Biotic Carrying Capacity of Ecosystems as a Framework for Conservation

Andrew Hansen

Montana State University

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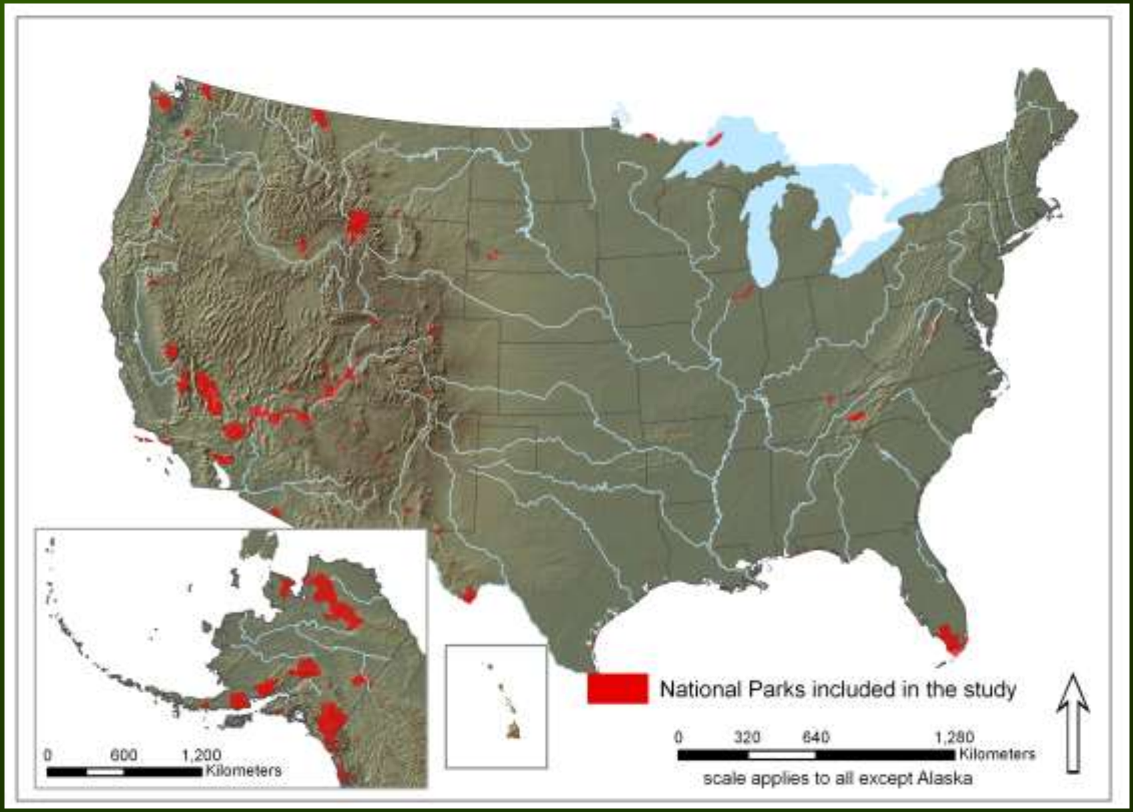
Advancement in Management?

Which of the many potential threats are the highest priorities in a given place?

- habitat fragmentation
- natural disturbance
- sensitive species
- invasive species
- disease
- exurban development
- backcountry recreation
- protected areas
- other issues?

70 Largest US National Parks



Are there general properties of ecosystems that could be used to set conservation goals more effectively?

Goal

Present a framework for grouping ecosystems based on "biotic carrying capacity" that better allows us to anticipate conservation priorities and effective management strategies.

Topics

- Conceptual basis
- Evaluation of underlying hypotheses
- A framework for grouping ecological systems
- Management strategies that may be effective within each group
- Next steps

Theoretical Roots of Conservation Biology

Hutchinson (1959), "What factors limit the number of species in a place"?

- habitat heterogeneity
- habitat area
- trophic structure
- evolutionary processes
- available energy

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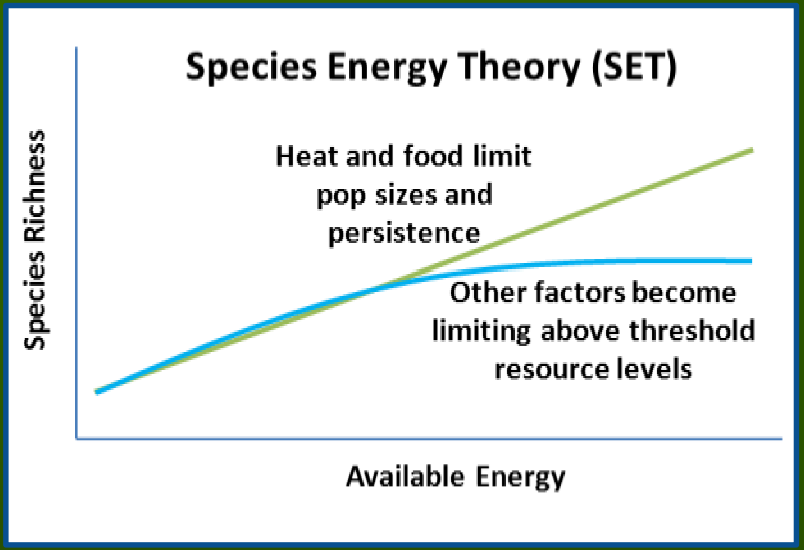
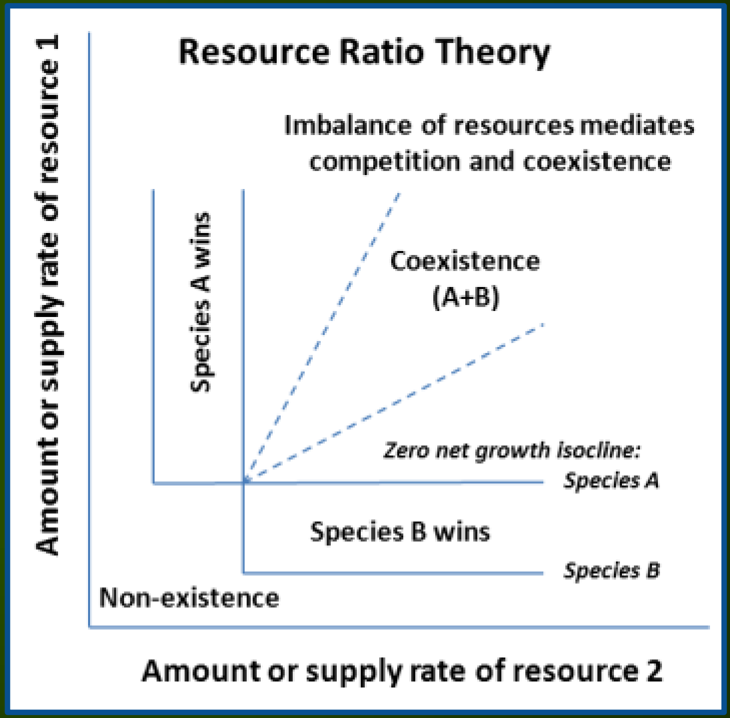
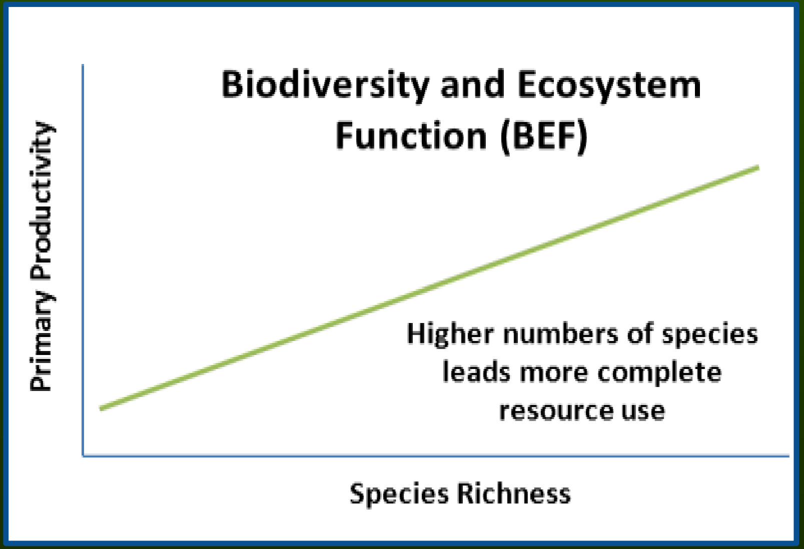
Relevant Theory on 'Energy' and Species Richness



Wright 1983



Tillman 1980, 1982



Chapin et al. 2000, Tillman 2000, Fridley et al. 2001

Towards an Inclusive Model

Brown et al. 2001:

- **(1) resources and conditions set the potential of a local ecosystem to support species richness (called species carrying capacity or S_K)**
- **(2) actual richness is a product of how those resources and conditions are allocated among species and by the size of the regional species pool.**

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This perspective distinguishes the rules governing the capacity to support biodiversity from those governing how that capacity is allocated among species.

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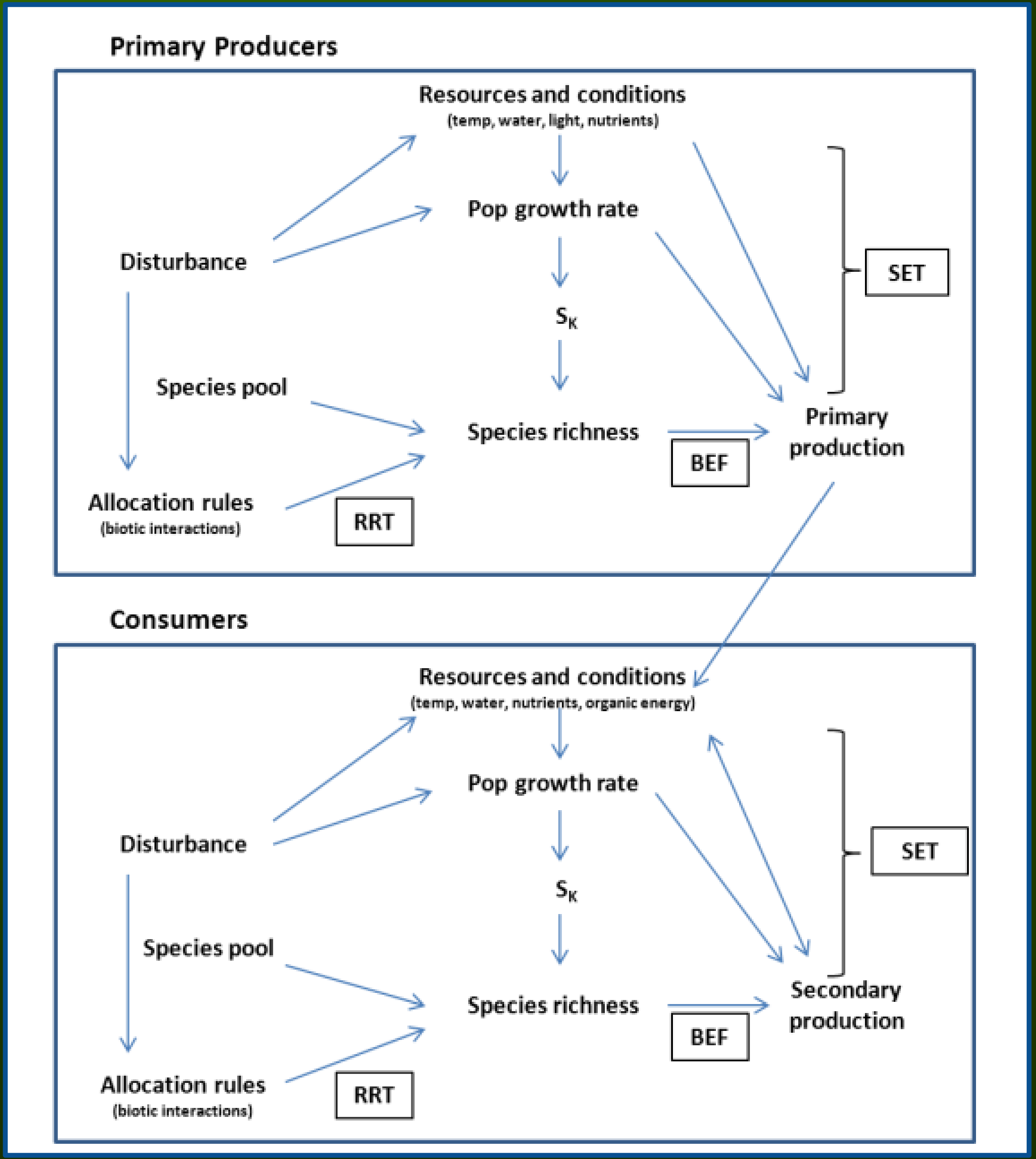
This perspective distinguishes the rules governing the capacity to support biodiversity from those governing how that capacity is allocated among species.

I suggest that it is the capacity of ecosystems to support biodiversity that varies predictably across the Earth and that provides the means to group ecosystems for conservation.

Towards an Inclusive Model

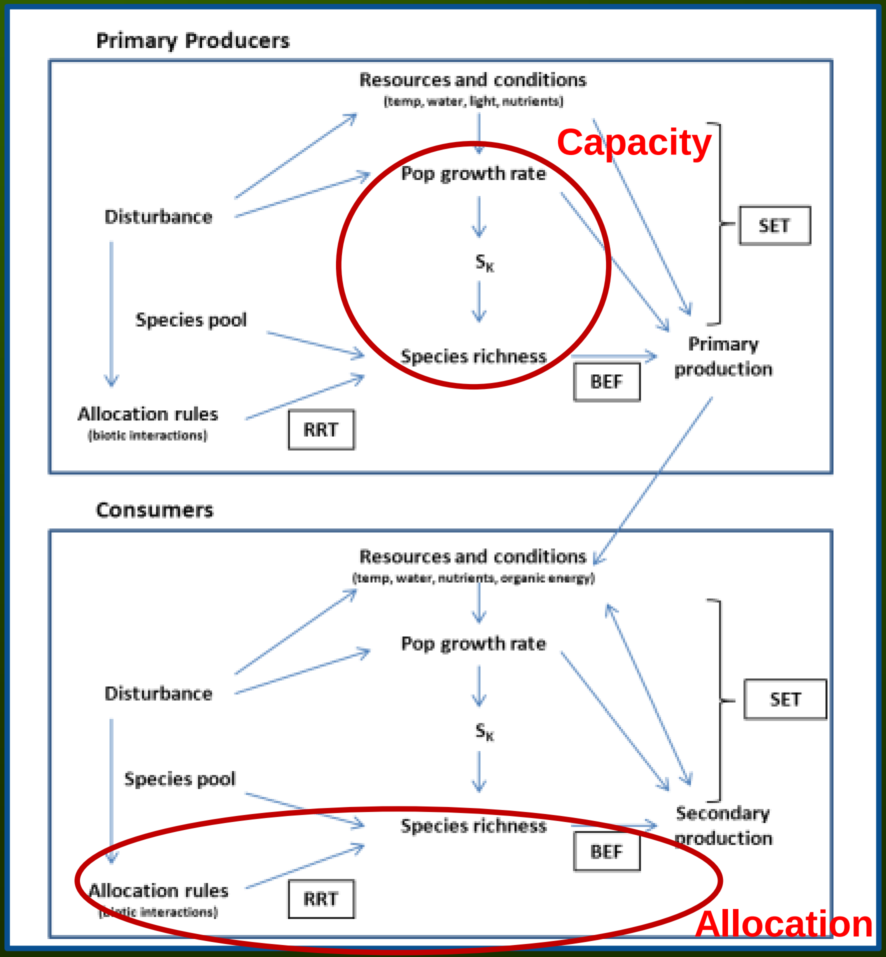
Building on:
Brown et al. 2001;
Cardinale et al. 2009



Towards an Inclusive Model

This model reduces confusion:

- **SET deals with "capacity" while RRT and BEF deal with how this capacity is "allocated" among species through competitive interactions.**



Biotic Carrying Capacity of Ecosystems

Biotic carrying capacity (B_K) - the limits on individual organisms, populations, communities, and rates of ecological processes set by resources and conditions within an ecosystem.

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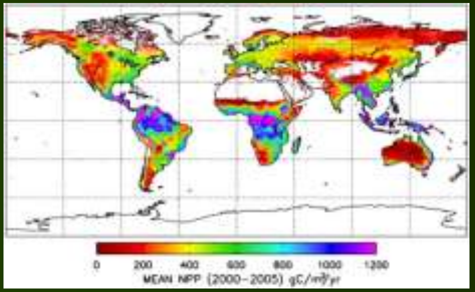
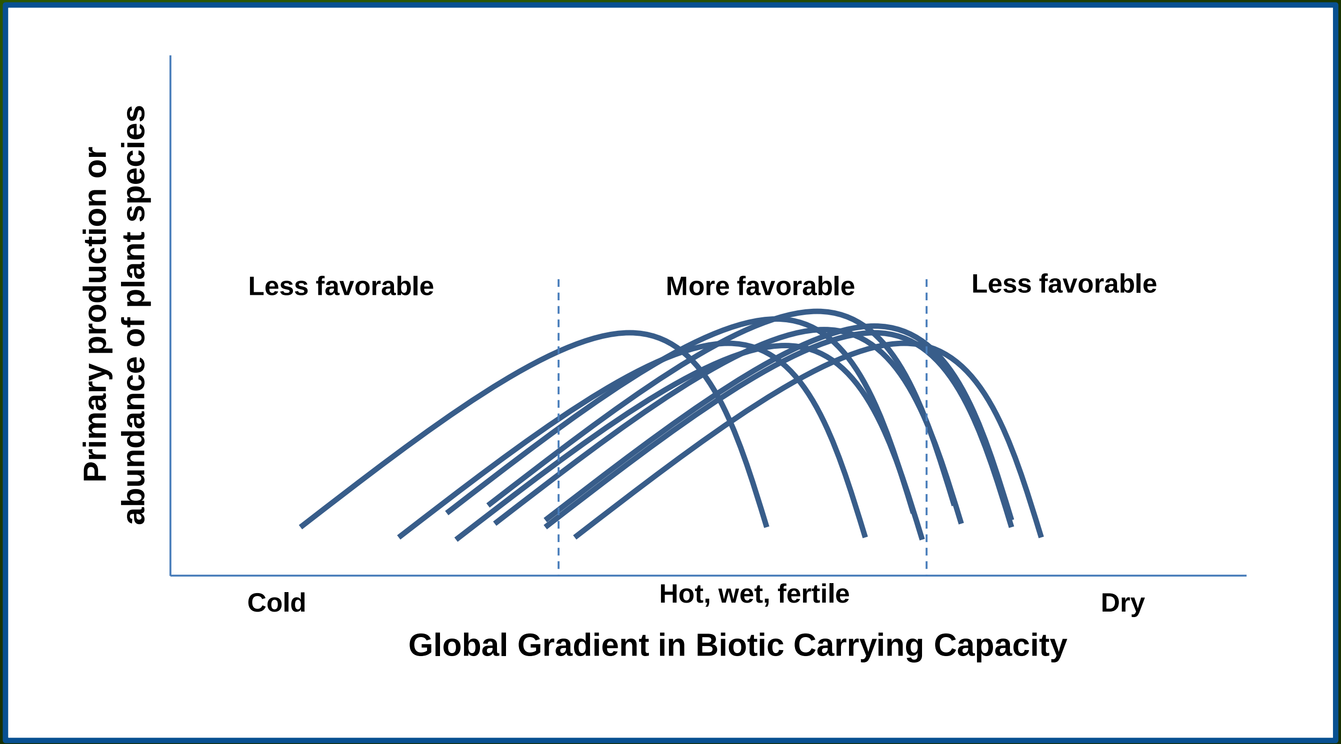




Biotic Carrying Capacity of Ecosystems

Hypothesis: The fundamental traits of ecosystems relative to conservation vary with B_K.

Home range size ?

Pop growth, abundance, persistence ?

?

Carrying capacity of species richness ?

Recovery following disturbance ?

Microhabitat diversity ?

Biotic interactions ?

Number of trophic levels ?

Intensity of human land use ?

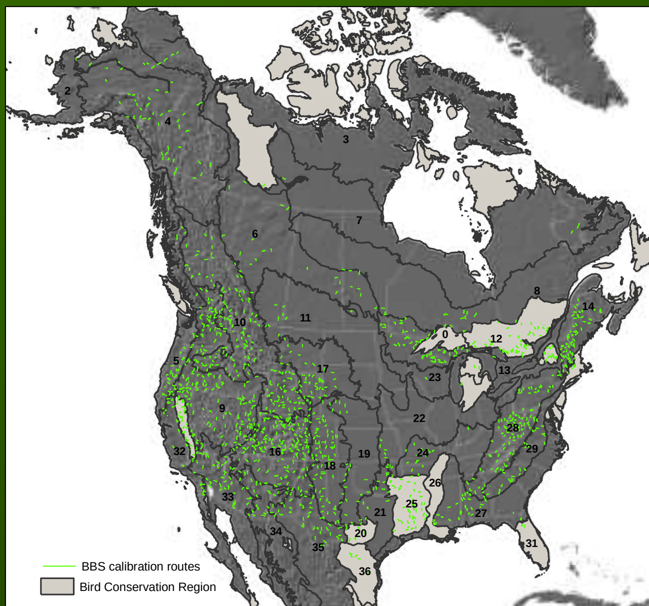
Low B_K
Cold, dry, and/or infertile

High B_K
Warm, wet, and fertile

Hypotheses on the Effects of Ecosystem B_K on Biodiversity

Topic	Relationship with B_K	Key Reference	Weight of Evidence	Implication for Conservation and Management
Pop growth rt, abundance, extinction risk	+ or flattening,	Evans et al. 2005a	Strong Strong Partial	Small population issues including extinction risk are more pronounced in low B_K systems.
Home range size	-	Haresrad and Bunnell 1979	Strong	Larger home ranges in low B_K systems increase frequency of wildlife roaming outside of protected area boundaries and incurring human-induced mortality.
Large ungulate migrations	+ with patchiness	Oiff et al. 2002	Inadequately tested	Maintenance of migration habitats is a higher priority in environments with intermediate productivity and patchiness in productivity, and high soil fertility.
Source/sink pop dynamics	+ with patchiness	Naves et al. 2003	Strong	Human activities that alter sources or sinks may cause the extinction of the metapopulation.
Species richness	+, flattening, or unimodal	Wright 1983	Strong	Knowledge of S_K can be used to prioritize locations for protection and restoration.
Disturbance / Succession	Interacts with productivity	Huston 1979, 1994	Strong	The rate of prescribed disturbance should vary with ecosystem $B_{K.}$
Within-patch veg structure	Interacts with productivity	MacArthur et al. 1966	Intermediate	Management for structural complexity should be a higher priority in productive than unproductive forests.
Habitat edge effects	+ with biomass	McWethy et al. 2009	Intermediate	Edge effects are less of a problem in low-biomass ecosystems such as boreal or subalpine forests.
Trophic cascades	"Top-down" in under low energy	Melis et al. 2009	Inadequately tested	Predator restoration is most important in low B_K systems.
Land use intensity	+, flattening, or unimodal	Luck et al. 2010	Strong	Land use is most intense in ecosystems with higher species richness due to effects of B_K.

Carrying Capacity for Species Richness for Landbirds across North America



USGS Breeding Bird Survey data
BBS native diurnal landbirds

$$S_K = aGPP - aGPP^2 - \%SCV + PET$$

%SCV: Interannual variation in GPP

Adj. R2 = 0.70

Hypothesis	Typical Predictors
Kinetic energy	Temperature (mean annual)
	Temperature (mean June)
	Potential evapotranspiration
Water	Precipitation (mean annual)
	Precipitation (mean June)
	Evapotranspiration (annual sum)
Potential Energy	NDVI (mean annual or mean June)
	Gross Primary Productivity (mean annual)
	Gross Primary Productivity (June)
	Seasonality (June GPP/annual GPP)
	Interannual variation in GPP
Habitat complexity	Elevation range
	Cover type variation
	Percent tree

Hansen et al. 2011. Global Ecology and Biogeography

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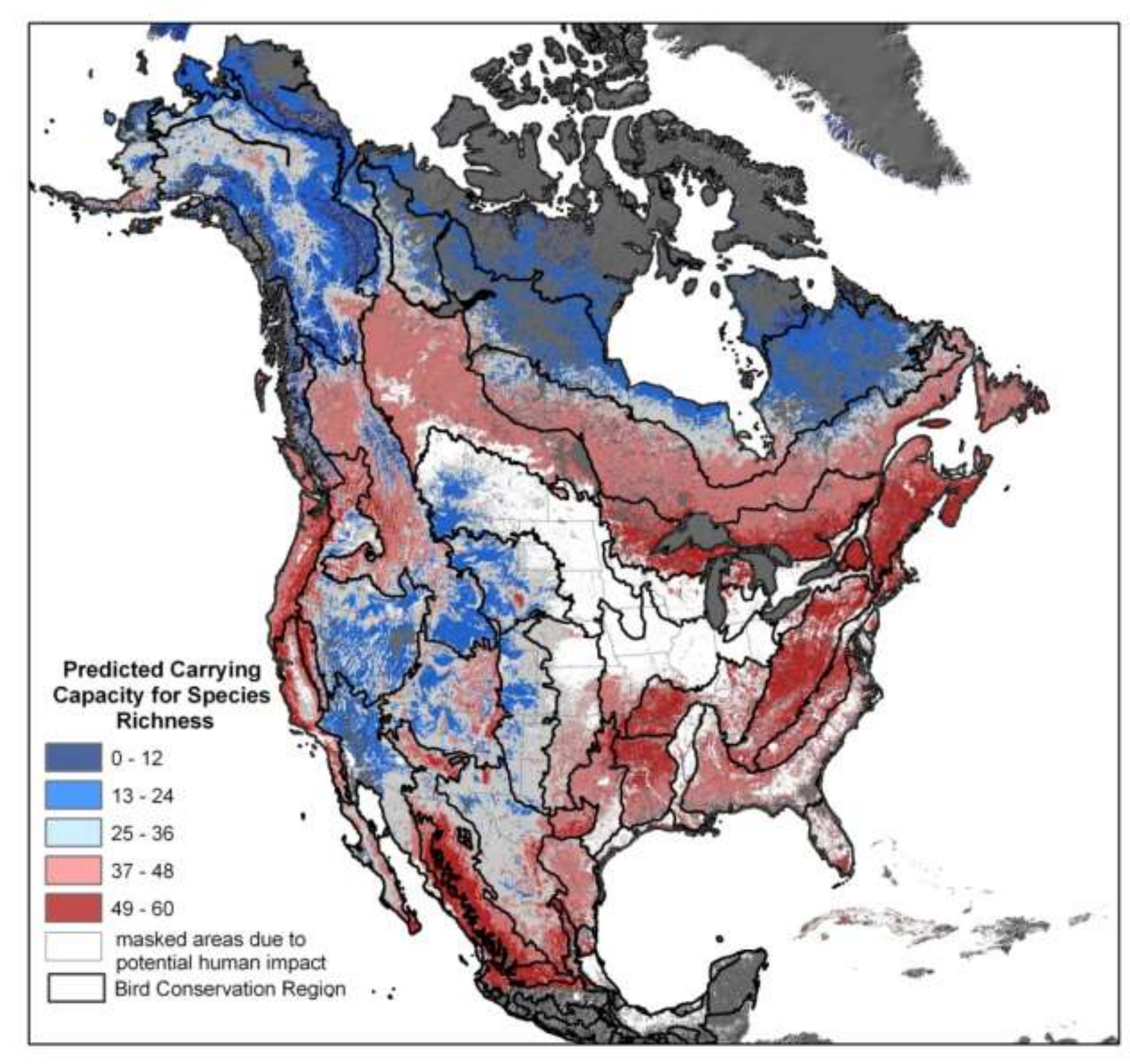


Hansen et al. 2011.

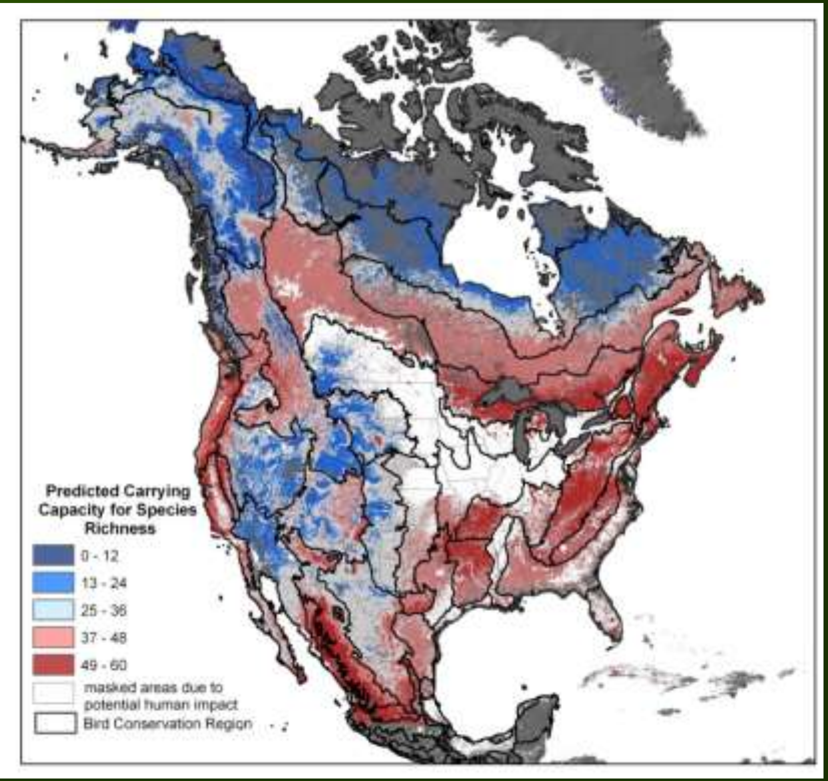
Hypotheses on the Effects of Ecosystem Energy on Biodiversity

Topic	Relationship with Energy	Key Reference	Weight of Evidence	Implication for Conservation and Management
Carrying capacity for species richness	+, flattening, or unimodal	Brown et al. 2001	Strong	Knowledge of S_K can be used to prioritize locations for protection and restoration.

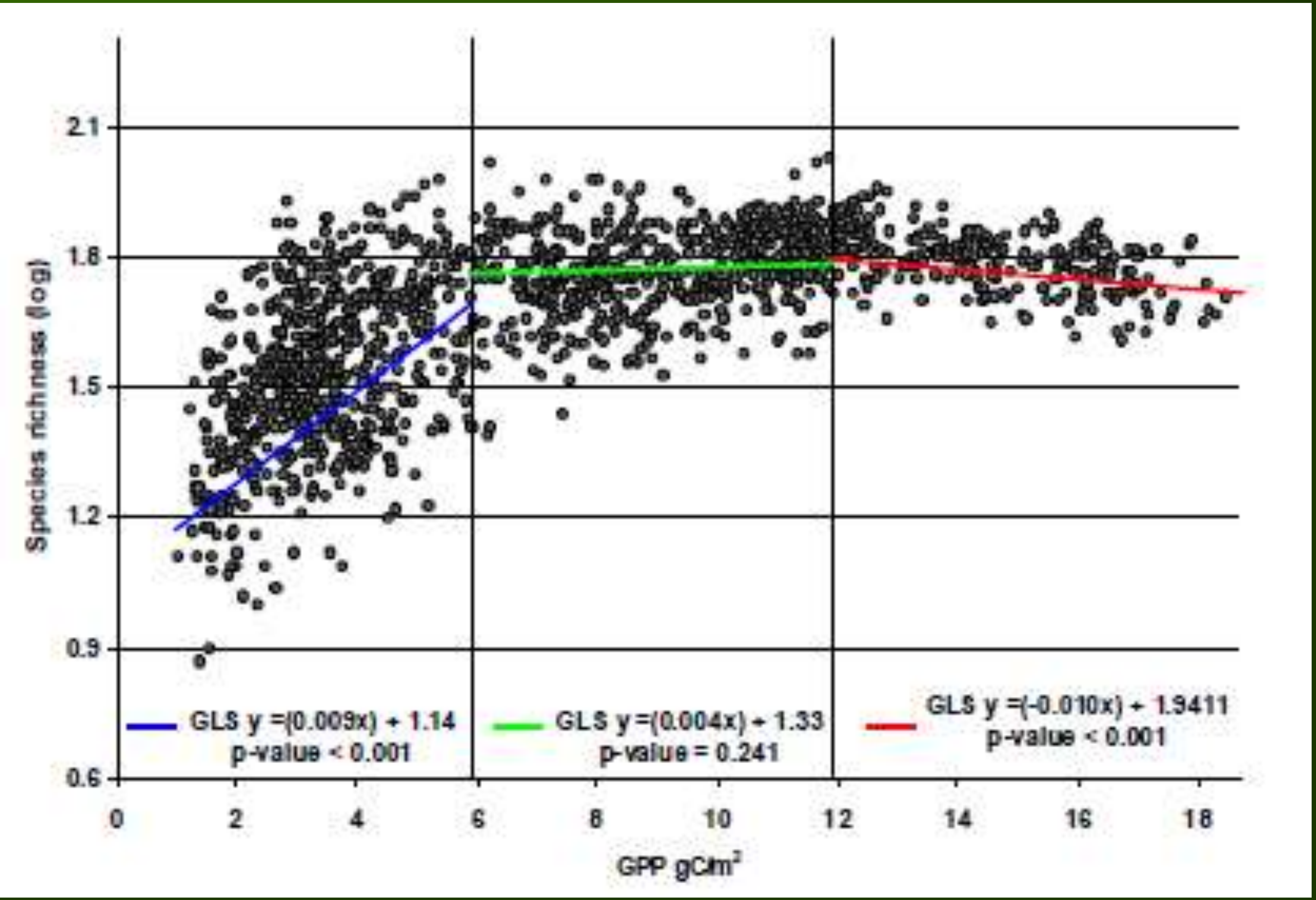
Implications

Locations of high S_K and low human impact should be high priorities for protection because they represent continental hotspots for native species.

Locations of high S_K and high human impacts may be high priorities for restoration.



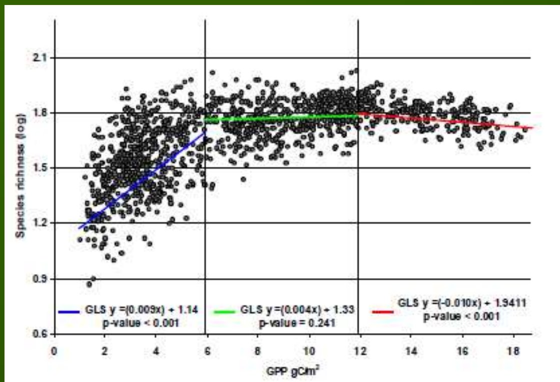
Ecosystem Energy and Species Richness: North America



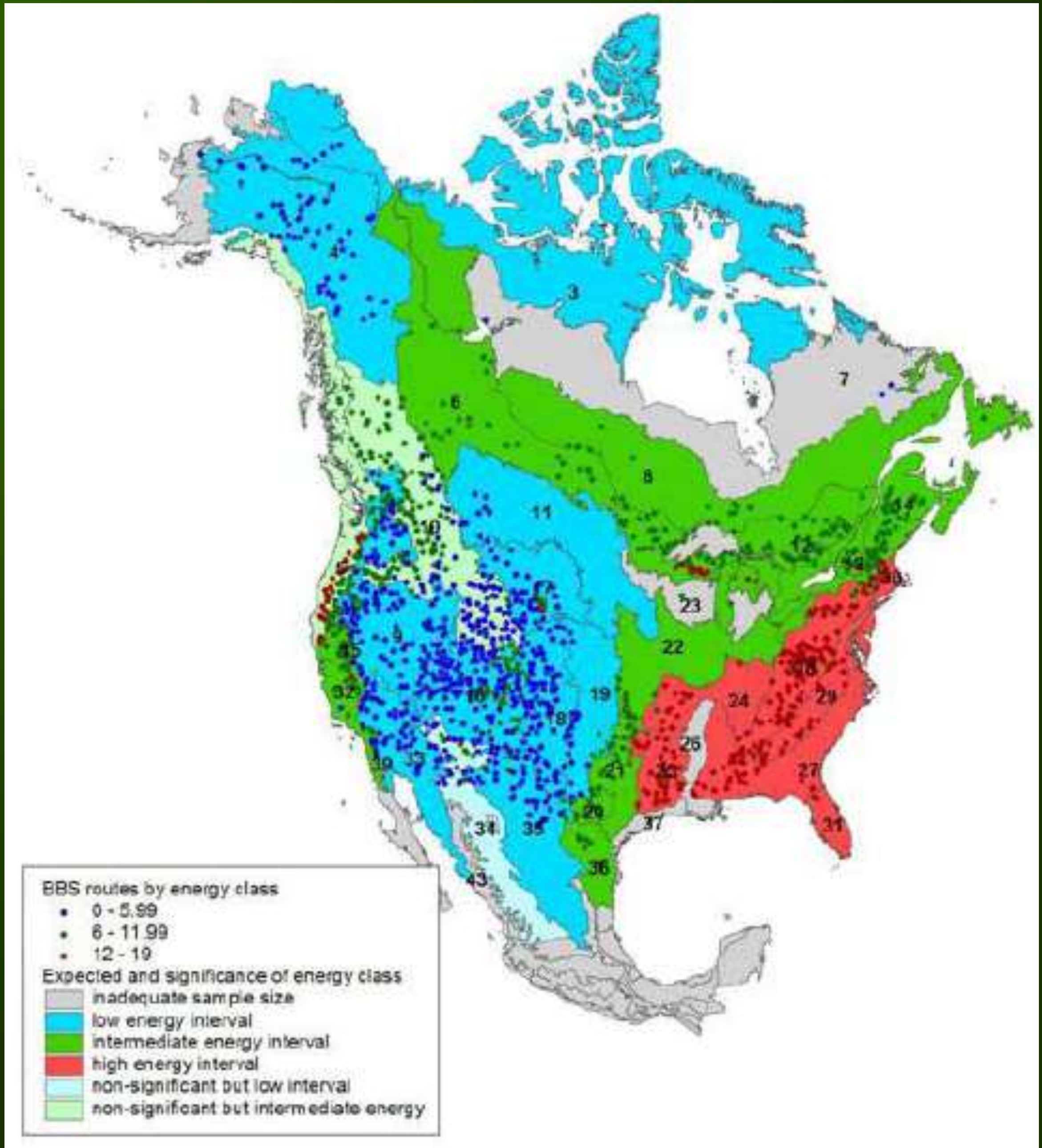
Best model: GPP, breakpoint, adj R2 = 0.55

Phillips et al. Ecological Applications. 2010

Ecosystem Energy and Species Richness: North America



Geographic regions differ in the slope of the species energy relationship.



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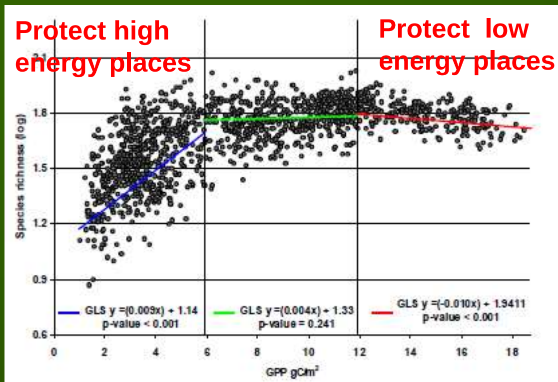

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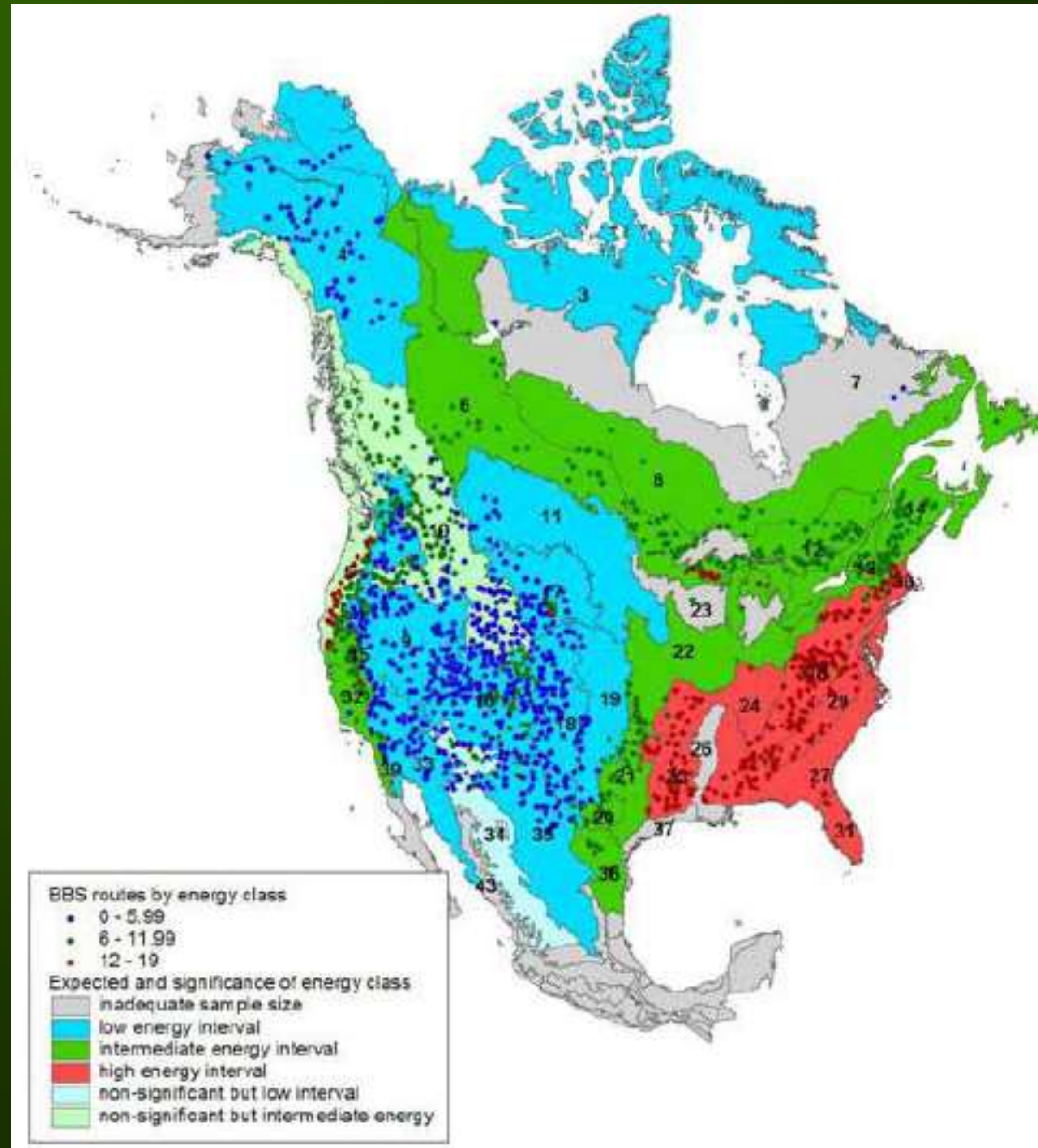

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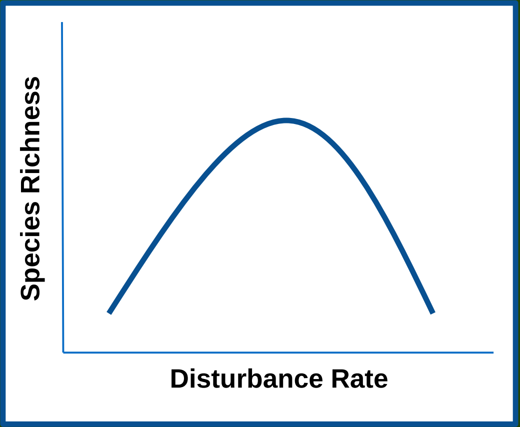

Intermediate Disturbance Hypothesis
(Connell 1978)

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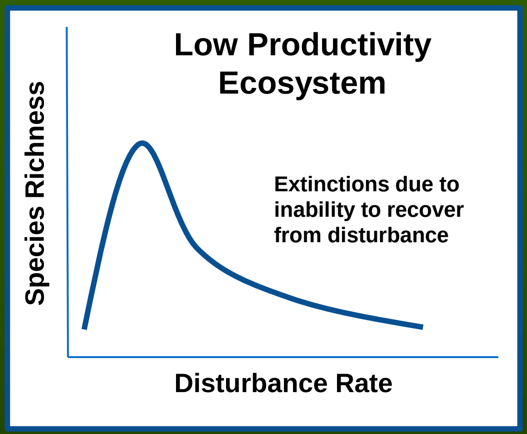
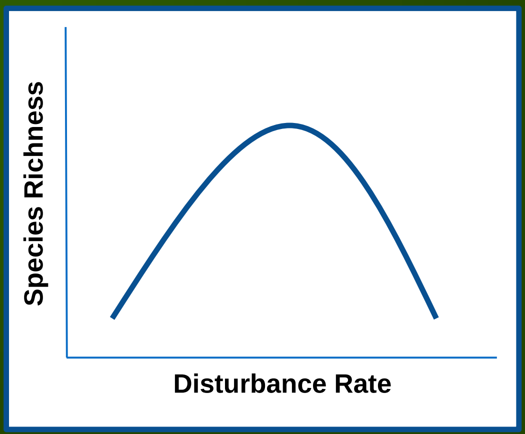
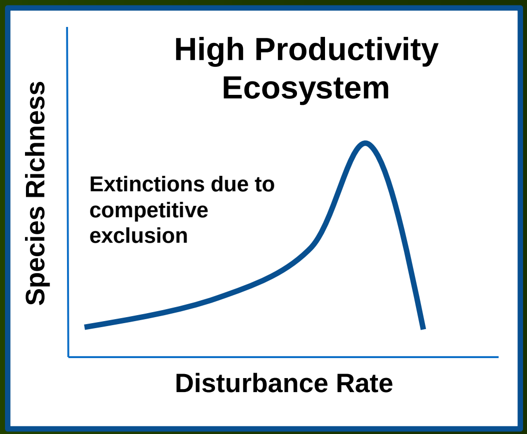




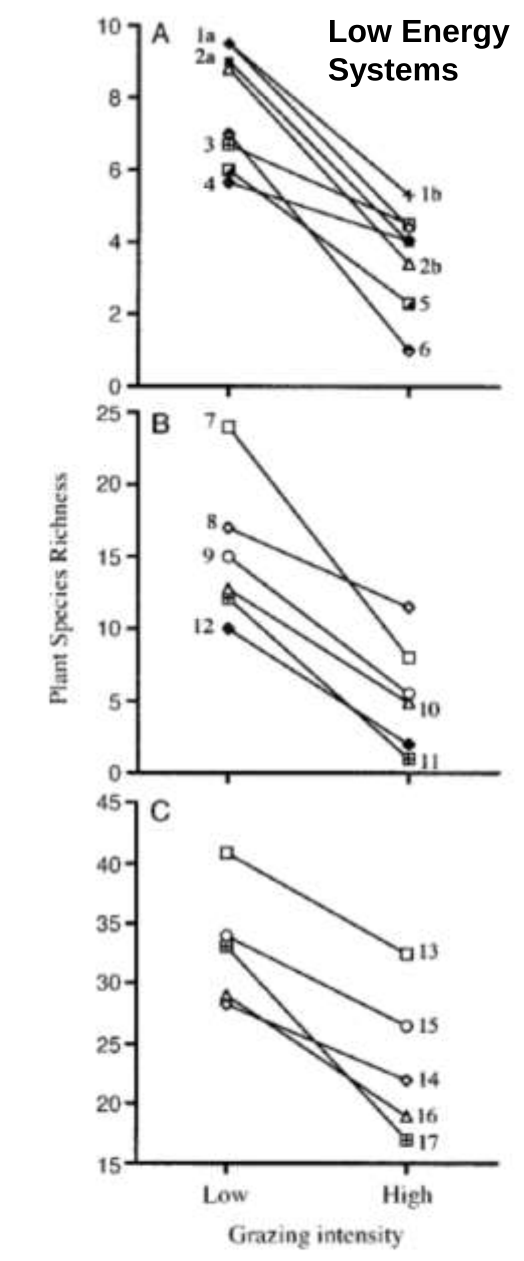


Increased disturbance reduces species richness.

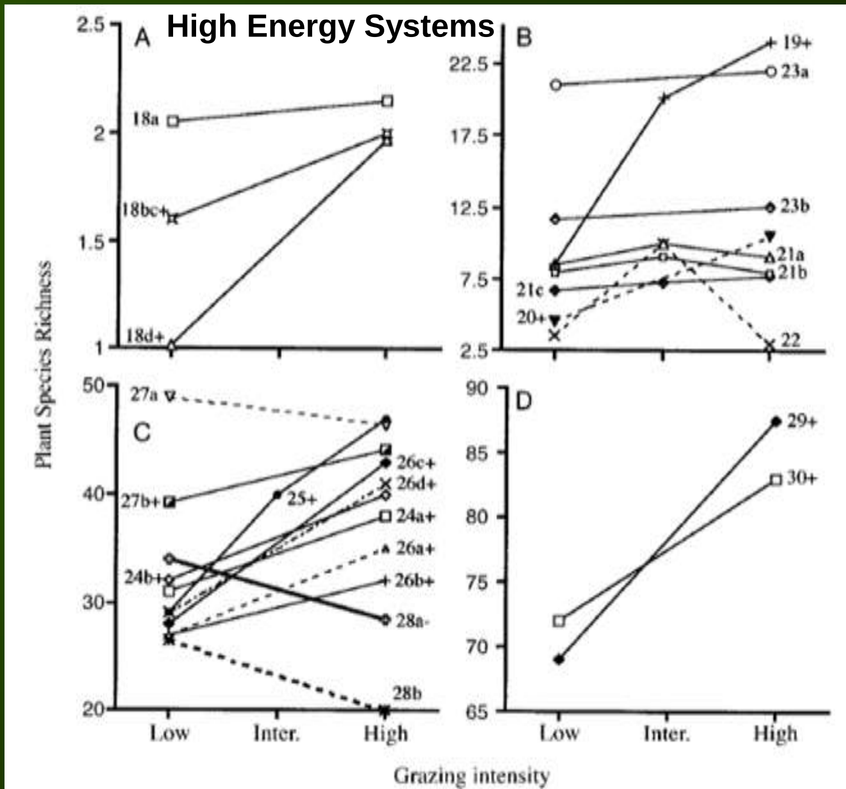
Increased disturbance increases species richness.

Dynamic Equilibrium Hypothesis

Hypotheses on the Effects of Ecosystem Energy on Biodiversity



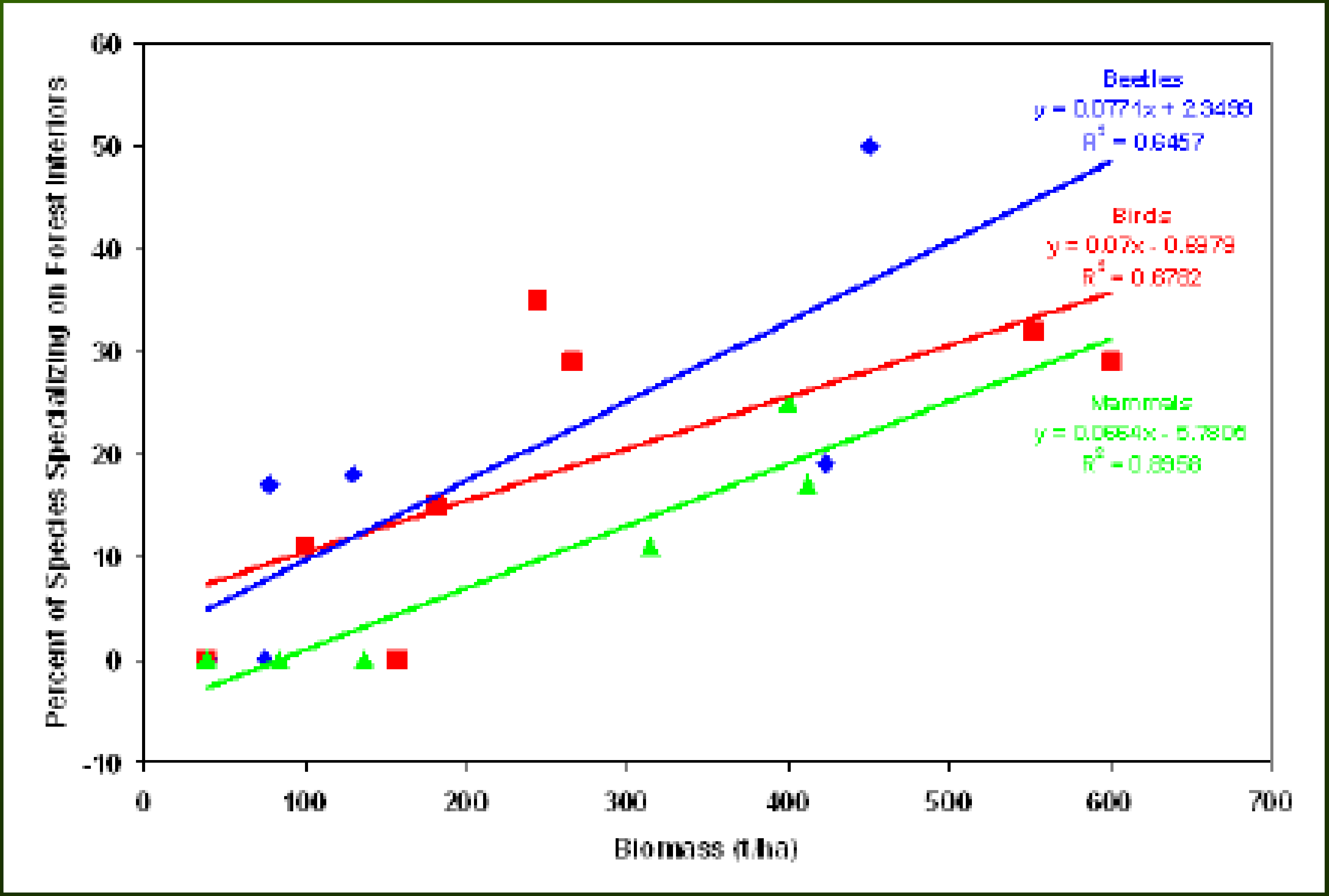
Proulx and Mazumder (1998) - Meta analysis of 30 studies of plant species richness in lake, stream, grassland, and forest grazing systems.



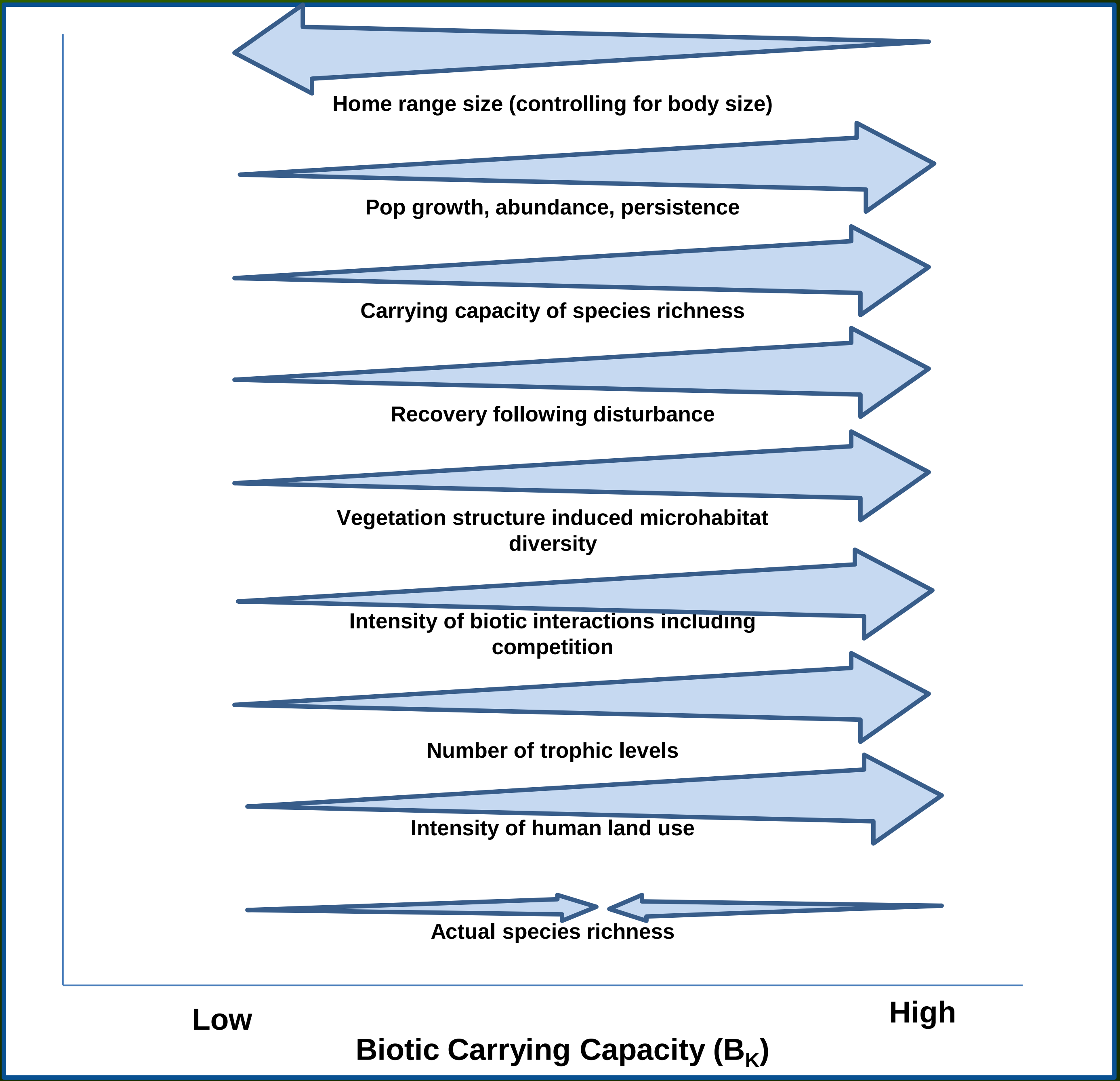
All 19 comparisons from non-enriched or nutrient-poor ecosystems exhibited significantly lower species richness under high grazing than under low grazing.

14 of 25 comparisons from enriched or nutrient-rich ecosystems showed significantly higher species richness under high grazing than under low grazing.

Effects of Forest Fragmentation Across A Gradient in Forest Biomass



Predicted Traits of Populations, Communities, and Landscapes Based on Biotic Carrying Capacity

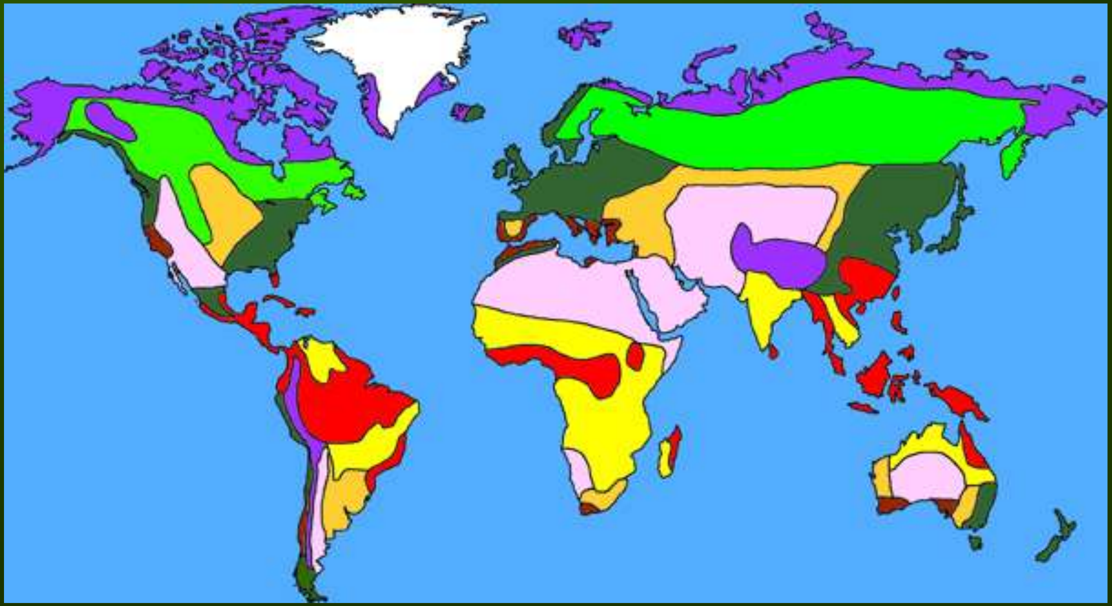


Generalizations of Traits of Ecosystems

Conclusion:

Ecosystem B_K is sometimes a strong causal factor influencing biodiversity and that it often interacts with disturbance and habitat structure in influencing diversity.

Can we group ecosystems accordingly?



Earth's Terrestrial Biomes

Generalizations on Traits of Ecosystems

Traits

Habitat Heterogeneity	Biotic Carrying Capacity: Low, Variable		Biotic Carrying Capacity: Intermediate		Biotic Carrying Capacity: High	
High natural seral stage or habitat diversity	Low pop. growth rates, small pop. sizes, higher extinction rates Large home ranges Migratory pop. Spatially explicit pop. dynamics Low S_K High stress following disturbance Weak competitive exclusion Weak response to veg. structure or patch edge Top down effects more likely Lower land use intensity but concentrated in local hotspots	Low species richness Very low invasiveness	Very high Low S_K Moderate competitive exclusion Moderate response to veg. structure or patch edge Very high land use intensity throughout landscape High invasive introductions	High species richness Moderate invasiveness	Higher pop. growth rates, larger pop. sizes, lower extinction rates Few migratory pop. Intermediate S_K Rapid recovery following disturbance Rapid competitive exclusion Strong response to veg. structure or to patch edge Strong biotic interactions Bottom up effects more likely High land use intensity concentrated in lower energy places	Very high species richness Very high invasiveness
Low natural seral stage or habitat diversity		Very low species richness Low invasiveness		Intermediate species richness Slightly lower invasiveness than above		Moderate species richness Moderate invasiveness

Low, Variable — Intermediate — High

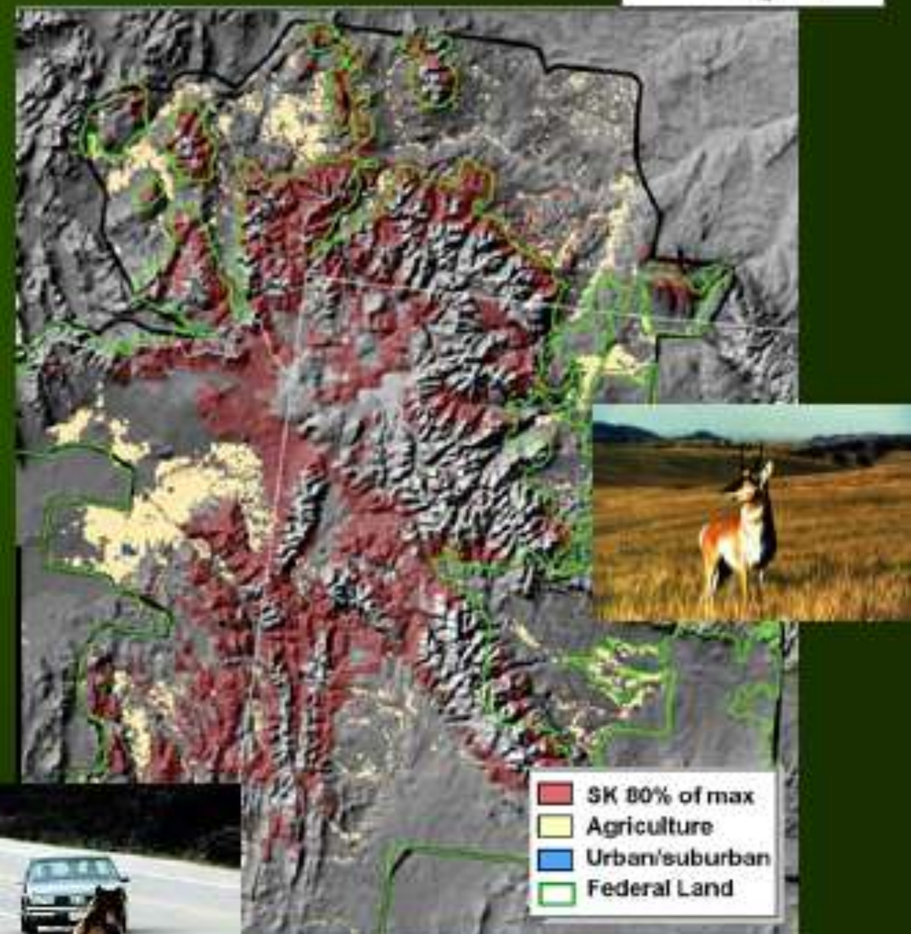
Biotic Carrying Capacity

Framework for Prioritizing Management

Conservation Category	Ecosystem B_K		
	Low	Medium	High
Individual species			
Sensitive Species			
Invasive Species			
Ecological processes			
Disturbance			
Productivity			
Landscape composition			
Biophysical gradients			
Source and sink habitats			
Seral Stages			
Within-stand structure			
Landscape configuration			
Connectivity			
Patch size/edge			
Biotic interactions			
Trophic cascades			
Competitive exclusion			
Land Use			
Protected areas			
Matrix			
Restoration			
Public education			
Overarching conservation priorities			

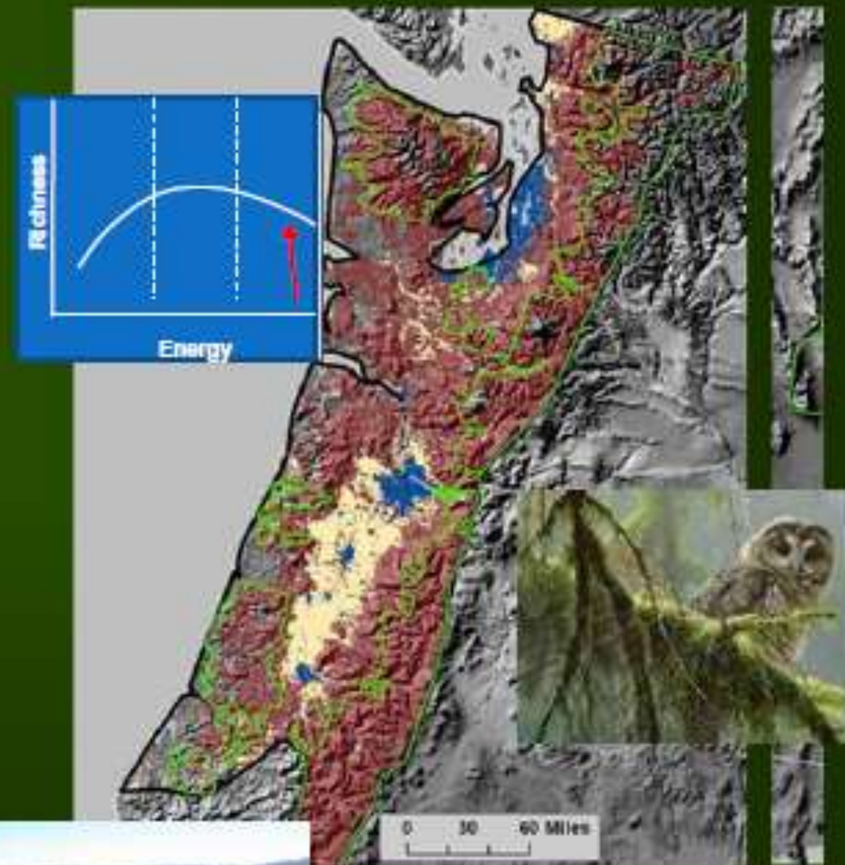
Low BK System: Greater Yellowstone

Conservation Category	Low Energy
Sensitive Species	Focus on species at risk due to low population sizes, large home requirements, migratory habits, source/sink dynamics
Disturbance	Manage to reduce disturbance in settings where high post-disturbance stress puts native species at risk
Landscape Pattern	Manage for large areas of habitat and well connected habitat for species with small populations and large home ranges, and/or migratory habits
Protected Areas	Should be larger and include representative biophysical gradients
Land Use	Focus conservation easements on high energy places and migration corridors Discourage development in hotspots
Overarching Priorities	Maintain large, well connected natural landscapes that include the full gradient of biophysical conditions and provide for wildland species needing large areas



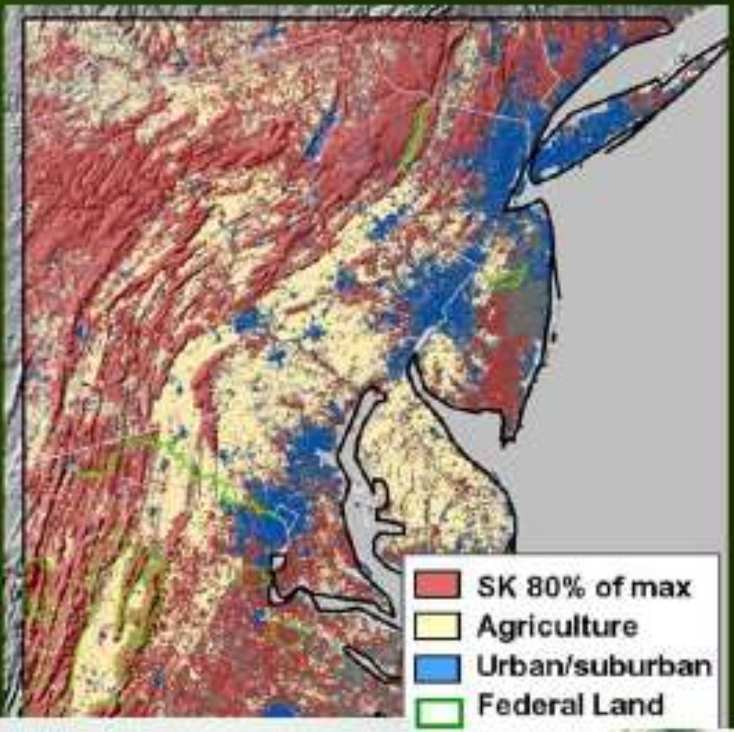
High B_K System: Pacific Northwest

Conservation Category	High Energy
Sensitive Species	Focus on seral stage, vegetation structure, and patch edge or interior specialist species
Disturbance	• relatively high rates in some locations to break competitive dominance and favor early seral species; • relatively low rates in some locations to maintain late seral species. • Maintain high levels of structural complexity in all seral stages. • Reduce erosion and leaching associated with disturbance.
Landscape Pattern	Manage for diverse range of patch sizes and spatial configurations
Protected Areas	Can be smaller but should include disturbance initiation and runout zones.
Land Use	Focus conservation easements on: • Low energy hotspots • places with high natural disturbance.
Overarching Priorities	Manage disturbance and vegetation pattern to maintain the large number of microhabitat specialists and high potential species richness.

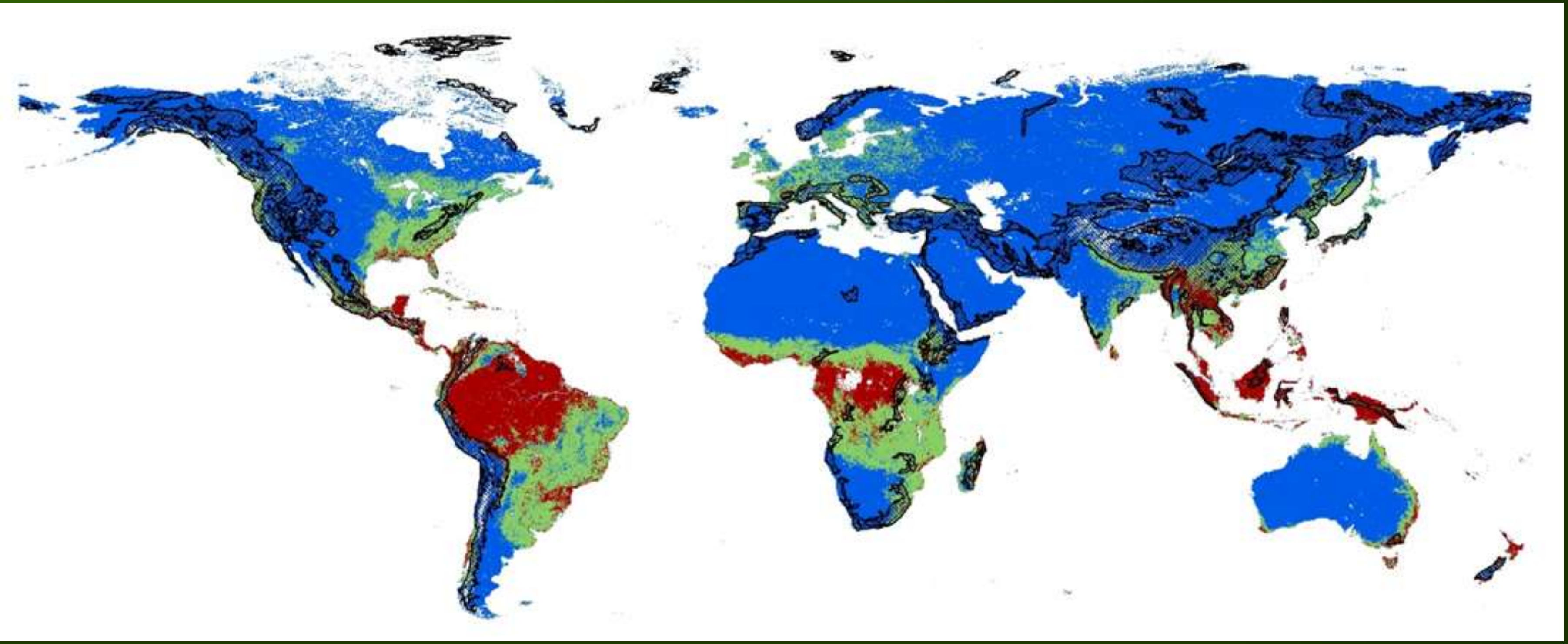


Mid B_K System: Mid Atlantic US

Conservation Category	Medium Energy
Sensitive Species	Focus on species sensitive to human impacts
Invasive Species	Manage to reduce the high level of introductions of exotics due to intense land use
Disturbance	Similar to High Energy
Landscape Pattern	Similar to High Energy
Protected Areas	Manage to buffer protected areas from surrounding human influence.
Land Use	• Focus conservation easements on remaining natural areas • and discourage development in remaining natural areas. • Emphasize restoration of degraded places • Educate citizens on "backyard" conservation
Overarching Priorities	Mitigate the heavy human influence in these systems which have the potential to be global hotspots for biodiversity.



Global Distribution of Ecosystem Types



Low B_K

Intermediate B_K

High B_K

High Topographic Complexity

Next Steps

- Test the framework with global data sets.
- Workshops with TNC, WCS, NPS, and USFS conservationists and managers to refine and evaluate approach.
- Incorporate consideration of climate change.

Take-Home Points to Ponder

- Conservation biology can become a more predictive science and help managers to identify up front the biggest problems in their place.
- General properties of ecosystems can be used to set conservation goals more effectively. Ecosystem biotic carrying capacity and habitat heterogeneity are candidates.
- In the future, conservation biology text book opens with a table of ecosystems grouped by vulnerabilities.