Land Use Change Around Protected Areas and Consequences for Biodiversity

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Funding: NASA Land Cover Land Use Change Program

The Concept of Nature Reserves

Thomas Moran, *Grand Canyon of the Yellowstone*, 1872, Department of the Interior Museum, Washington, D.C.

Thomas Moran Hayden Expedition 1871

By removing humans, natural ecosystems were expected to continue to maintain ecological processes and native species.

Loss of Reserve Function

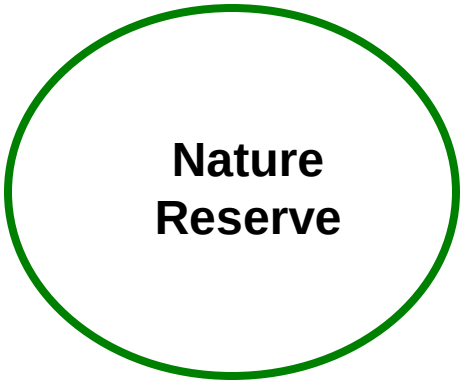
- **Ecological Processes –**
  - **•Climate**
  - **•Disturbance**
  - **•Nutrients**
- **Biodiversity**
  - **•Invasive species**
  - **•Extinction of native species**
    - **- 11 of 13 western US national parks have lost 5-21% of original large mammal species (Parks and Harcourt 2002)**

Land Use Intensification Around Reserves

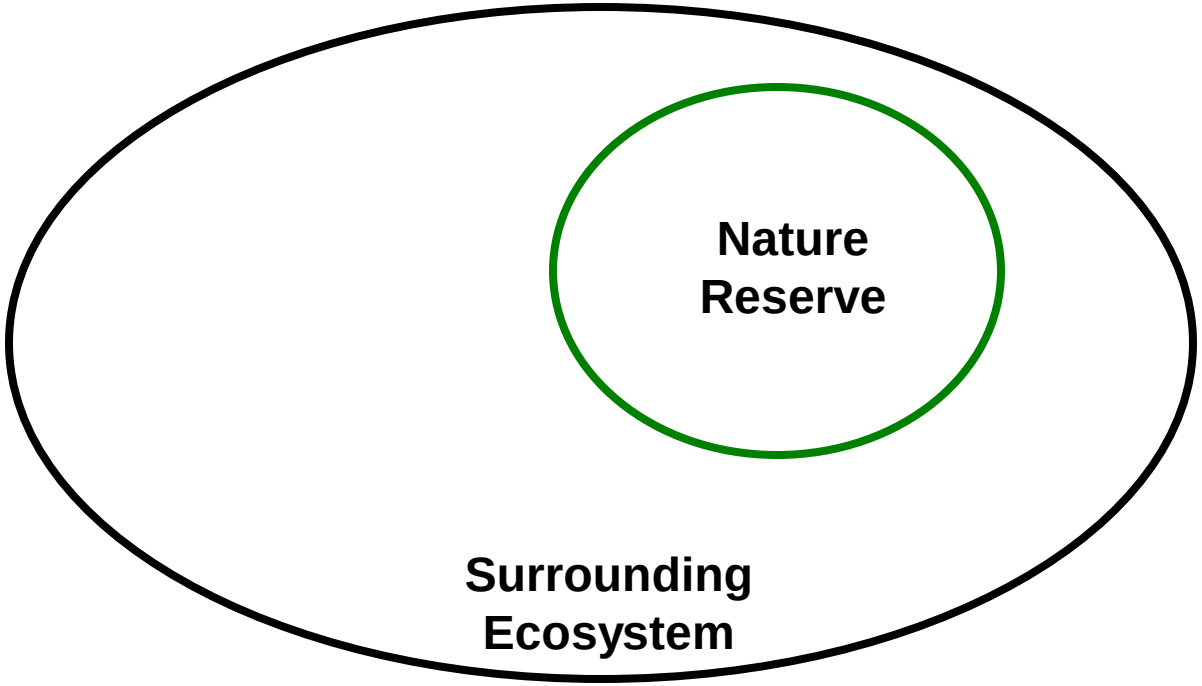
Boundary of Ngorgora Conservation Area

What are the consequences of land use change around reserves for biodiversity within reserves?

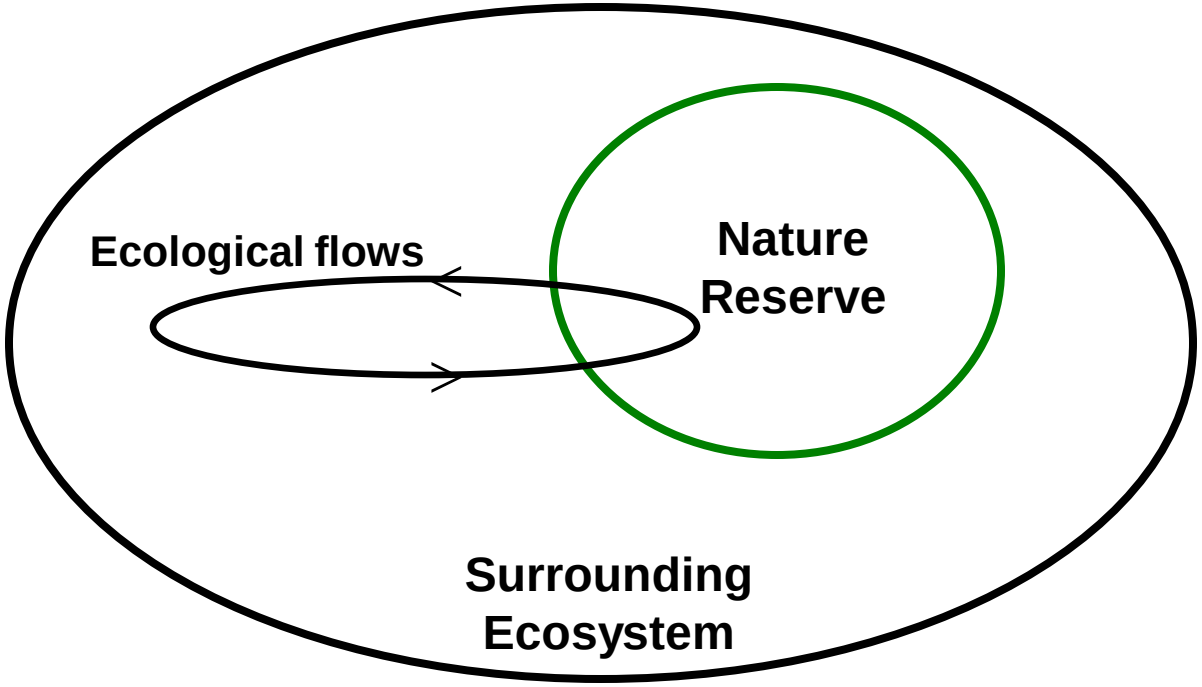
Nature Reserves as Parts of Larger Ecosystems



Nature Reserves as Parts of Larger Ecosystems

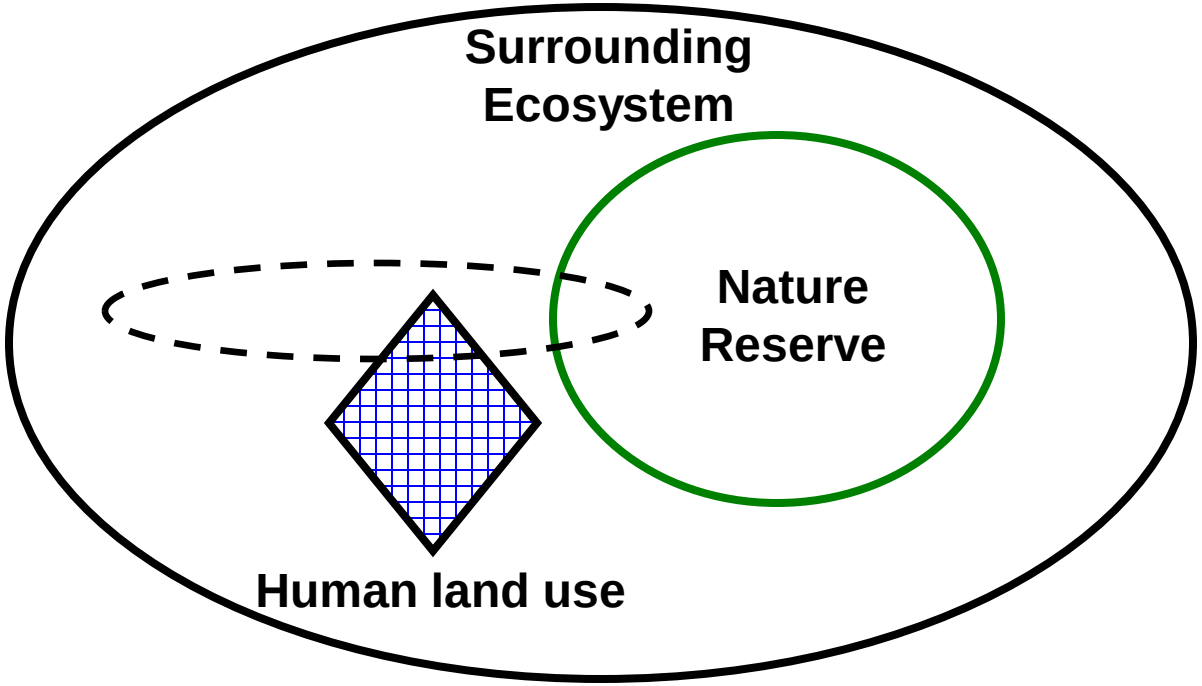


Nature Reserves as Parts of Larger Ecosystems



Nature reserves are often connected to the surrounding landscape by movements of materials, disturbance, and organisms

Nature Reserves as Parts of Larger Ecosystems



Land use intensification outside of nature reserves may disrupt these flows and alter ecological processes and biodiversity within reserves.

Larson's Conceptual Model of Nature Preserves

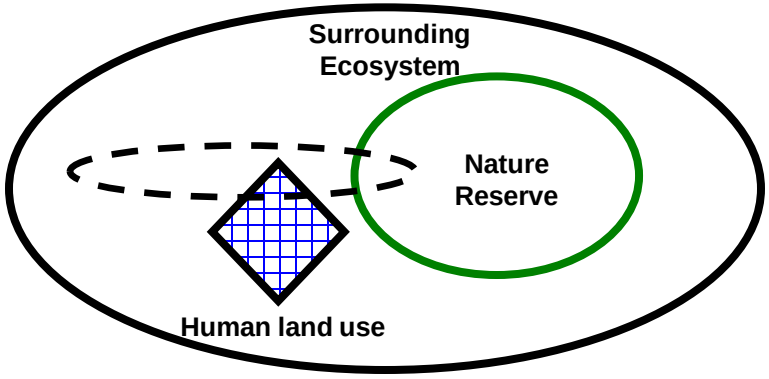
Wildlife preserves

Study Objectives

- **Quantify rates and types of land use change around reserves.**

- **Assess effects on biodiversity within reserves.**
  - **Habitat area**
  - **Species extinction rates based on habitat area**
  - **Individual species abundances**
  - **Biodiversity hotspots**

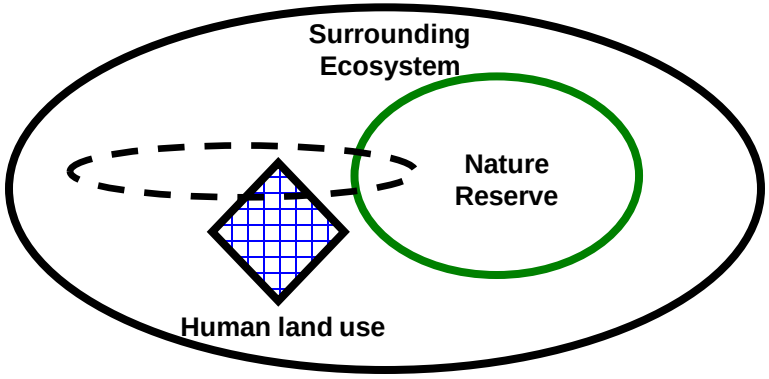
- **Evaluate MODIS data as a means of regional-scale land cover monitoring.**



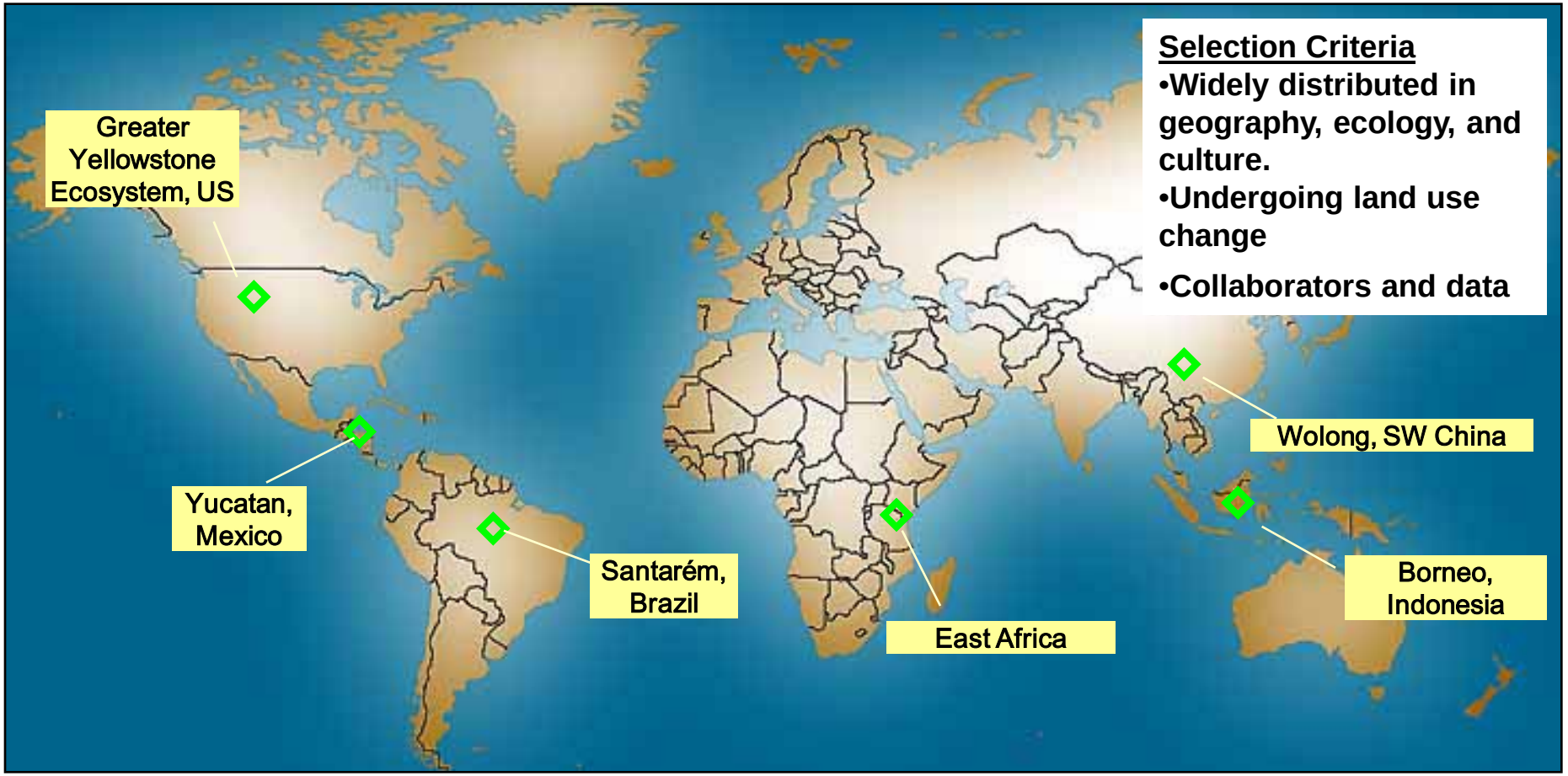
General Products

- **Elucidate the ecological mechanisms by which land use outside of reserves influences biodiversity within reserves.**

- **Develop criteria for regional-scale management to maintain reserve function and biodiversity.**



Study Regions



Western Hemisphere

Yellowstone:	Temperate/boreal	Coniferous-wet/dry	Mountains
Yucutan:	Subtropical	Broadleaf-wet/dry	Flat
Santarem:	Tropical	Broadleaf-wet	Flat

Eastern Hemisphere

Wolong:	Subtropical	Broadleaf-wet/dry	Mountains
Indonesia:	Tropical	Broadleaf-wet	Mountains

Africa

East Africa:	Subtropical	Savanna	Mountains

Intensive Study Regions

Greater Yellowstone Ecosystem, US

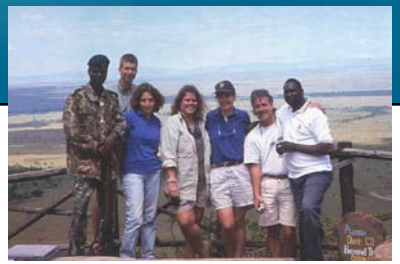
Yucatan, Mexico

Santarém, Brazil

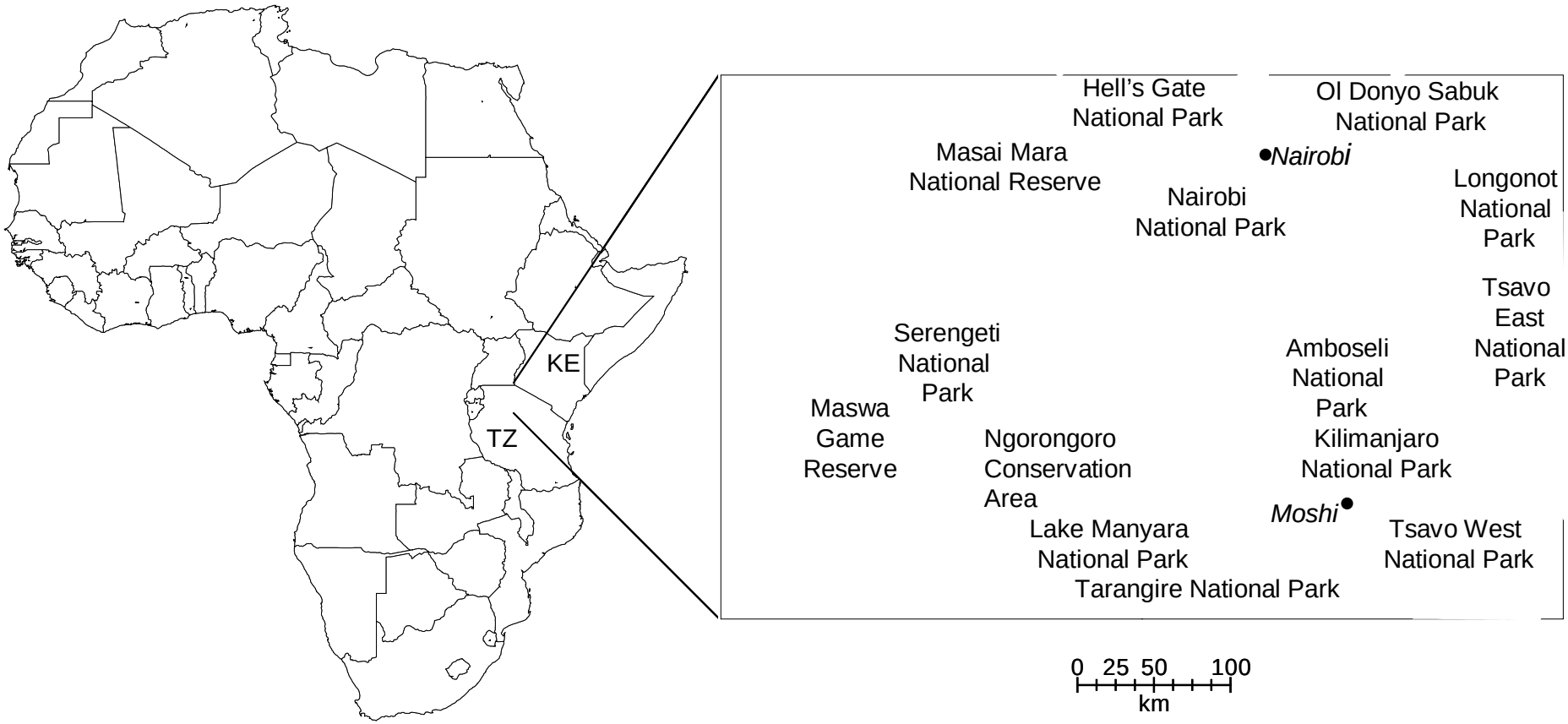
Wolong, SW China

Borneo, Indonesia

East Africa

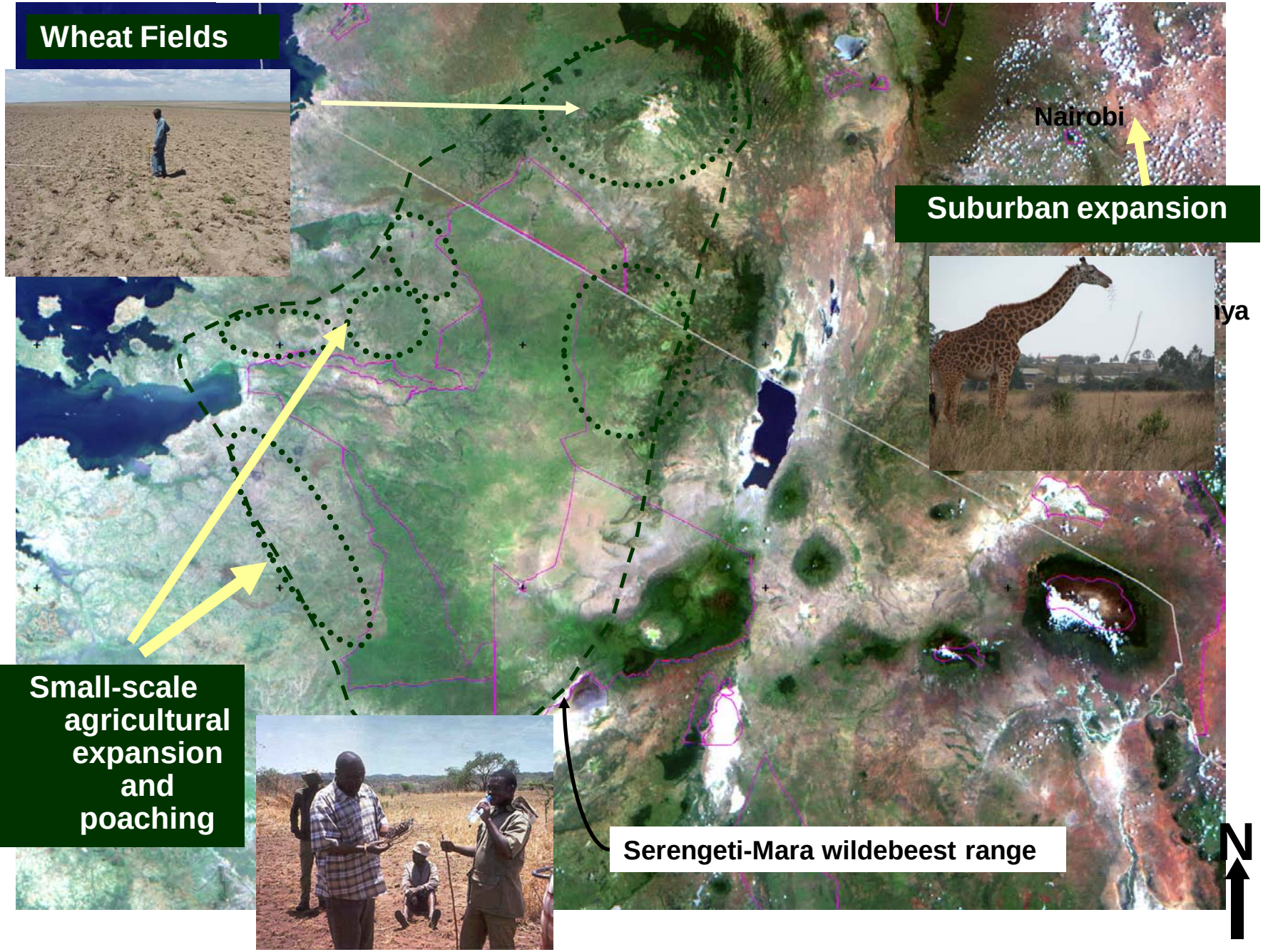


Maasai East Africa: Land Use Change

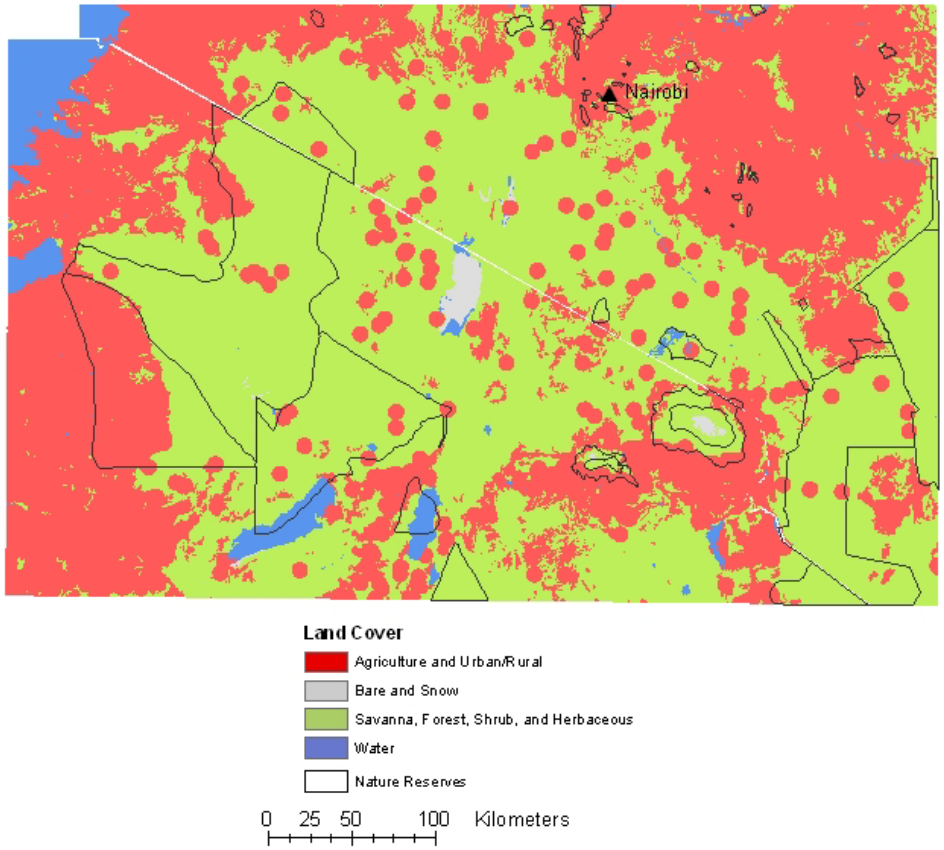


Maasai East Africa: Nomadic Pasturalism

Maasai East Africa: Land Use Change

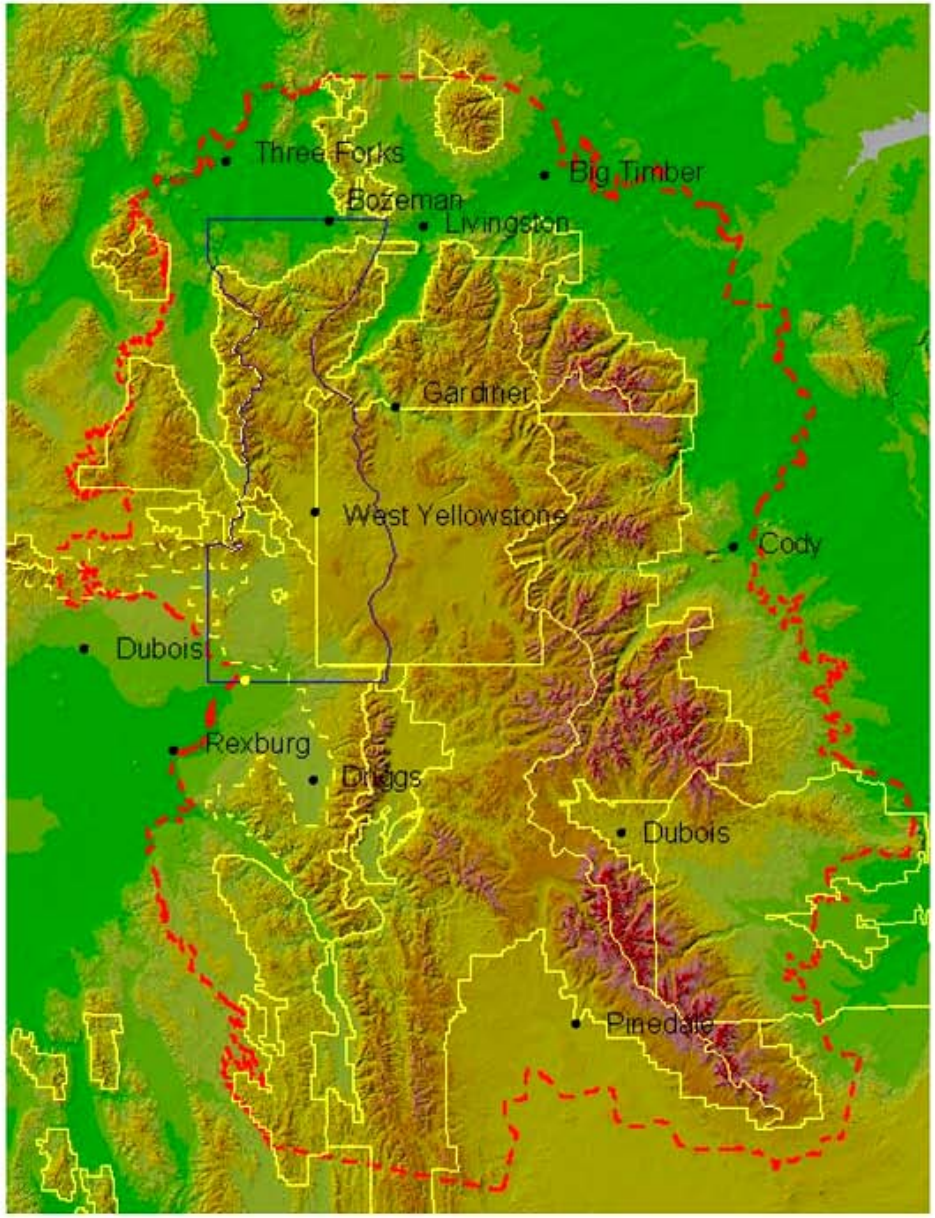


Maasai East Africa: Loss of Wildland Habitats

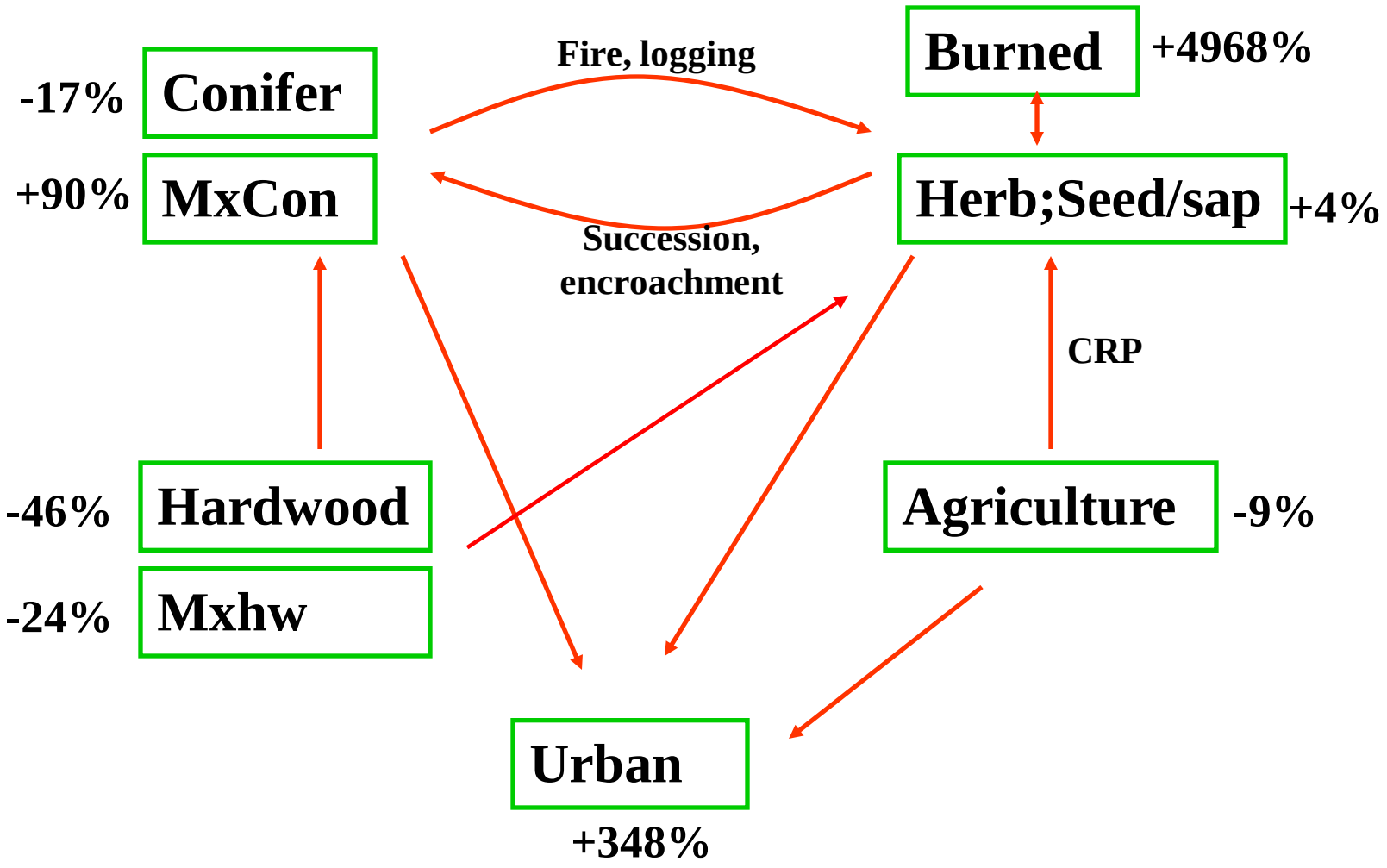


Site	Total Area (km^2)	Total % Converted	% Unprotected Lands Converted	% Remaining Habitat Found Outside Reserves
Maasailand	193,405	45	53	66

Greater Yellowstone

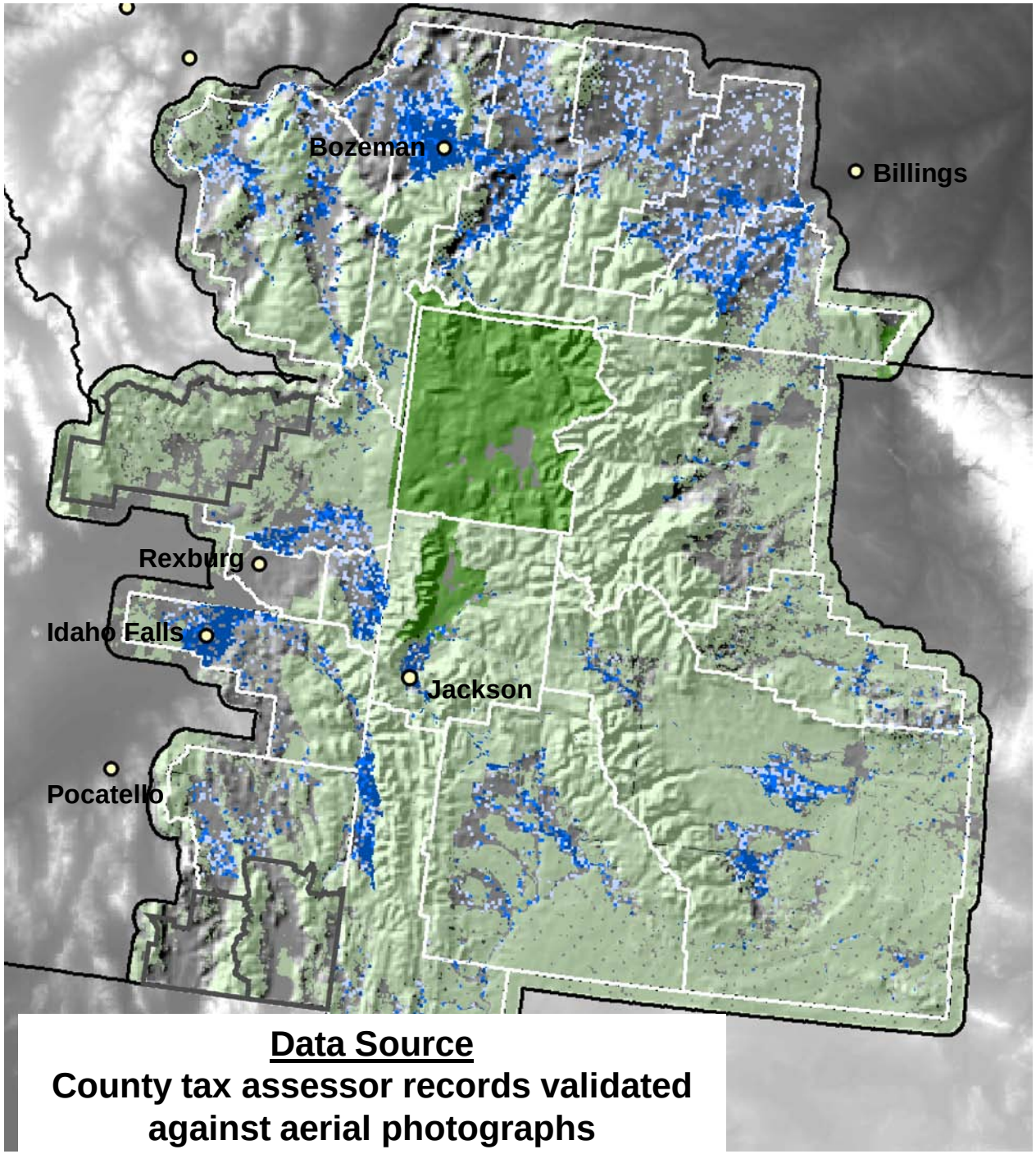


Land Cover/Use Change in GYE: 1975-1995



GYE Rural Residential Development

Rural Homes



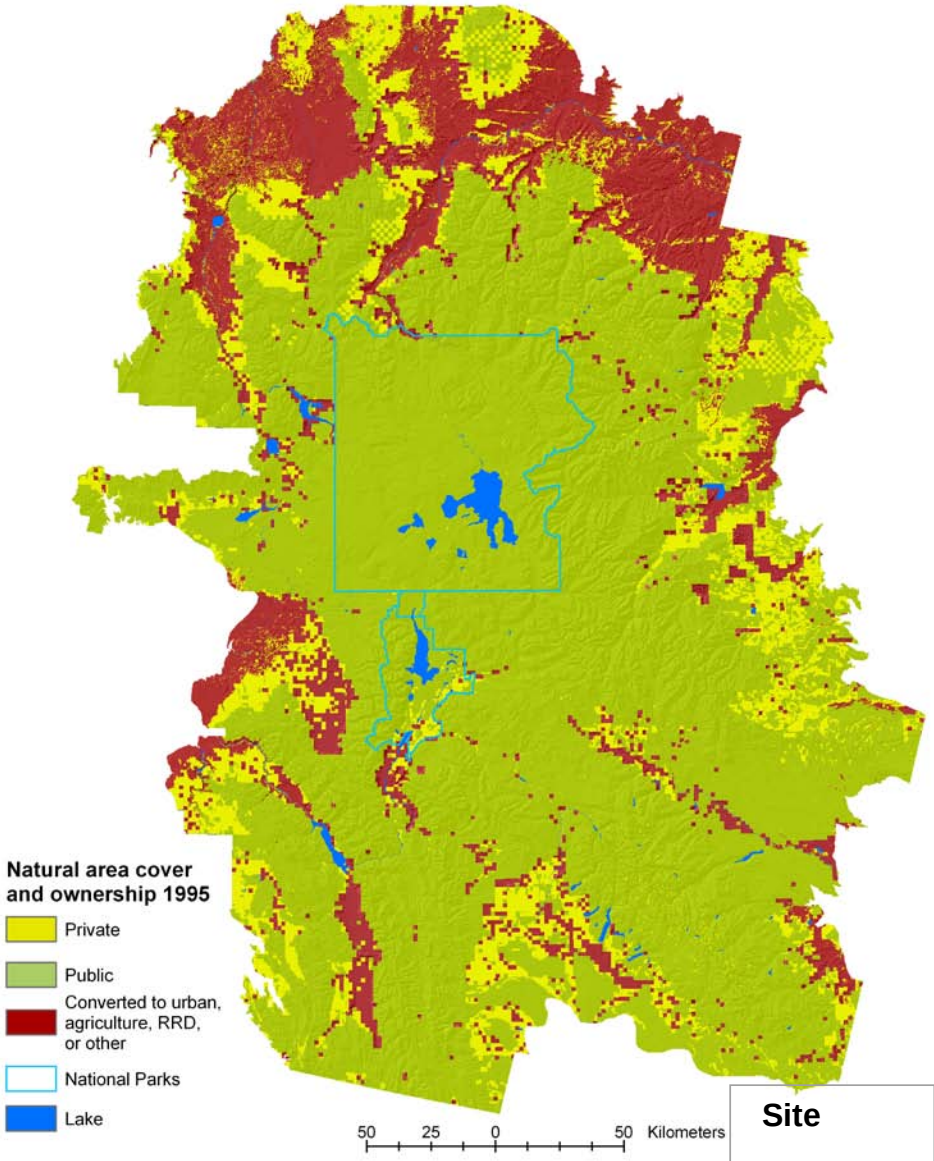
National Park Service
Other federal lands
County boundaries

Home density
Low ⟷ High
Counties without home density data

- **Population has increased 55% 1975-95**
- **Rural homes increased 108% 1975-99**

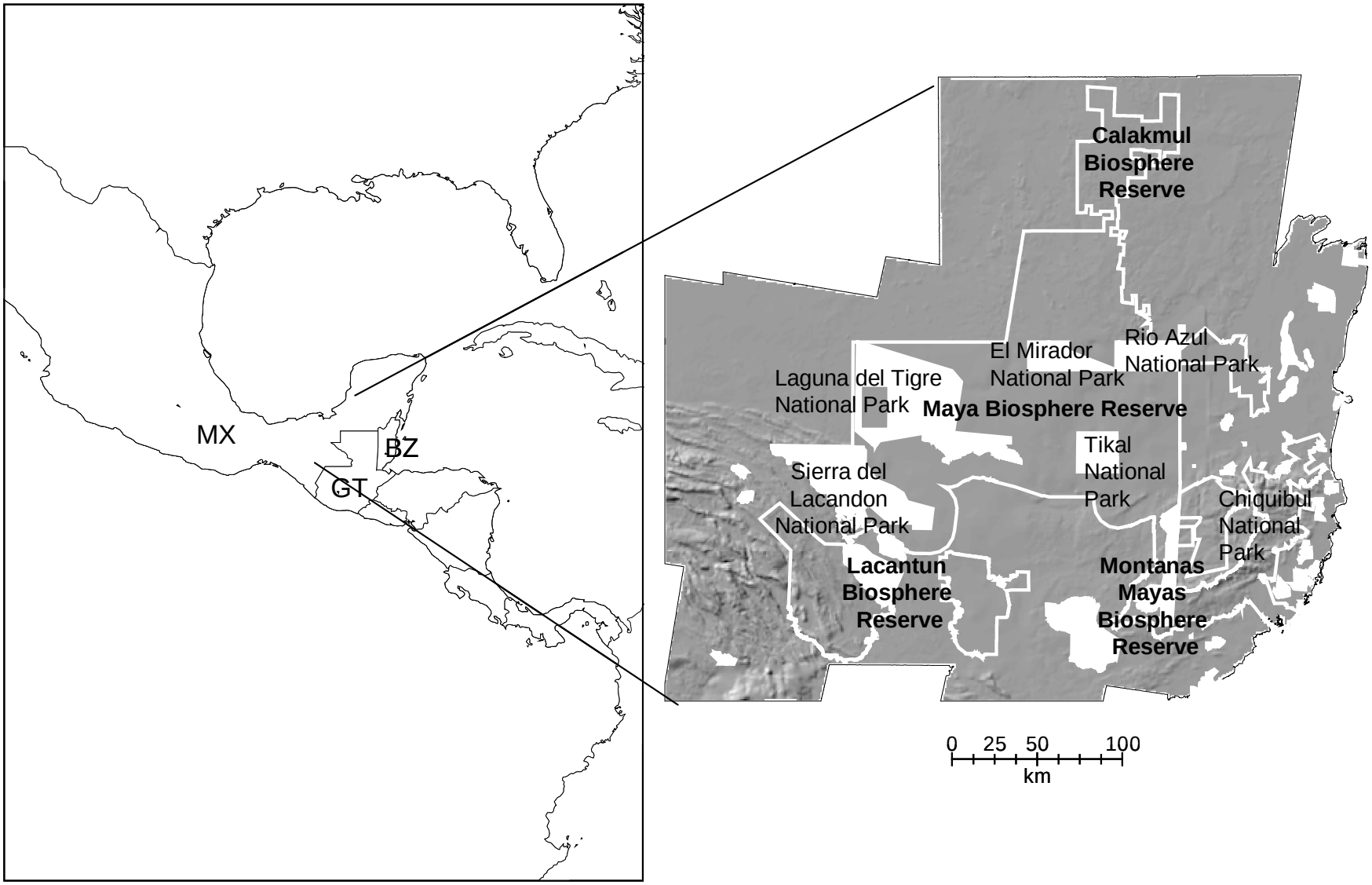
Data Source
County tax assessor records validated against aerial photographs

GYE: Loss of Wildland Habitats



Site	Total Area (km^2)	Total % Con-verted	% Unprotected Lands Converted	% Remaining Habitat Found Outside Reserves
GYE	95,363	11	37	20

Mayan Forest

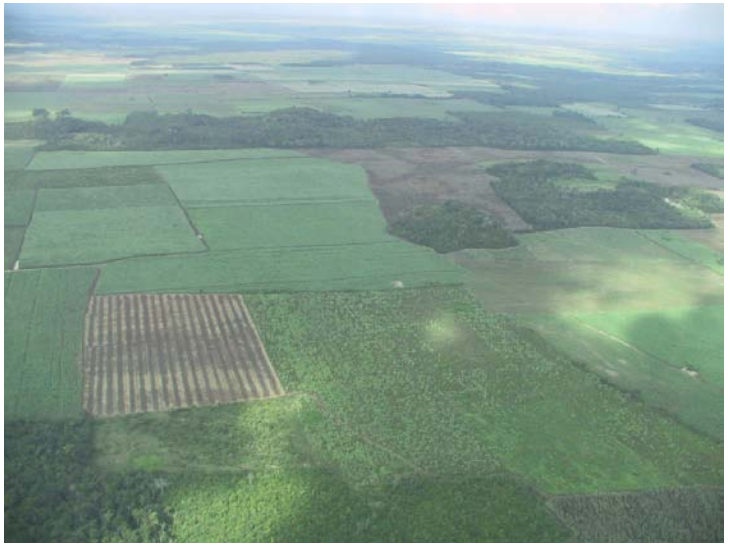


Mayan Forest:Land Uses

Primary Forest

Swidden Agriculture

Permanent Small-Plot Agriculture



Industrial Agriculture

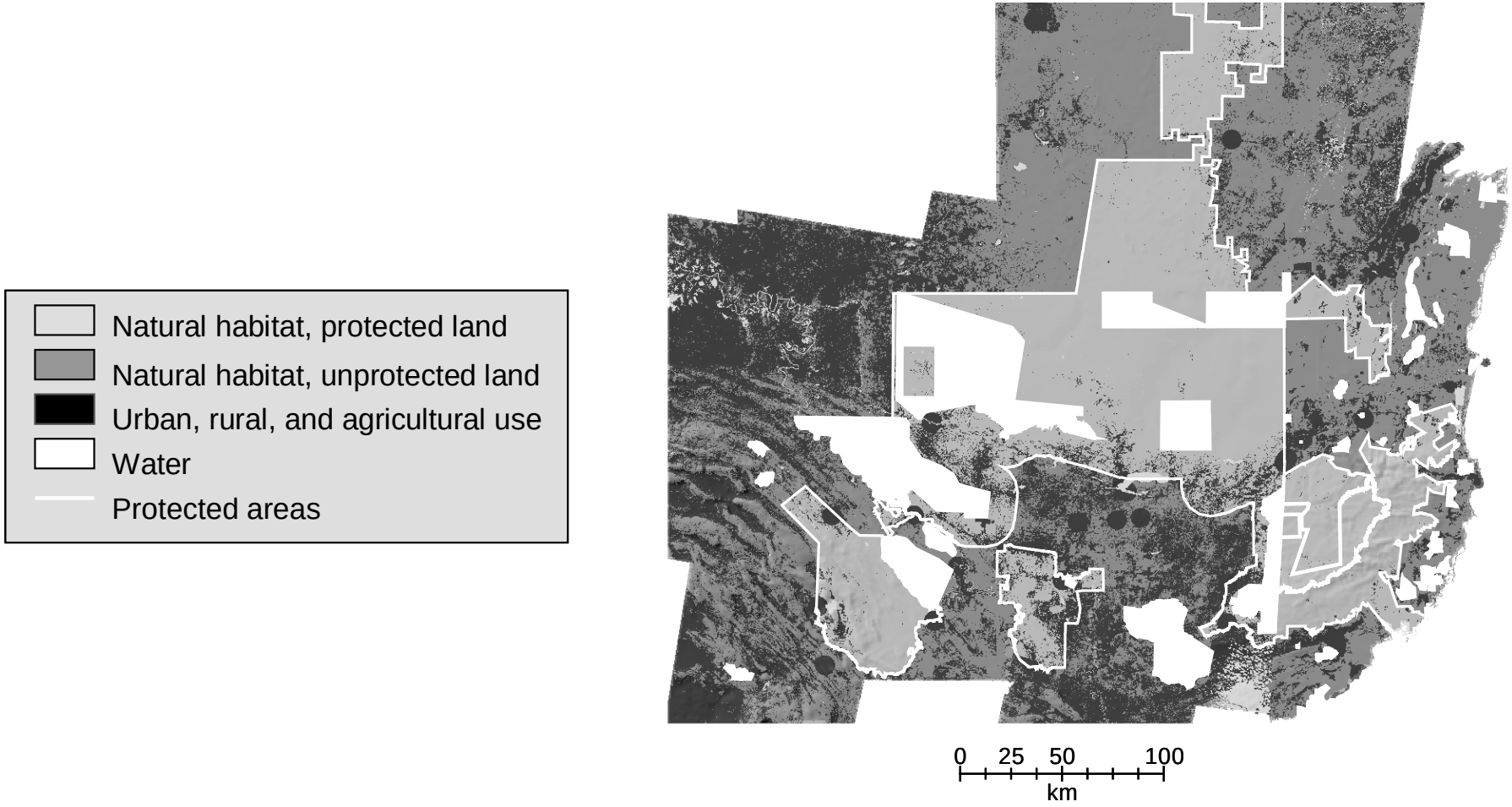
Mayan Forest: Land Cover/Use Change

Land Cover Classes	1969[1]	1987[2]	1997[2]
Primary Forest	11,042	10,356	10,068
Secondary Forest	111	634	845
Agriculture and Pasture	228	391	468

[1] Based on aerial photographs covering 63% of the study region or 11,318 km^2.
[2] Based on TM Landsat imagery for same area as photographs.

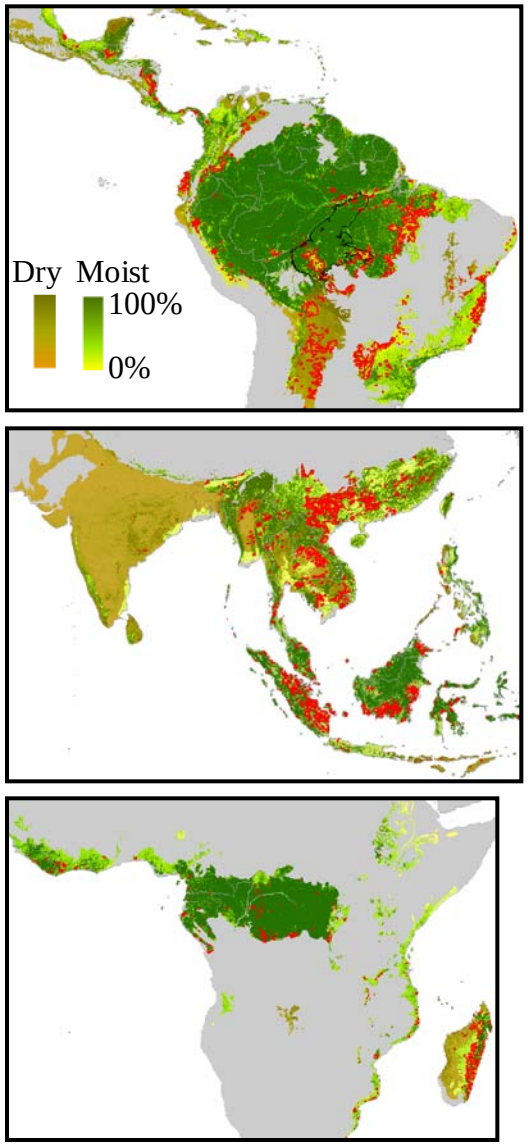
(After Turner et al., 2001)

Mayan Forest: Loss of Wildland Habitats

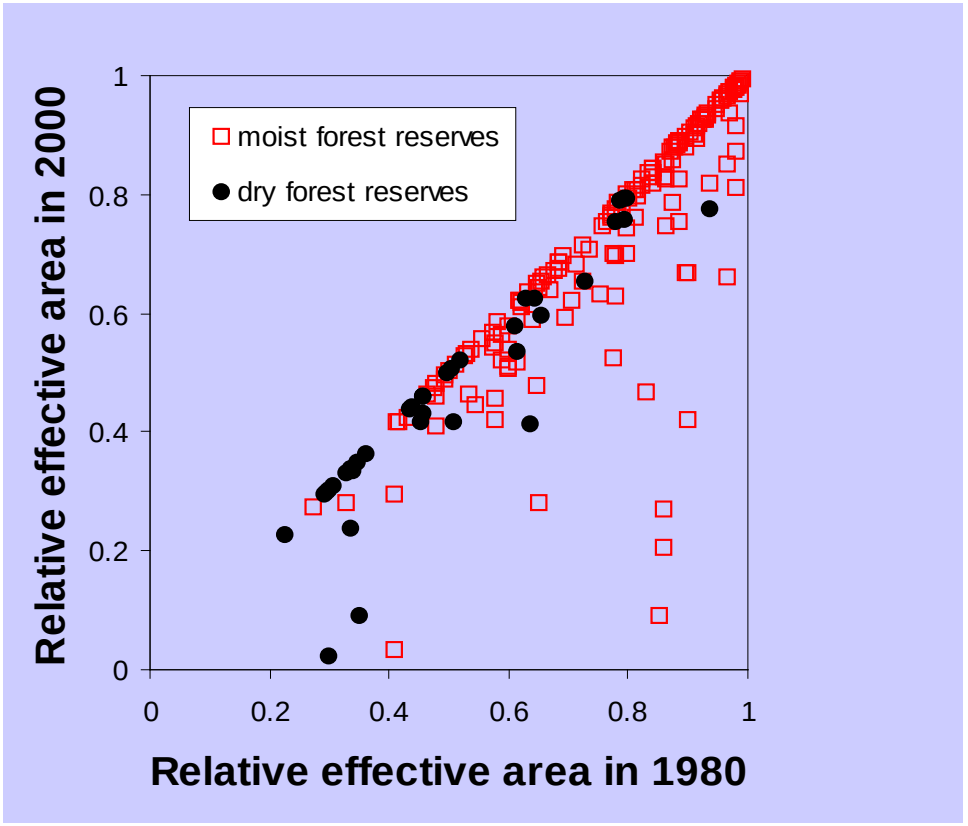


Site	Total Area ($km^{2)}$	Total % Converted	% Unprotected lands Converted	% Remaining Habitat Found Outside Reserves
Mayan Forest	**120.109**	**30**	**40**	**53**

Land Use Change Around 200 Reserves in the Tropics



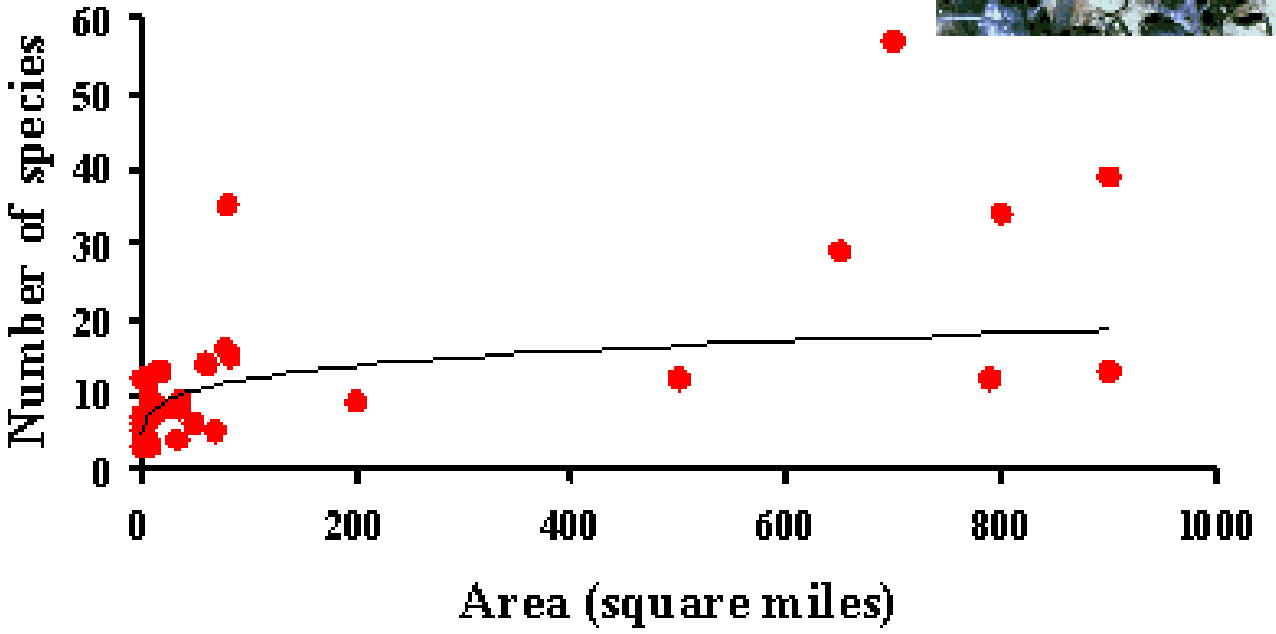
Locations of forest loss from 1980 – 2000 estimated from AVHRR



70% have experienced some decline in forest habitat in the surrounding 50km within the past ~20 yrs.

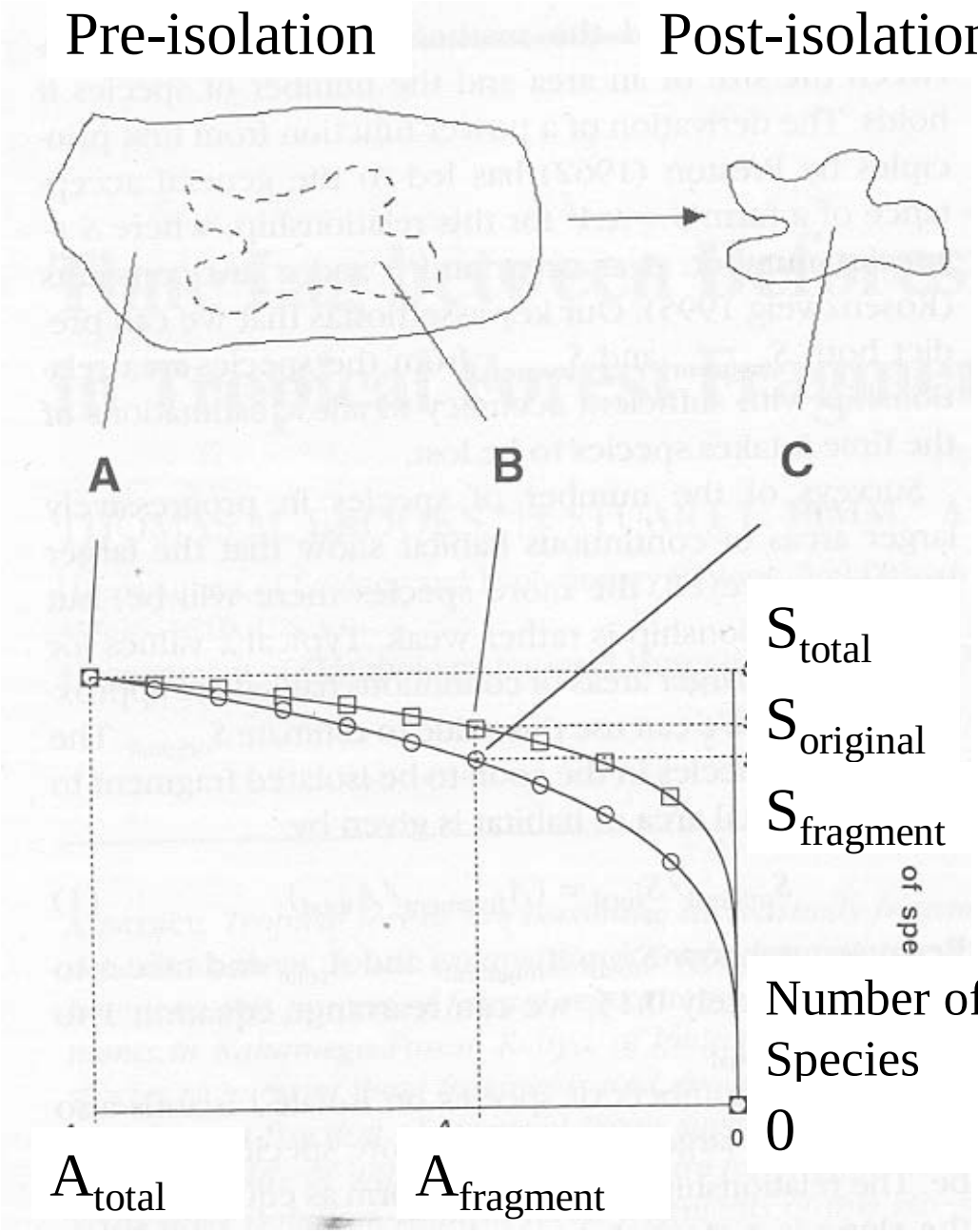
Extinction Rates Based on Species Area Relationship

Polynesian Ants



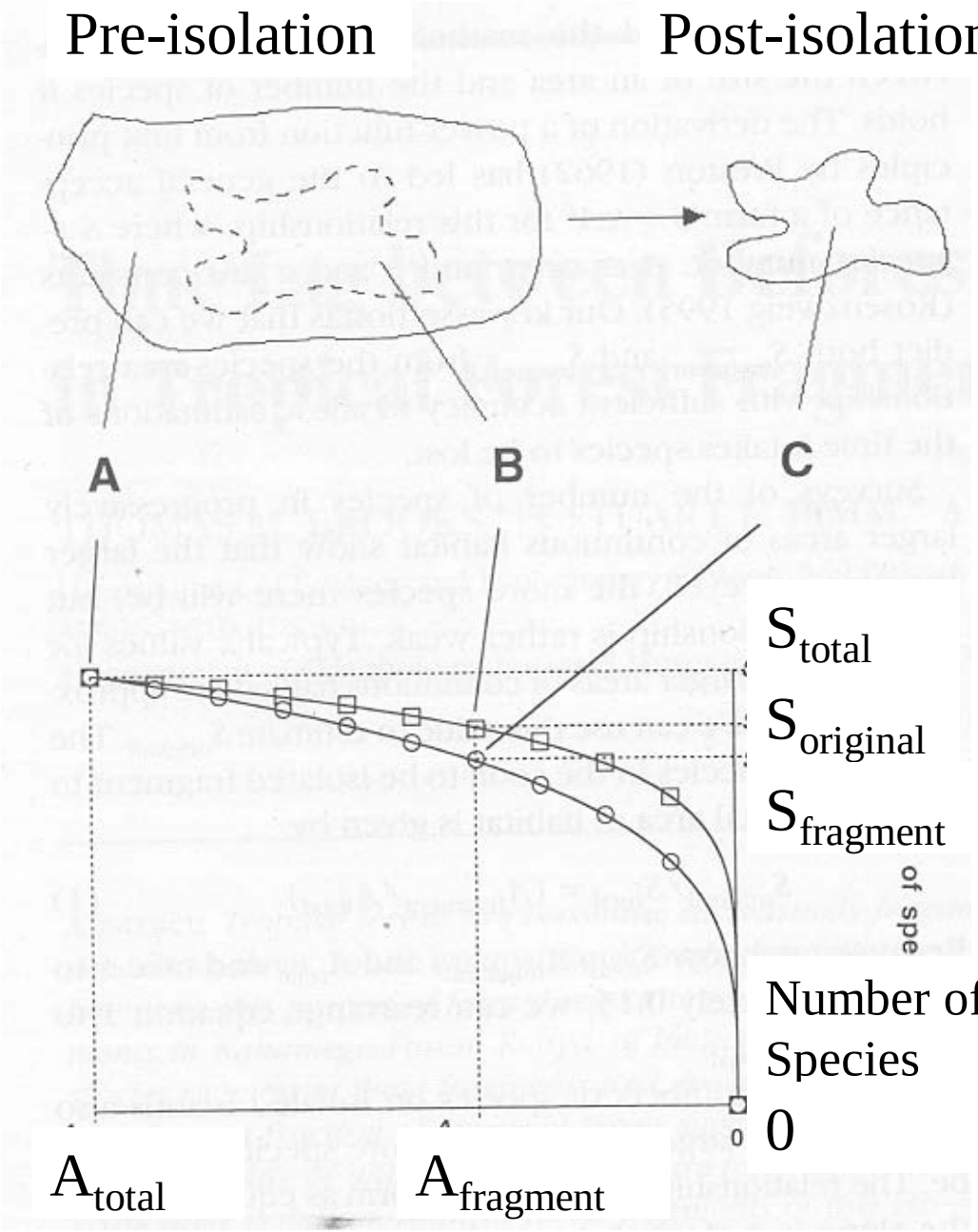
Basis: Larger habitat may support larger population sizes, reducing the likelihood of extinction.

Species Area Effects: Habitats Fragments



Brooks et al. 1999

Species Area Effects: Habitats Fragments



Implication:
Nature reserves will loose species as the natural habitats around them are reduced in size

Brooks et al. 1999

Extinction Rates: Methods

1. Estimate current area of wildland habitats.

2. Determine the number of bird and mammal species known to be present and breeding in each region from range maps.

3. Estimated species richness based on ratio of remaining to original area (entire study area) of natural habitat based on Brooks et al. 1999:

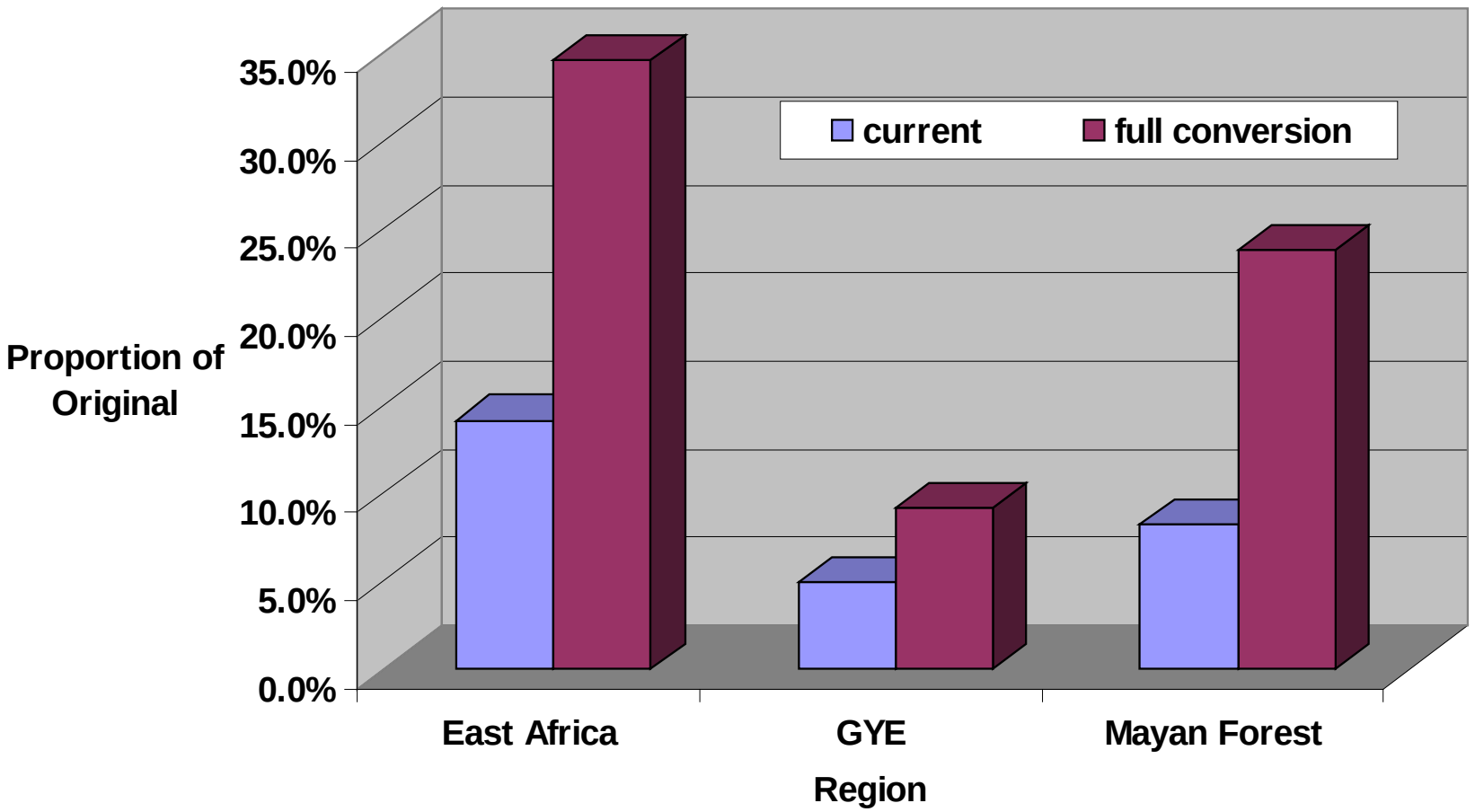
$$S_n = S_o (A_n/A_o)^z$$

New species richness=original species richness (new area/original area)$^{.25}$

4. Validated our results against the number of threatened species (GYE)

Species Area Effect: Results

Predicted Extinction Rates for Birds and Mammals



- 9-14% of species in these greater ecosystems are predicted to go extinct based on habitat loss to date.
- If all unprotected wildlands are converted, 9-35% of species are predicted to go extinct.

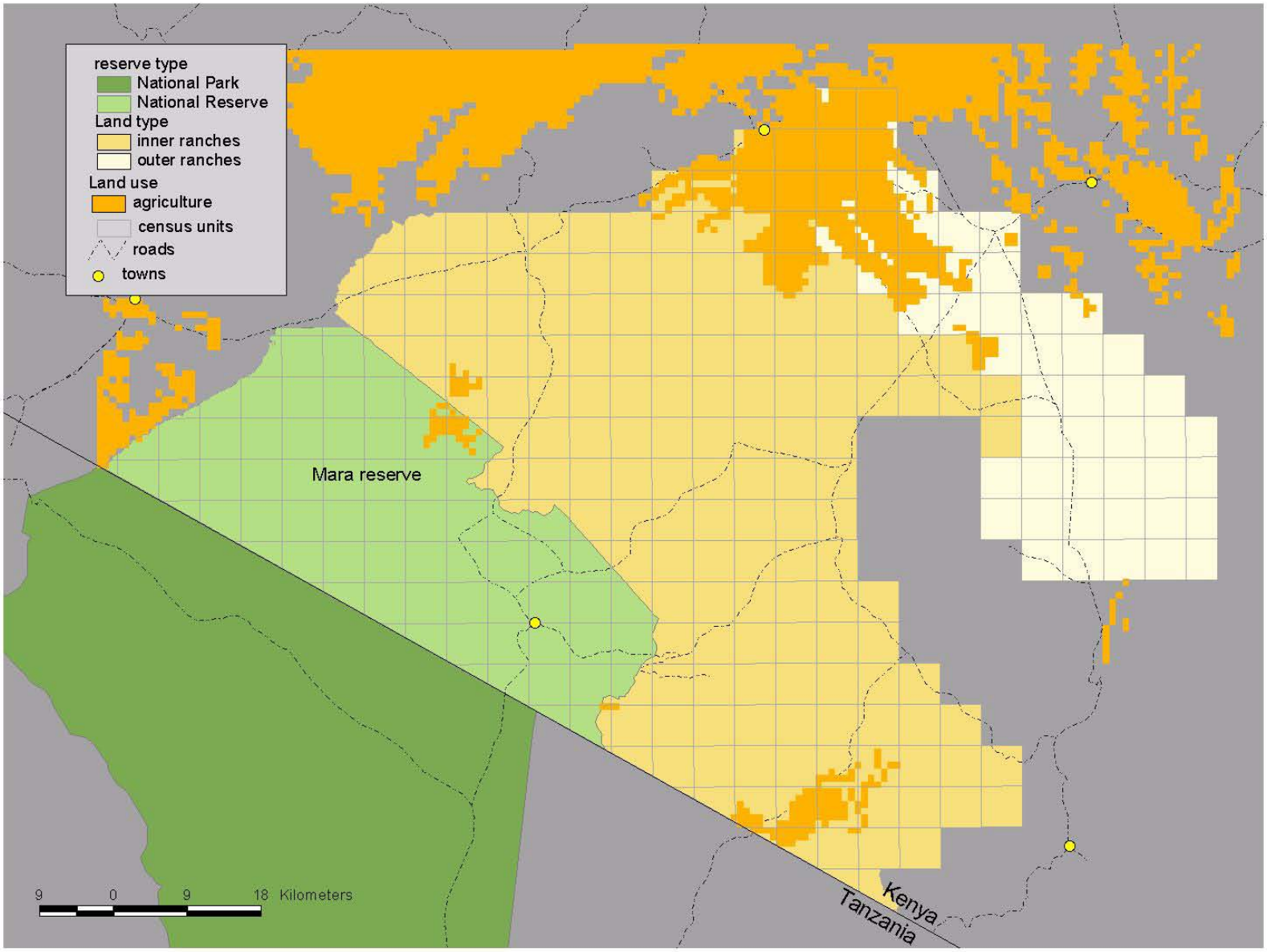
Species Abundance Data

Region	Taxonomic Group	Source	Resolution	Time Period
East Africa	Large mammal abundance by species	Kenyan and Tanzanian Govmts.	5 km	1977-99
GYE	Bird abundance by species	Breeding Bird Survey	50-km transects	1968-2002
Mayan Forest	Butterflies Birds Herptiles Trees	ECOSUR	Various	Various

Species Abundance/Hotspots Methods

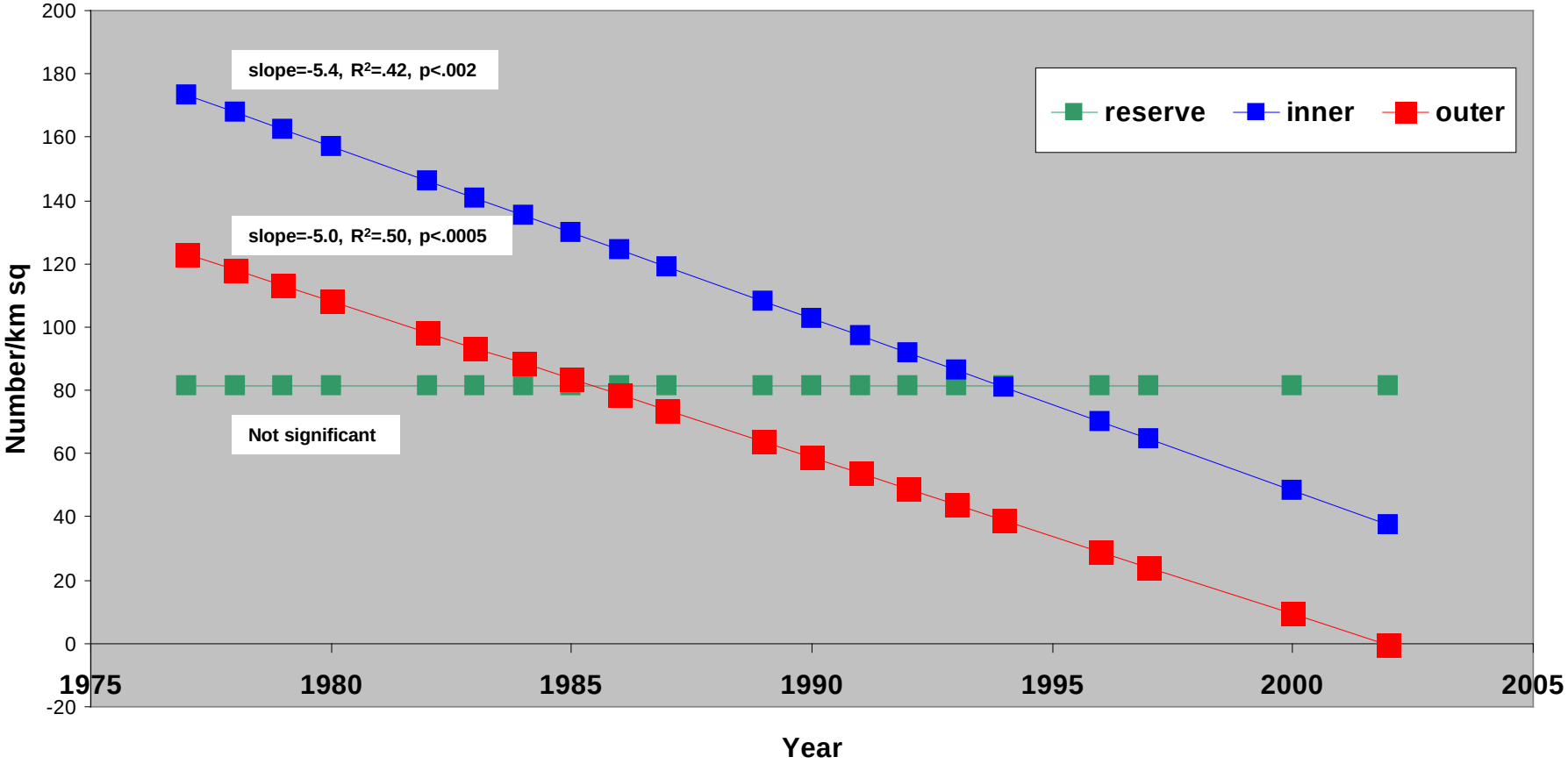
- Obtain data from field surveys of species abundances.
- Develop statistical relationship with biophysical and land use predictors.
- Use statistical relationship to extrapolate species abundance over the landscape.
- Analyze spatial distribution of species abundance to prioritize conservation.

Maasai Mara Greater Ecosystem



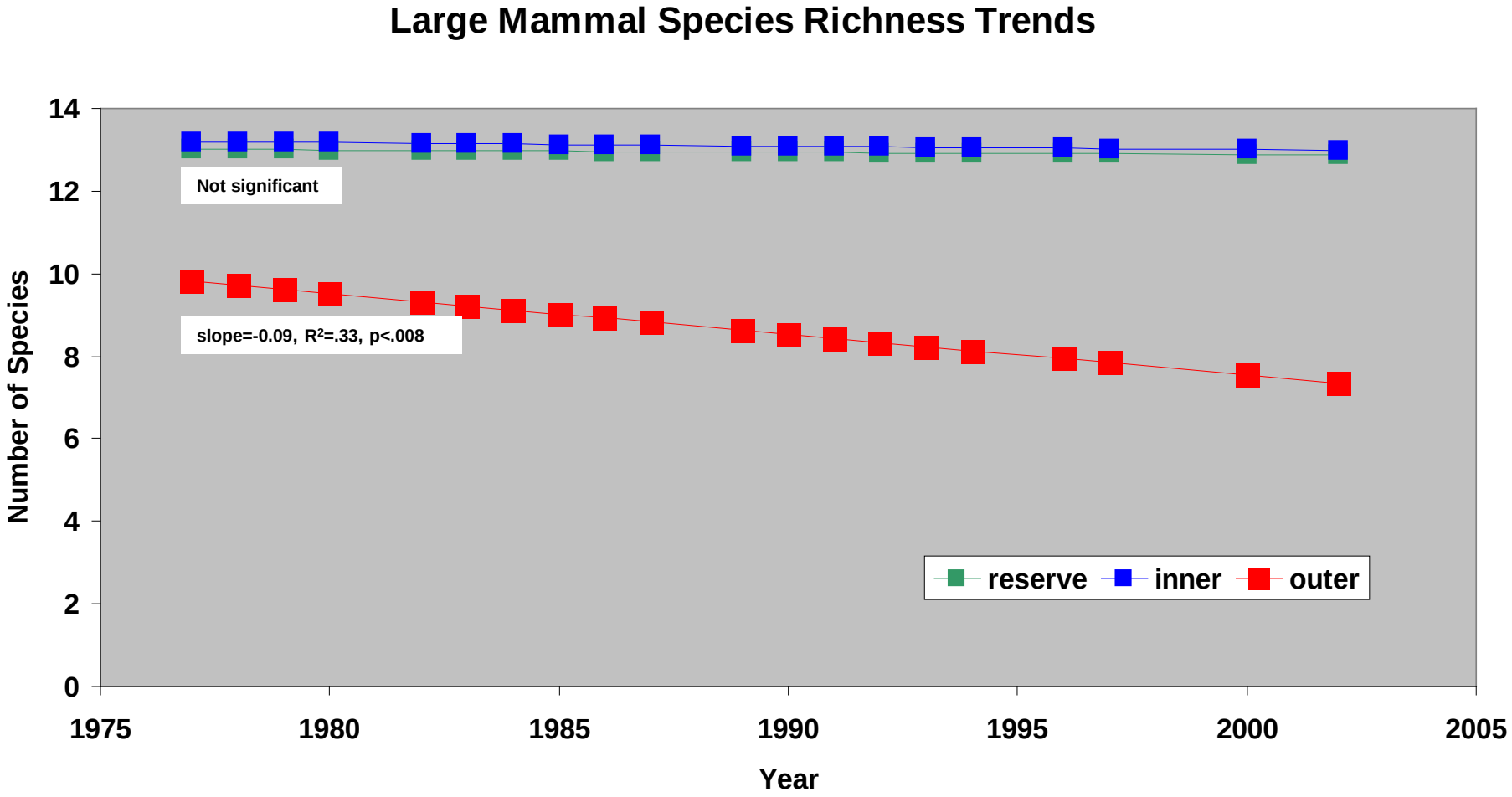
Species Abundances

Thompson's Gazelle Population Trends

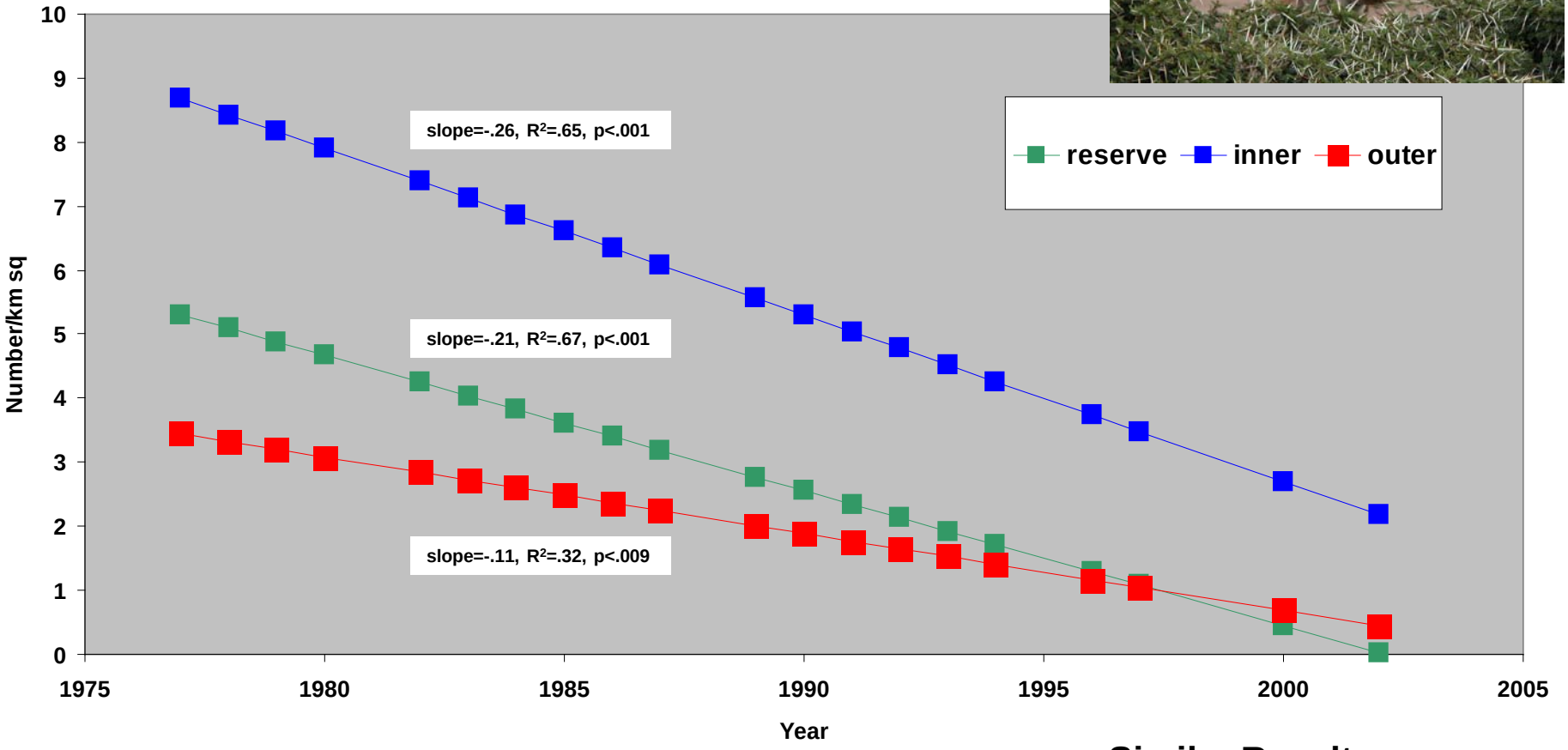


<u>Similar Results</u>

Burchell's zebra, Grants Gazelle

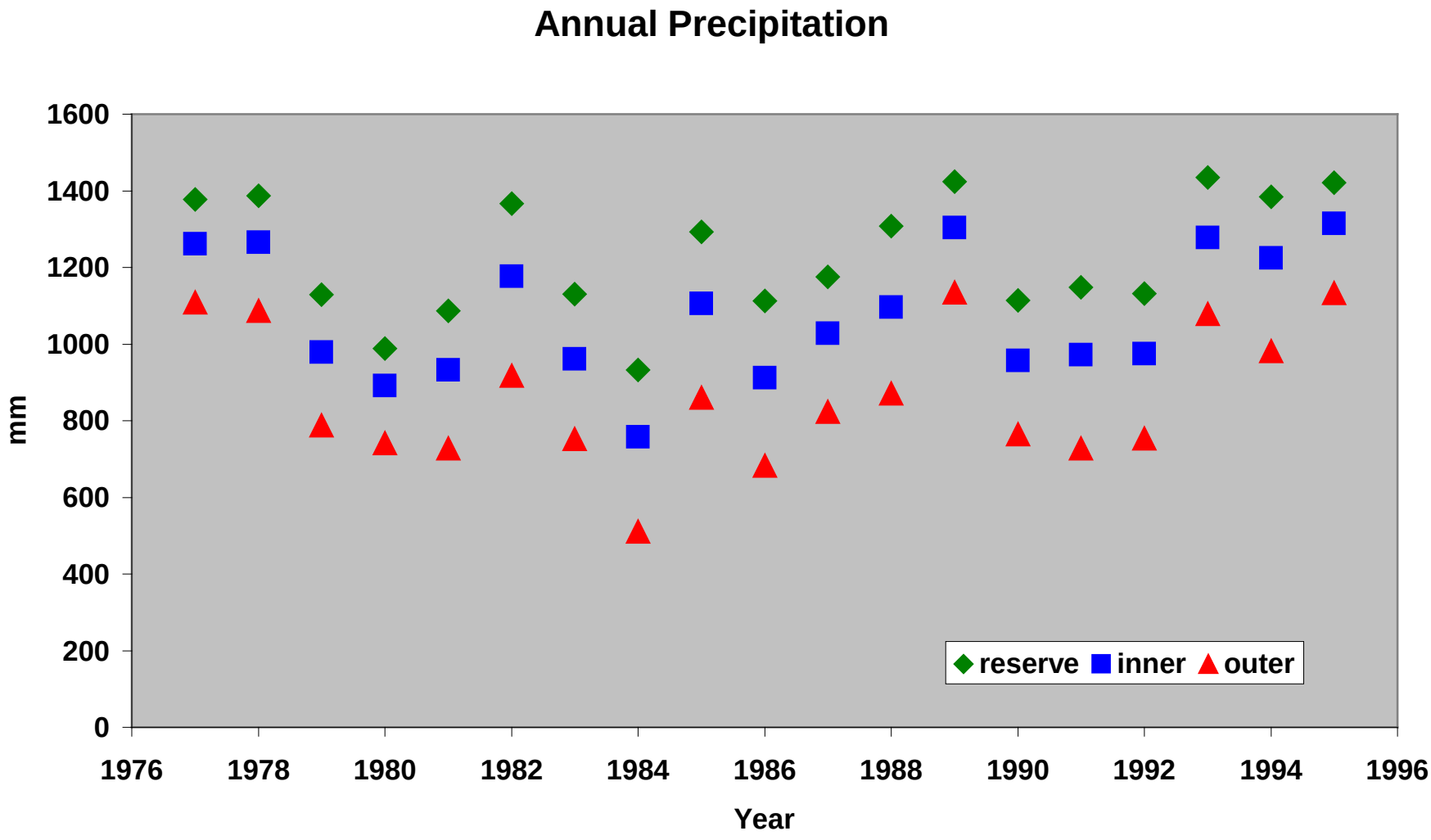

Large Mammal Species Richness Trends
Number of Species
14
12
10
8
6
4
2
0
1975
1980
1985
1990
1995
2000
2005
Year
Not significant
slope=-0.09, R²=.33, p<.008
reserve
inner
outer

Giraffe Population Trends



Similar Results

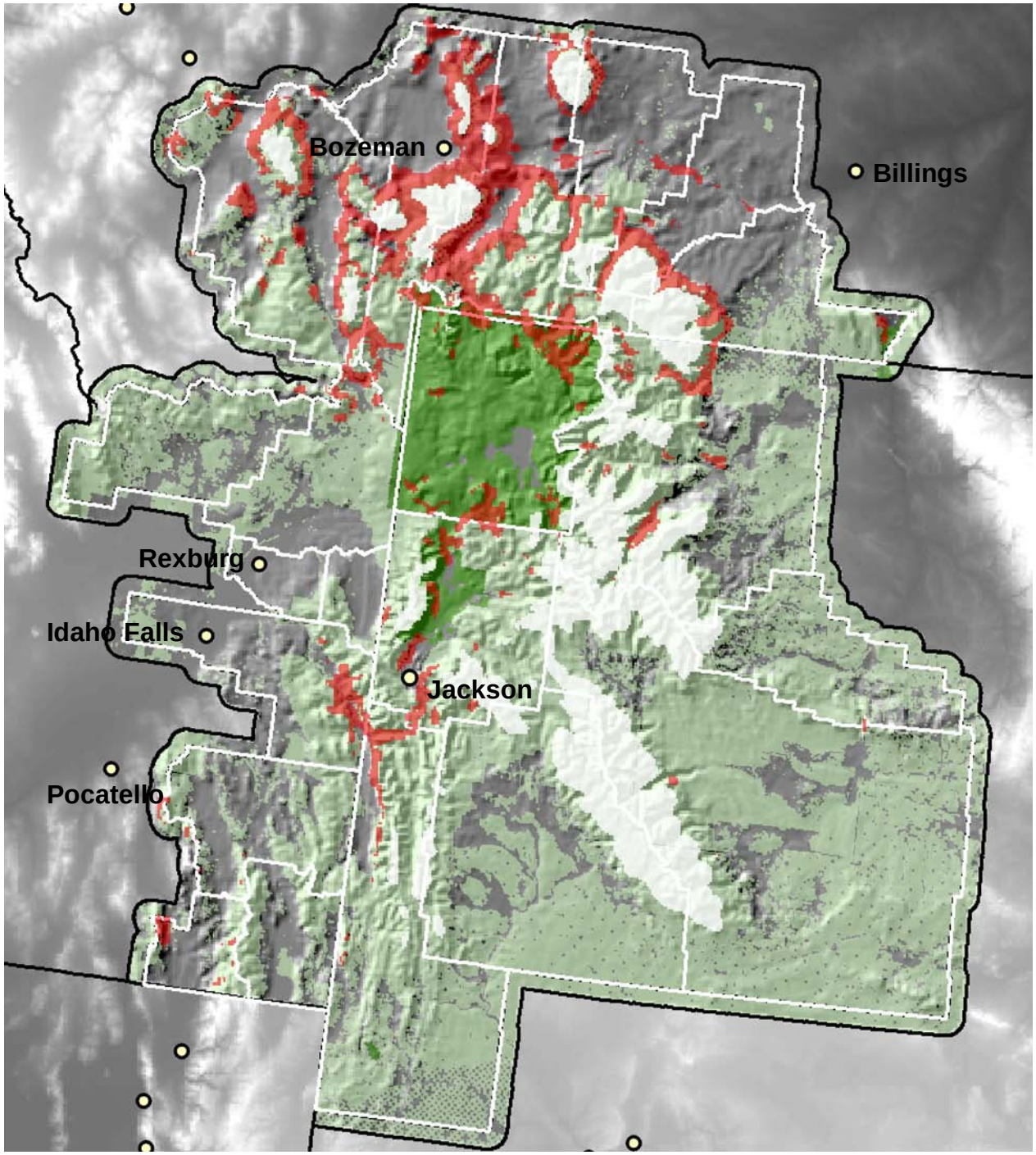
wildebeest, kongoni, impala, Thompson's gazelle, buffalo, warthog, waterbuck


Annual Precipitation
1600
1400
1200
1000
800
600
400
200
0
mm
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Year
reserve
inner
outer

Great Maasai Mara Ecosystem: Large Mammal Population Trends

13 Species Analyzed

- **3 species and species richness maintained in reserve but declined outside reserve.**
- **8 species declined both inside and outside reserve.**
- **1 species did not change across the study area (elephant)**
- **1 species increased outside reserve (ostrich)**

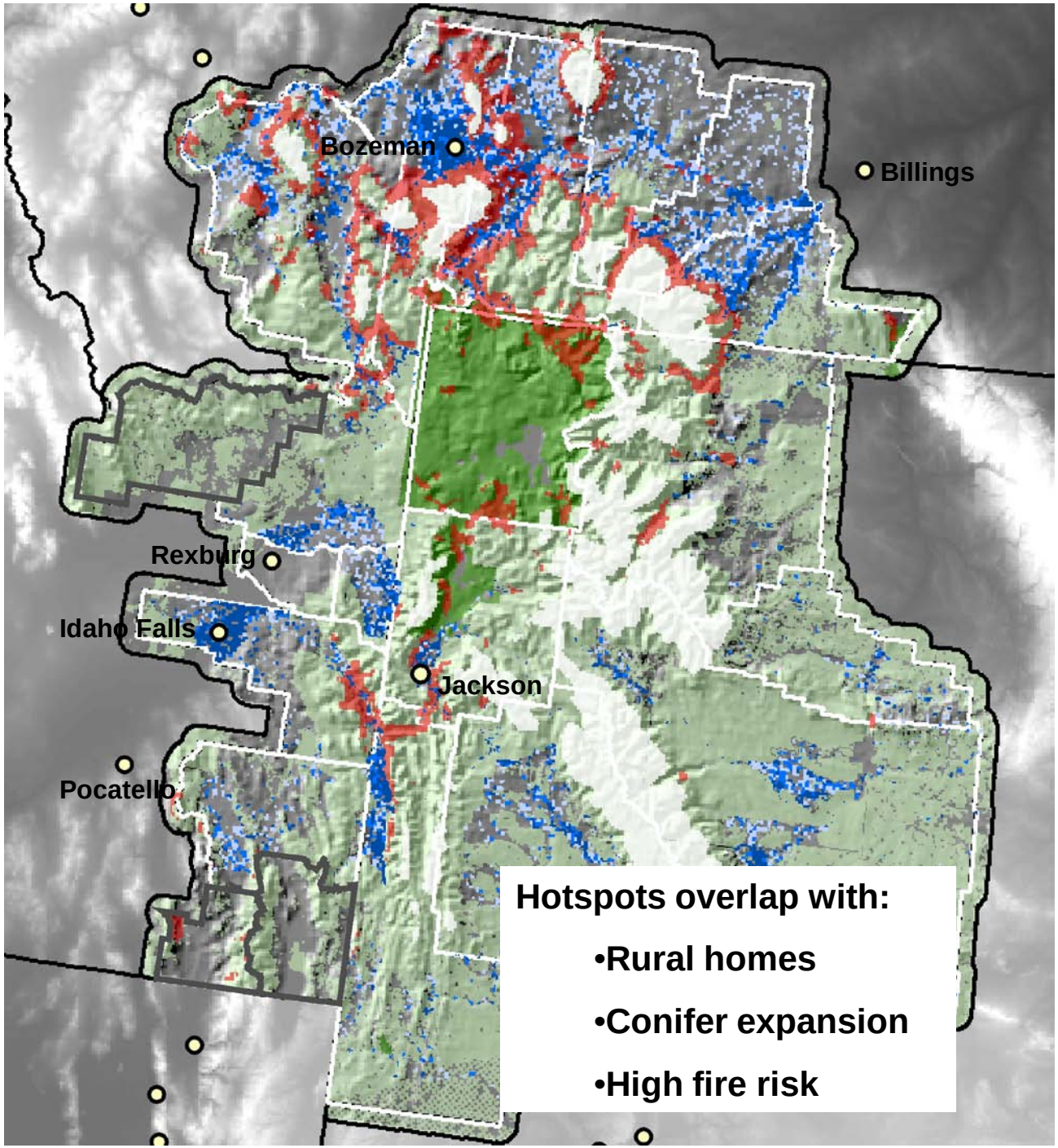


Predicted Bird Hotspots

- National Park Service
- Other federal lands
- County boundaries
- Biodiversity hotspots
- unclassified

Places where bird species richness and abundance are >60% of maximum

Hotspots cover 6.4% of area



Bird Hotspots and Rural Homes

National Park Service
Other federal lands
County boundaries
Biodiversity hotspots
Biodiversity modeling mask

Home density
Low ⟷ High
Counties without home density data

Hotspots overlap with:

- **Rural homes**
- **Conifer expansion**
- **High fire risk**

Percent of hotspots on:

Private land: 41%

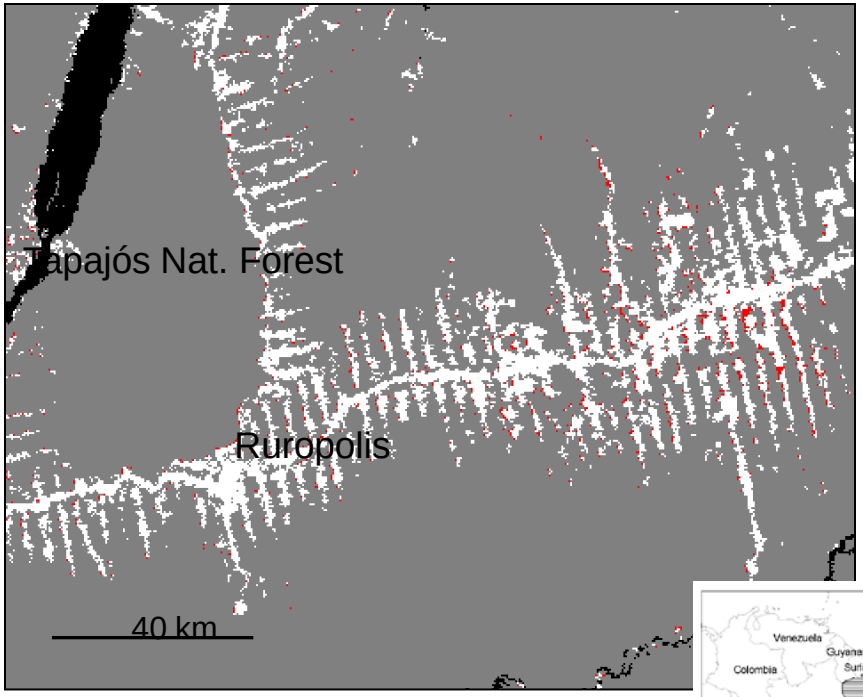
National parks: 12.3%

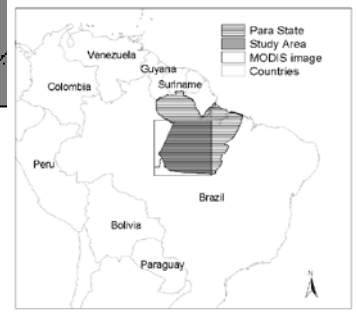
Ecological Mechanisms

Mechanism	Type
Change in effective size of reserve	Species Area Effect Minimum Dynamic Area Trophic Structure
Changes in ecological flows into and out of reserve	Disturbance initiation and runout zones Placement in watershed or airshed
Loss of crucial habitat outside of reserve	Ephemeral habitats Dispersal or migration habitats Population source sink habitats
Increased exposure to human activity at reserve edge	Poaching Displacement Exotics/disease

Hansen and DeFries (in prep)

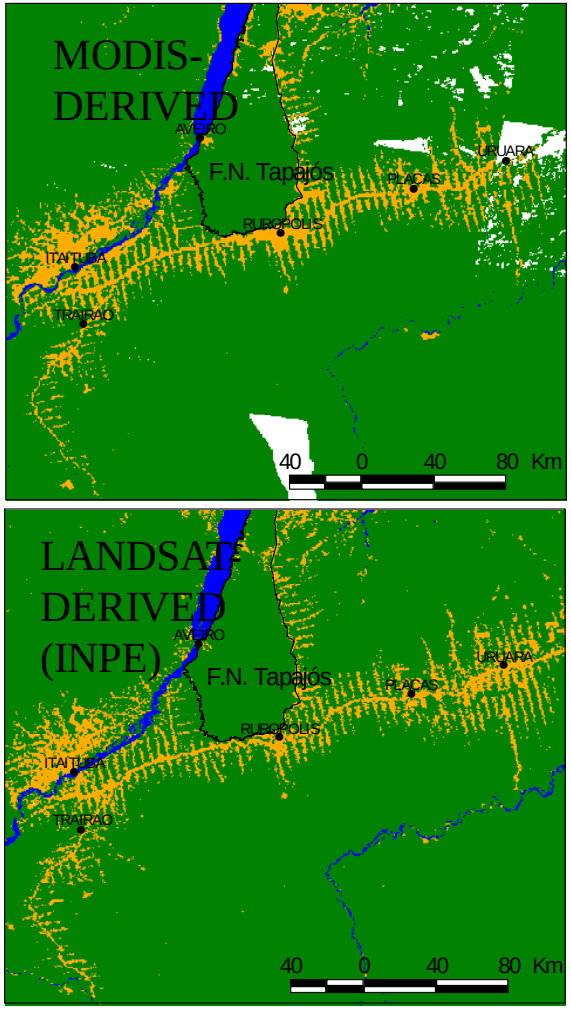
Is MODIS data effective at the regional scale to identify land cover and land cover change?





Forest MODIS
Water MODIS
Non-Forest MODIS
Non-Forest MODIS and Forest INPE

Misclassification of forest as non-forest (red) by MODIS land cover around Tapajós National Forest, Brazil.



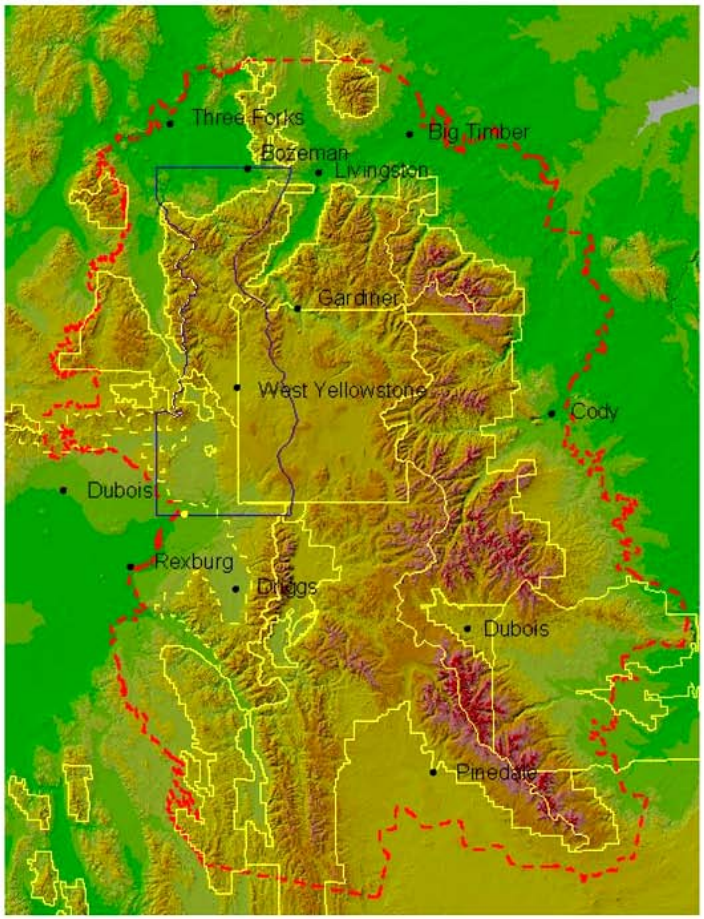
Water
Forest
MODIS - Non-forest / INPE - Deforestation
Clouds
• Cities

Is MODIS data effective at the regional scale to identify land cover and land cover change?

Yes.

- **MODIS is effective for monitoring land cover (except for small patches).**
- **MODIS also promising for phenology and fire.**
- **With ancillary data (human census, settlements, climate, etc), satellite-based monitoring can be highly effective.**

Regional Management

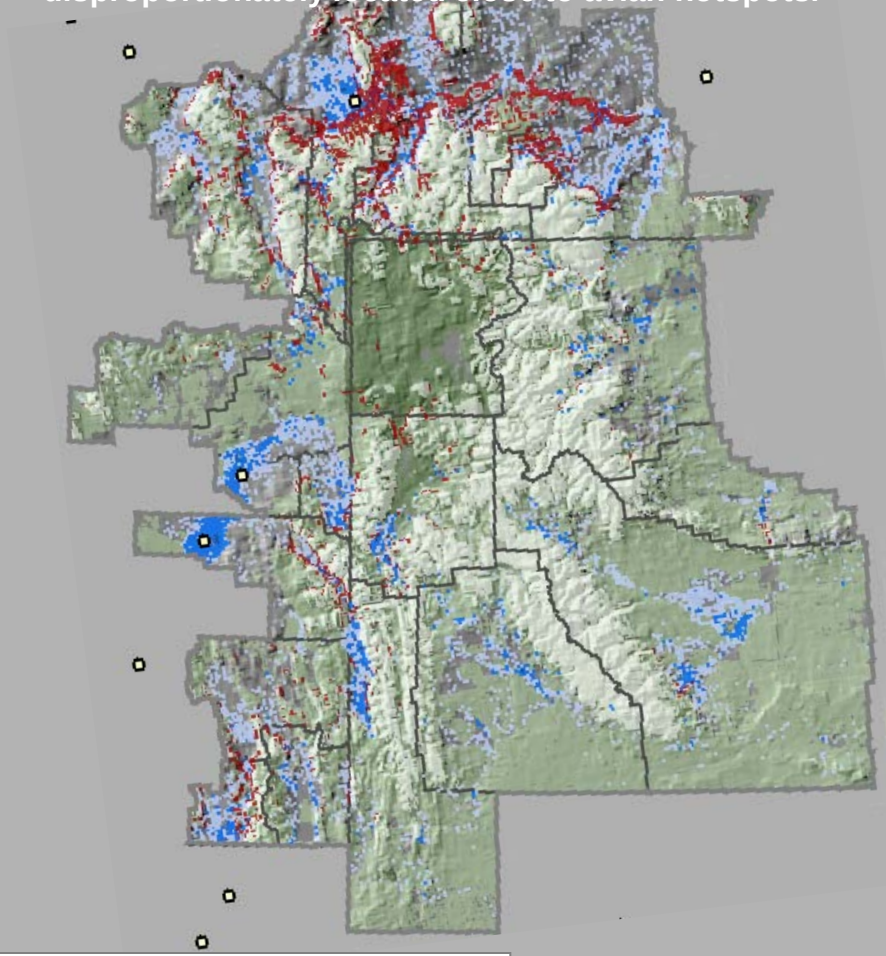


Criteria for Regional Management

Mechanism	Type	Design Criteria
Change in effective size of reserve	Species Area Effect Minimum Dynamic Area Trophic Structure	Maximize area of functional habitats
Changes in ecological flows into and out of reserve	Disturbance initiation and runout zones Placement in watershed or airshed	Identify and maintain ecological process zones
Loss of crucial habitat outside of reserve	Ephemeral habitats Dispersal or migration habitats Population source sink habitats	Maintain key migration and source habitats
Increased exposure to human activity at reserve edge	Poaching Displacement Exotics/disease	Manage human proximity and edge effects

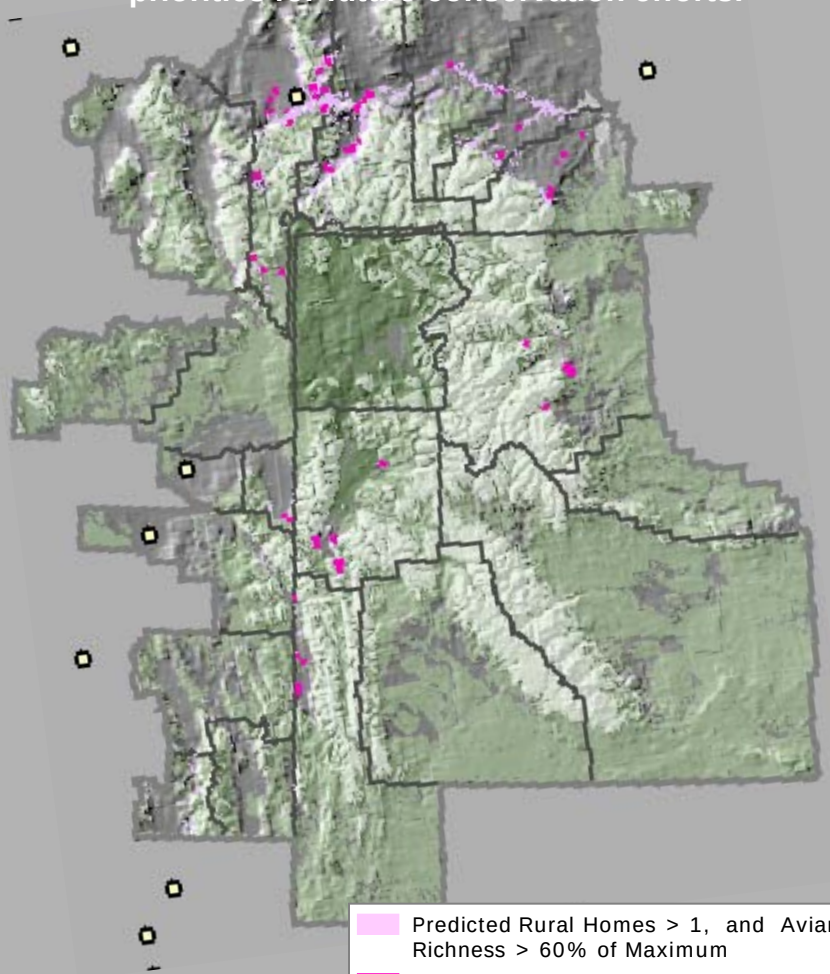
Criteria for Regional Management

Areas predicted to have high avian richness are also the same areas receiving the most pressure from human land use: rural homes were disproportionately located close to avian hotspots.



Current Home Density
Low ⟷ High
Avian richness > 60% of maximum
Greater Yellowstone Area boundary
County boundaries
Yellowstone National Park

Within areas of high avian biodiversity, those places that are currently undeveloped but have high future development potential should be considered high priorities for future conservation efforts.

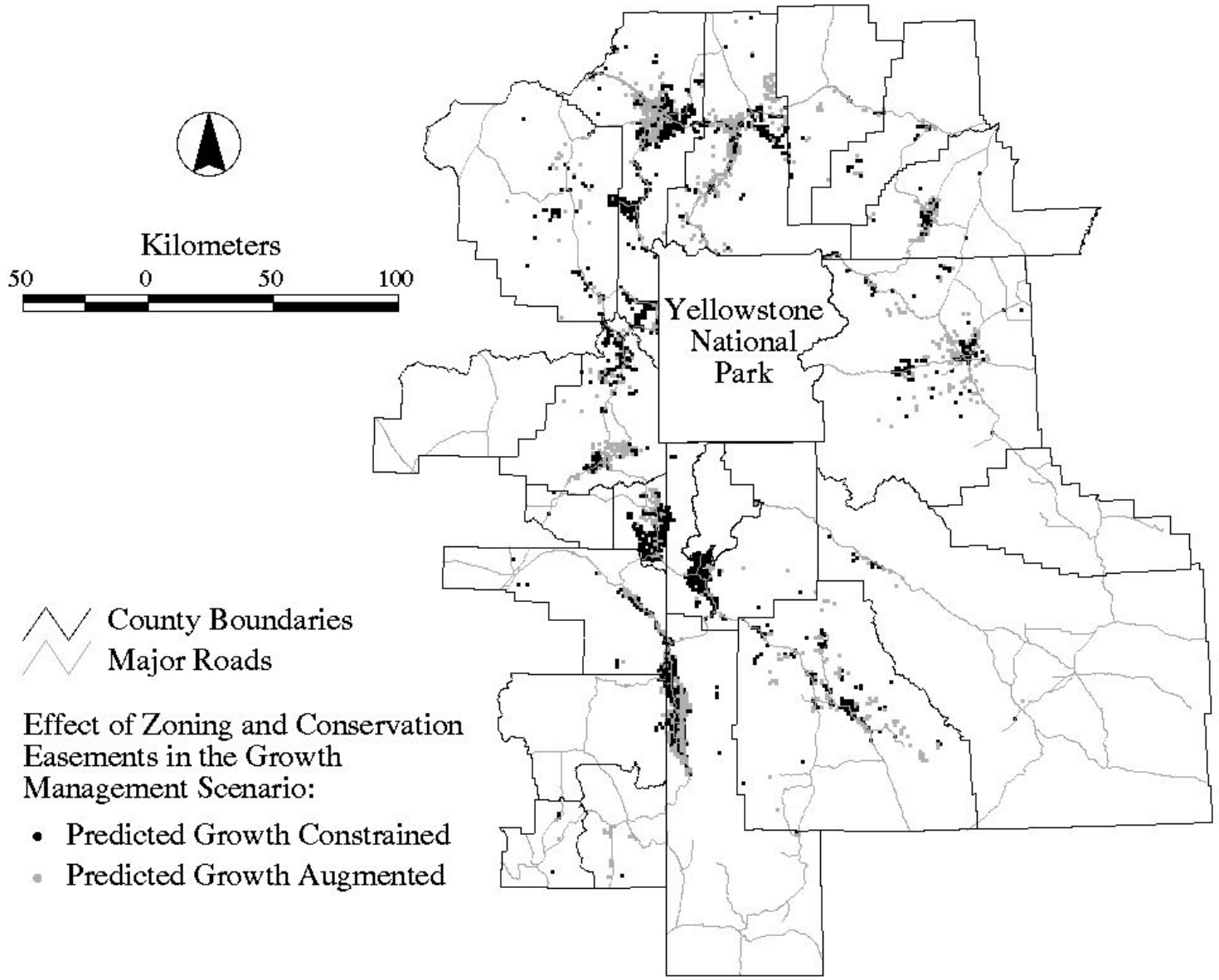


Predicted Rural Homes > 1, and Avian Richness > 60% of Maximum
Current Housing Density < Exurban, Predicted Housing Density > Exurban, and Avian Richness > 60% of Max.
Greater Yellowstone Area boundary
County boundaries
Yellowstone National Park

Conclusions

- Land use is intensifying around many of the world's nature reserves.
- Loss of habitat area around reserves is predicted to be associated with the extinction of 5-14% of the bird and mammal species in the three study regions.
- Several East African mammal species have declined substantially in and around a reserve near under land use intensification.
- Hotspots for biodiversity and intense human land use often overlap in the same small portion of the landscape.
- Knowledge of the ecological mechanisms linking land use and biodiversity provides a basis for regional management for sustainability.

Future Growth Scenario – Sustain Conservation Values



Land Use Types and Ecological Mechanisms

Type of land use change	Effective reserve size	Ecological Process zones/flows	Crucial Habitats	Edge Effects
Resource Extraction:				
Logging	x	x	x	
Mining		x	x	
Poaching				x
Food production:				
Subsistence farming				x
Small-scale farming	x	x	x	x
Large-scale commercial farming	x	x	x	x
Recreation:				
Tourism				x
Infrastructure:				
Roads/other transport			x	x
Dams		x	x	
Residential/commercial:				
Settlements				x
Urban/suburban			x	x