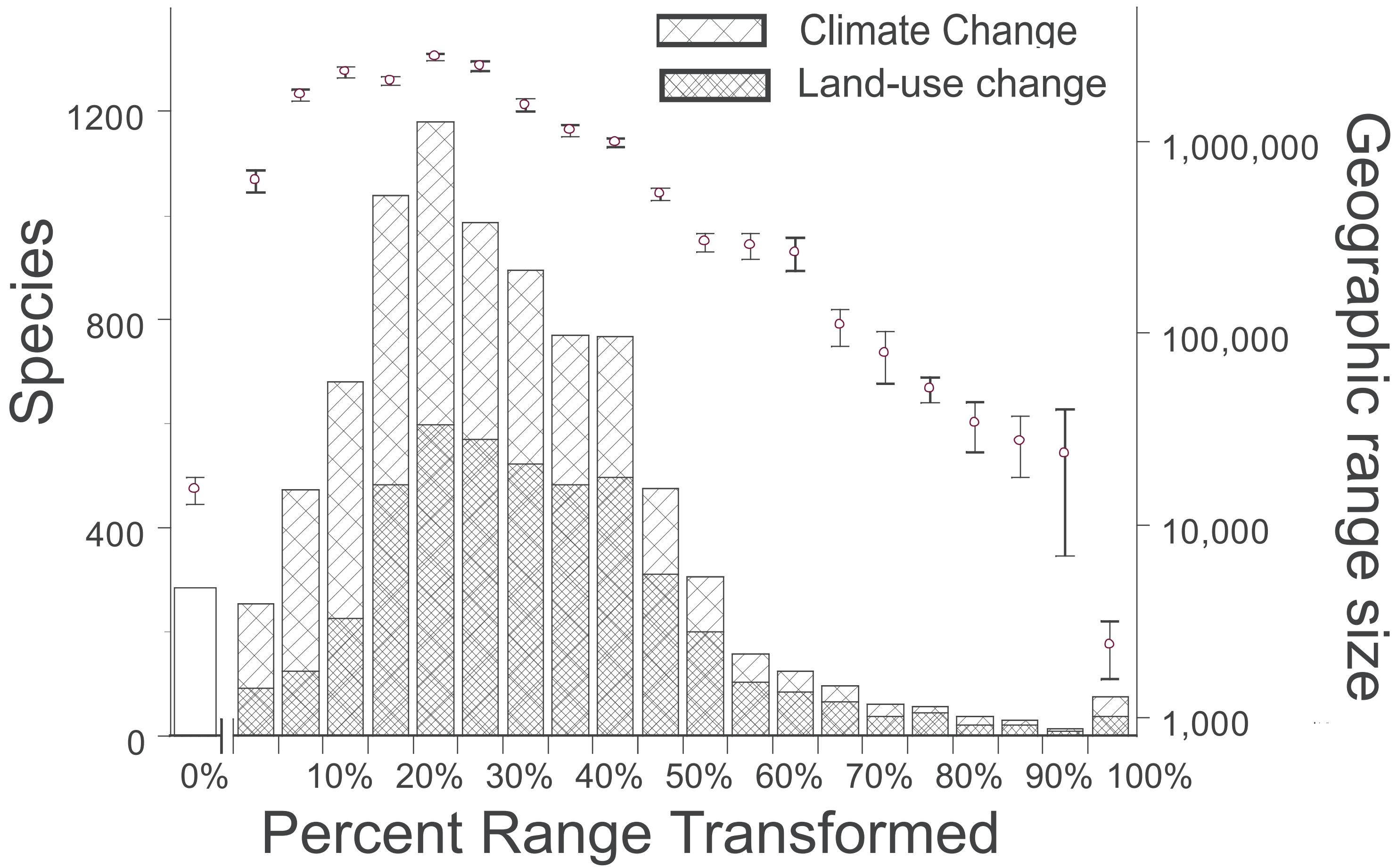
Predicted Proportional Loss in Range Size
All the World's Land Birds



Adapting Mosaic 2100

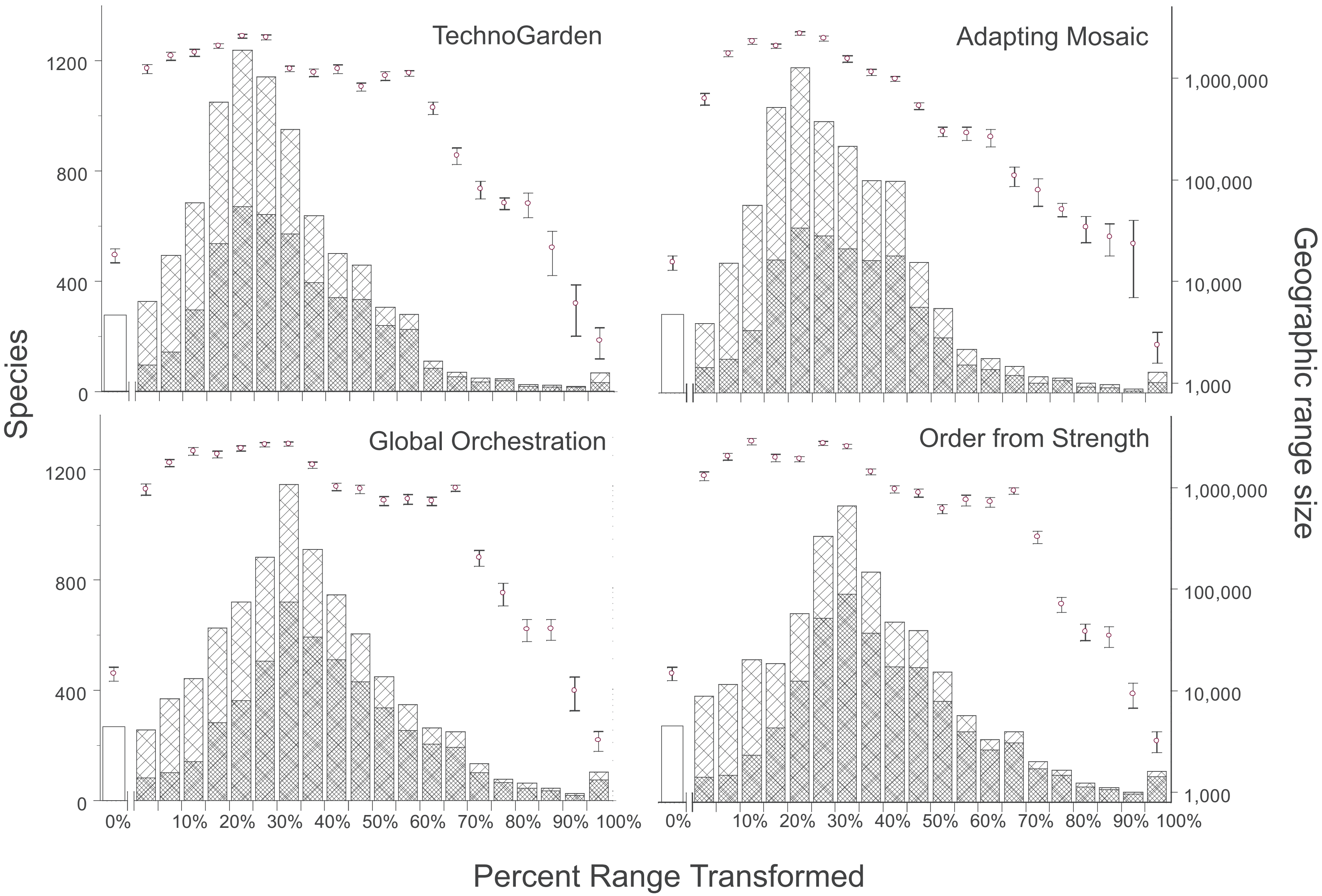
Jetz, Wilcove & Dobson
(2007)

Predicted Proportional Loss in Range Size



Adapting Mosaic 2100

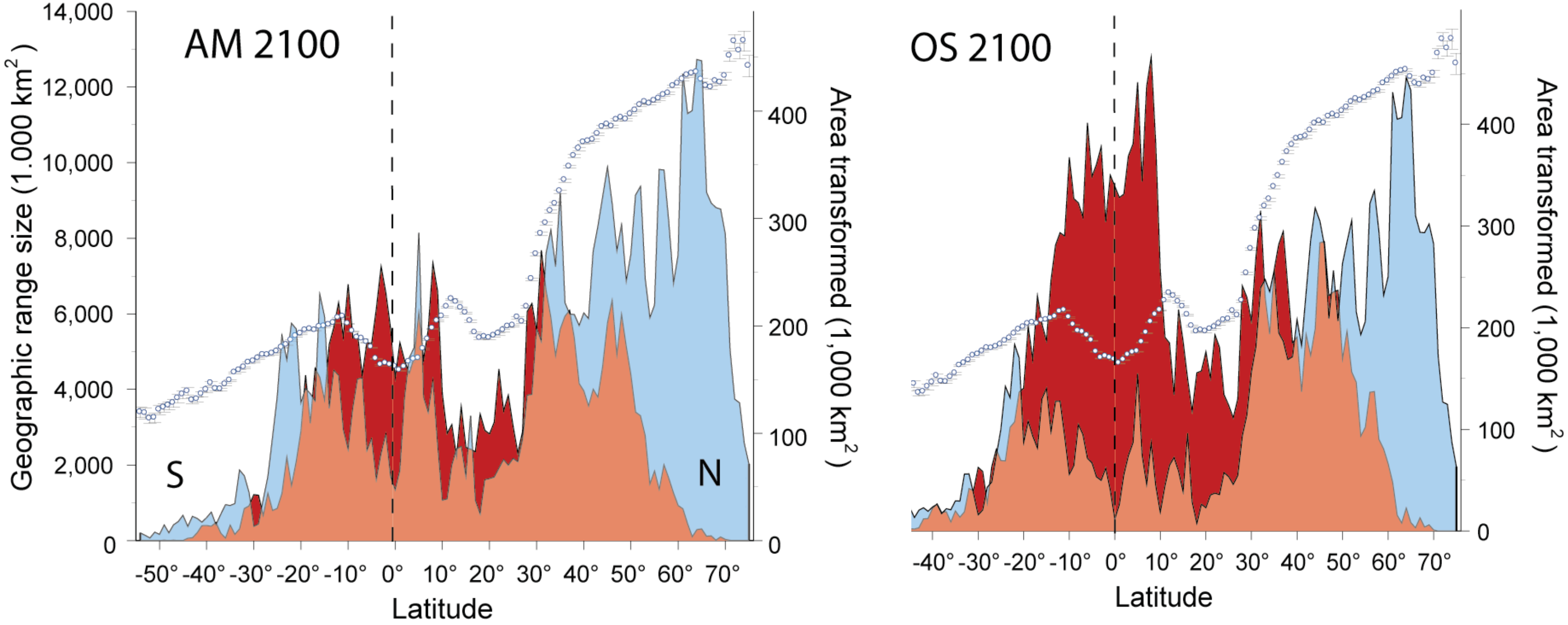
Predicted Proportional Loss in Range Size



Environmental Change:
The Impact on Biodiversity I

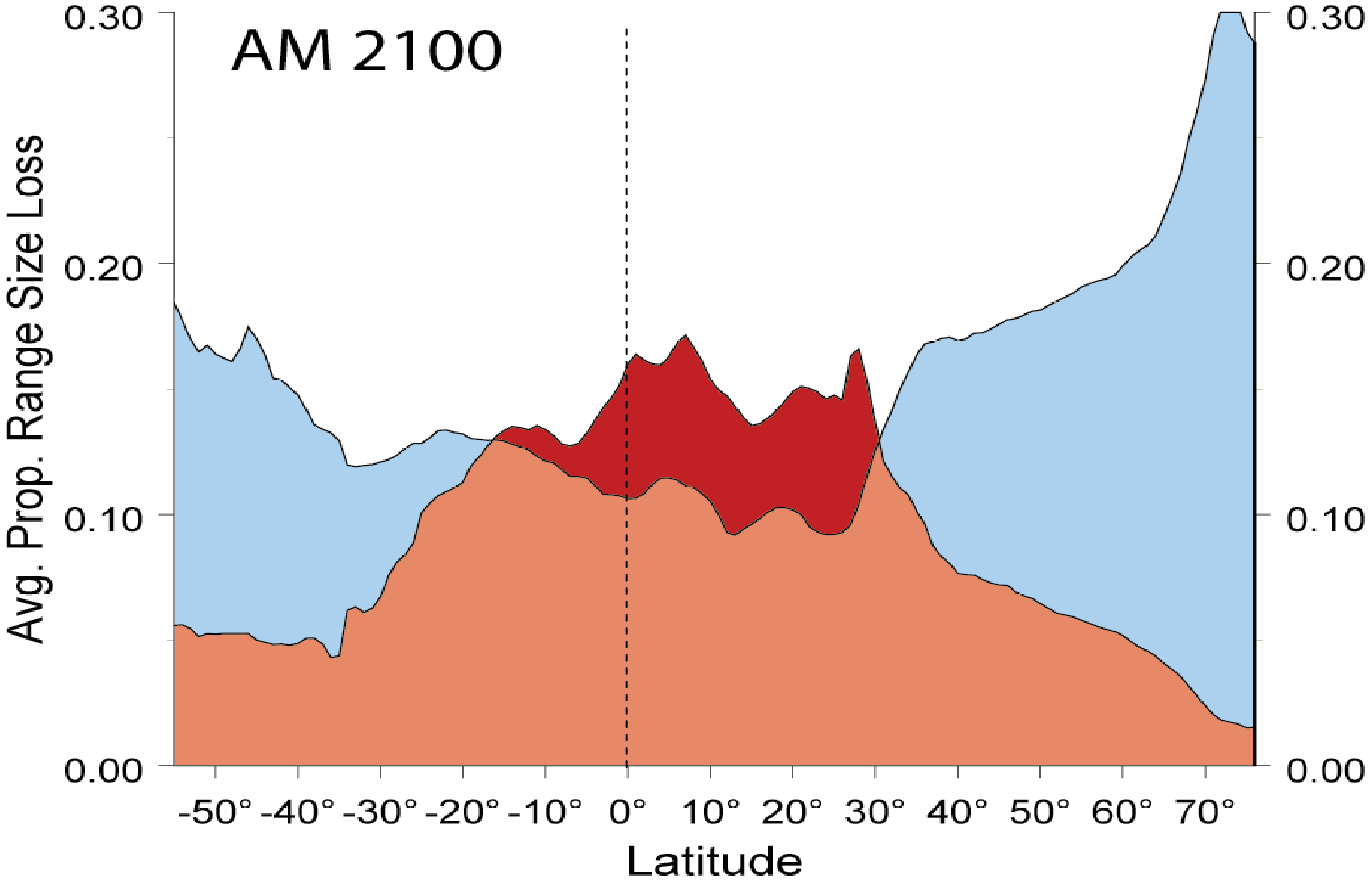
	IPCC	Year	≥ 50% Range Lost: Species	≥ 50% Range Lost: Range lost to Hab.
TechnoGarden	**B1**	***2050***	448	43%
		2100	988	45%
Adapting Mosaic	**B2**	***2050***	398	39%
		2100	952	48%
Global Orchestration	**A1**	***2050***	540	70%
		2100	1,767	72%
Order from Strength	**A2**	***2050***	906	79%
		2100	1,804	84%

Latitude, Range Size and Type of Change



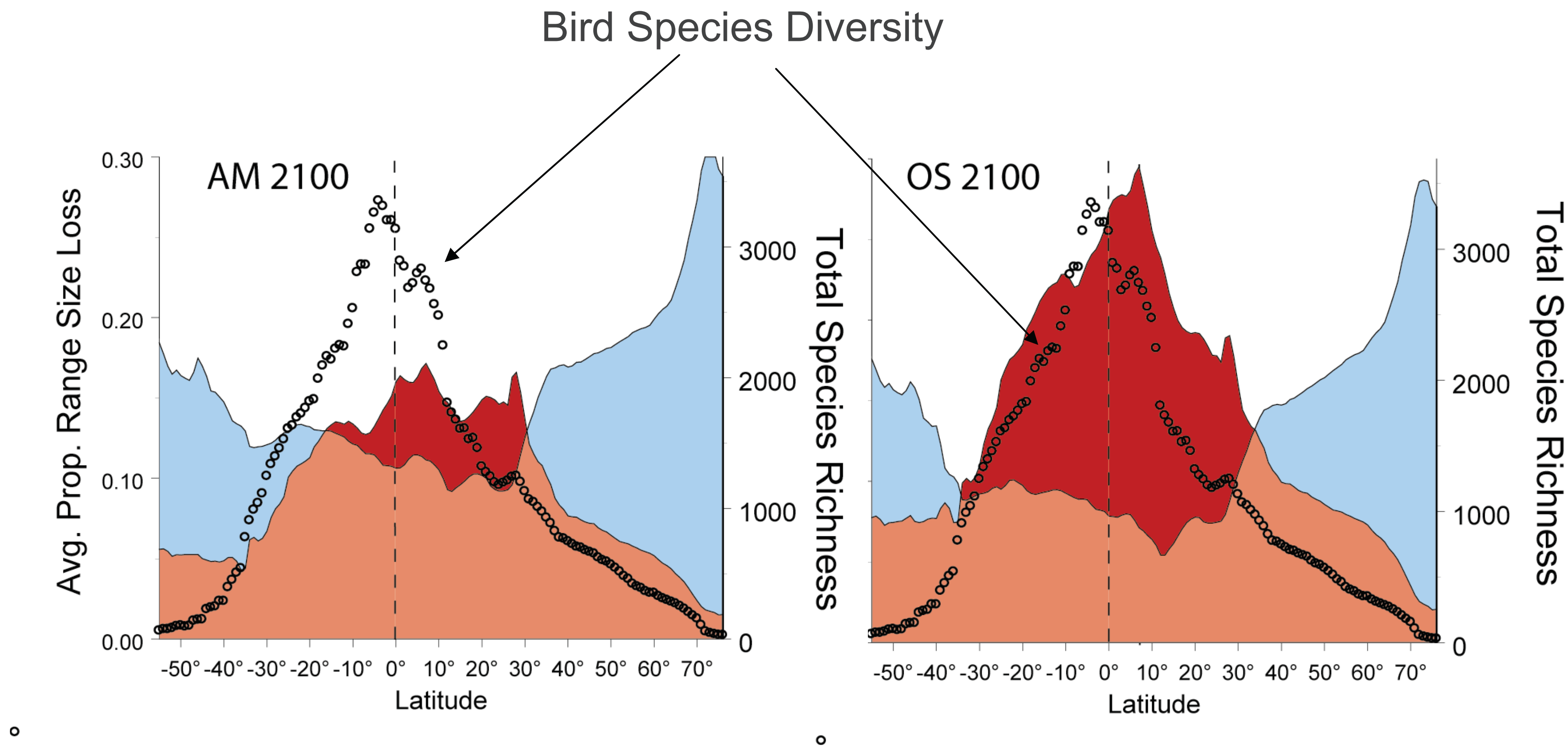
Red: Land-use change
Blue: Climate Change

Latitude and Proportional Range Loss



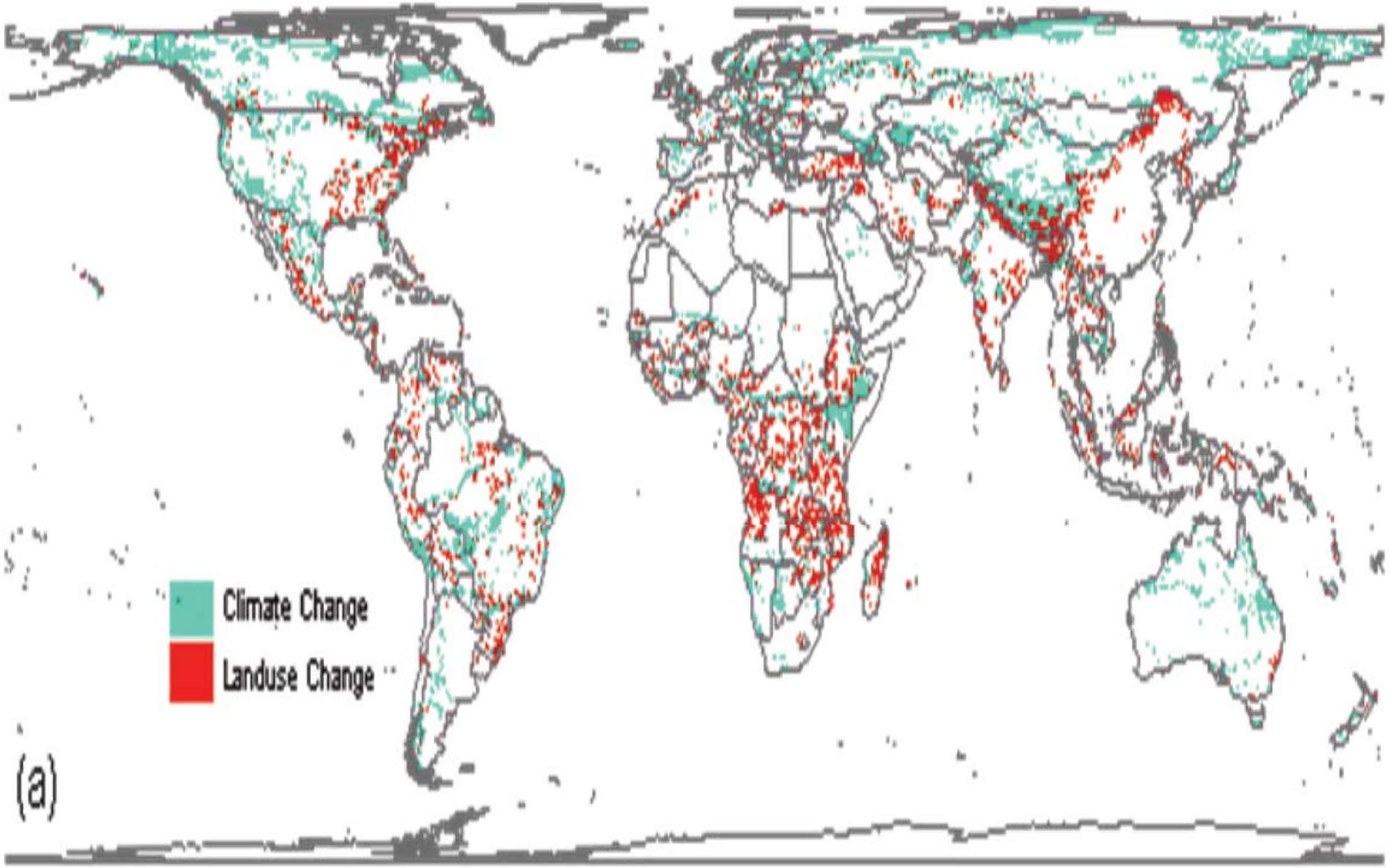
Red: Land-use change
Blue: Climate Change

Latitude and Proportional Range Loss

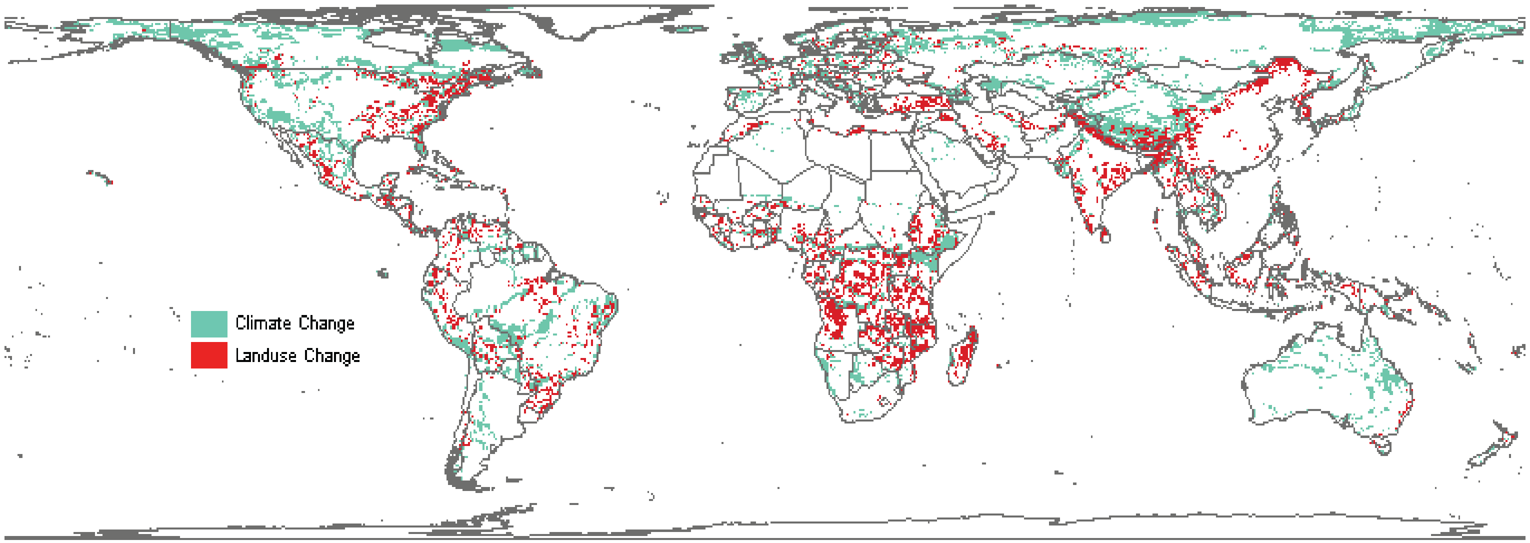


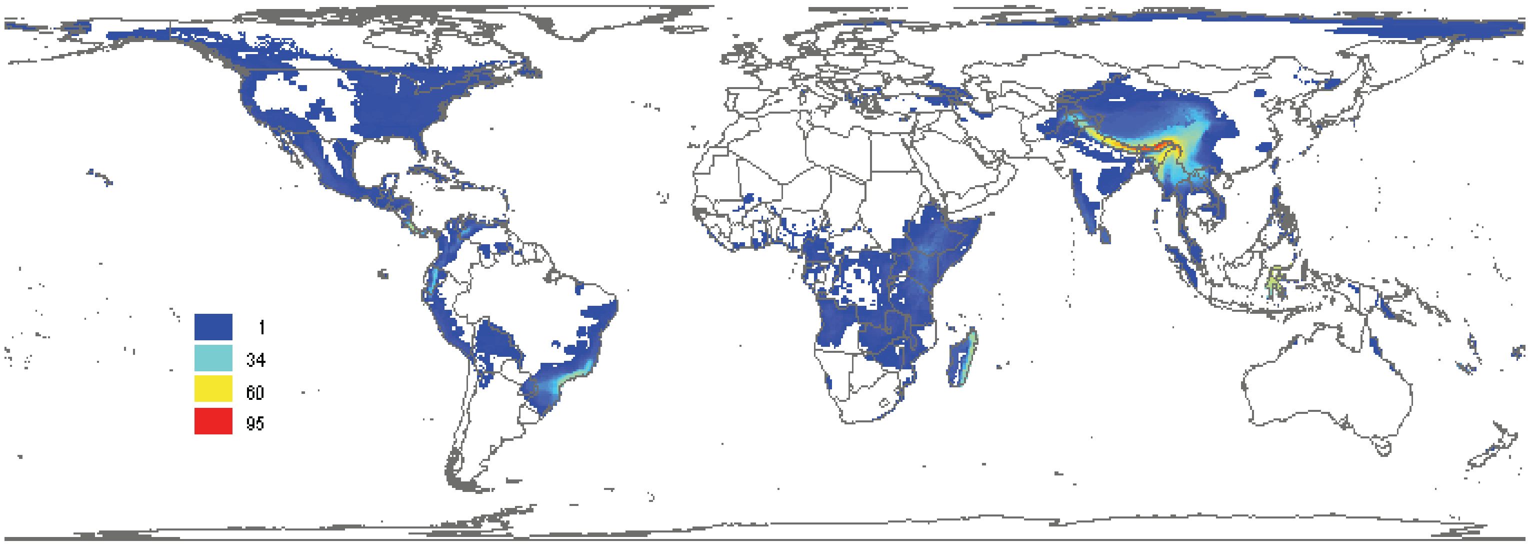
Red: Land-use change
Blue: Climate Change

Adapting mosaic



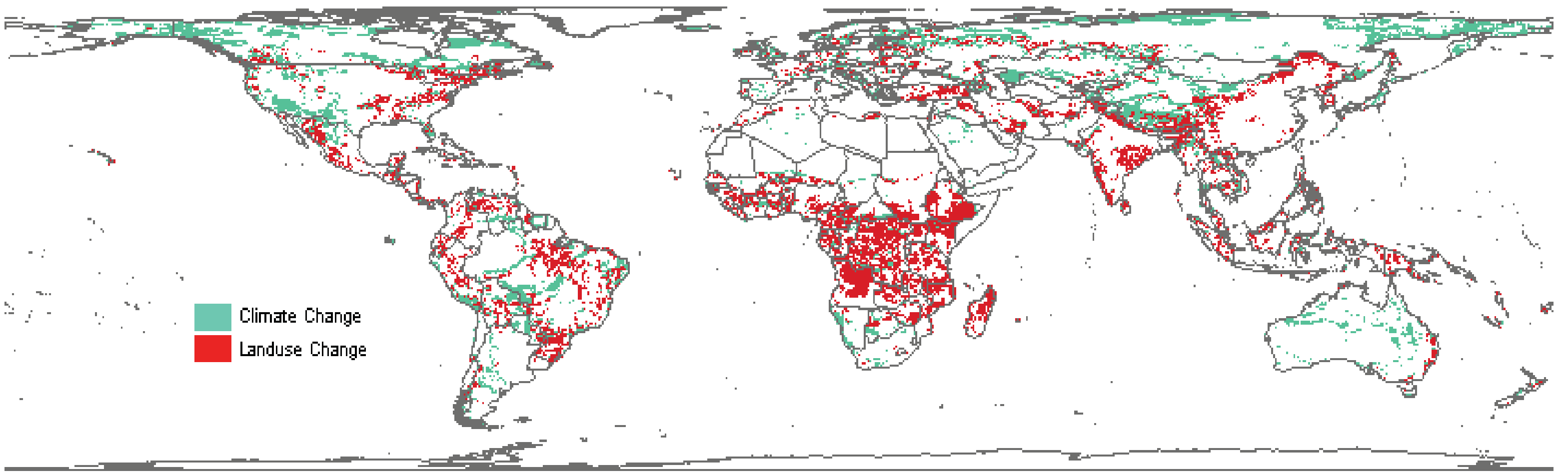
The geographic pattern

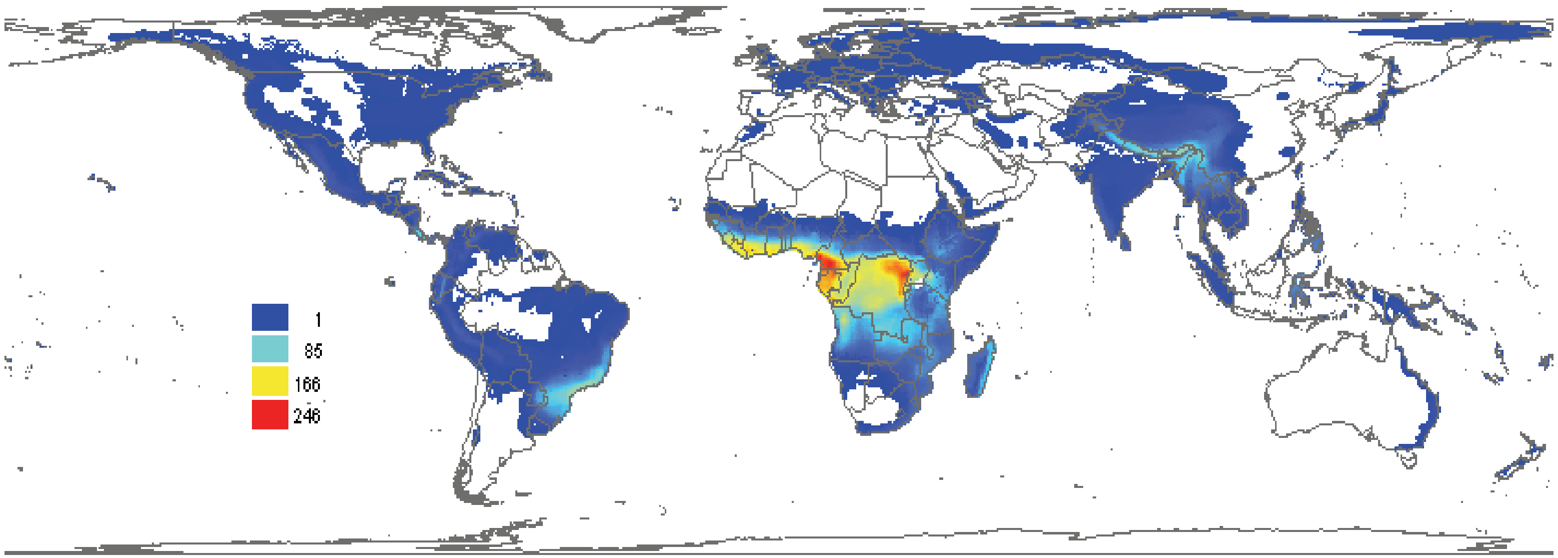




Adapting Mosaic, 2100

The geographic pattern





Order from Strength, 2100

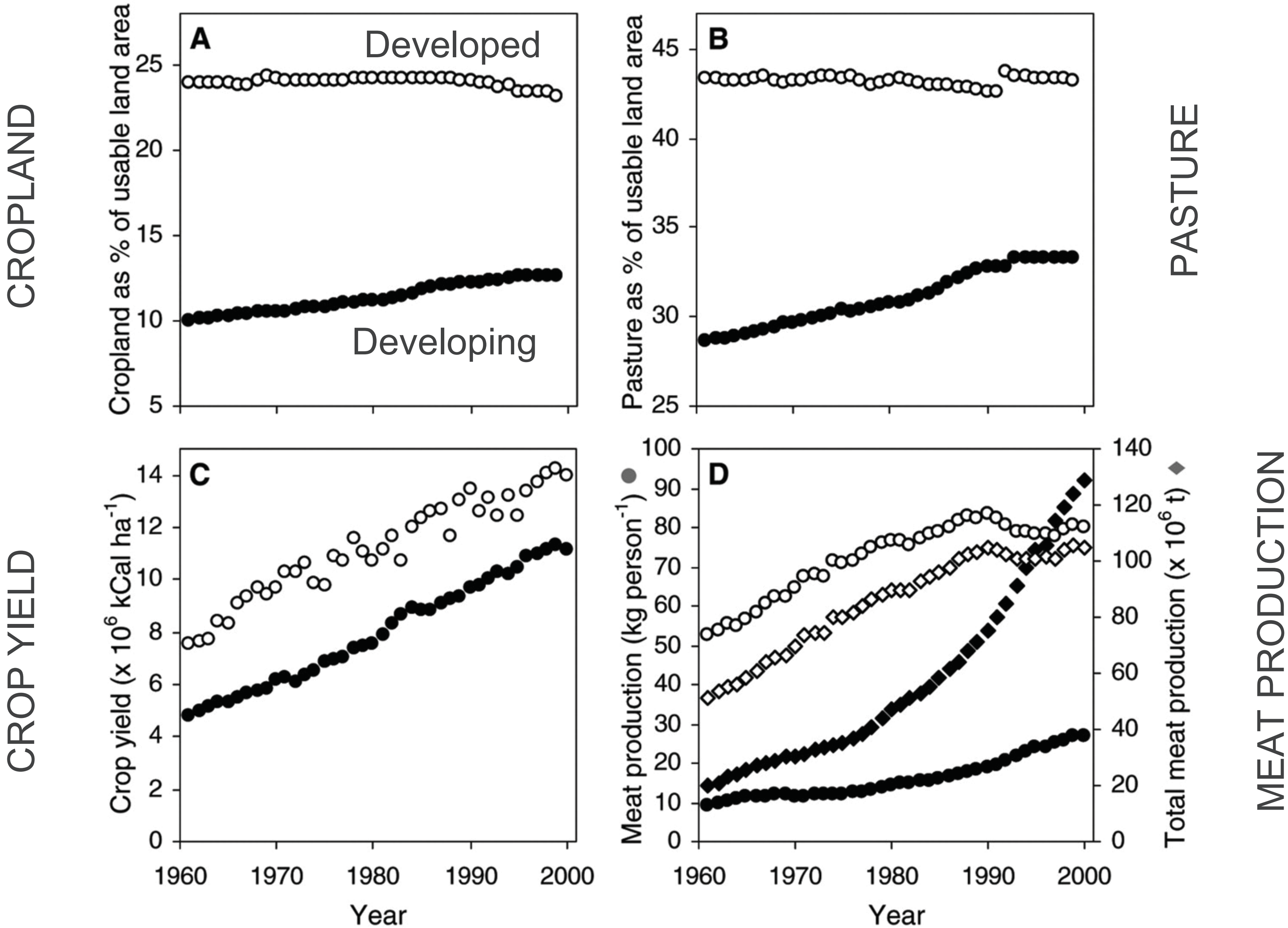
Additional Questions

- Assumption “total loss”. To which degree may species survive / adapt to changed habitats?
- Assumption “range stationarity”. To which degree may species be able to shift their ranges in response to climate change?
- Assumption “minimum area requirement > ½ 0.5° quadrat”. To which degree will species be still represented and thus covered by sub-pixel habitat availability?
- Assumption “area of occupancy”: To which degree is the area of occupancy overestimated, i.e. proportional range loss underestimated?
- How well does the current reserve system buffer species from projected land use changes, but not from effects of climate change?

Conclusions

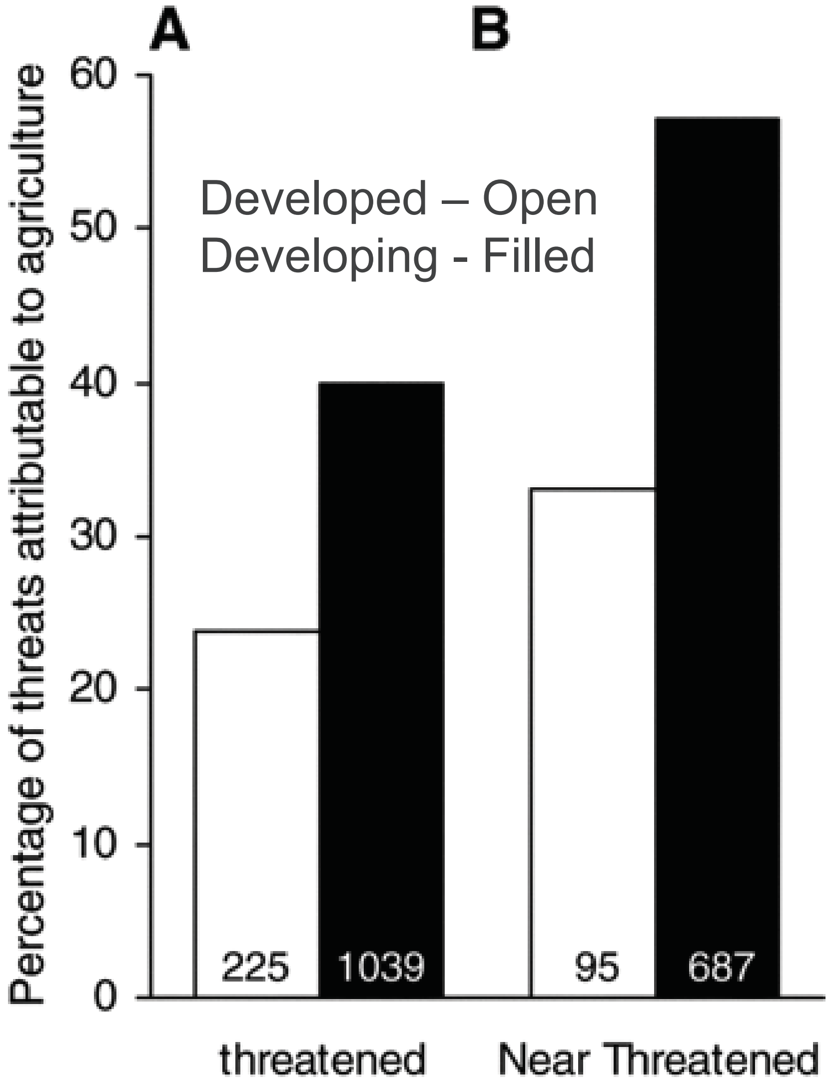
- Land-use change will dominate range contractions, particularly in the tropics, while climate change will dominate in higher latitudes
- The species that are most vulnerable to these changes are only poorly identified by the current threat categorizations.
- The causes, magnitude and geographic patterns of potential range loss vary across socioeconomic scenarios
- While climate change will severely impact biodiversity, in the near future land-use change is is likely to lead to greater species loss.
- Habitat preservation should be a main priority of decision-makers and conservation practitioners

Green, Cornell, Scharlemann & Balmford,
Science, 28 January 2005



Green, Cornell, Scharlemann & Balmford,
Science, 28 January 2005

Global
Red List
For Birds



Millennium Ecosystem Assessment: New Approaches to Multi-Scale Analyses

Assessing the Condition and Multi-scale Impacts of Cultivated Systems

Stanley Wood[1], Ken Cassman[2] & Joanne Gaskell[1]

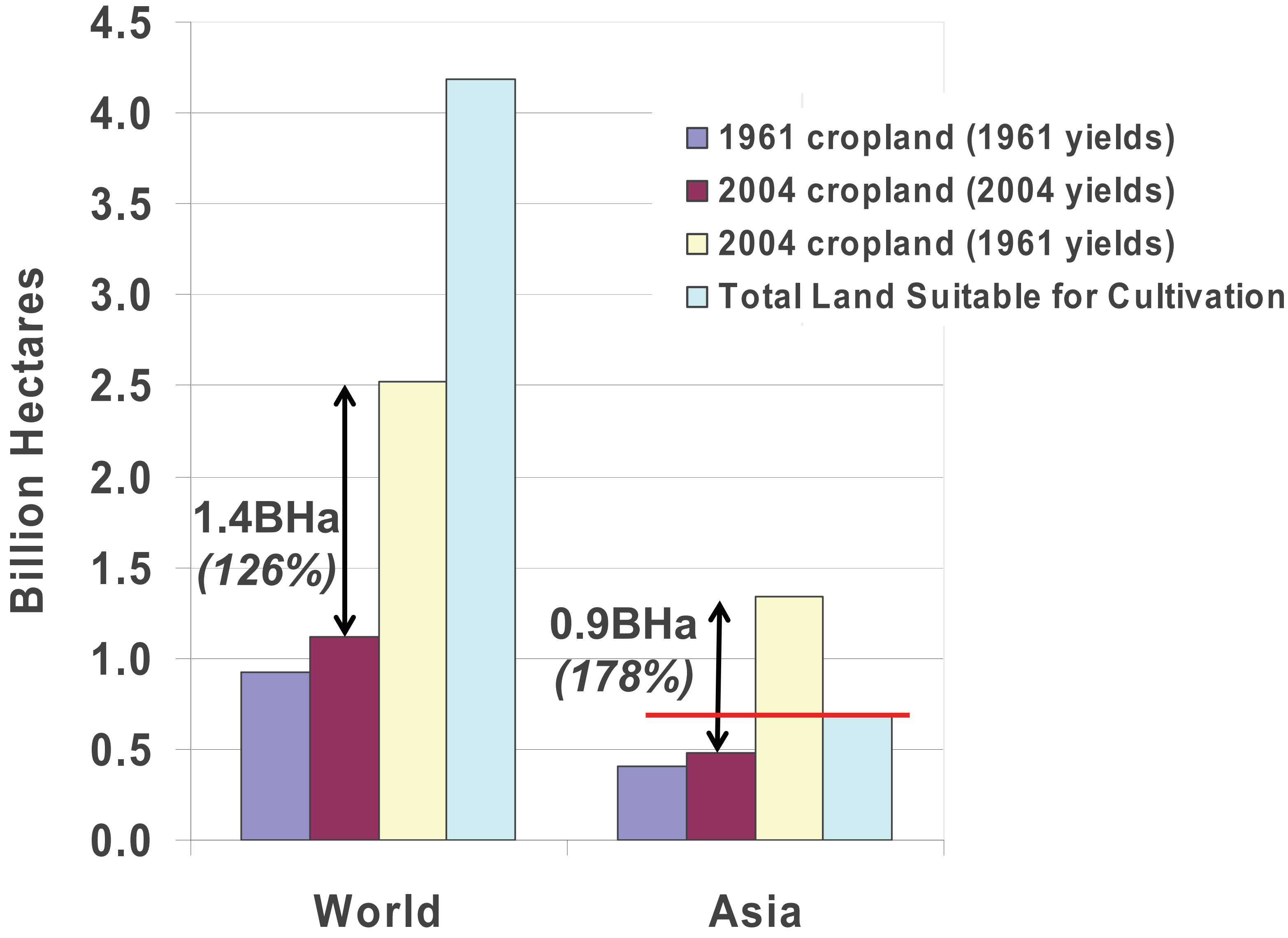
[1]International Food Policy Research Institute

[2]Department of Agronomy and Horticulture, University of Nebraska

2005 AAAS Annual Meeting
17-21 February 2005
Washington, DC.

Land “Spared” By Intensification (1961-2004)

(Cereals, Roots/Tubers, Oils, Pulses, Sugar, Fiber Crops)



Ecosystem services

- Services supplied by natural ecosystems to the human economy.

- How do we classify these?
  - MA Classification – resilient or brittle?
  - Or – a more biological/mechanistic classification

- Can we predict how they will collapse?
  - How do we map services onto biological diversity?

Classifying Ecosystem Services

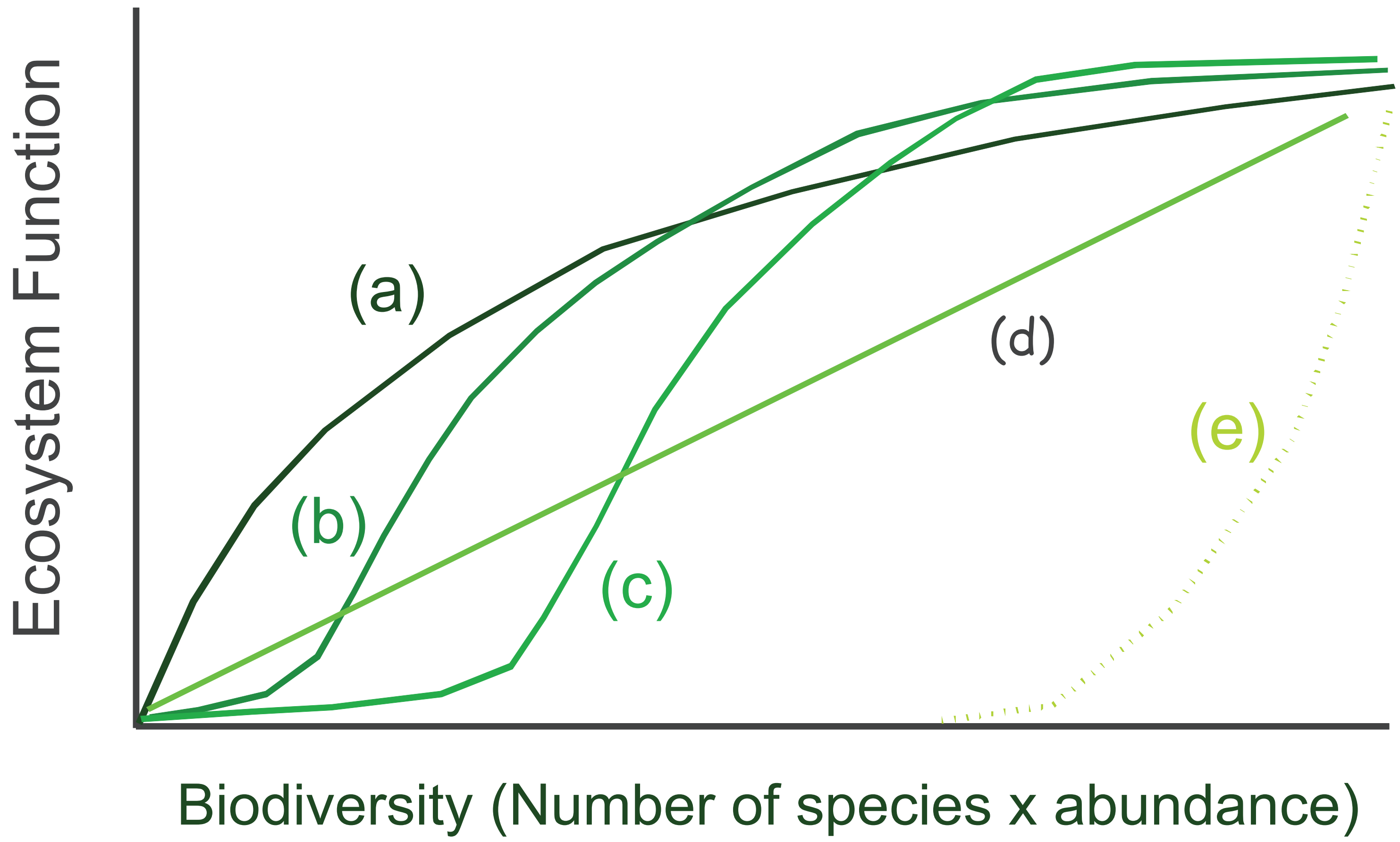
- Provisioning,
  - include food, such as fish, game-meat, fruit and berries from wild trees, fire wood, and fresh water. Have to be harvested!
- Regulating,
  - ultimately make life possible for humans and other non-voting species.
  - include climate and air quality control, detoxification, storm protection and regulation of disease and pest outbreaks.
- Supporting,
  - include primary production and the oxygen it generates, pollination of wild and domestic plants, soil formation and nutrient cycling.
- Cultural
  - includes recreation and ecotourism – create revenue and jobs
- Preserving
  - provide unknown future benefits to humans: new drugs and foods

Do Ecosystem Services map onto Trophic level?

- Top trophic levels – aesthetic goods and services, some food – marine fish
  - Brittle, quickly lost as habitat lost
- Plants – oxygen production and CO_2 removal, fibers, forestry
  - More resilient, vary linearly with area?
- Basal trophic levels – soil retention, nutrient cycling, removal of toxins
  - Most resilient, persist in modified habitat?

Possible functional forms

(Salas et al in Mooney, 1996)



(a) -> (e) decreasing resilience

Resilience of ecosystem services

Ecosystem service	'Resilience' function
Purification of air	a
Purification of water	a/b
Carbon sink	a
Water source	b/d
Local harvest of food	b/c
Pollination of local agriculture	b/c
Buffering invasive species and pathogens	c/d
Recreational and spiritual value	c/d

Less resilient, more brittle ->

Strong tendency to move up trophic level, down resilience scale.

Ecosystem type

Ecosystem function

Curve that fits change in function with biodiversity loss
Andy's a through e
0 indicates irrelevant

a indicates low sensitivity of ecosystem service to biodiv loss

Ecosystem service	Cultivated	Drylands	Forests an	Urban syst	Inland wate	Coastal	Marine	Polar	Mountain	Island
	Ecosystem type									
Provisioning										
food			e							
biochem and pharm			c?							
genetic			c							
fuel			a							
fibre			a							
ornamental			e							
fresh water			a							
minerals, sand			0							
Regulating										
air quality			a							
climate regulation			a							
water regulation			a							
erosion control			a							
water purification and waste treatment			b							
regulation of human diseases			c							
biological control			d							
detoxification			c							
storm protection			c							
Cultural			c							
cultural diversity and identity										
spiritual and religious										
knowledge systems										
educational values										
inspiration										
aesthetic values										
social relations										
sense of place										
cultural heritage										
recreation and ecotourism										
Supporting										
primary production			a							
O2 production			a							
pollination			invasives issue							
soil formation			a							
soil retention			a							
nutrient cycling			c							
provision of habitat			c							

Classify as a -> e
a = most resilient
e = least resilient

Services performed by Species low in trophic level tend to be 'a', etc

Ecosystem service

Ecosystem type

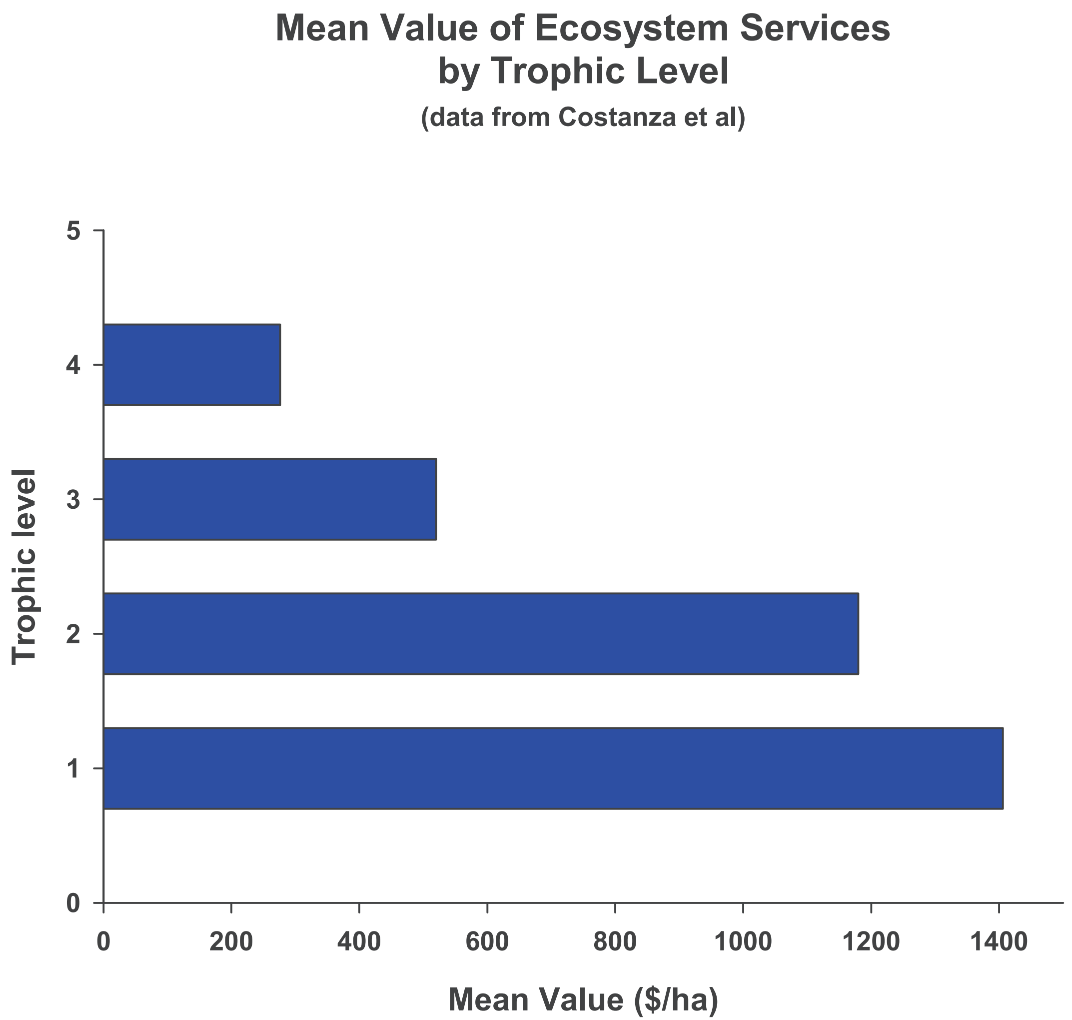
Anthropogenic Terrestrial……….-> Aquatic, Marine

Table 1

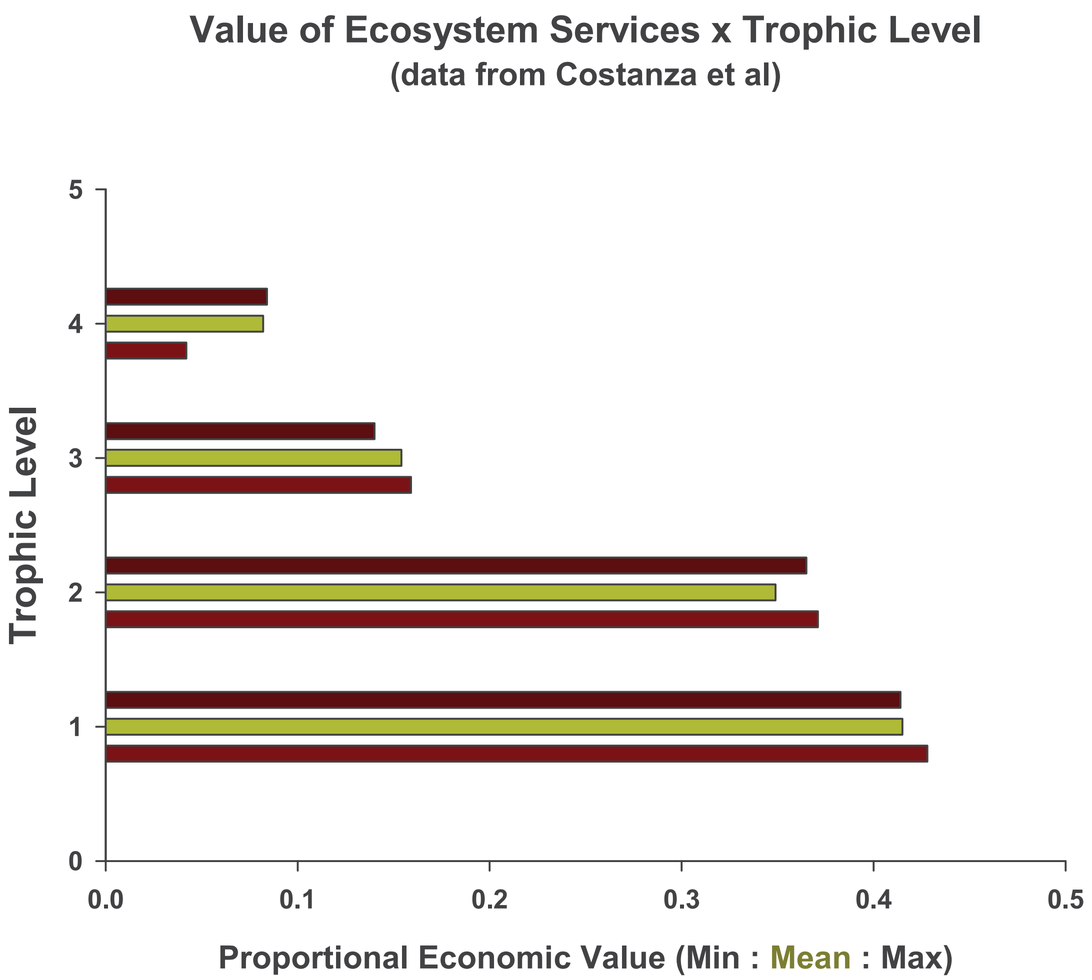
Ecosystem service	Ecosystem type									
	Urban syst	Cultivated	Drylands	Forests an	Coastal	Inland wate	Island	Mountain	Polar	Marine
Provisioning										
Fresh Water	a	e	a	a	0	c	a	a	a	0
Fiber	a	a	a	a	a	e	a	a	e	a
Fuel wood	a	e	a	a	e	0	a	a	e	e
Food	a	a	a	e	a	e	a	a	e	e
Genetic resources	0	e	c	c	e	c	c	c	c	c
Biochem and pharmaceuticals	0	a	c	c	e	c	c	c	e	e
Ornamental Resources	0	a	e	e	e	e	e	e	c	e
Regulating										
Air quality	b	a	a	a	a	a	a	a	a	a
Climate regulation	c	a	a	a	a	a	a	a	a	a
Erosion control	c	a	a	a	e	e	a	a	a	0
Storm protection	a	a	a	c	e	c	a	a	a	0
Water purification and waste treatment	c	a	b	b	e	a	c	c	a	a
Regulation of human diseases	e	e	b	c	?	d	c	c	a	a
Detoxification	c	a	c	c	e	a	c	c	e	a
Biological control	d	e	d	d	e	e	c	c	a	e
Cultural										
cultural diversity and identity	c	a	d	d	c	e	e	e	c	c
recreation and ecotourism	d	a	d	d	c	e	e	e	c	c
Supporting										
Primary production	a	a	a	a	a	a	a	a	a	a
O2 production	a	a	a	a	a	a	a	a	a	a
Soil formation & retention	a	a	a	a	e	a	a	a	a	0
Pollination	c	e	c	c	a	0	c	c	e	0
Nutrient cycling	c	e	c	c	c	a	c	c	e	a
Provision of habitat	d	e	c	c	e	d	c	c	a	e

"What did you do in the M.A. Dad?

WHAT IS THE ECONOMIC VALUE OF EACH TROPHIC LEVEL?



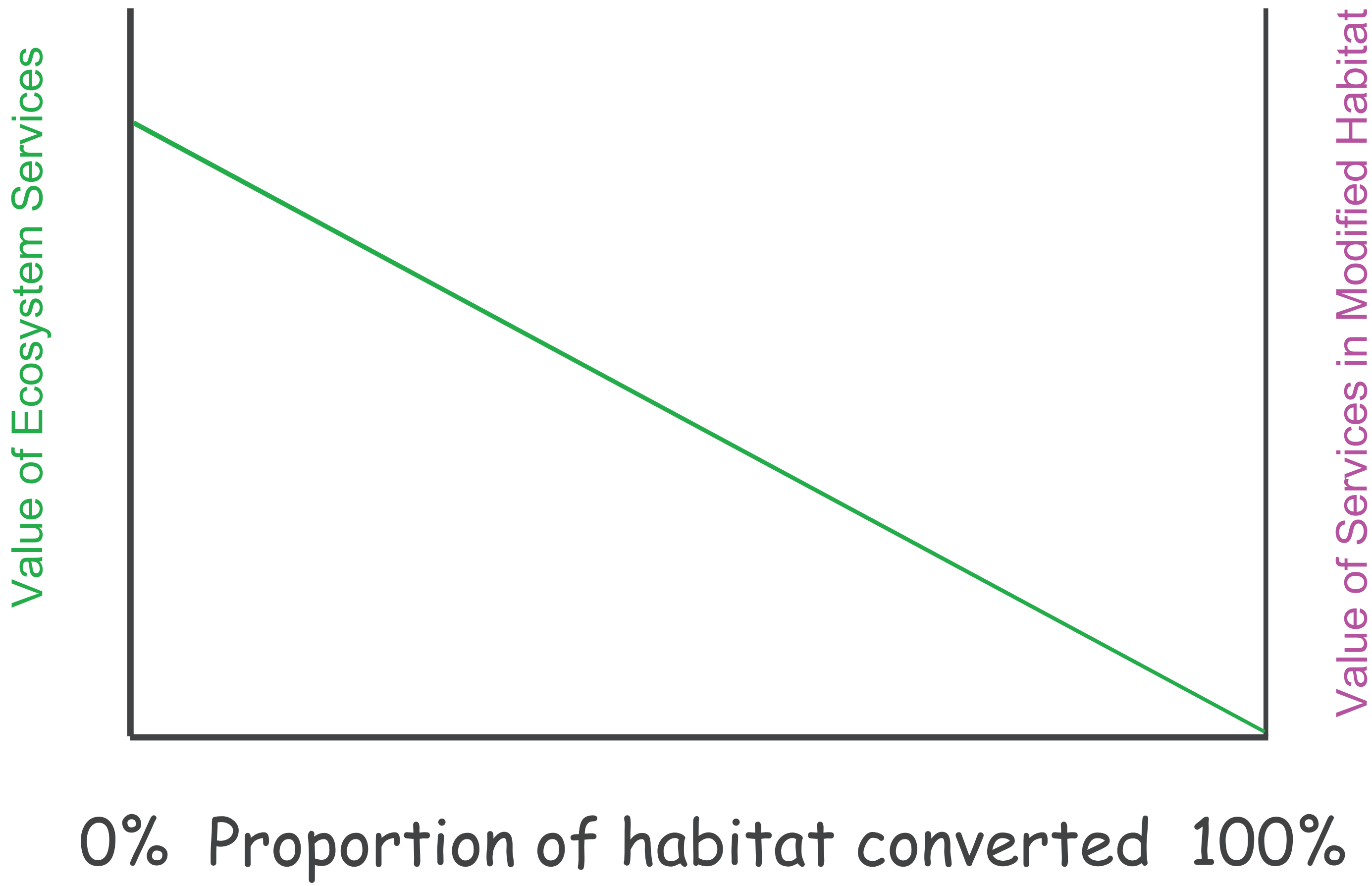
PROPORTIONAL VALUE OF ECONOMIC SERVICES BY TROPHIC LEVEL



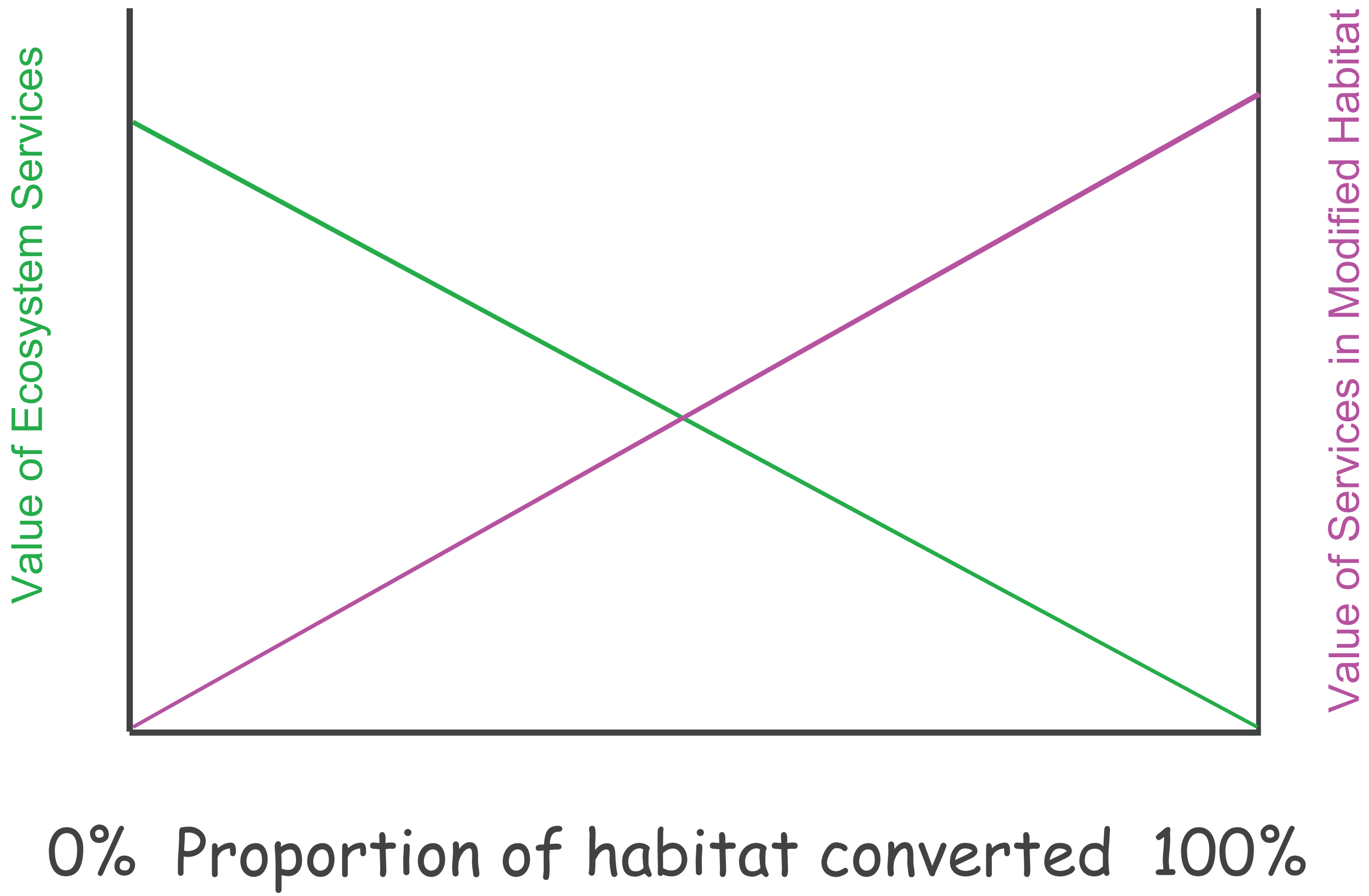
NOTE : This may mean that ALL species are of equal economic value!


The edge of the Serengeti……

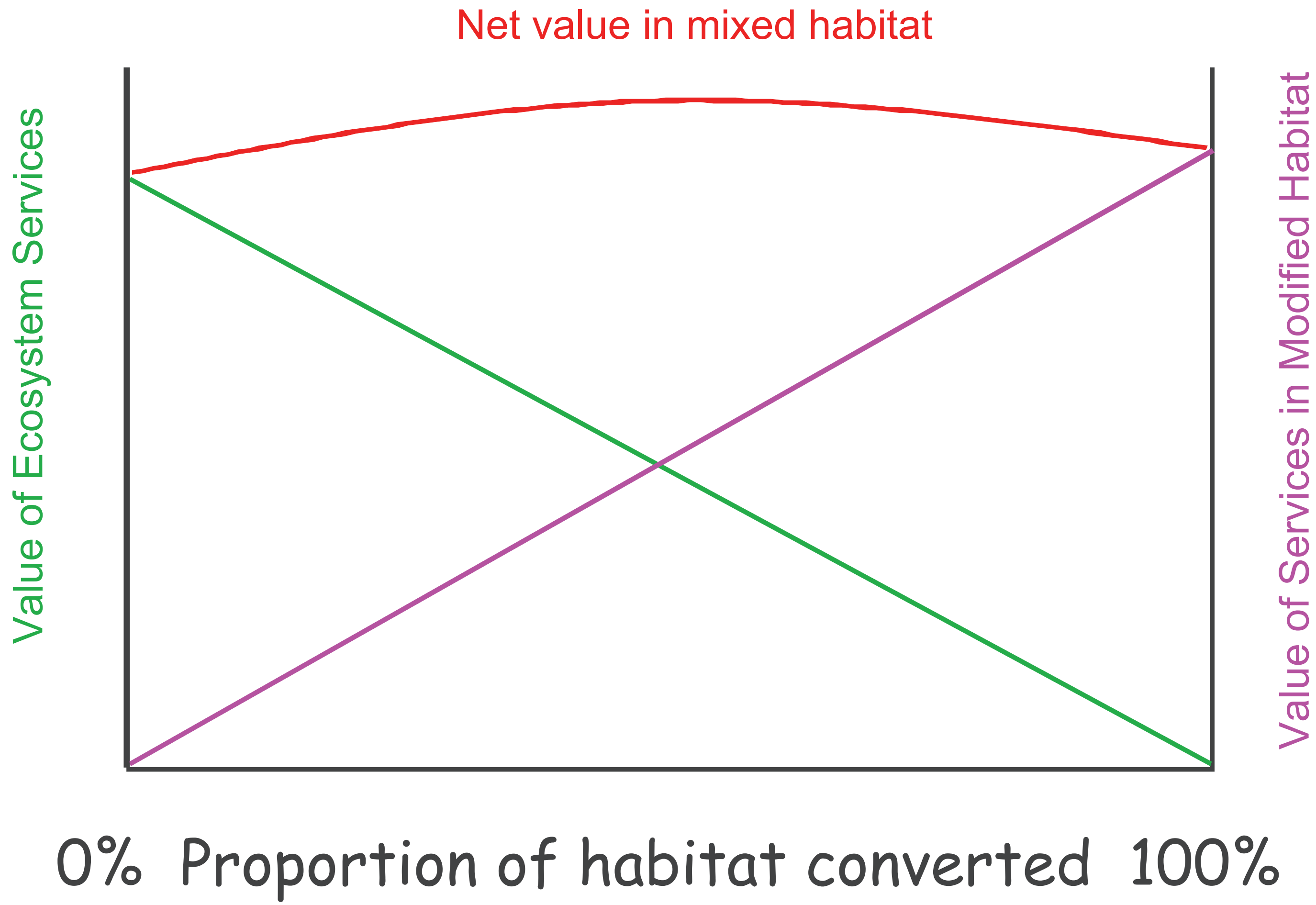
Decline in value of ecosystem services as land is converted from pristine to human-modified



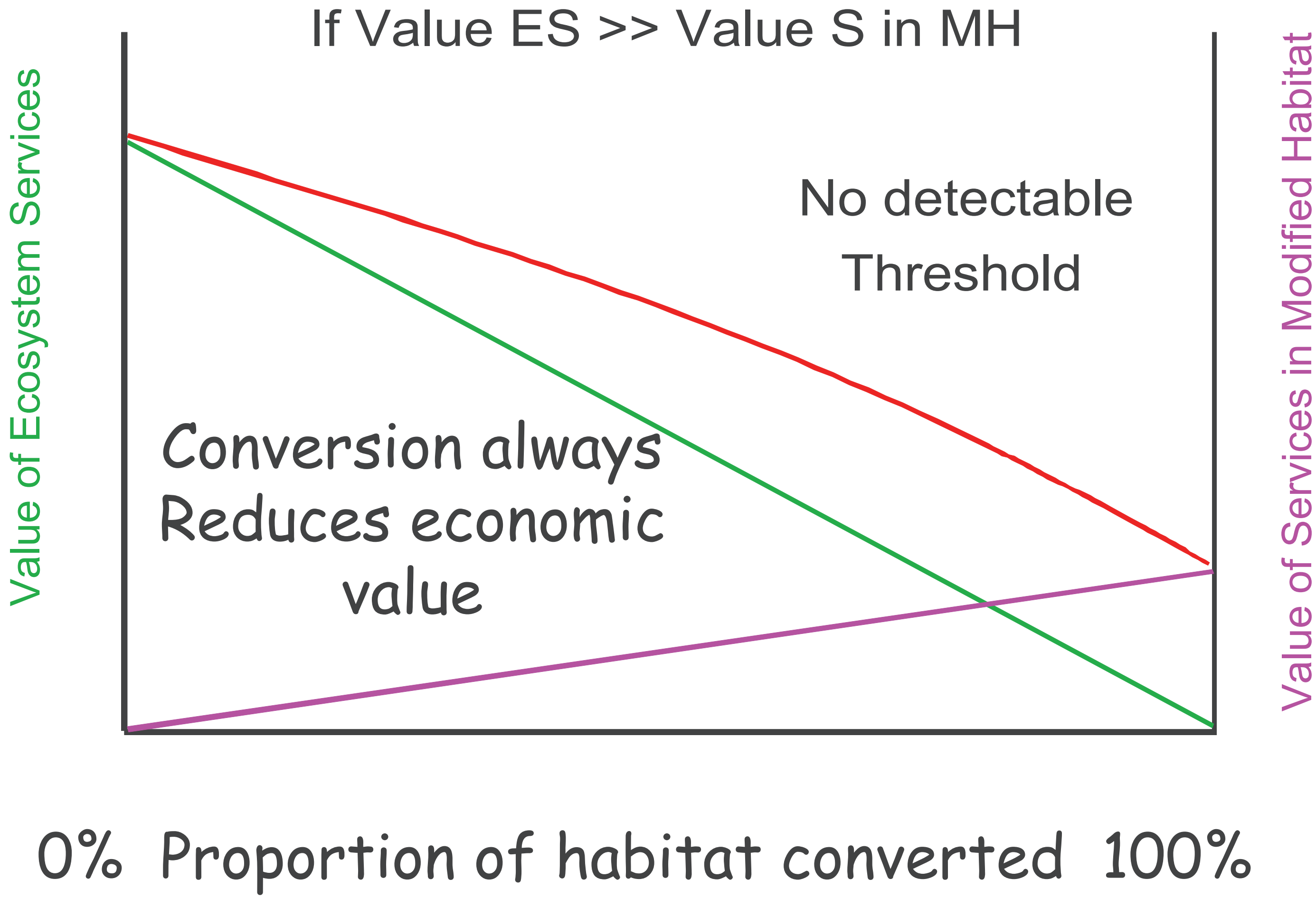
Land conversion creates a different, new source of revenue



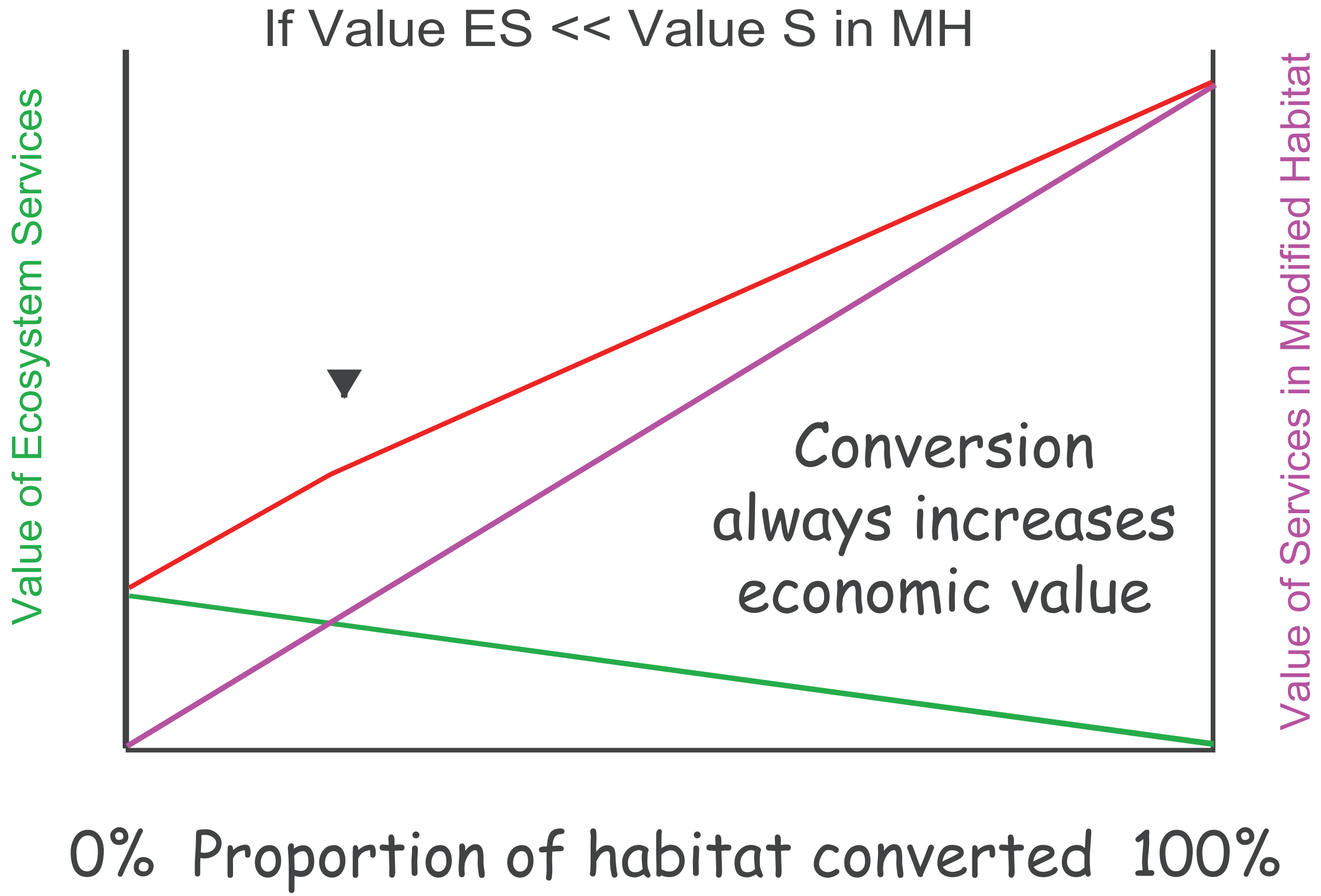
Net value at any time is sum of ecosystem services and services provided by converted land



But the world may be asymmetrical…

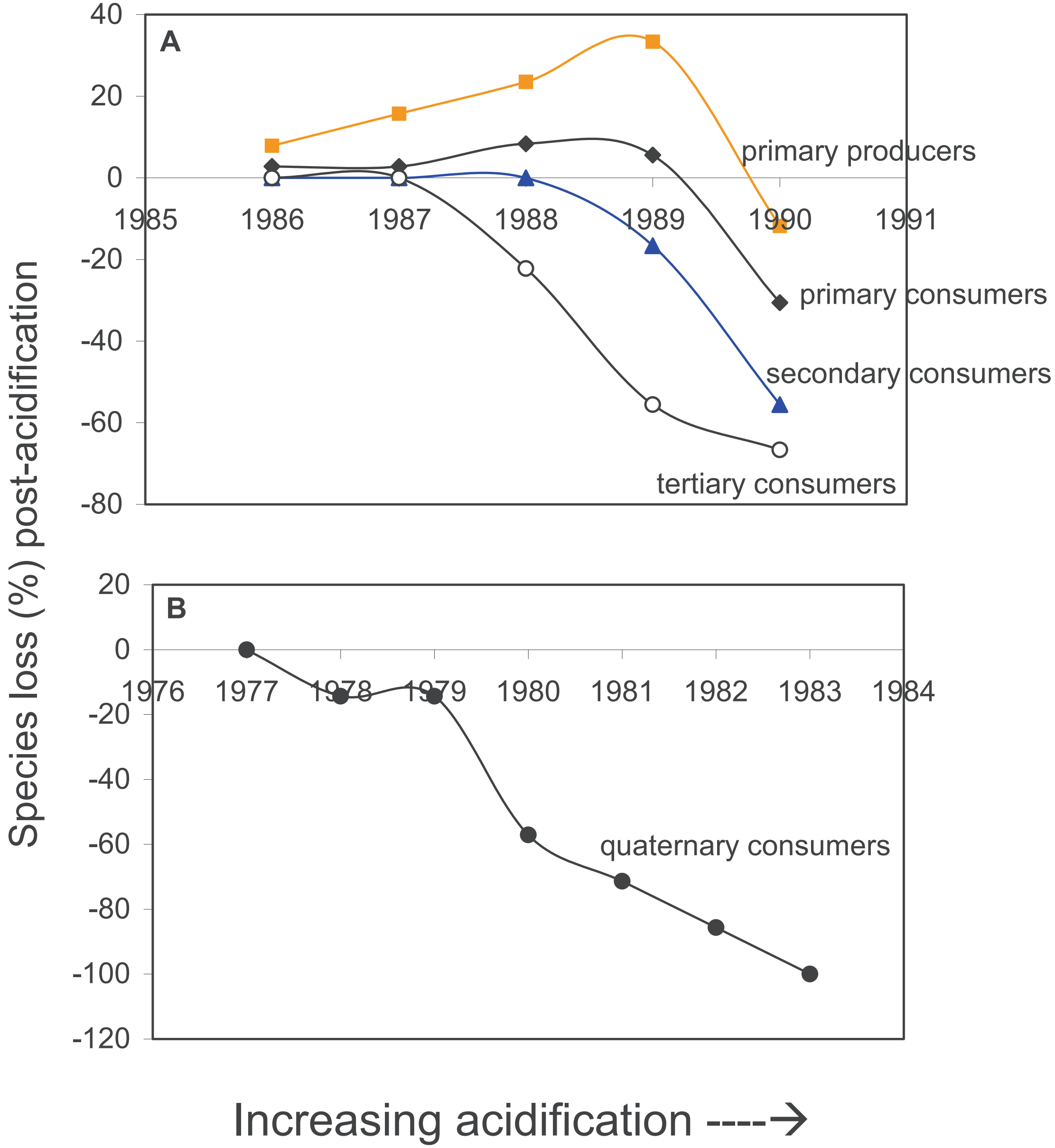


Or we may underestimate the value of ecosystem services

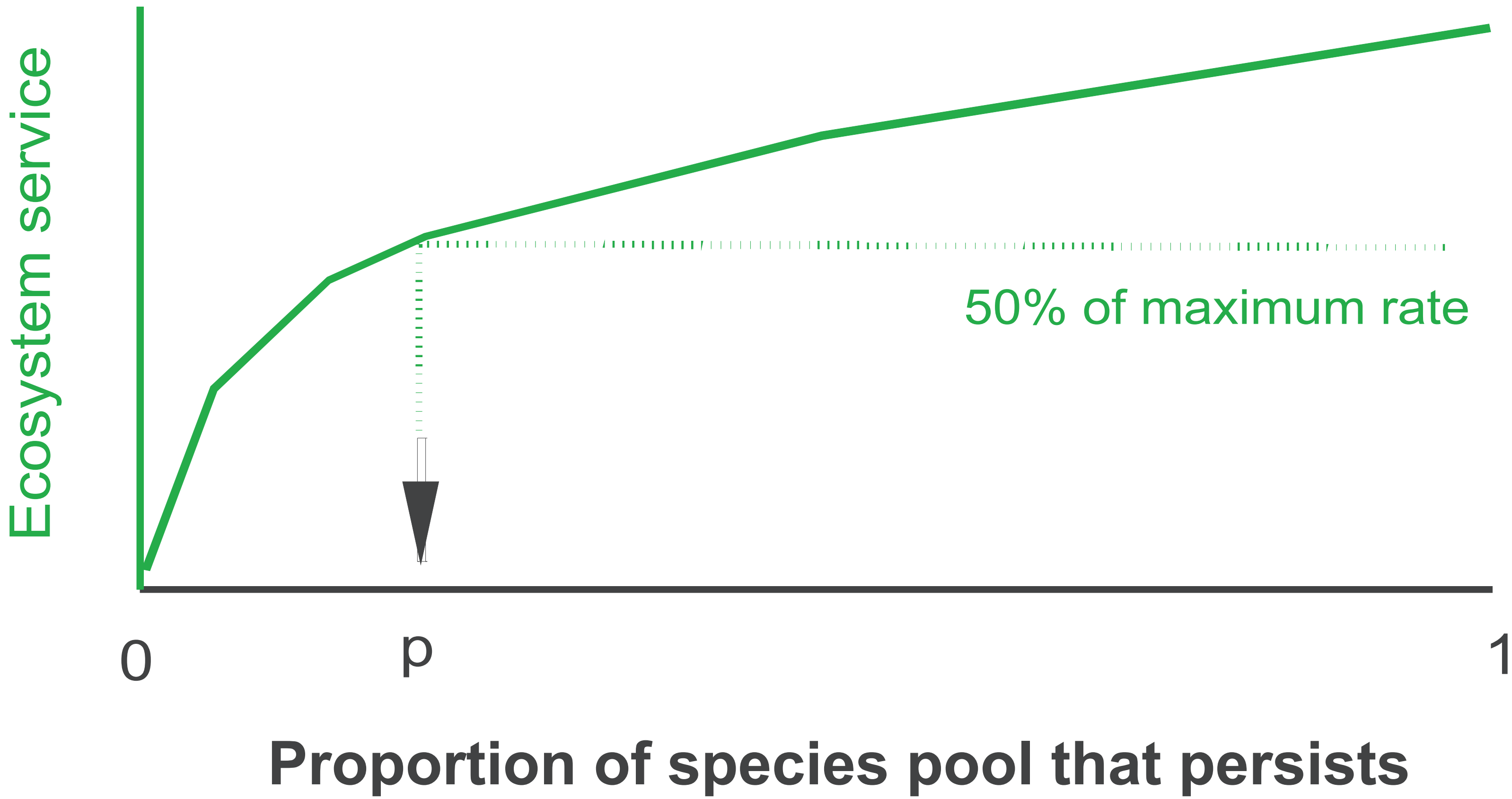


Little Rock Lake Food Web – Trophic change through time

Annual species loss (as % of pre-acidification species number) in response to gradual experimental acidification in two north temperate lakes. A) Four lower trophic levels in Little Rock Lake, WI, USA: primary producers (initial N = 51 phytoplankton species); primary consumers (initial N = 36 primarily_herbivorous zooplankton species); secondary consumers (initial N = 9 omnivorous zooplankton species); and tertiary consumers (initial N = 9 primarily carnivorous zooplankton species); and B) quaternary consumers in Lake 223, Ontario, Canada: (initial N = 7 fish species). For A), initial pH = 5.59, final pH = 4.75; for B) initial pH = 6.49, final pH = 5.13.

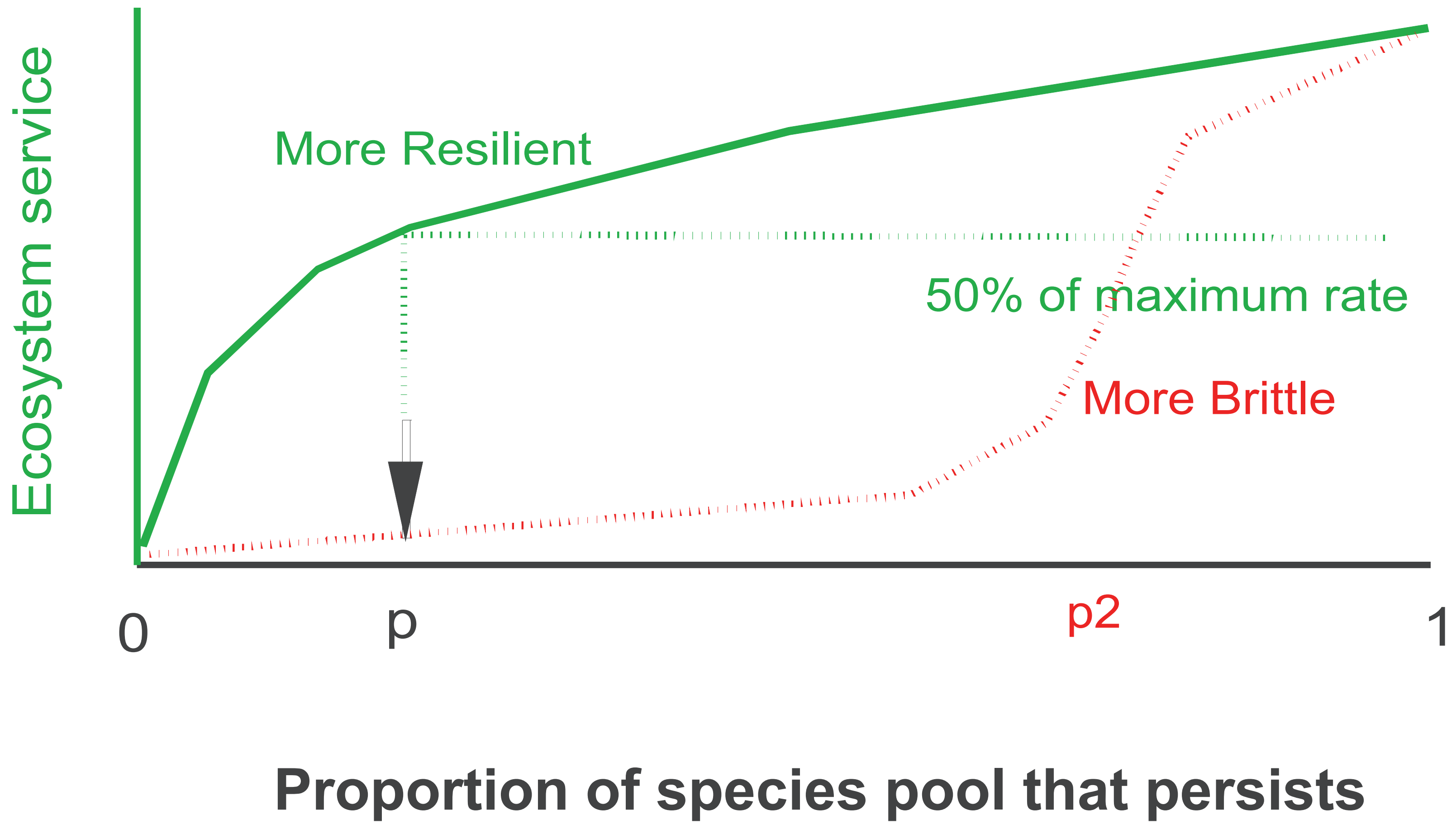


How could we quantify the relationship between species diversity
and the supply of ecosystem services?



Note for Nerds – Essentially a Michaelis-Menton function or Type II Functional Response

Shape of the relationship should change as we move between ‘more resilient’ and ‘more brittle’ services



Which suggests the slopes might change for species on different trophic levels

Dependence on 'pristine' habitat

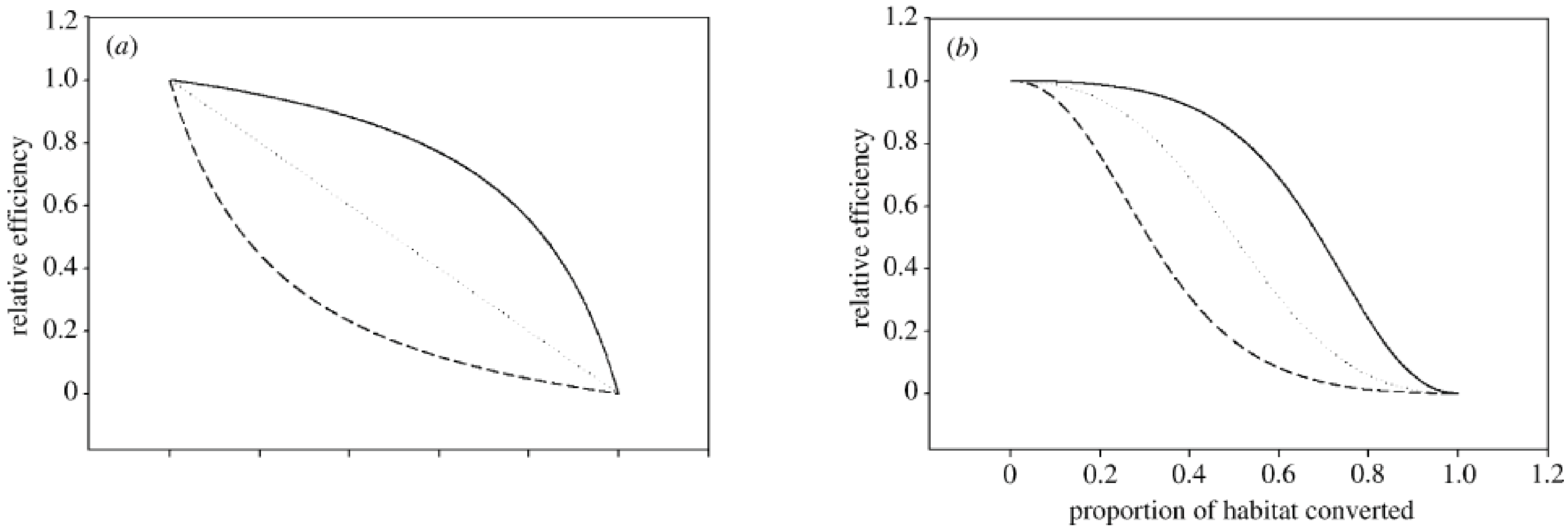
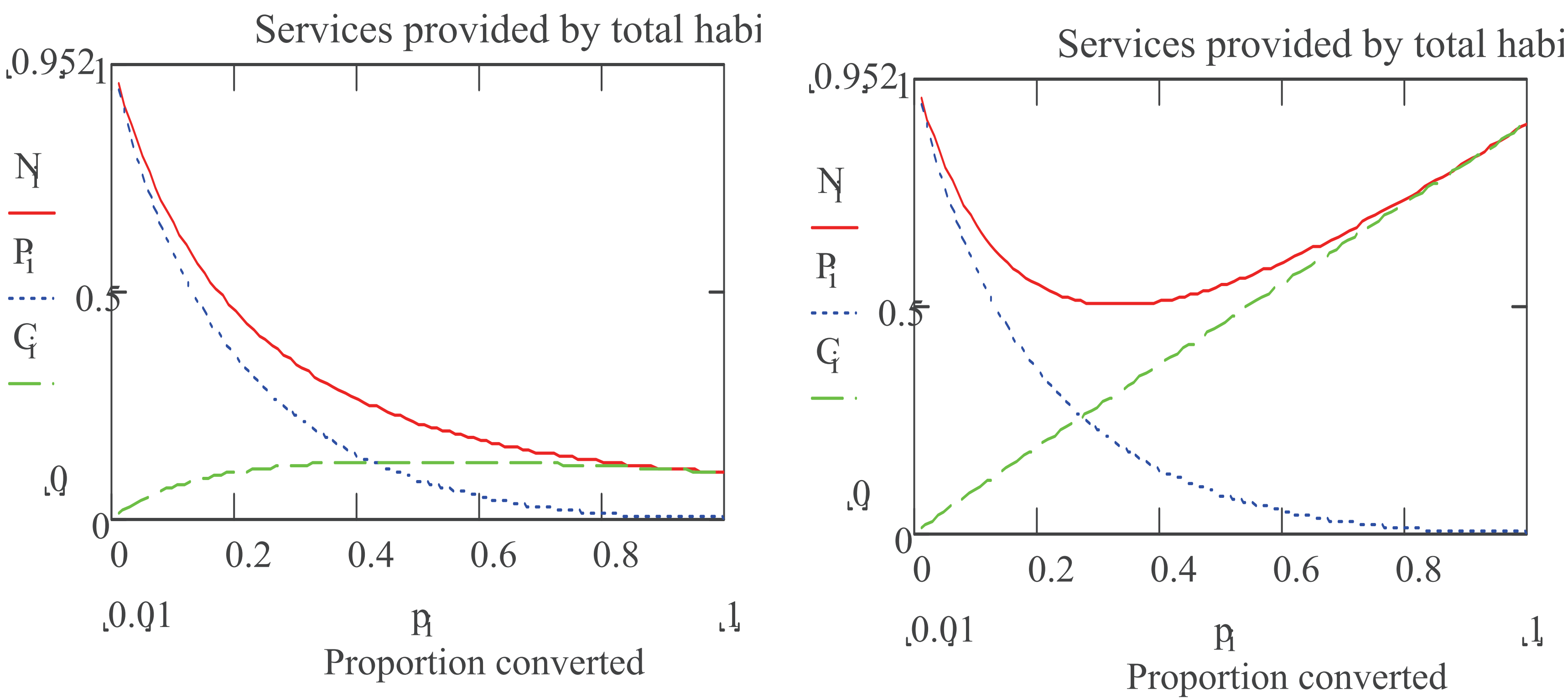


Figure 4. The phenomenological relationship between the supply of ecosystem services and either the proportion of habitat converted or the proportion of the original host community that has been lost. In (*a*) we assume the τ-term in equation 12.2 equals unity, the curves are then drawn for $ES_{50}=0.8$ (upper solid line); $ES_{50}=1$ (middle dotted line); and $ES_{50}=5$ (lowest dashed line). In (*b*) we have set $\tau=2$ (corresponding to services from a higher trophic level), the same three values of ES_{50} are then used as in (*a*).

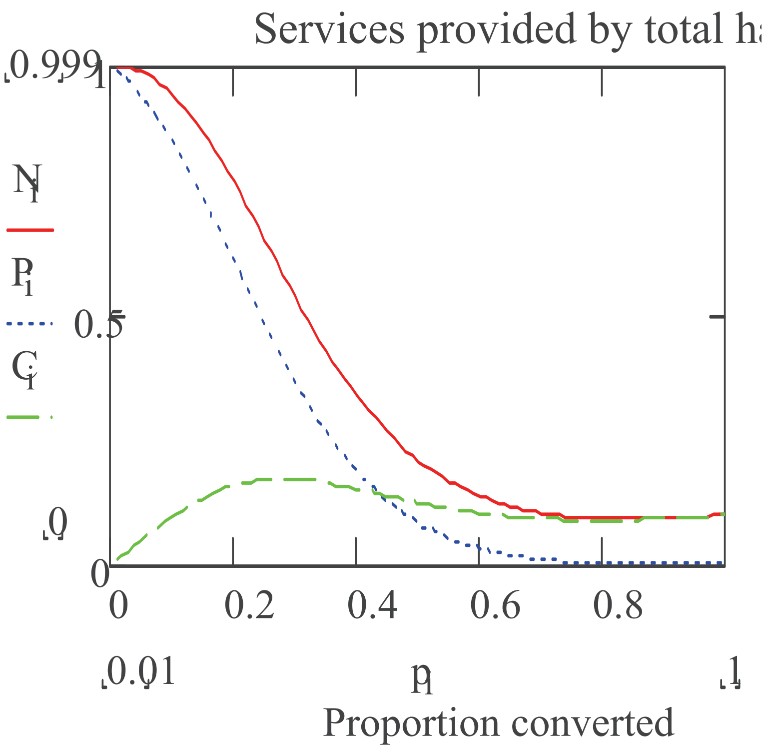
Assume ES = MS

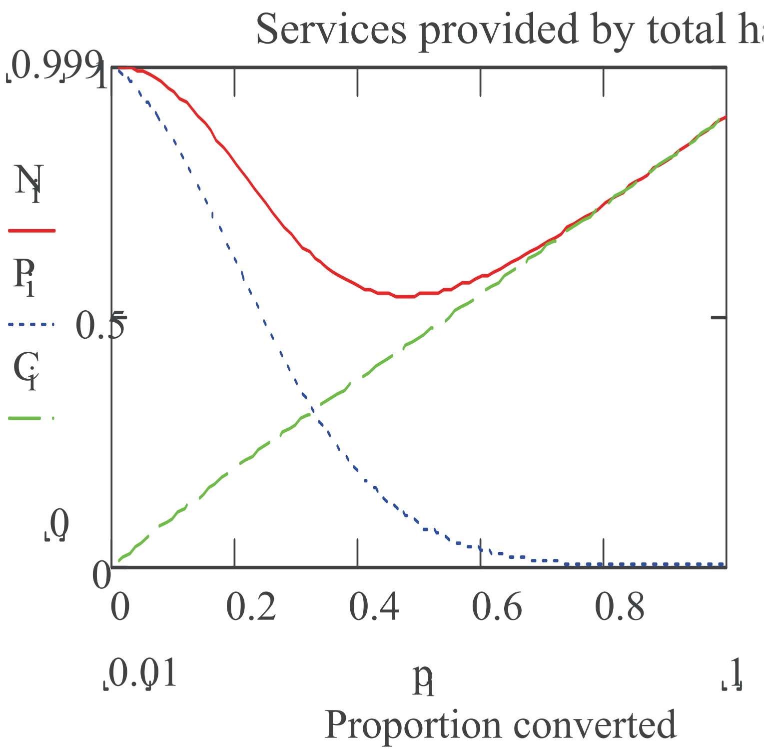


- High (90%) <- Dependence -> Low (10%)

Type II threshold at 10% conversion

Assume ES = MS

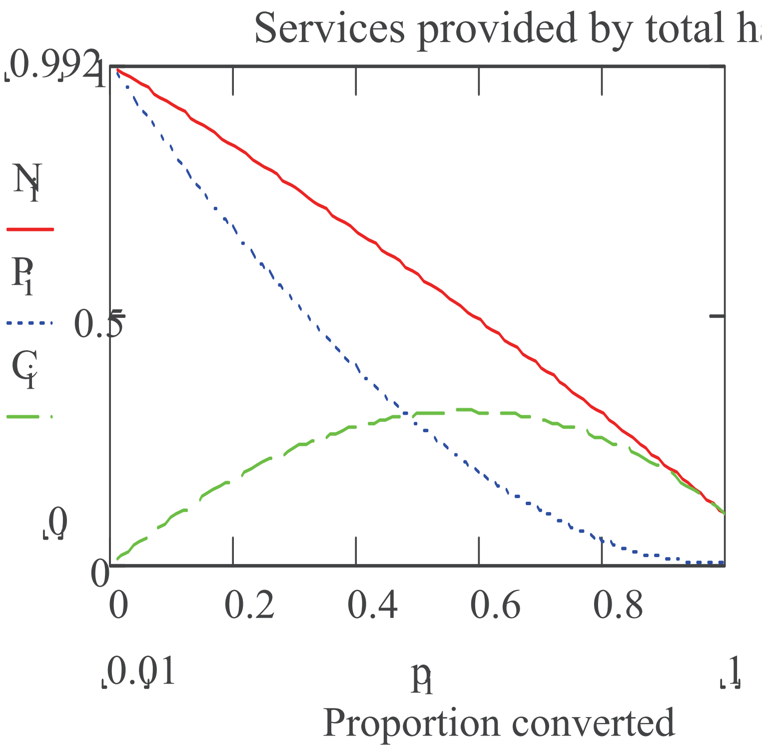


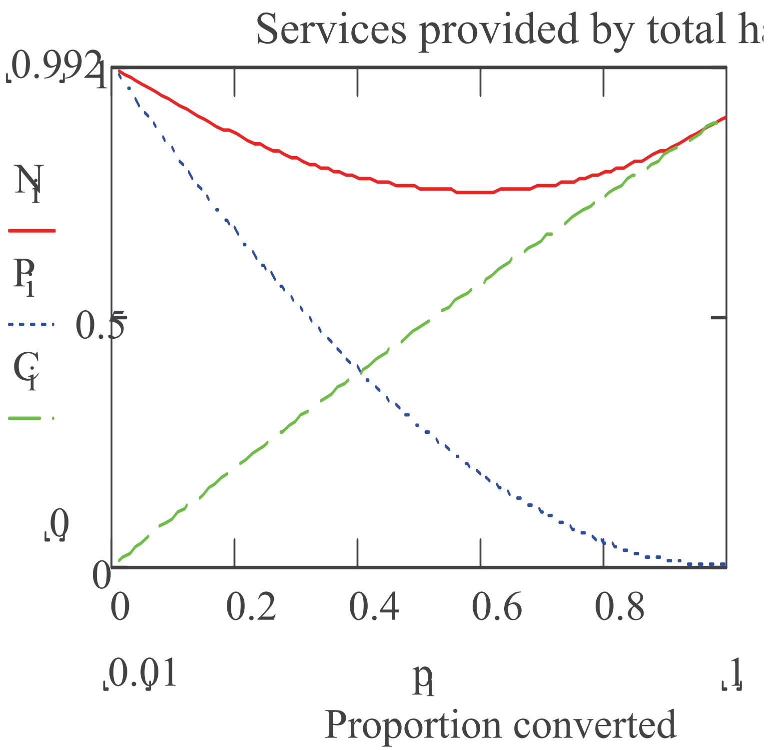


- High (90%) <- Dependence -> Low (10%)

Type III threshold at 10% conversion

Assume ES = MS

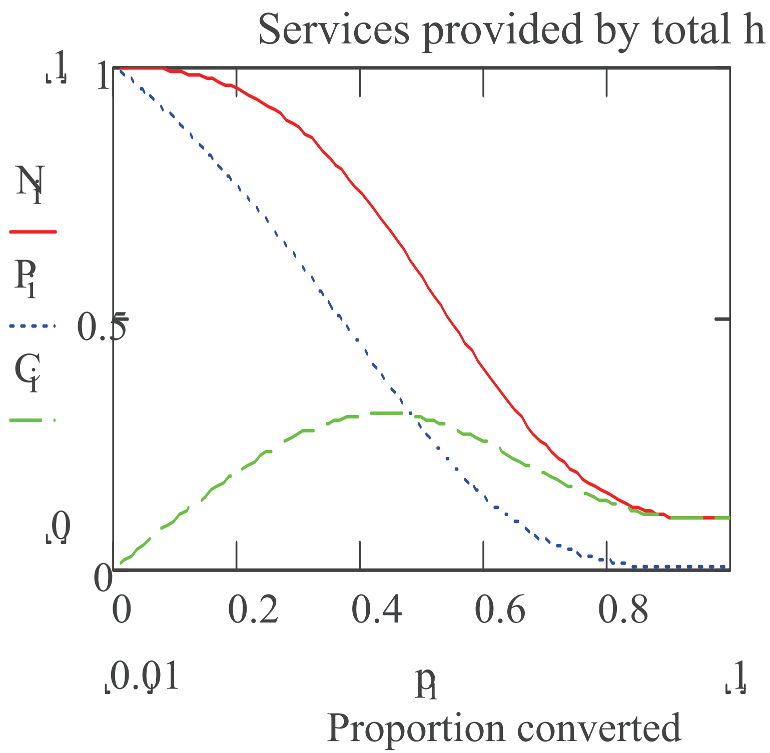


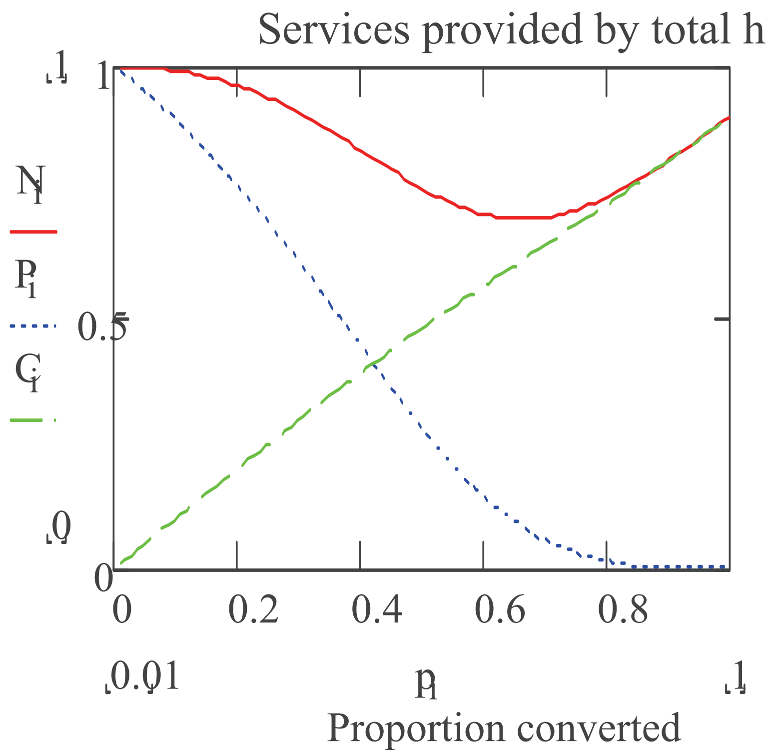


- High (90%) <- Dependence -> Low (10%)

Type II threshold at 80% conversion

Assume ES = MS





- High (90%) <- Dependence -> Low (10%)

Type III threshold at 90% conversion

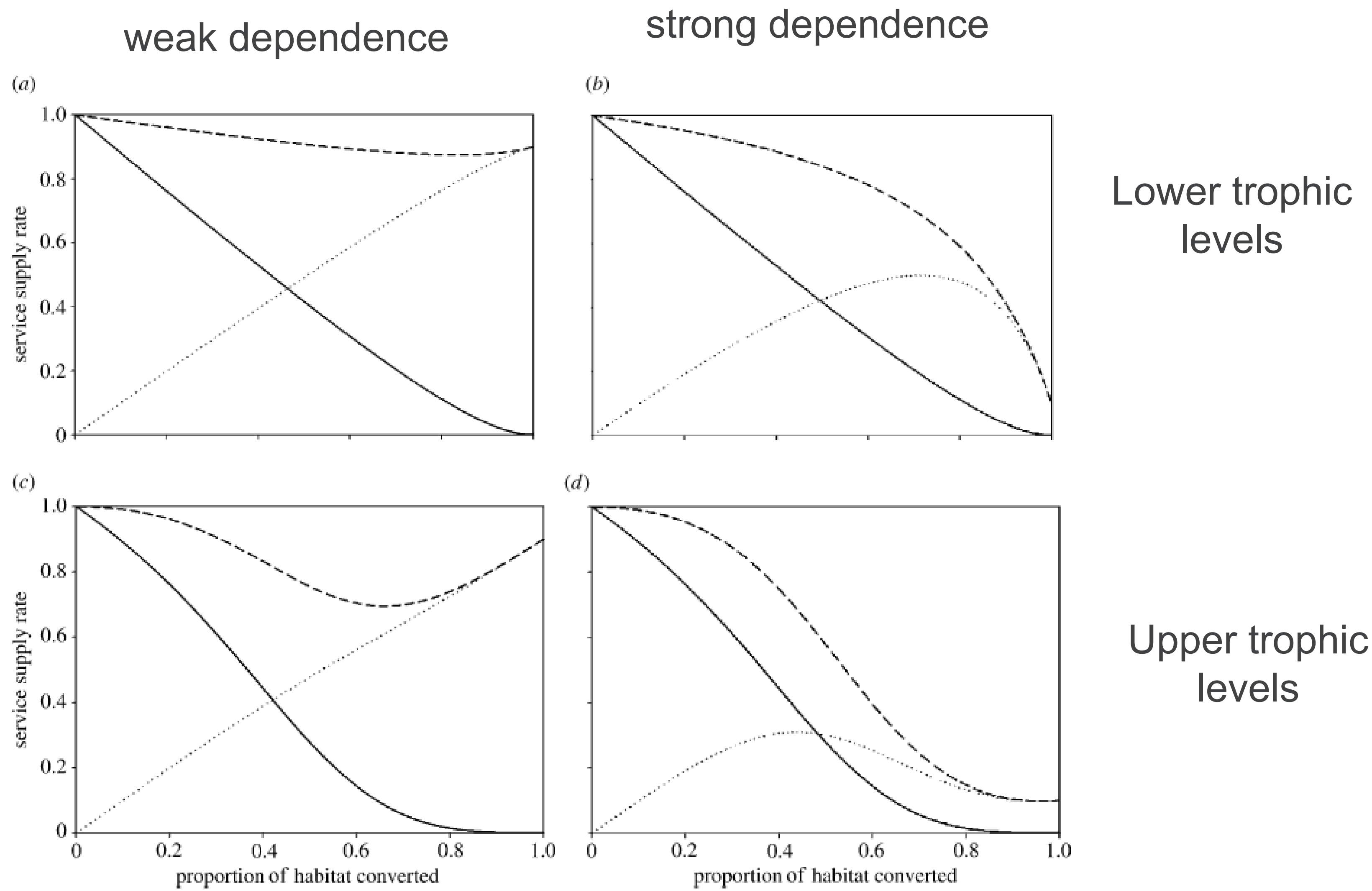
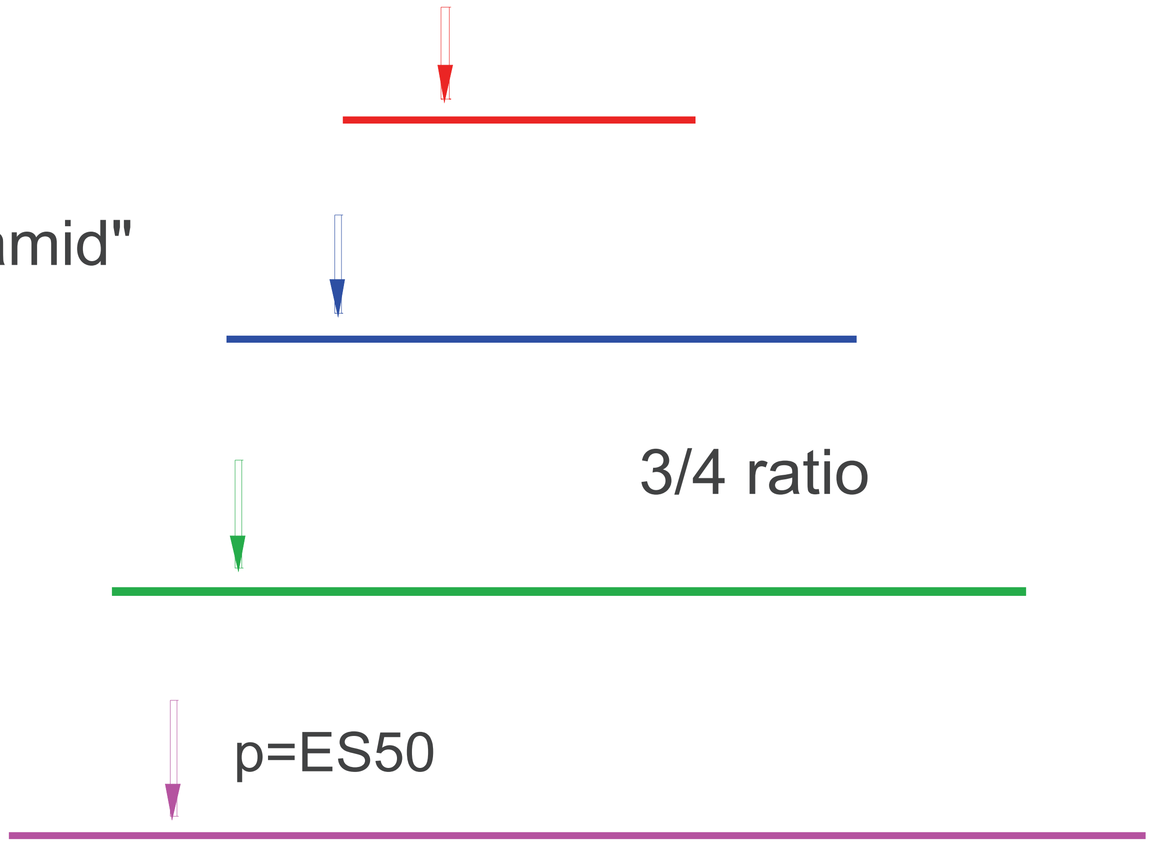


Figure 5. Net services provided by a habitat at different levels of conversion. Four different scenarios are presented, in each the services provided by the natural habitat are presented as a (downward sloping) solid line, the new services provided by the modified habitat are depicted by upward sloping dotted lines. The net services are illustrated by the uppermost, broken line. Scenarios (*a*) and (*b*) illustrate the case for resilient services ($p=0.8$) that are undertaken by species at low trophic levels. Scenarios (*c*) and (*d*) are for brittle and less resilient services ($p=0.2$) undertaken by species at higher trophic levels. In (*a*) and (*c*) the services in the modified area of habitat are only weakly dependent upon services in the pristine habitat ($d=0.1$). In (*b*) and (*d*) the services in the modified habitat are strongly dependent upon services provided by the remaining pristine habitat.

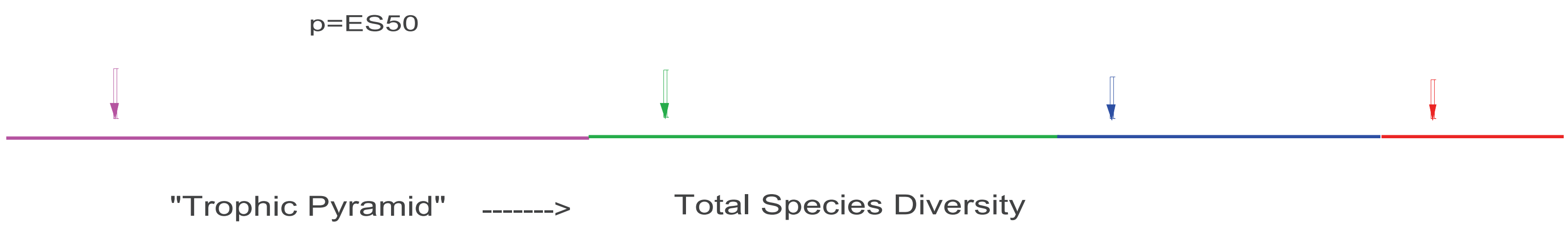
Trophic diversity and ecosystem function

"Trophic Pyramid"



Trophic diversity and ecosystem function

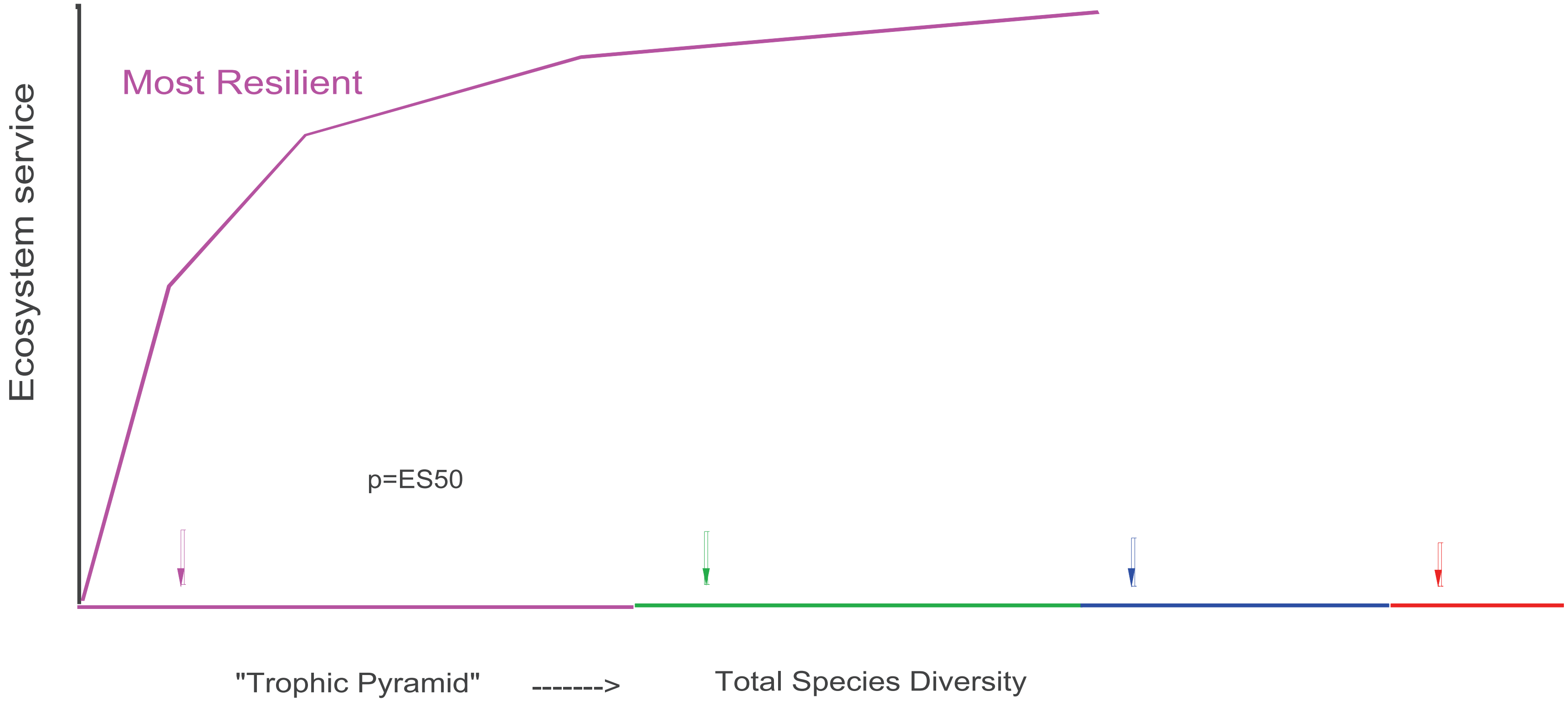
Re-arrange as a ‘interval’ community ordered by trophic position



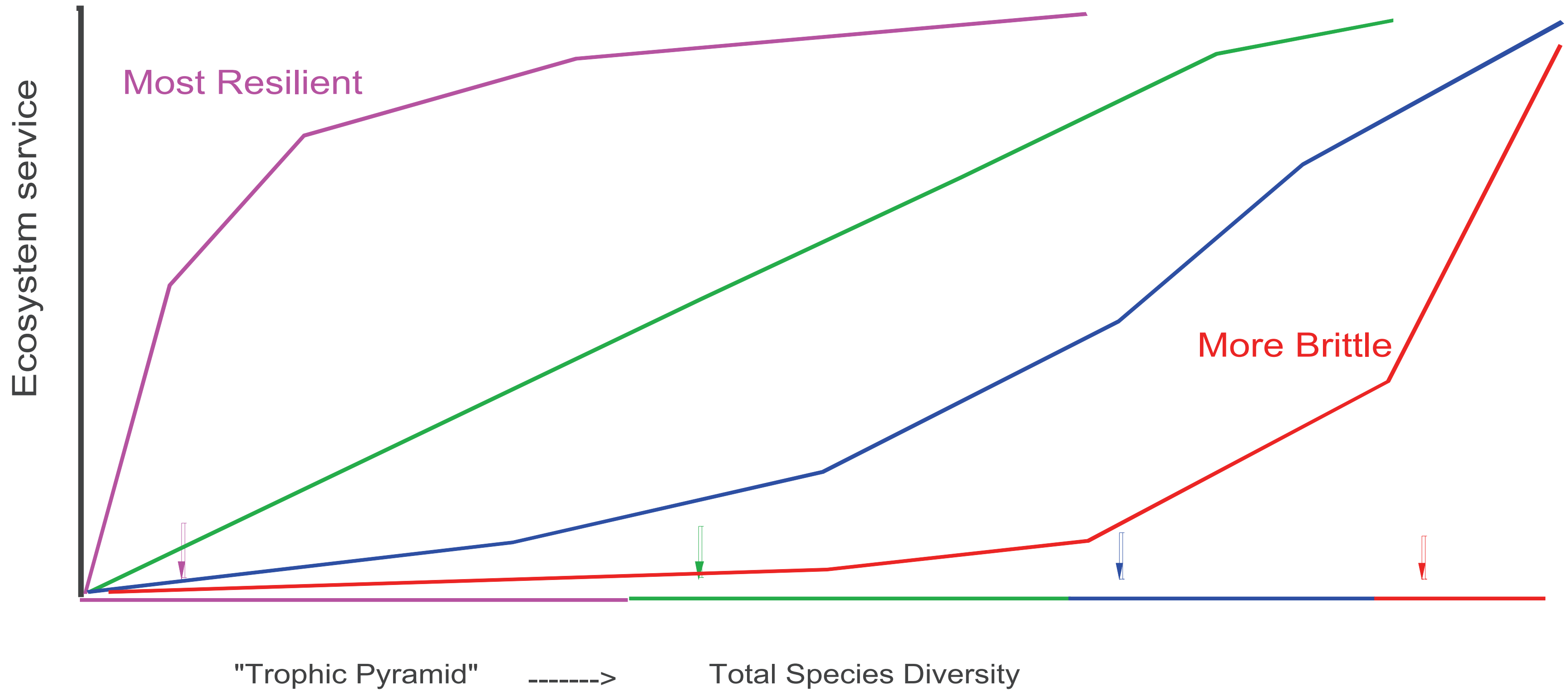
Total species diversity --------→

(*sensu* Joel Cohen’s ‘Cascade Model’ and Martinez & Williams ‘Niche Model’)

Trophic diversity and ecosystem function



Trophic diversity and ecosystem function



Proportion of maximum ecosystem service supplied as net biodiversity declines

$$p_\tau = 1 - \left(\frac{1}{1 - \left(\frac{S}{T_\tau} \right)^{\tau.\tau}} \right)$$

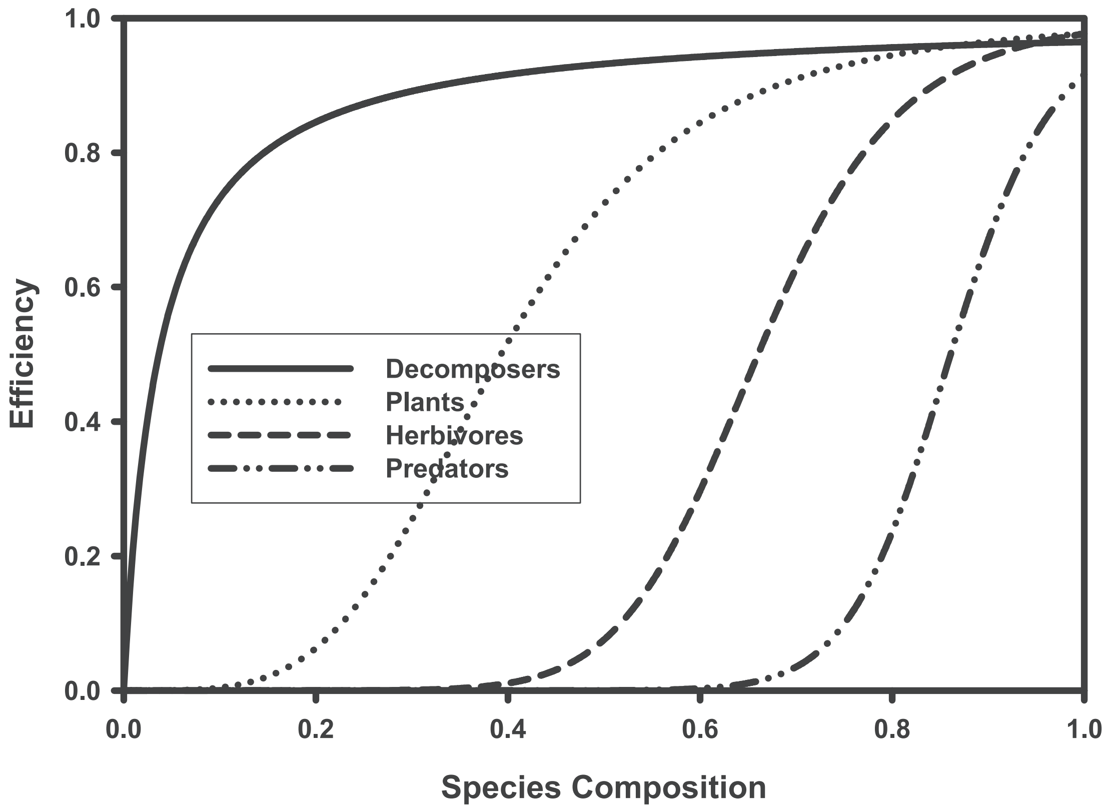
S = number of species left in community

Tau = trophic level

T= 50% Efficiency Threshold

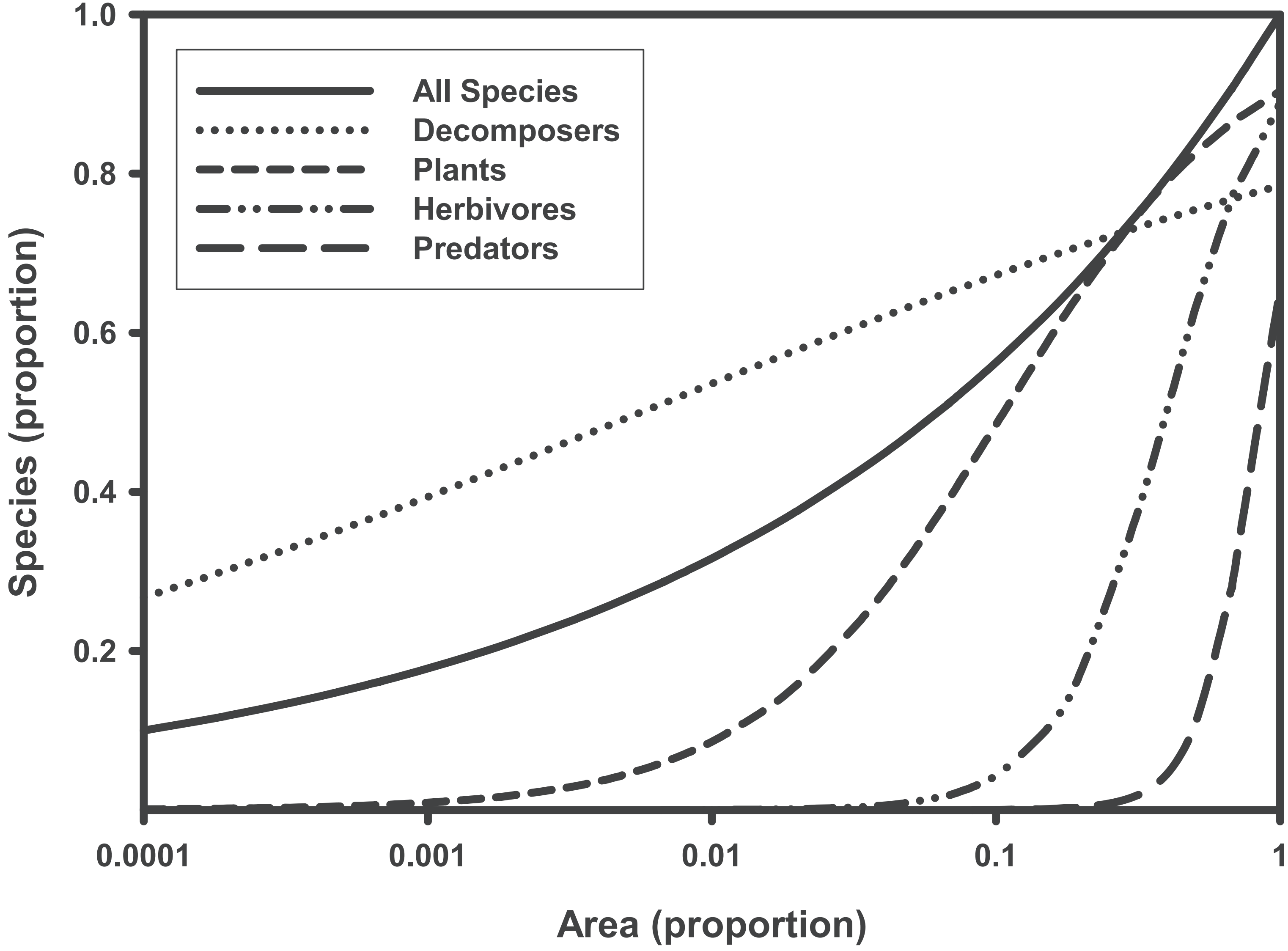
Assume thresholds occur at N+0.1S_{tau} : N is number spp at lower tau

Loss of service x trophic level



Then use species-area curves to convert this to loss of service as area eroded

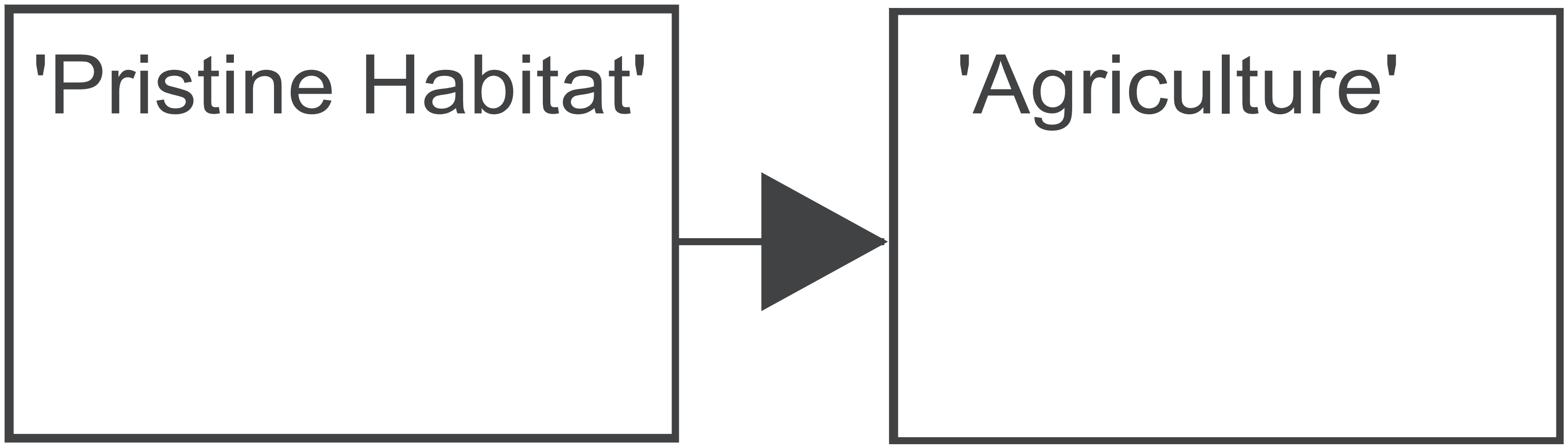
Species x Area x Trophic Level



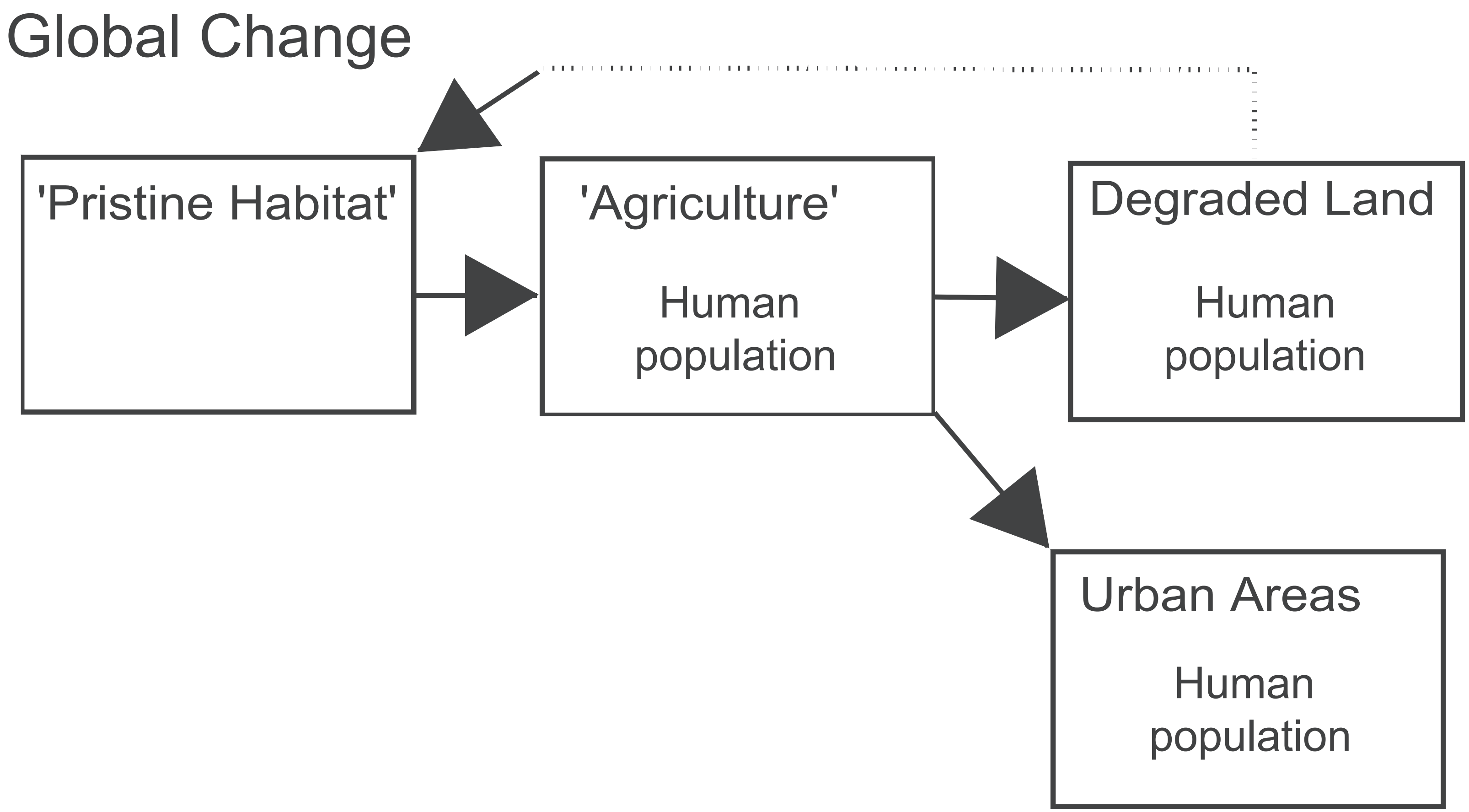
Global Change

'Pristine Habitat'

Global Change




Global Change
'Pristine Habitat'
'Agriculture'
Degraded Land


Global Change
'Pristine Habitat'
'Agriculture'
Human
population
Degraded Land
Human
population
Urban Areas
Human
population

Natural history of measles infection

Essentially a similar process to land use change!! ?

Birth rate

----------------Succesion/

------------>Restoration

Births

Susceptible Pristine

Infected Agriculture

Recovered Abandoned

---~~Vaccination~~--- Reserve Establishment ->

Basic land use change model

Forest $$\frac{dF}{dt} = sU - dPF$$

Agriculture $$\frac{dA}{dt} = dPF + bU - aA$$

'Degraded' $$\frac{dU}{dt} = aA - (b+s)U$$

Human Population $$\frac{dP}{dt} = rP\frac{A-hP}{A}$$

Simple logistic as a function of land currently under agriculture

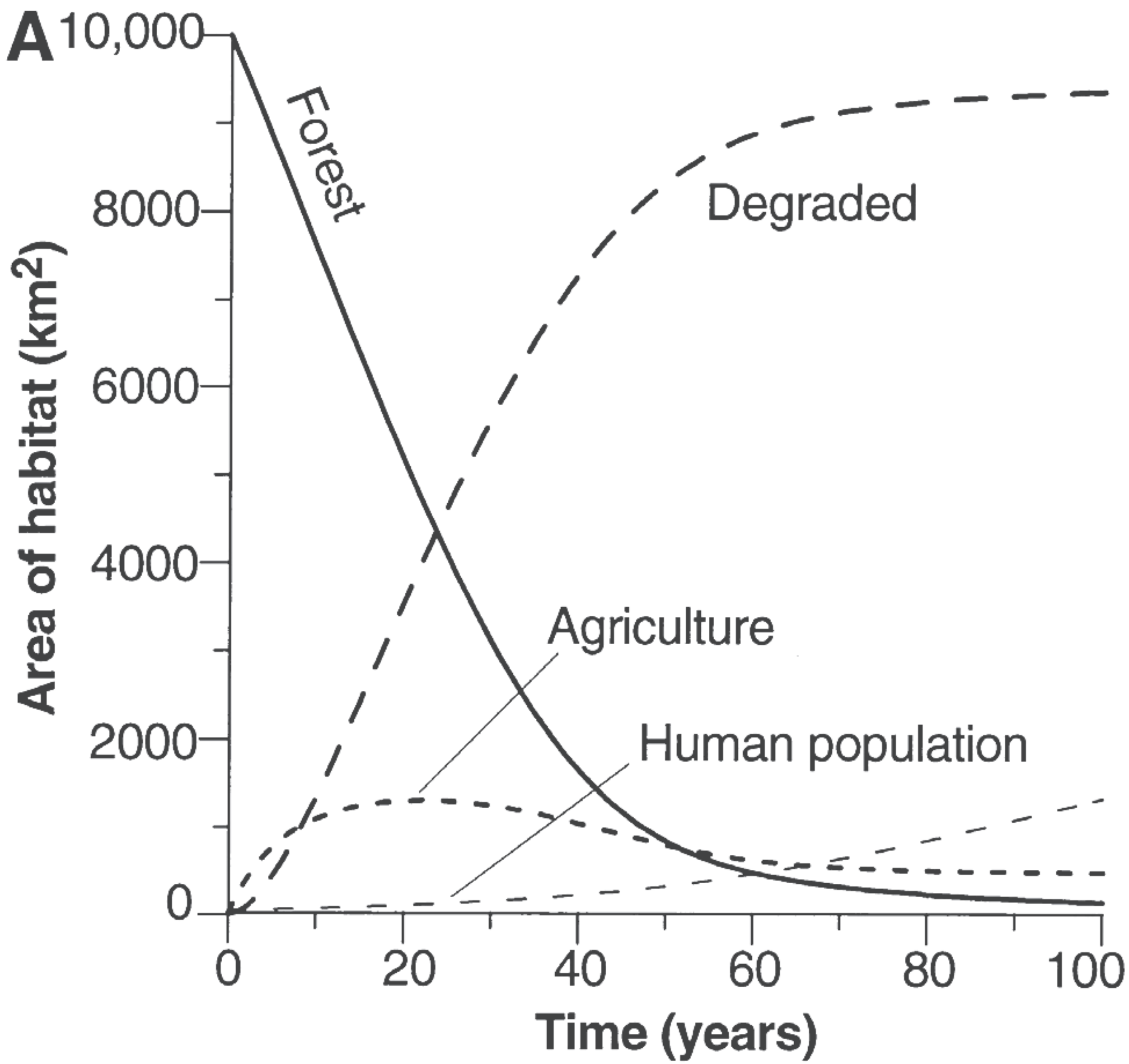
Settles monotonically to equilibrium

$$A^* = hP^*$$

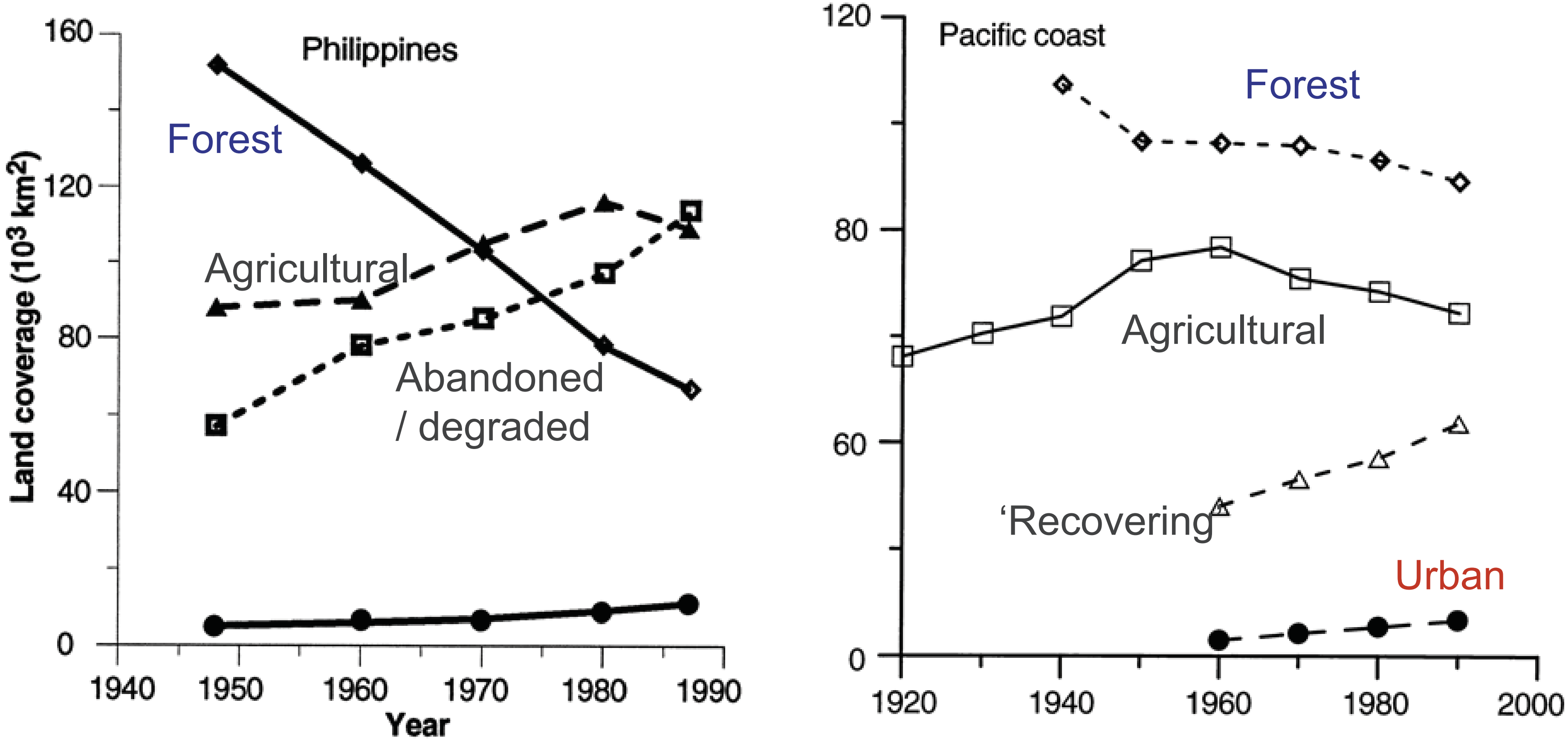
$$U^* = \frac{aA^*}{(s+b)}$$

$$F^* = \frac{ah}{d}\left(\frac{s}{s+b}\right)$$

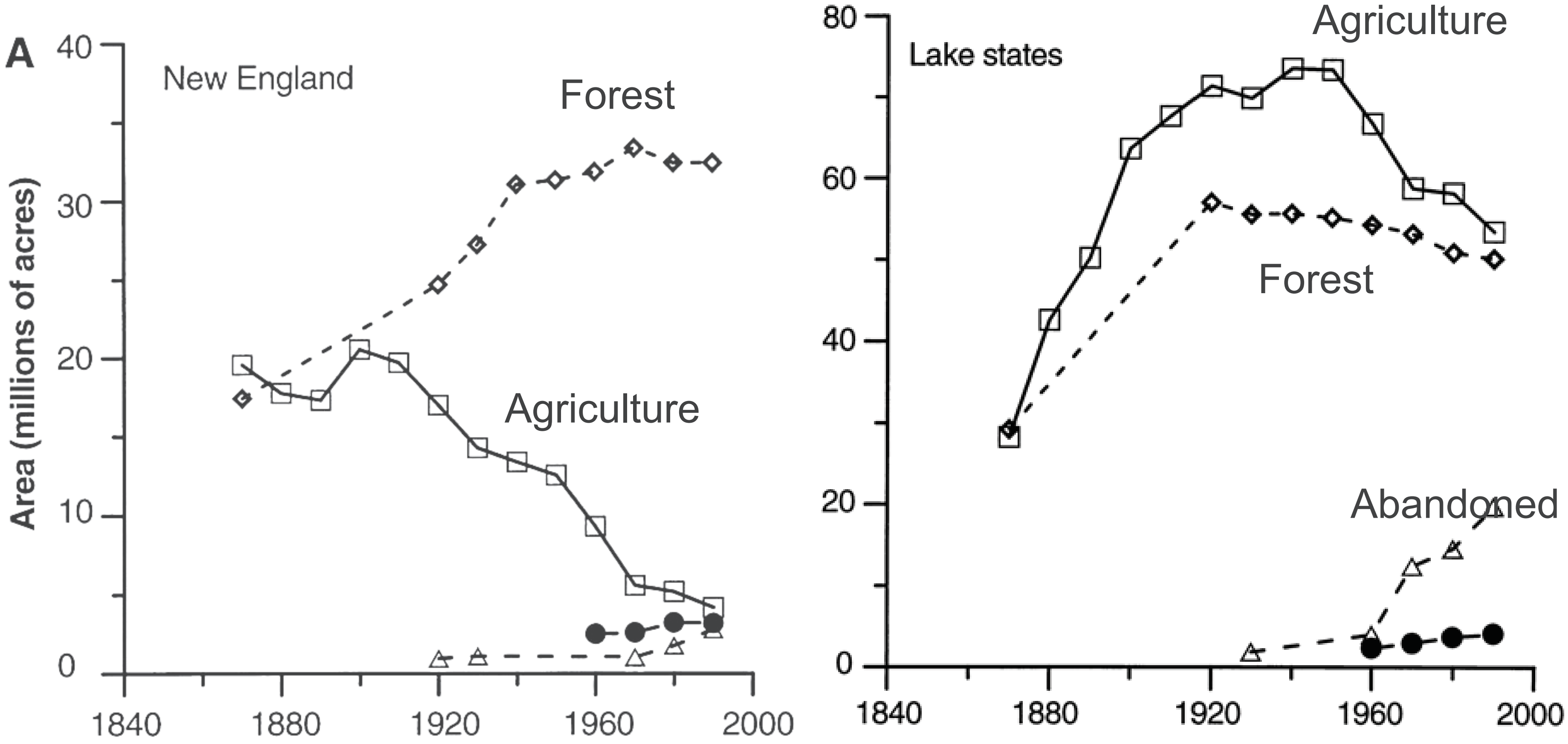
$$P^* = \frac{F_0 - \left(\left(\frac{ah}{d}\right)\left(\frac{s}{s+b}\right)\right)}{h\left(\frac{a}{s+b}+1\right)}$$


A
10,000
8000
6000
4000
2000
0
Area of habitat (km²)
Forest
Degraded
Agriculture
Human population
0
20
40
60
80
100
Time (years)

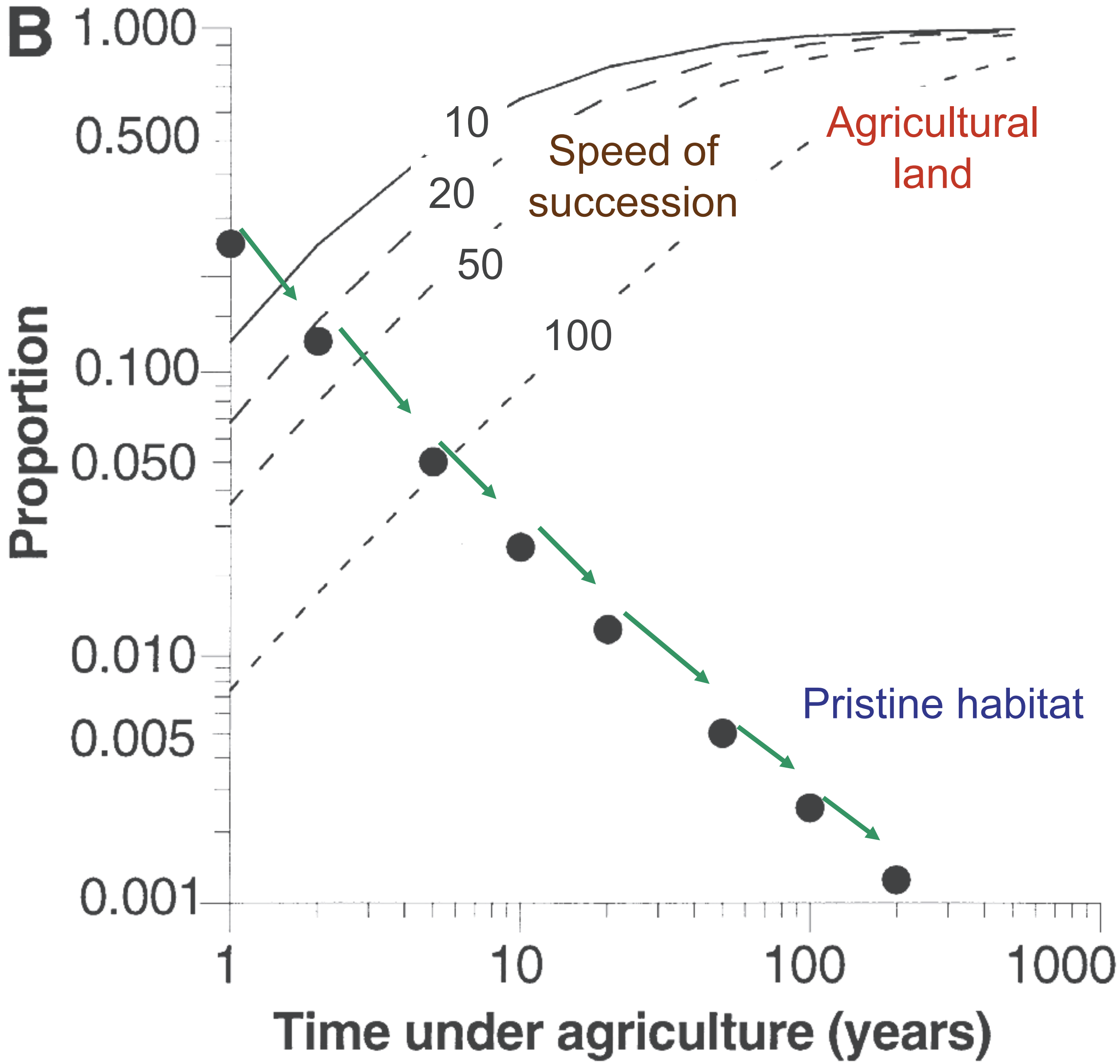
Land use change in the Phillipines and Pacific coast US



Land use change in New England and the Lake States (OK – the Mid-West!)

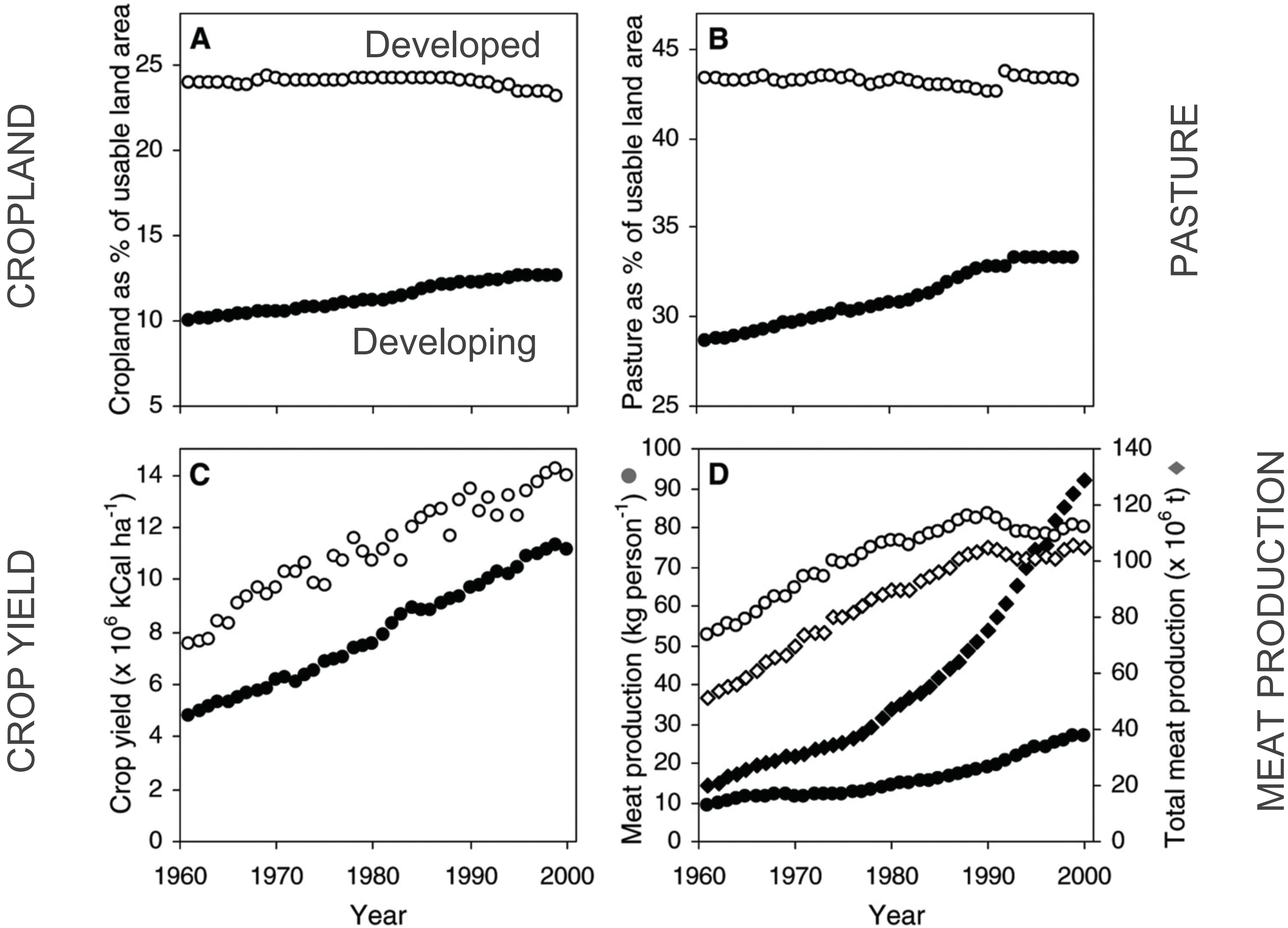


Equilibrium proportions of different habitat use under different mean persistence times

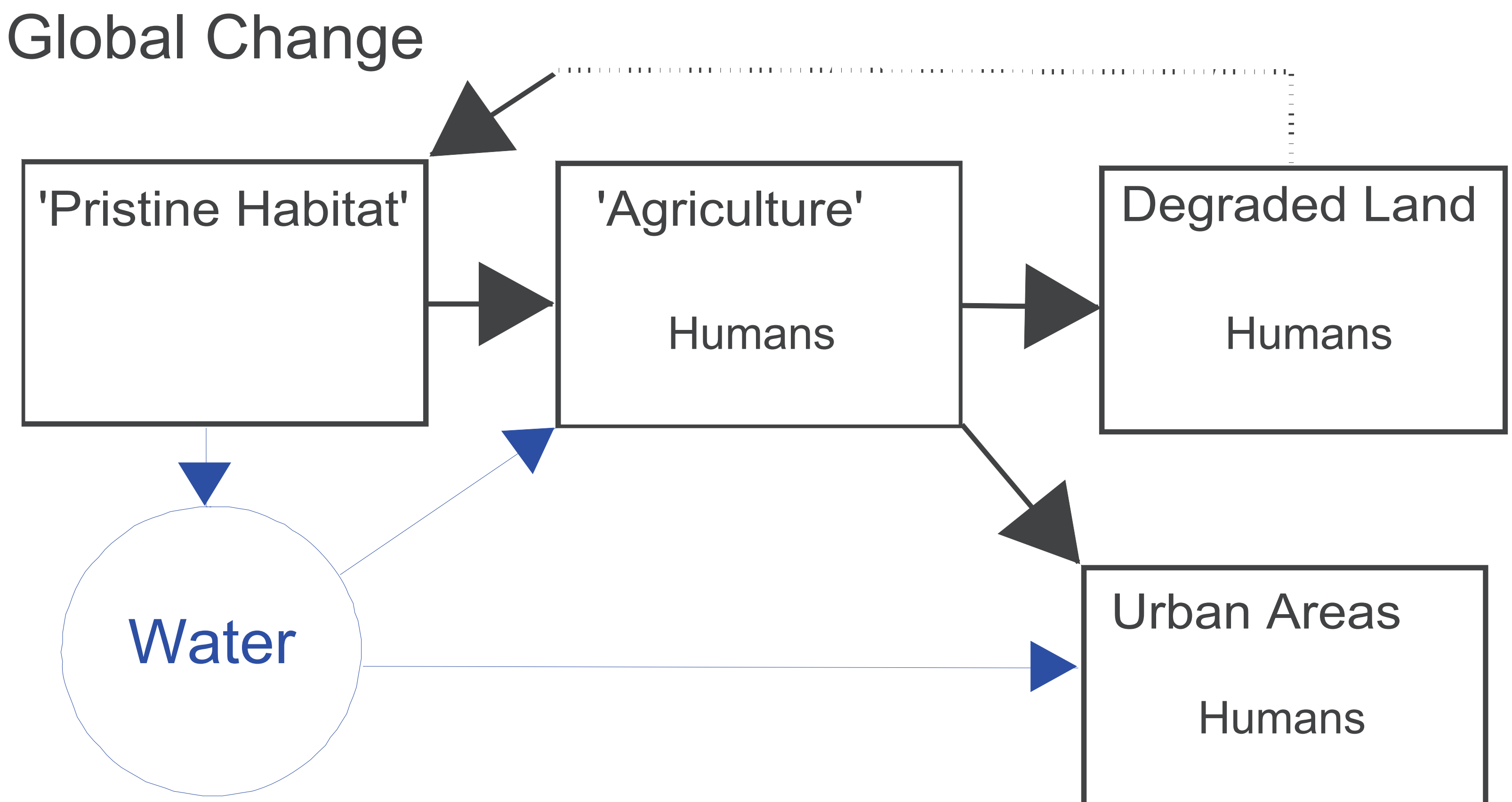


Global trends in land-use change

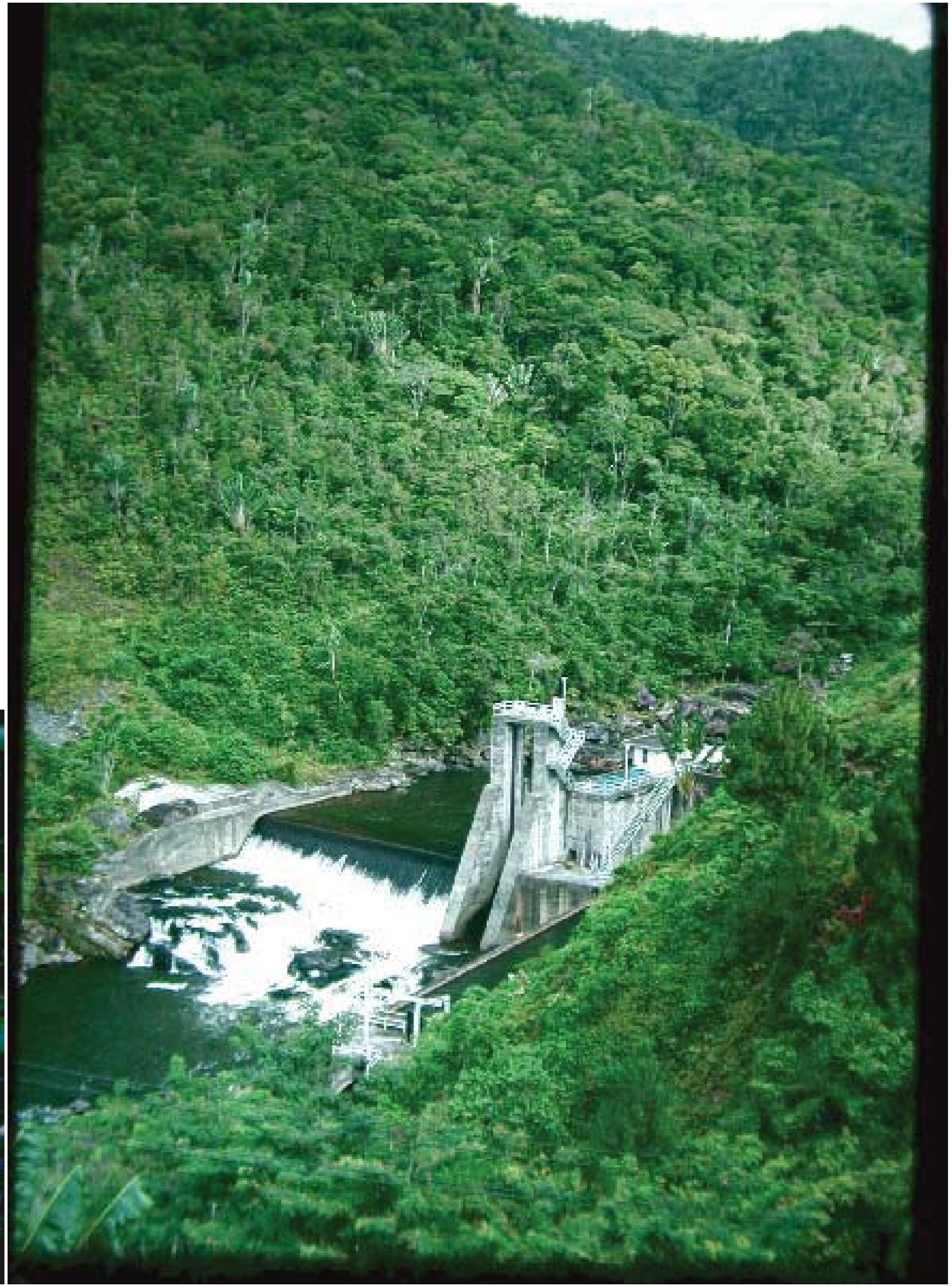
Green, Cornell, Scharlemann & Balmford, Science, 28 January 2005



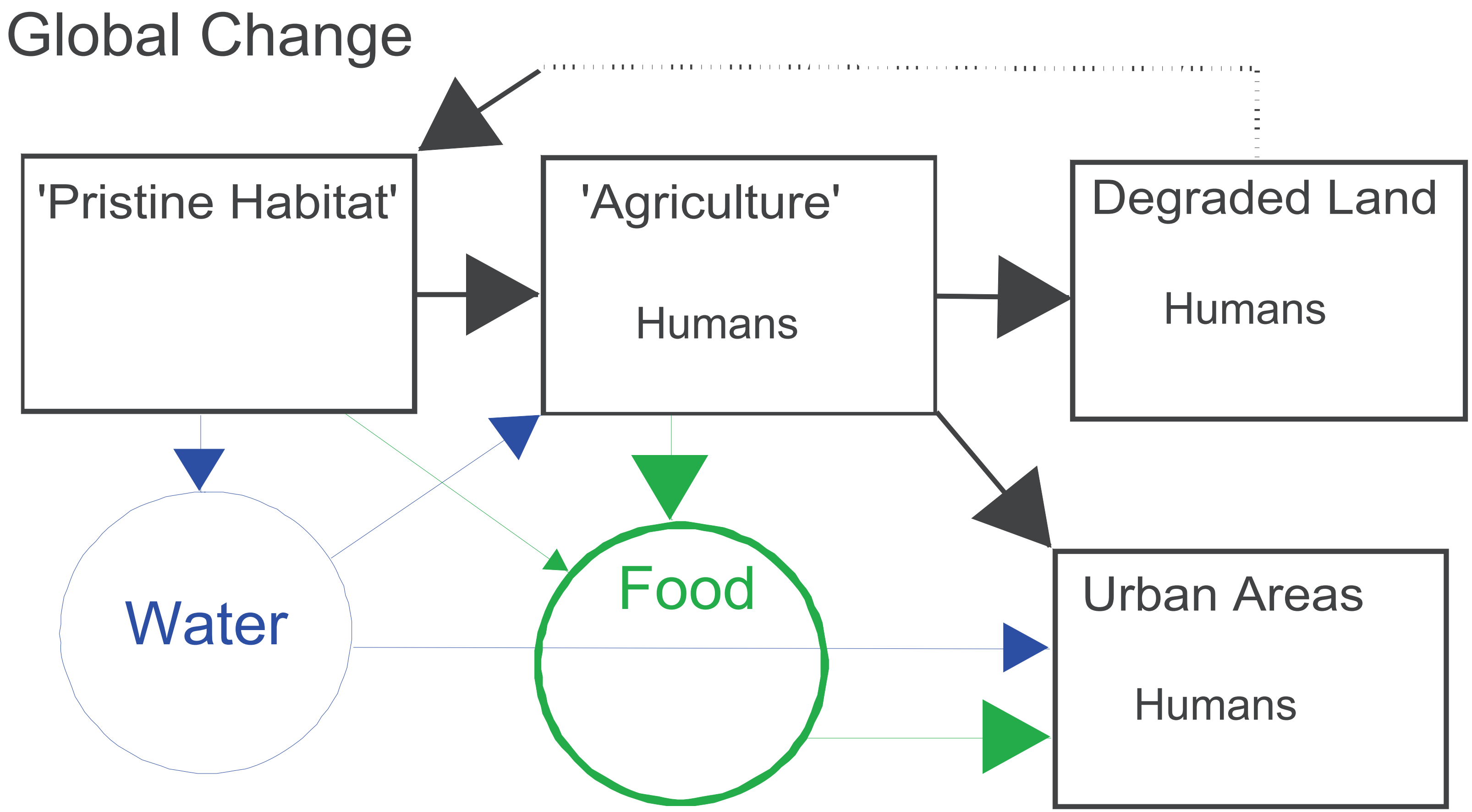
What happens if agricultural productivity is dependent upon forested habitat?



Ranomafana NP, Madagascar



So what happens if we include Ecosystem Services in our land use change model?



Modified land use change model

Forest $$\frac{dF}{dt} = sU - dPF$$

Agriculture $$\frac{dA}{dt} = dPF + bU - aA$$

'Degraded' $$\frac{dU}{dt} = aA - (b+s)U$$

Human Population $$\frac{dP}{dt} = rP\frac{A-hP}{A}$$

$$\longrightarrow \quad \frac{dP}{dt} = rP\left(\frac{AF - hP(1+\frac{F_{50}}{F})}{AF}\right)$$

Type 2 Functional Response
A~> AF/(F+F50)

Settles monotonically to equilibrium

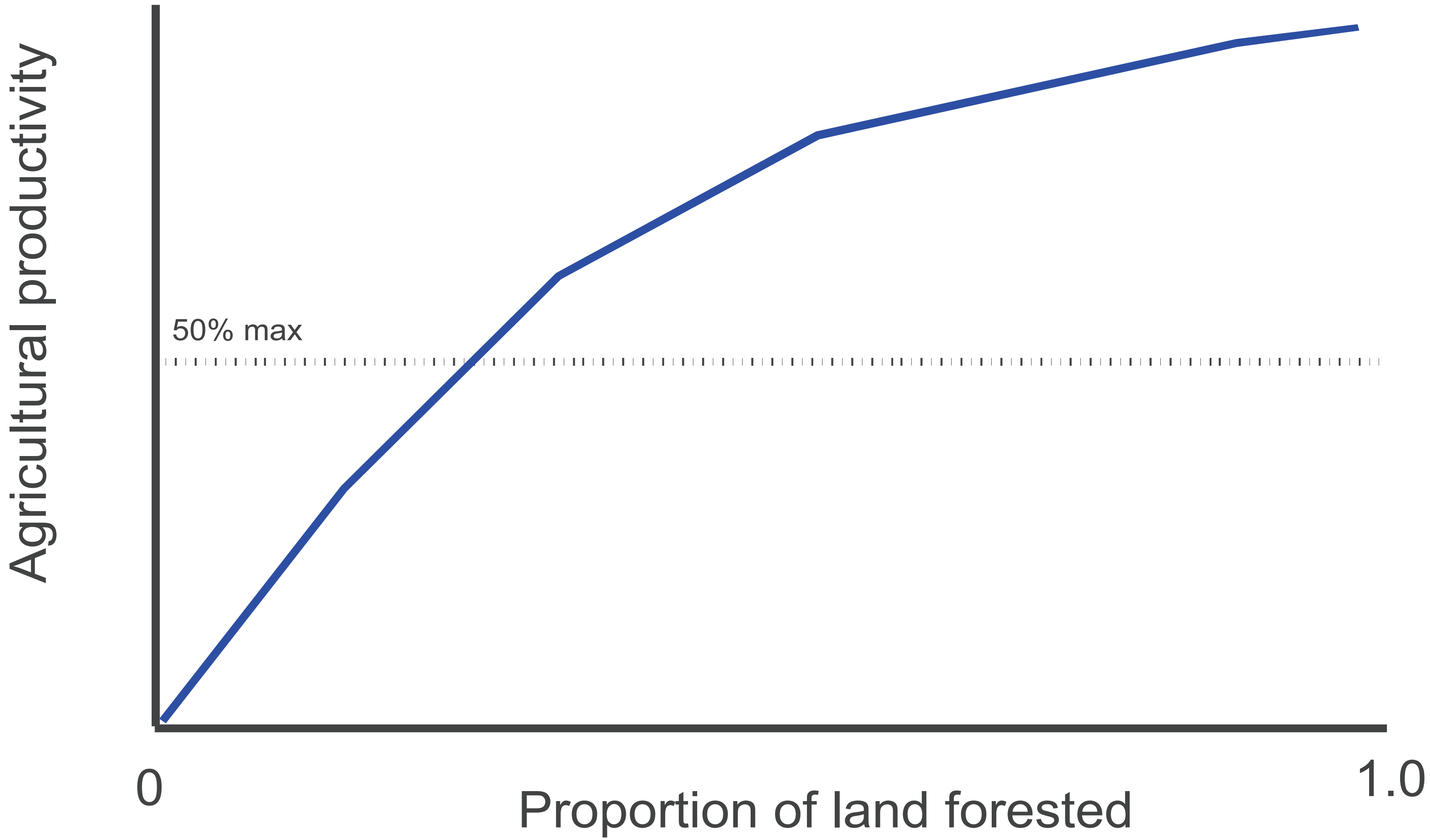
$$P^* = \frac{F_0 - \left(\left(\frac{ah}{d}\right)\left(\frac{s}{s+b}\right)\right)}{h\left(\frac{a}{s+b}+1\right)}$$

$$A^* = hP^* \qquad U^* = \frac{aA^*}{(s+b)} \qquad F^* = \frac{ah}{d}\left(\frac{s}{s+b}\right)$$

$$P^* = \frac{F^*(F_0 - F^*)}{h\left(F_{50} + F^*\right)\left(\frac{a+b+s}{b+s}\right)}$$

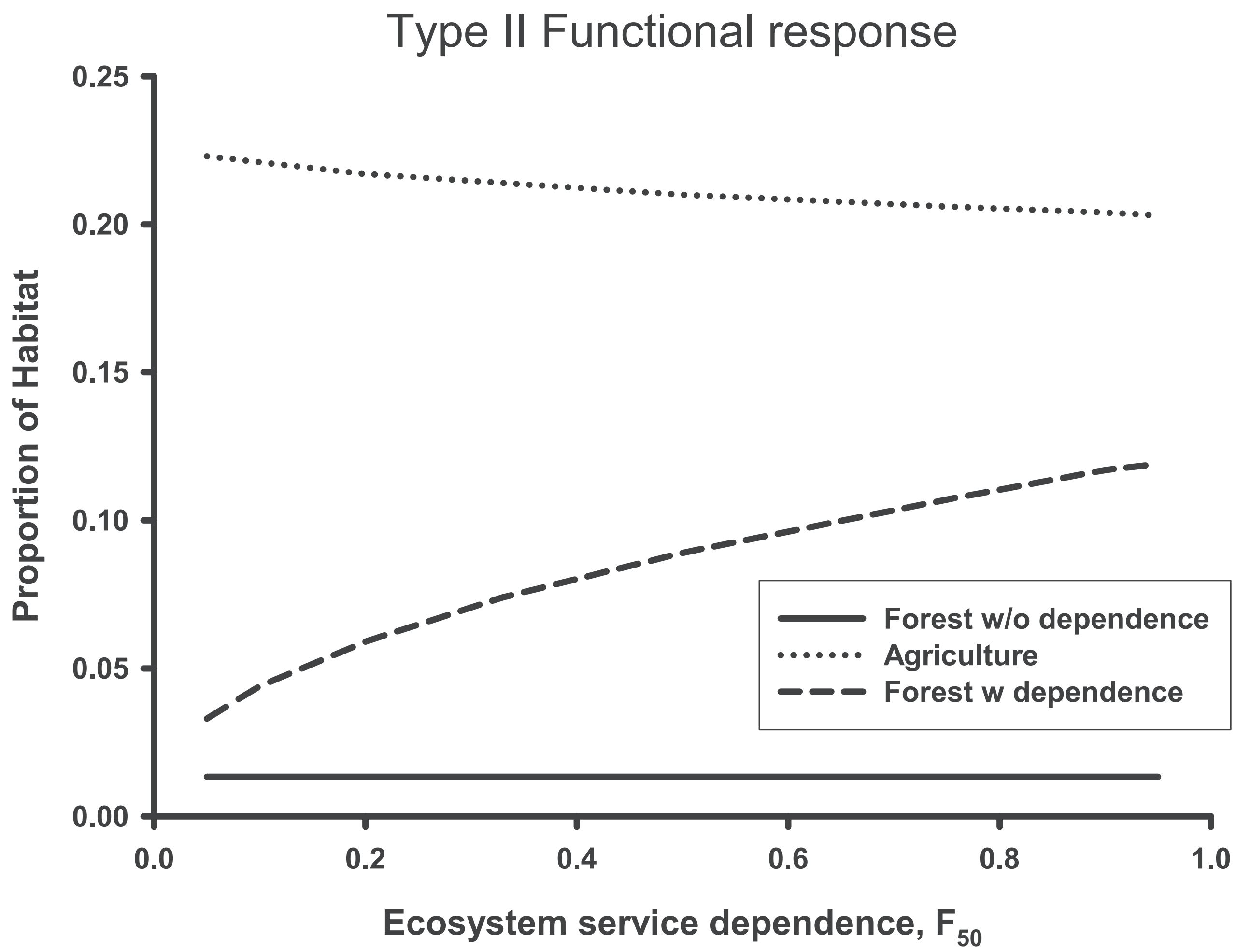
$$A^* = hP^*\left(1 + \frac{F_{50}}{F^*}\right) \qquad F^* = \tfrac{1}{2}c_1 \pm \tfrac{1}{2}\left(c_1^2 + 4c_1F_{50}\right)^{1/2} \qquad c_1 = \frac{sah}{d(b+s)}$$

Land-use change with agricultural dependence on water

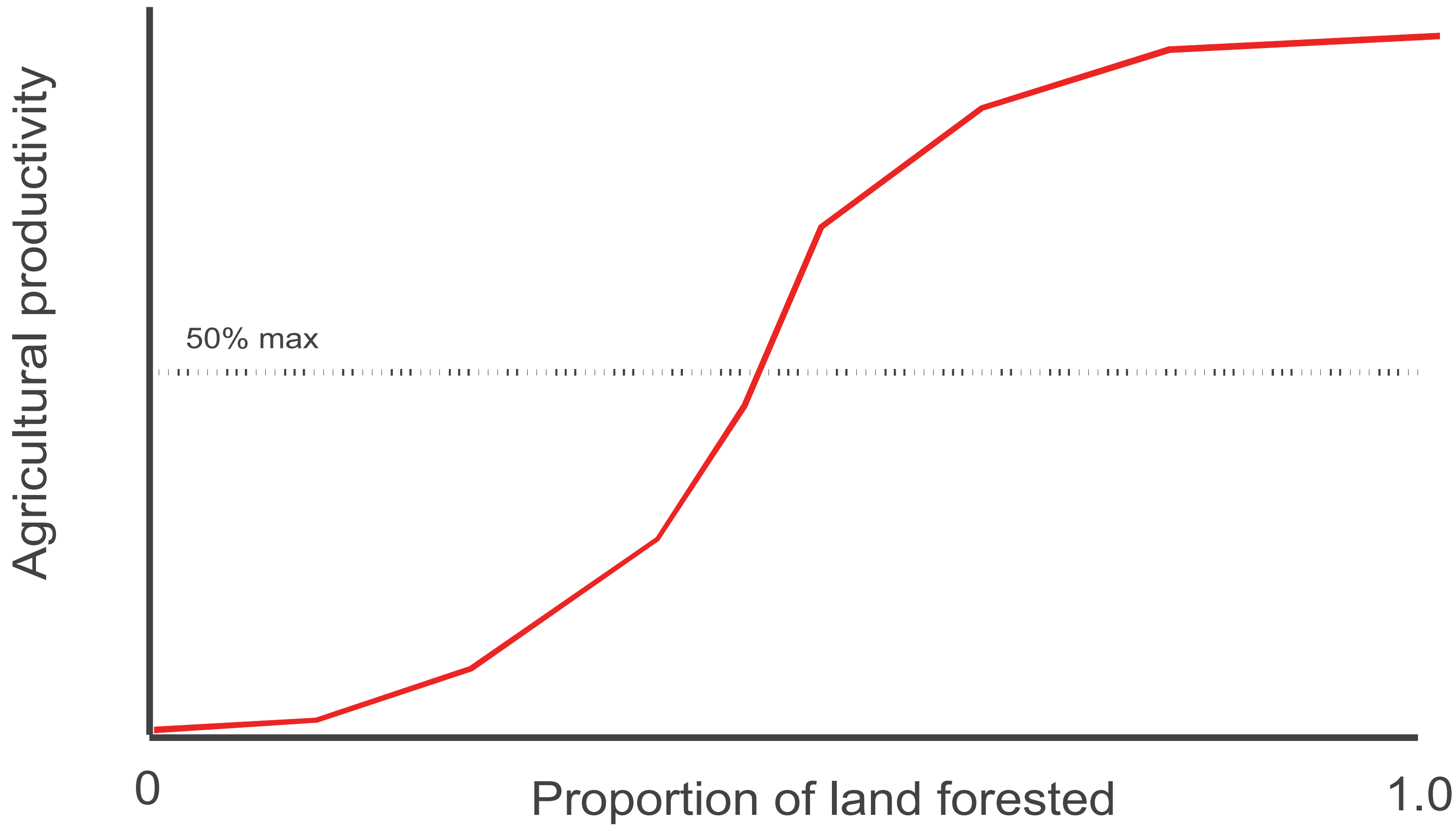


Equilibrium landscape proportions

Type I Dependence

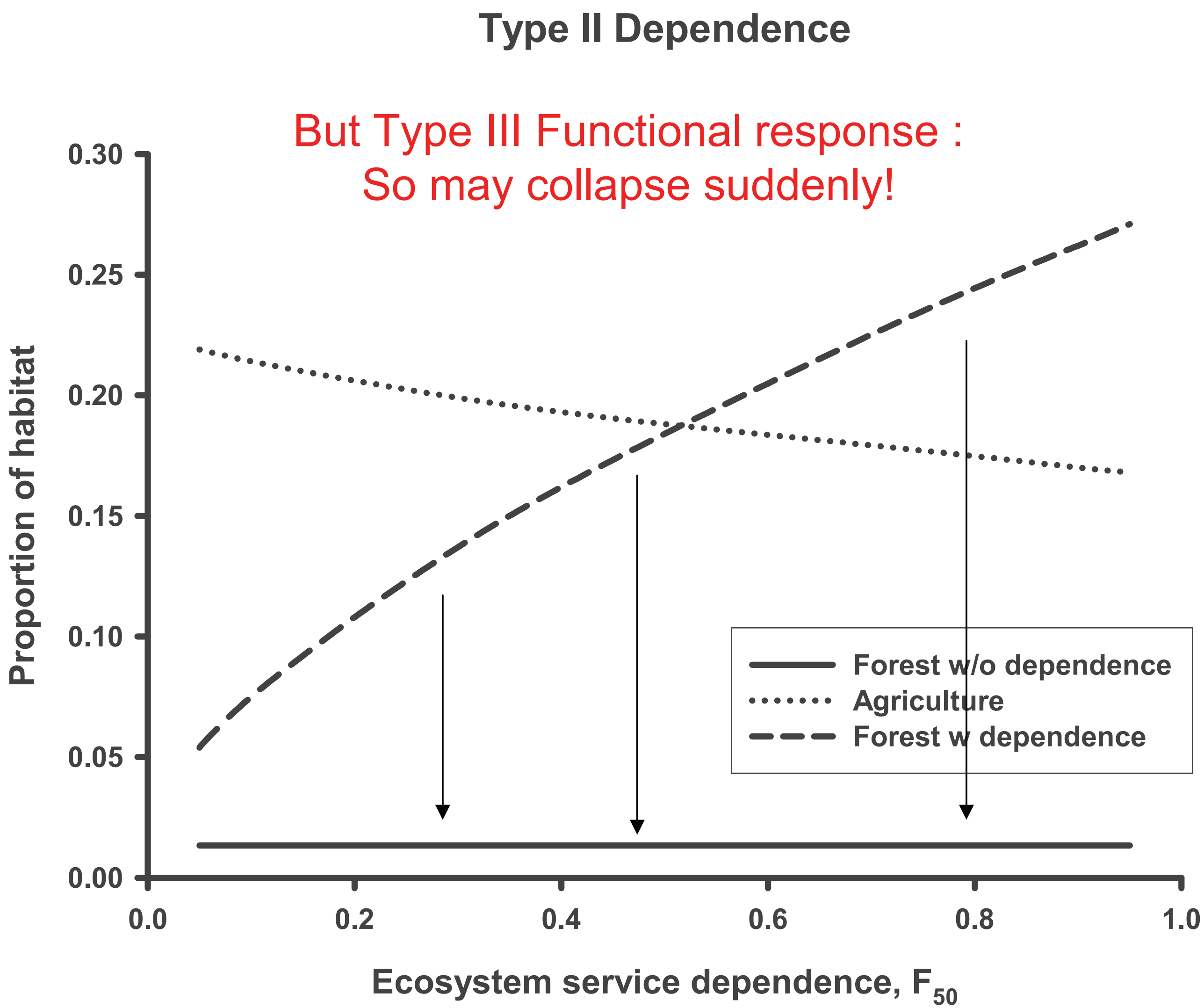


Land-use change with agricultural dependence on water

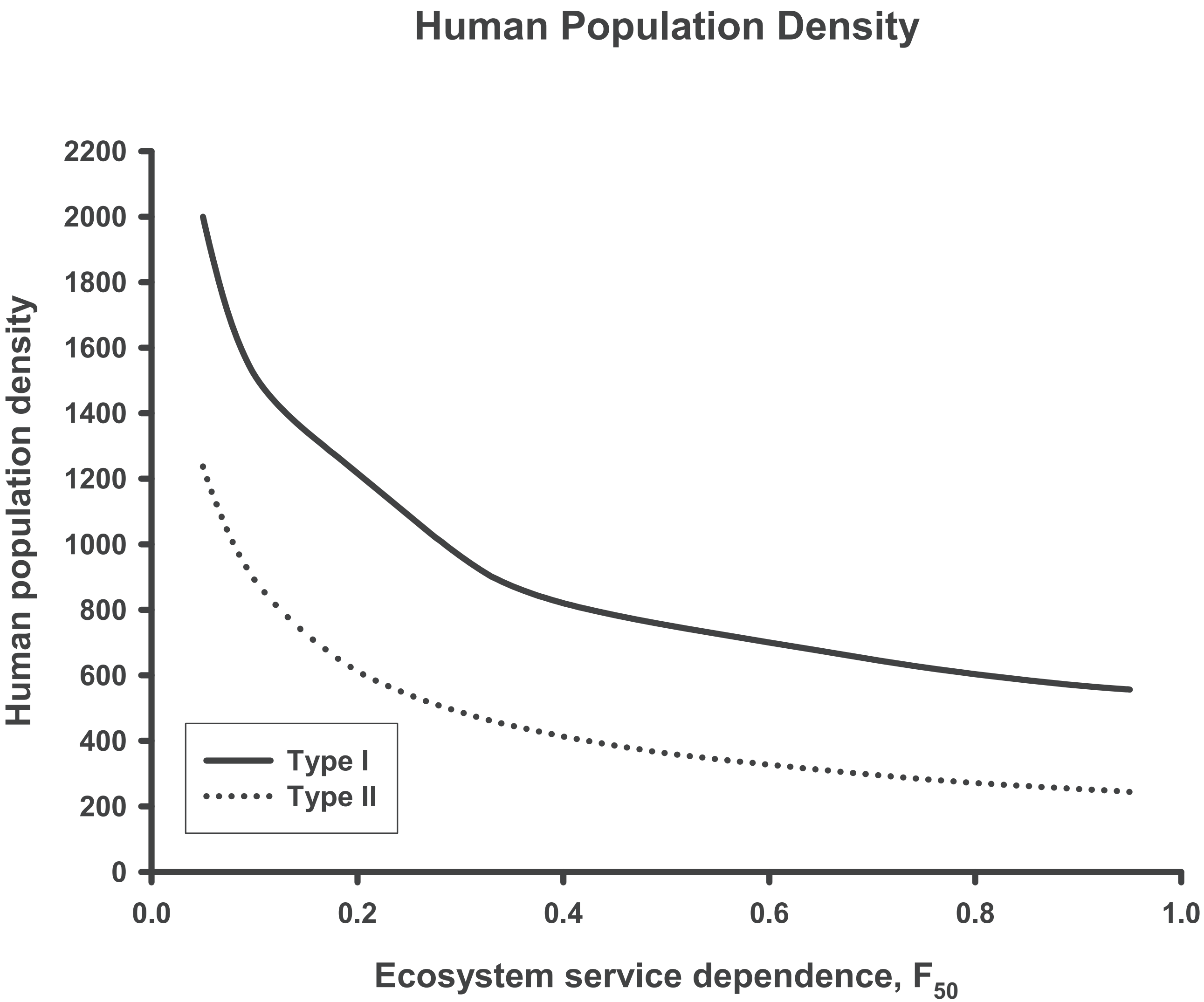


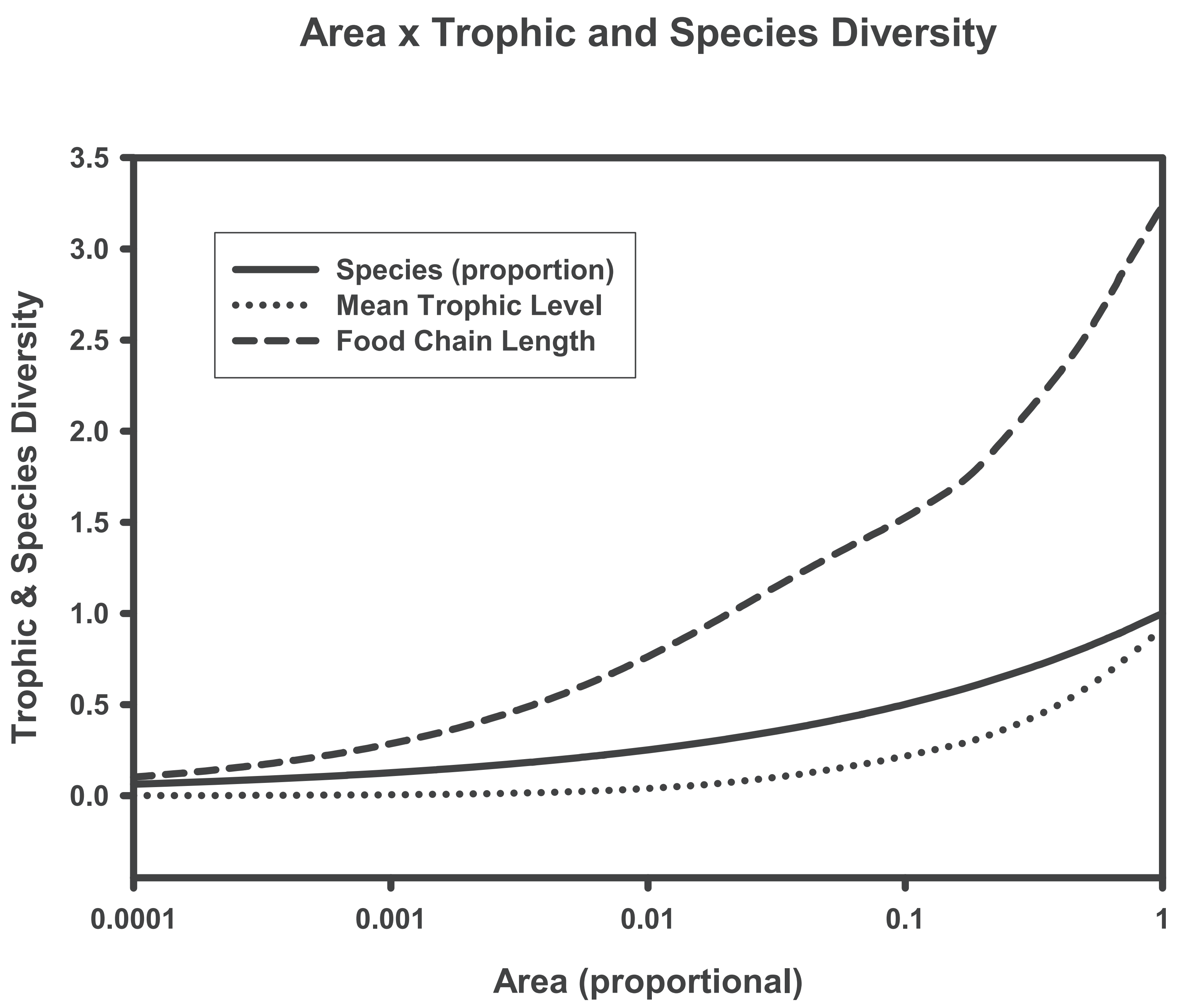
Type III Functional Response ---→ Multiple Stable States,

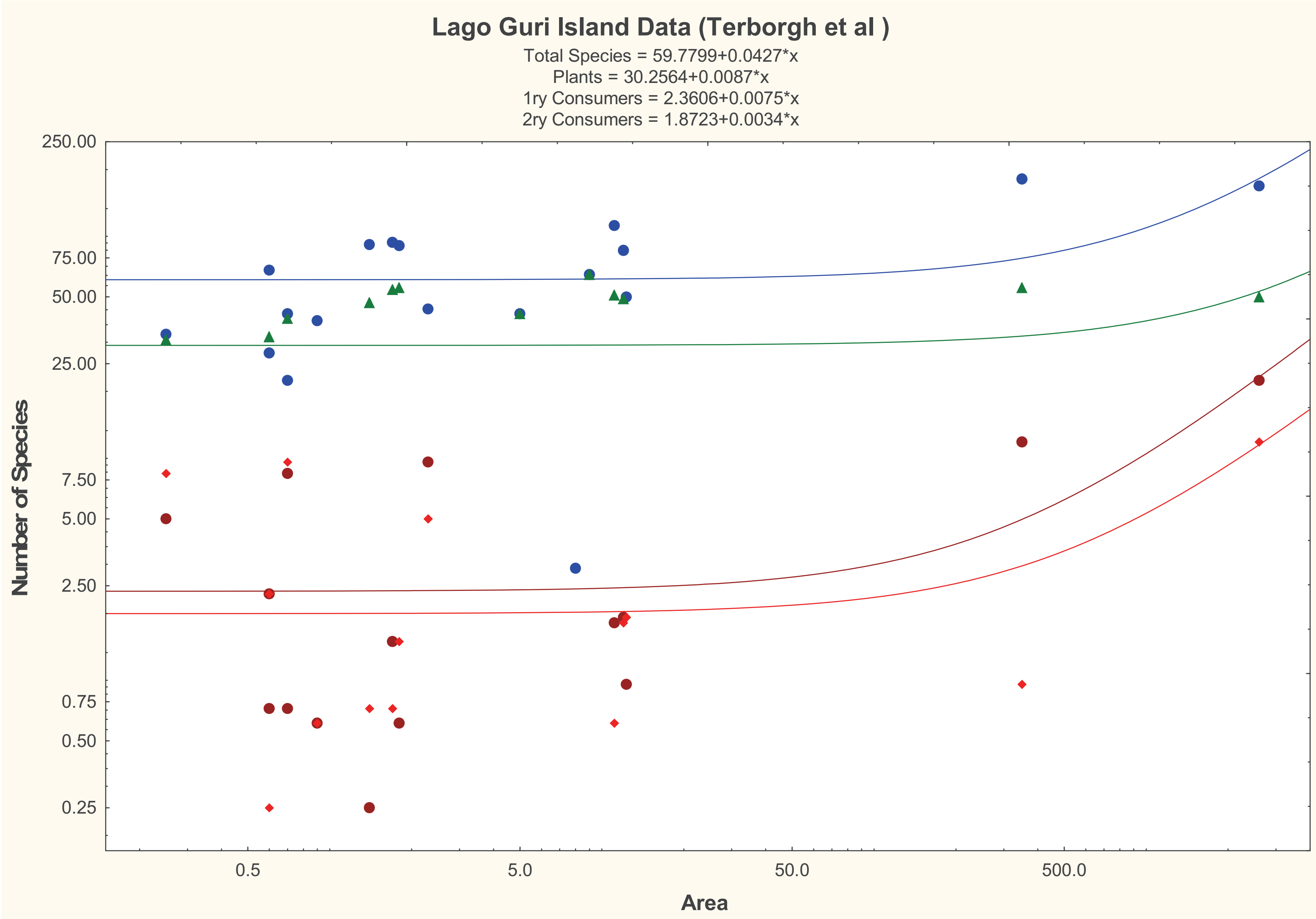
Equilibrium landscape proportions



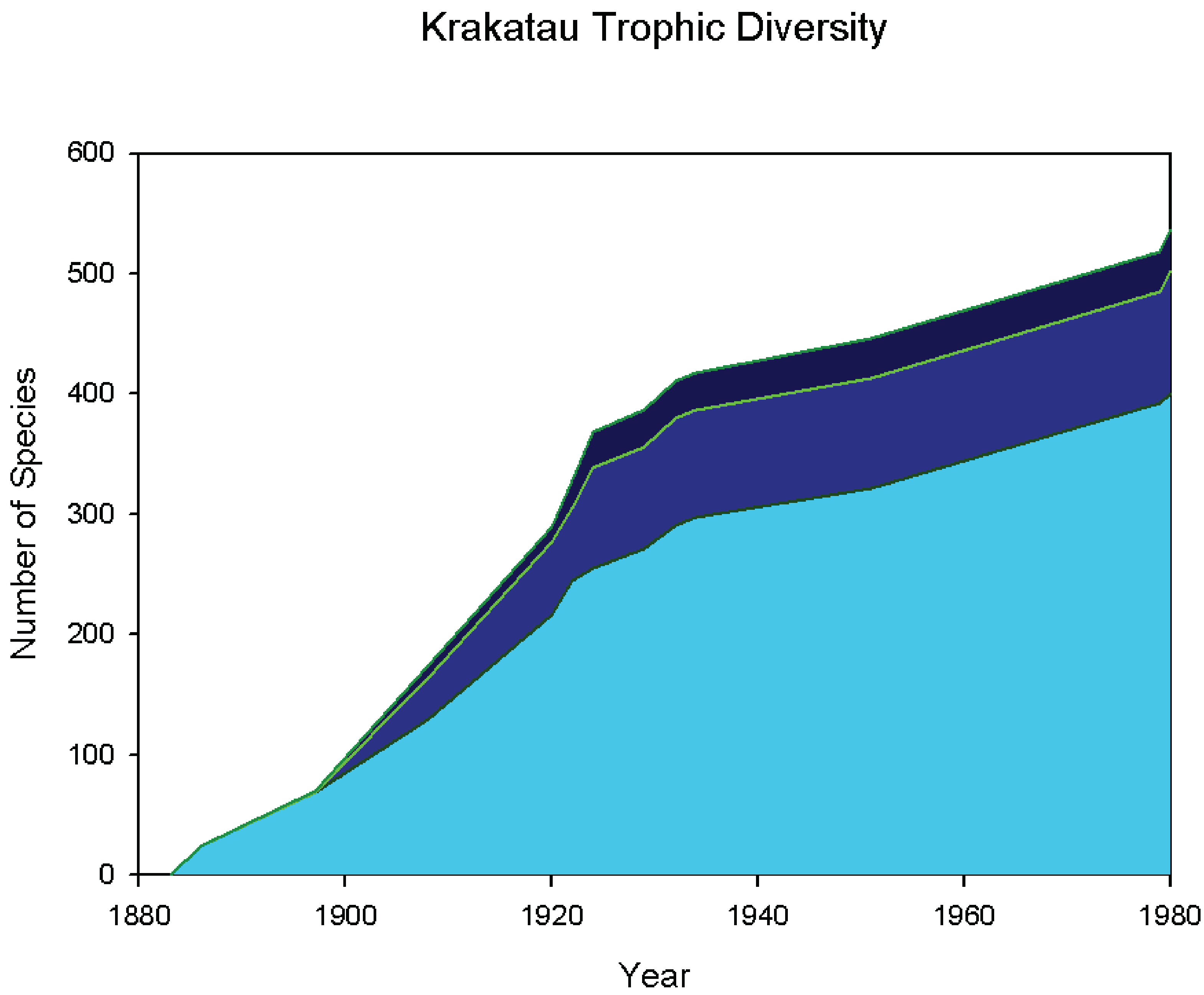
Equilibrium human population



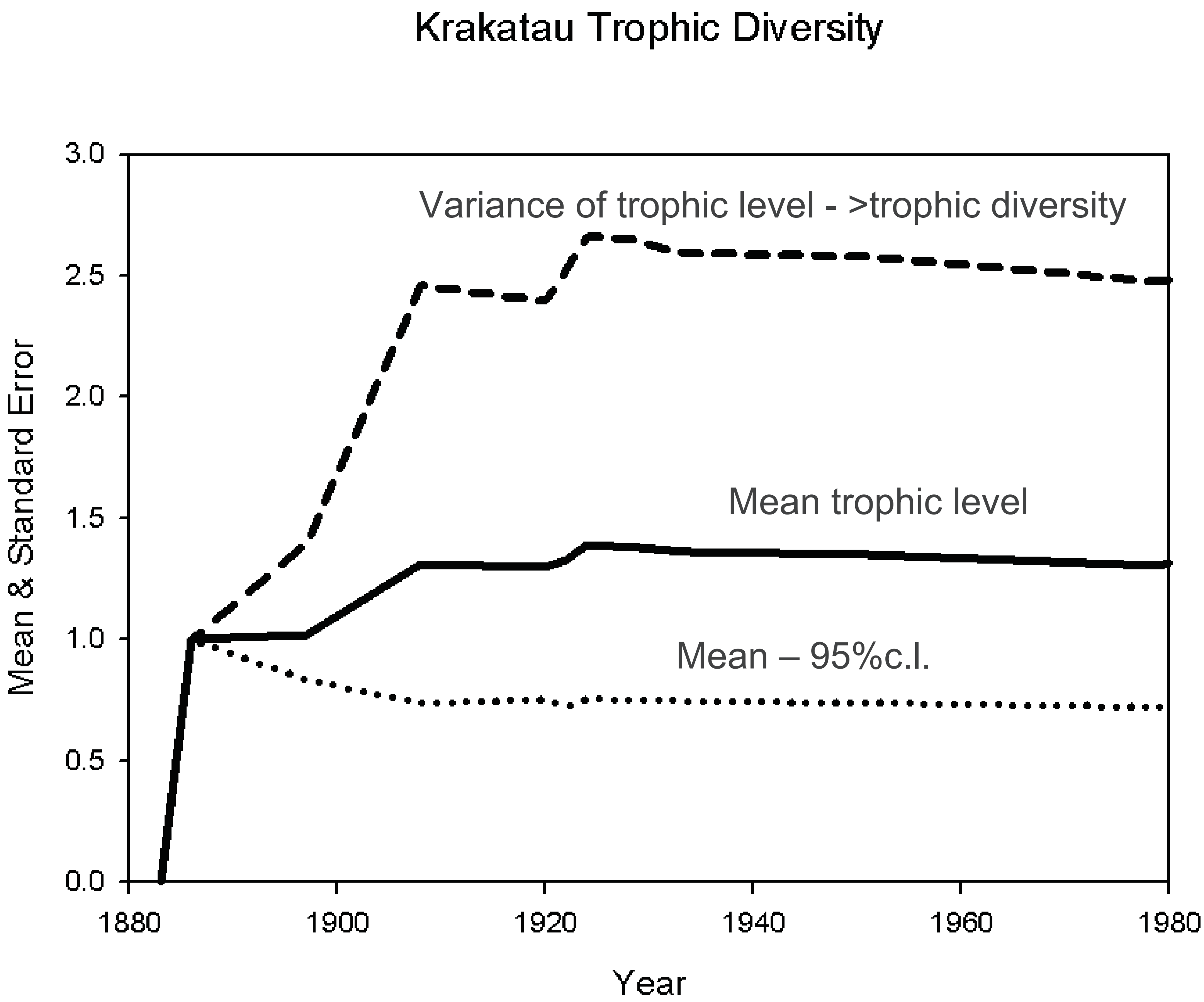

Area x Trophic and Species Diversity
Trophic & Species Diversity
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0001
0.001
0.01
0.1
1
Area (proportional)
Species (proportion)
Mean Trophic Level
Food Chain Length



Trophic diversity on Islands in Lago Guri, Venezuela, the graph illustrates trophic diversity on islands of different sizes in a recently flooded lake in Venezuela. The study provides the classical example of ecological meltdown when the loss of top predators leads first to an increase in the abundance of herbivores, before these in turn are lost leaving only plants on the smallest islands. John Terborgh's study in Venezuela



Krakatau Trophic Diversity
Number of Species
600
500
400
300
200
100
0
1880
1900
1920
1940
1960
1980
Year


Krakatau Trophic Diversity
Variance of trophic level - >trophic diversity
Mean trophic level
Mean – 95%c.l.
Mean & Standard Error
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1880
1900
1920
1940
1960
1980
Year

Conclusions

- Understanding the structure and dynamics of food webs is THE scientific challenge of the 21st Century.
- Understanding how Ecosystem Services map onto food-web structure and dynamics is a major challenge for conservation biology.
- Understanding how food webs-collapse as natural ecosystems are degraded may provide important insights into how ecosystem services will collapse.
- Many thanks to the MA Scenarios Team for many inspiring discussions.