Modeling Heterogeneous Ecosystems with Large Herbivores (Session 3)

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Aim of Talk

- Provide an overview of a spatially explicit modeling approach to assessing ecosystems with mixed grass and woody vegetation, and large herbivores.

The Challenges of Modeling the Dynamics of Ecosystems with Large Herbivores

- Spatial heterogeneity of vegetation, animal movements
- Climatic variability (seasonal, annual), climatic change
- Predict vegetation and forage production and composition
  - Mixtures of plant functional types (eg. grasses, shrubs, trees)
- Predict animal production – per animal, numbers of animals
  - Responses to forage, climate, water, management
- Account for effects of herbivory on vegetation and soils

The SAVANNA Landscape Ecosystem Model

- First developed with support from NSF in the 1980's for research on a Kenyan pastoral ecosystem (Turkana)
- Applications to US National Parks
  - Yellowstone, Rocky Mountain, Bighorn Canyon/ Pryor Mountain Wild Horse Range
- Global Applications
  - Venezuela, Canada, Inner Mongolia, Australia, Morocco, Spain, Tanzania, Kenya, S. Africa

An Integrated Modeling Approach – Equal Attention to Animals, Plants, their Interactions

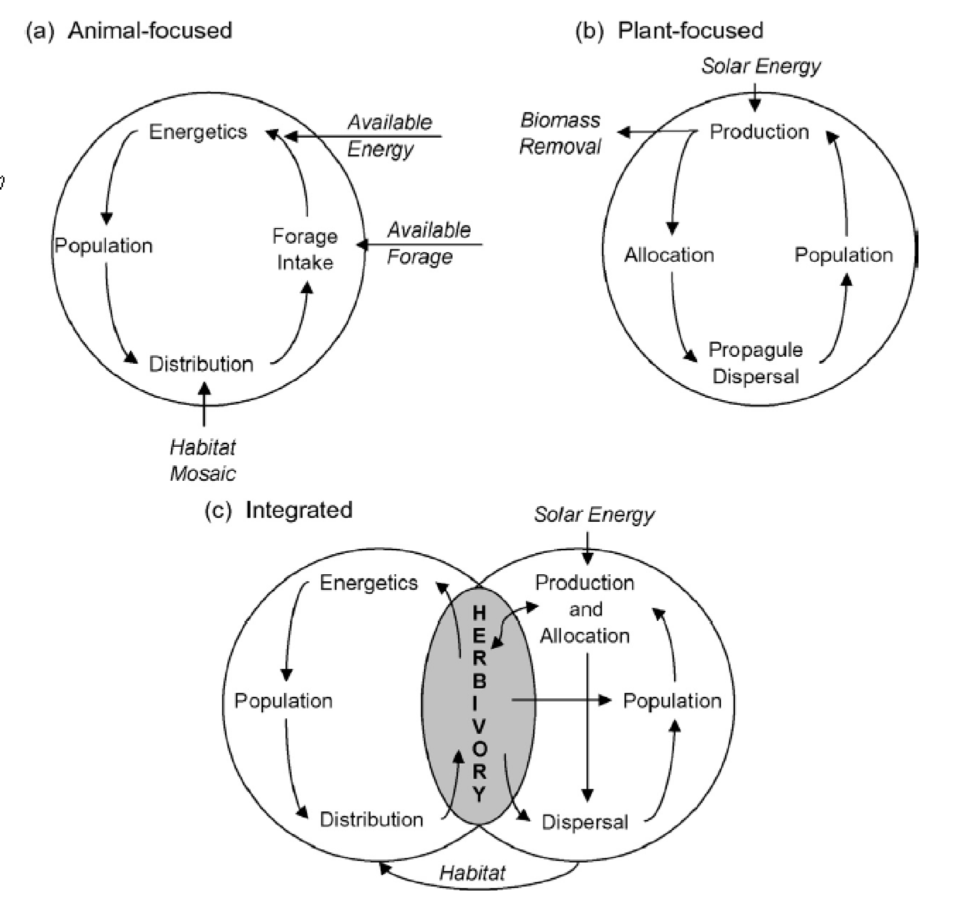
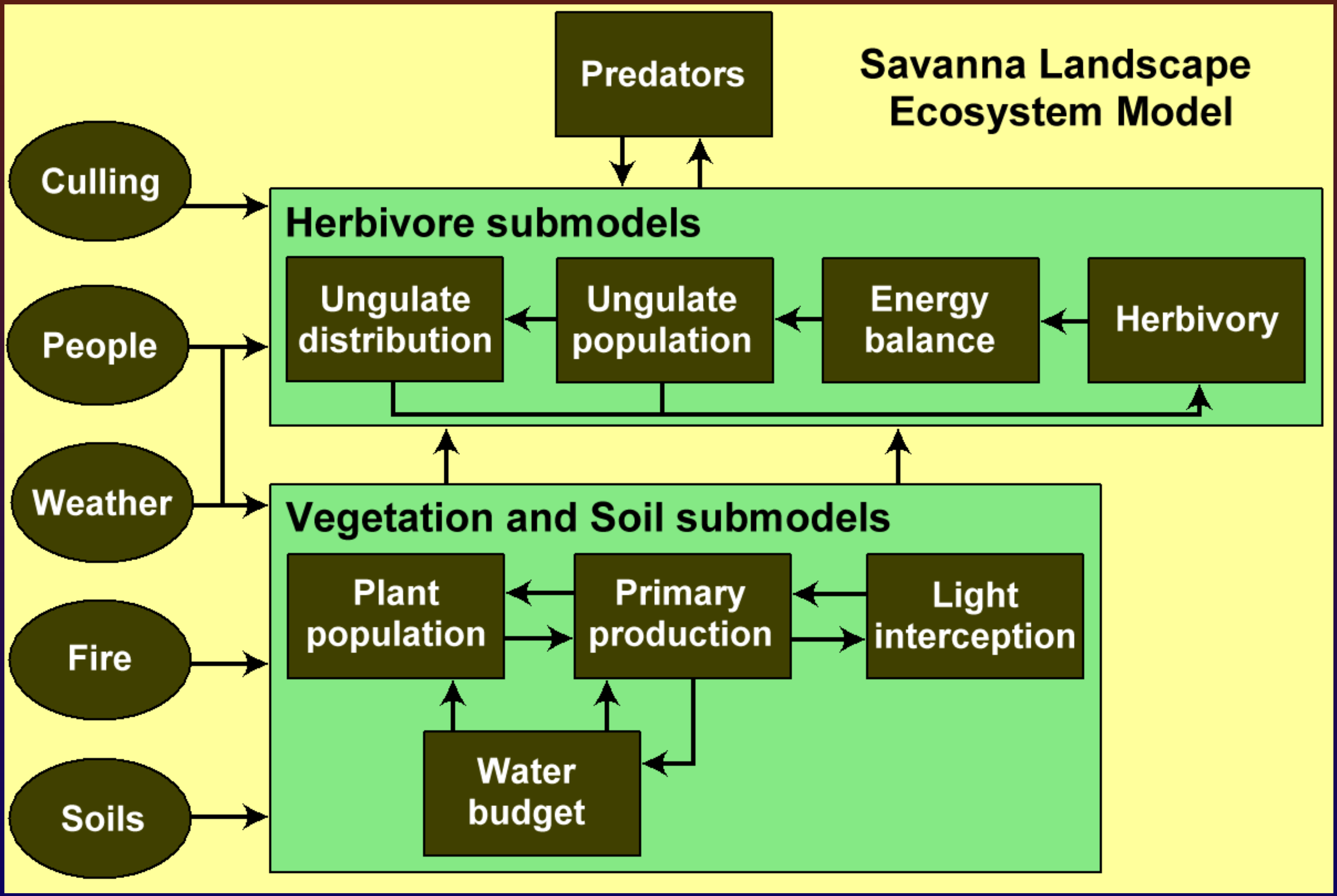


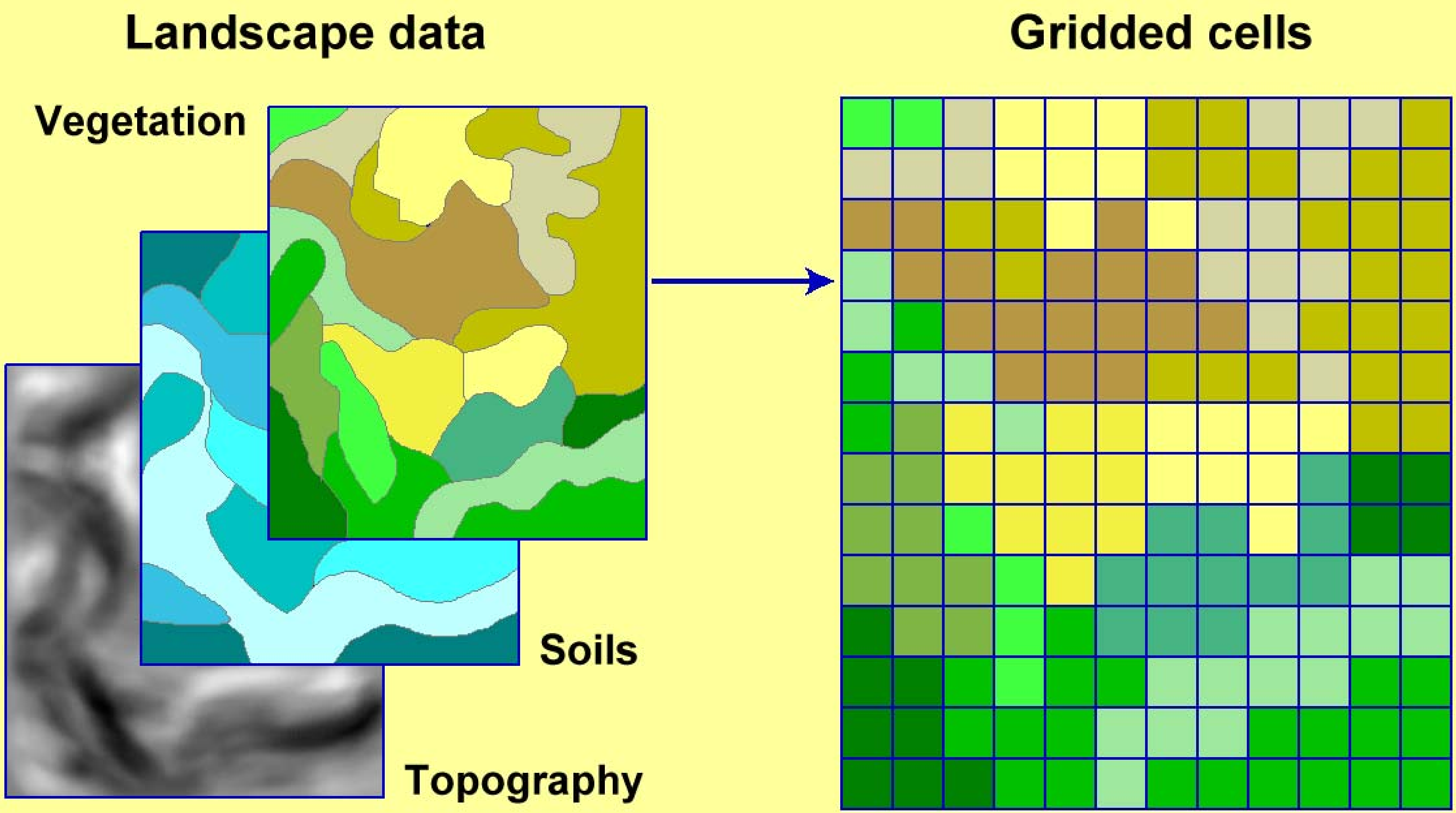
Figure 12.1. Three general approaches to modeling interactions among large herbivores and vegetation: (a) animal-focused, plant-focused, and (c) integrated.


Savanna Landscape Ecosystem Model
Predators
Culling
People
Weather
Fire
Soils
Herbivore submodels
Ungulate distribution
Ungulate population
Energy balance
Herbivory
Vegetation and Soil submodels
Plant population
Primary production
Light interception
Water budget

Spatial Heterogeneity?

- GIS inputs of topography, vegetation and soils, coupled with ecophysiological properties data
- Climatic variation in space – precipitation maps, temperature maps are created each month using elevation corrected spatial interpolation
- Animal redistributions in response to forage, other factors
- Water redistributions and effects on plant growth

Savanna - A Spatial Ecosystem Model



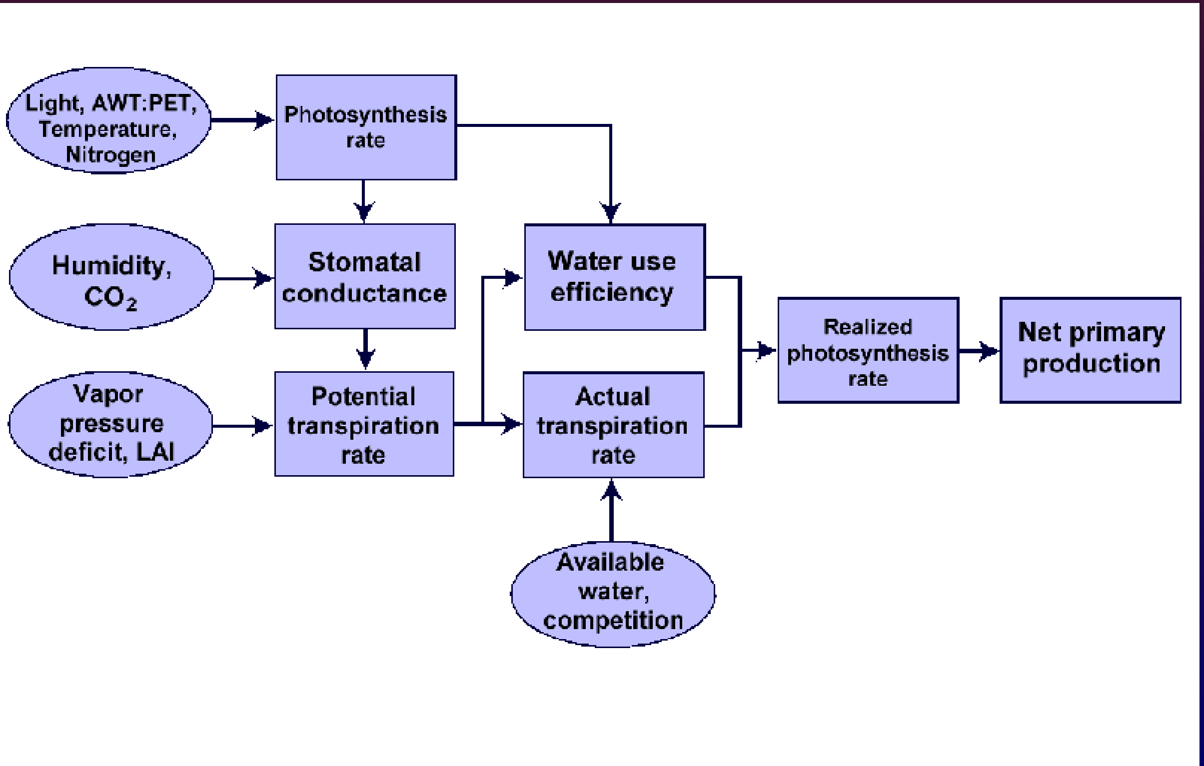
Climatic Variability?

- Plants respond to water, temperature, radiation
- Rainfall and temperature data inputs for multiple weather stations in study area
- Humidity, wind speed from main weather station
- Cloud cover, from humidity and precipitation
- Solar radiation, from sun angle, cloud cover

Vegetation Production and Composition?

Net Primary Production (NPP) Submodel

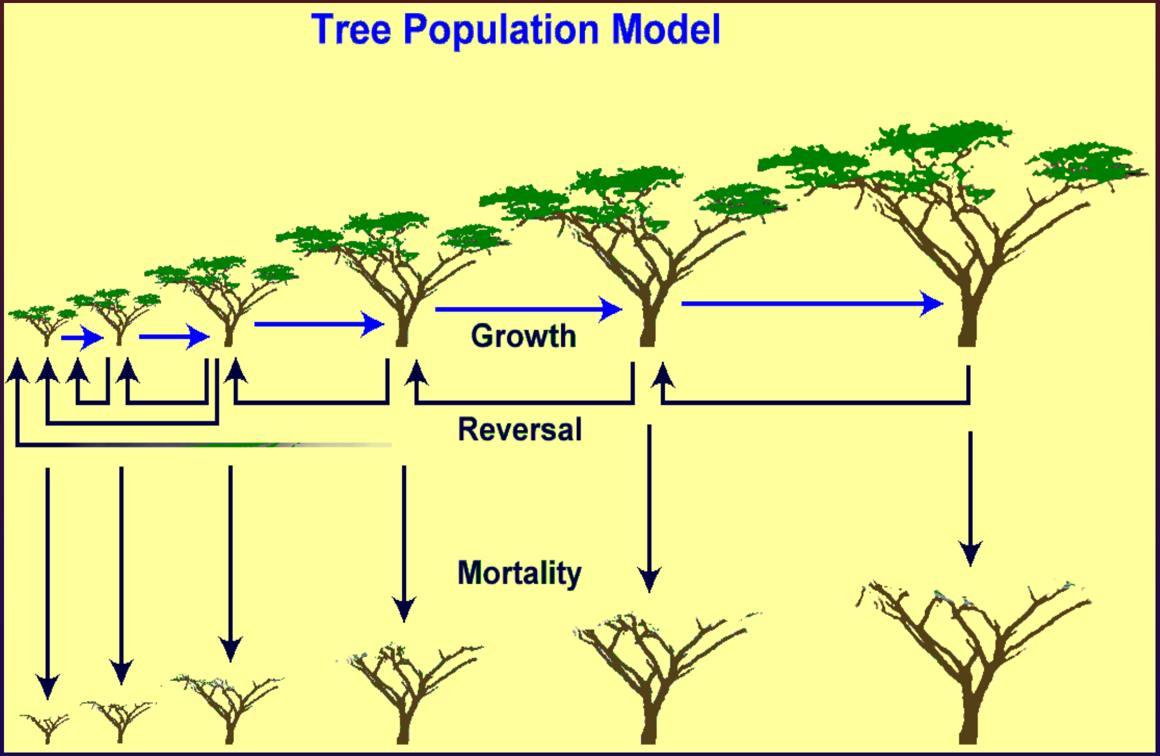
- Linkage between photosynthesis and transpiration
- Respiration – function of plant N, temperature, available CHO
- Labile carbon reserves modeled and required for regrowth
- Live and dead biomass dynamics



Decomposition and Nitrogen Recycling
(Based on the CENTURY Model)

- Soil fertility is central to long-term sustainability
- Soil organic matter (SOM) formation and breakdown, three SOM pools with different turnover rates
- Nitrogen immobilization and mineralization during decomposition – source of plant available nitrogen
- Climatic effects are represented

Woody Plant Dynamics –
Canopy Cover, Numbers, Sizes



Plant numbers – from the population model

Plant size – from the plant growth model

Cover – Outcome of numbers and size

Plant and Soil Responses to Herbivory?

- Negative and positive effects
  - Possibly an optimum level of grazing
- Loss of leaf area
  - Affects photosynthesis and transpiration
- Soil water conservation due to reduced LAI
- Enhanced nutrient recycling is possible
- Deplection of soil nutrients and C with excessive grazing

Animal Production?

- Forage intake - rate, diet selection
- Nutritional balance - responsive to forage intake, energy expenditure
- Population dynamics - based upon age/sex fecundity and survivorship, which are affected by nutritional condition.

Herbivore Forage Intake

- Increases with forage biomass up to a maximum rate (the functional response)
- Maximum intake rate expressed as kg/kg/d, based upon the Kleiber body size scaling relation (3/4 power law)
- Also affected by:
  - Forage quality, snow cover (where appropriate)
  - Forage height, animal reach height

Herbivore Diet Selection

Preference index approach:

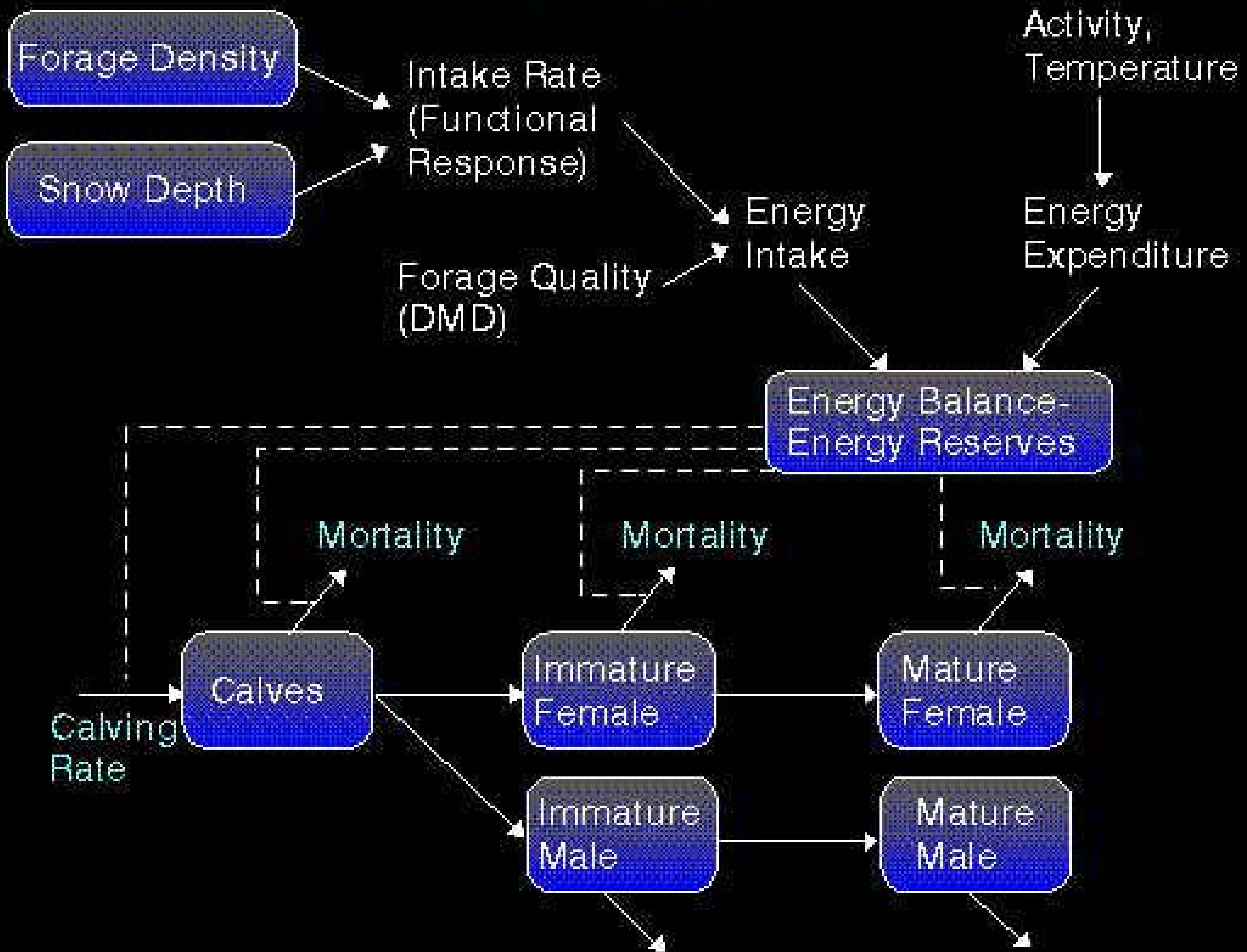
1) $Preference_i$ = Preference $Weight_i$ x $Biomass_i$

2) Sum preferences across species

3) Final $Preference_i$ = $Preference_i$ / Sum

Preference Weights are by tissue types as well as species.

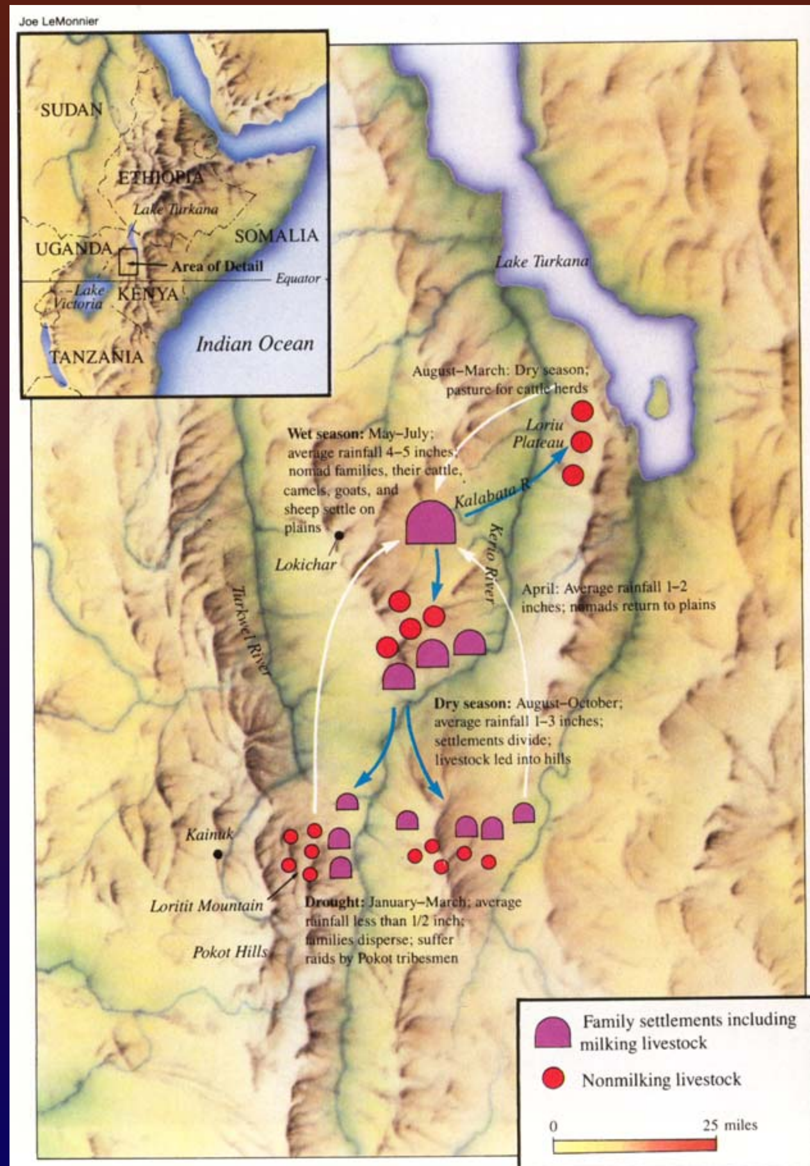
Ungulate Energy Balance - Population Model Linkage



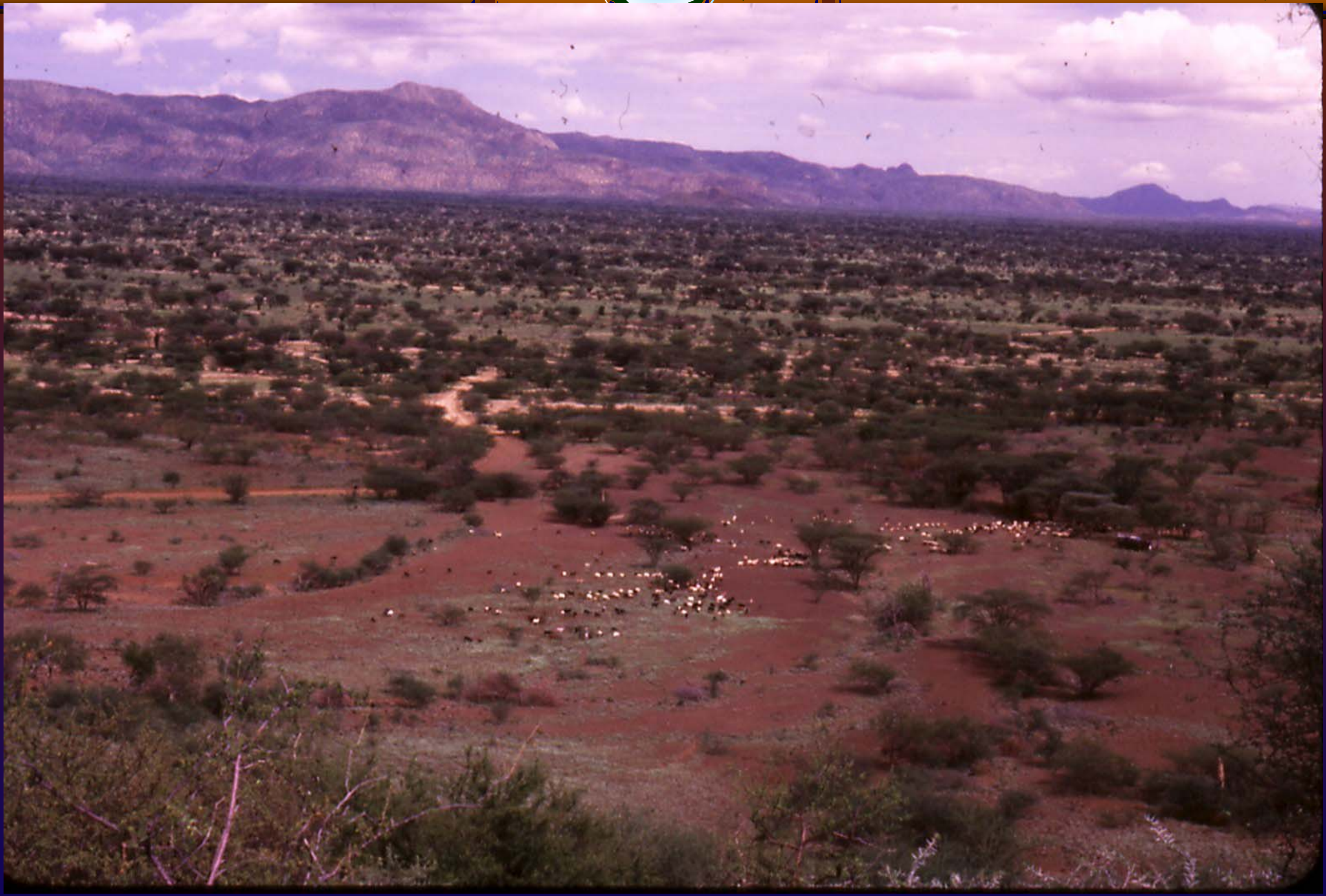
Herbivore Population/Herd Dynamics

- Age-sex classes (e.g. Leslie Matrix)
- Age and sex specific birth rates and mortality rates, but variable
- Simulated body condition affects recruitment and mortality rates

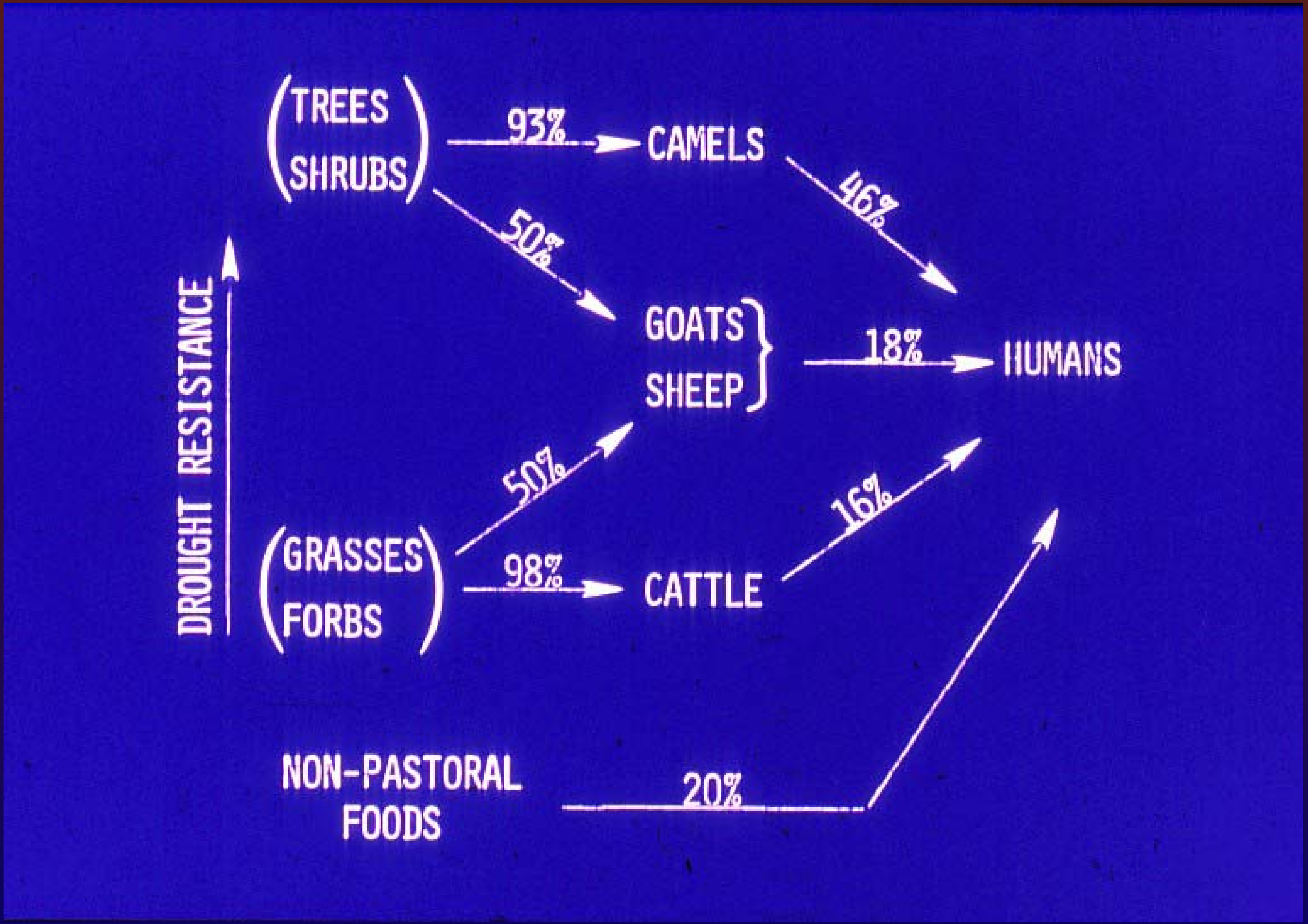
The South Turkana Ecosystem Project (STEP)



Joe LeMonnier
SUDAN
ETHIOPIA
Lake Turkana
SOMALIA
UGANDA
Area of Detail
Equator
Lake Victoria
KENYA
TANZANIA
Indian Ocean
Lake Turkana
August–March: Dry season; pasture for cattle herds
Loriu Plateau
Wet season: May–July; average rainfall 4–5 inches; nomad families, their cattle, camels, goats, and sheep settle on plains
Kalabata R.
Kerio River
Lokichar
April: Average rainfall 1–2 inches; nomads return to plains
Turkwel River
Dry season: August–October; average rainfall 1–3 inches; settlements divide; livestock led into hills
Kainuk
Loritit Mountain
Drought: January–March; average rainfall less than 1/2 inch; families disperse; suffer raids by Pokot tribesmen
Pokot Hills
Family settlements including milking livestock
Nonmilking livestock
0
25 miles



Energy Flows from Mixed Vegetation to Livestock and Humans



SAVANNA Modeling on the STEP

Showed how landscape structure and function affect ecosystem dynamics

- The landscape is a structurally diverse environment comprised of different vegetation life-forms varying in their phenological and drought response patterns.
- This forms the basis of a multifunctional set of trophic pathways which extend through 5 species of livestock to humans.
- Combined, these pathways yield low production efficiency and high maintenance costs, but stable flows of energy to humans.

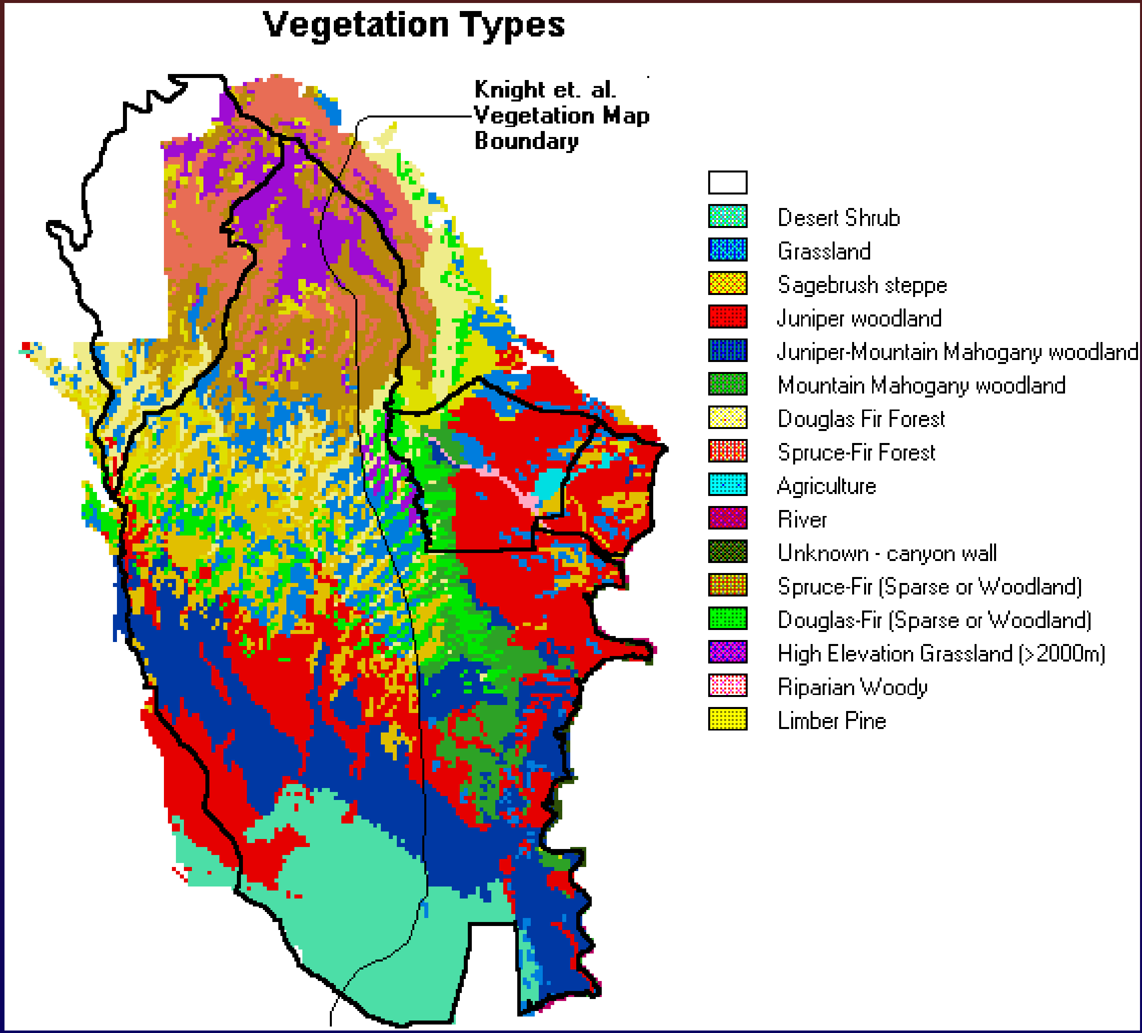
SAVANNA Modeling on the STEP

- Provided a formalized representation of the importance of spatial heterogeneity for ecosystem dynamics
- Showed the importance of movement in spatially and temporally variable environments
  - Pastoralists move in response to variable, often unpredictable resource availability on the landscape – as a result, spatial heterogeneity buffers temporal variability

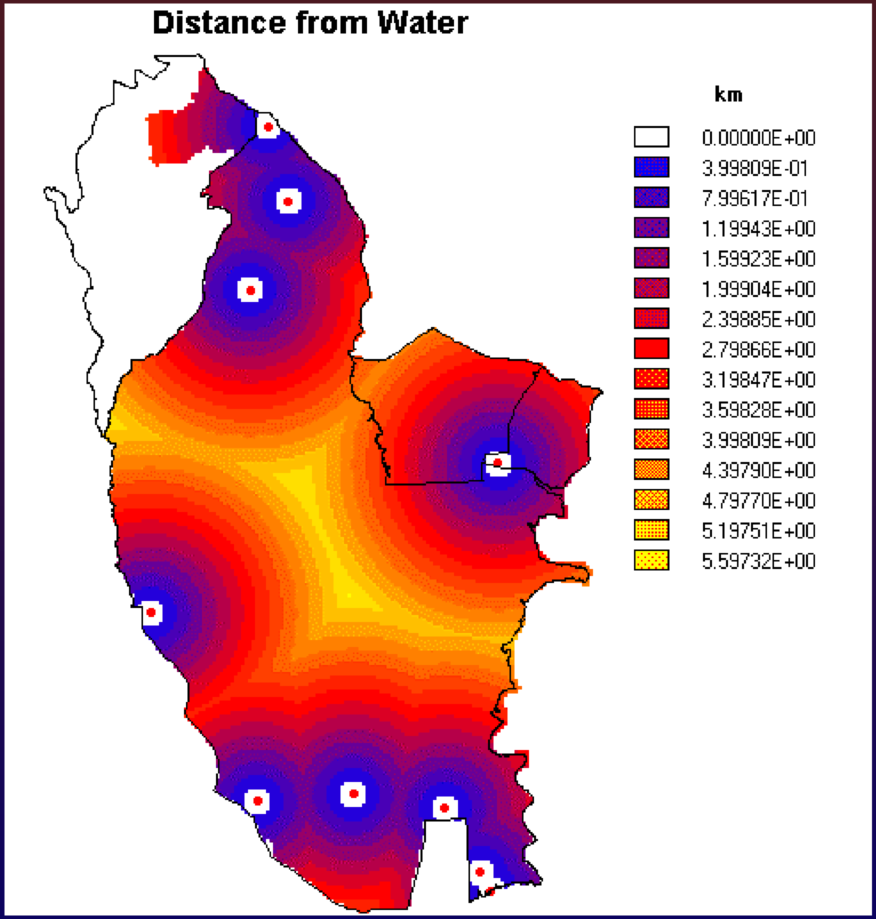
Example Application – Ecosystem Modeling of the Pryor Mountain Wild Horse Range

- Objective - assess effects of different numbers of horses on ecosystem structure and function.

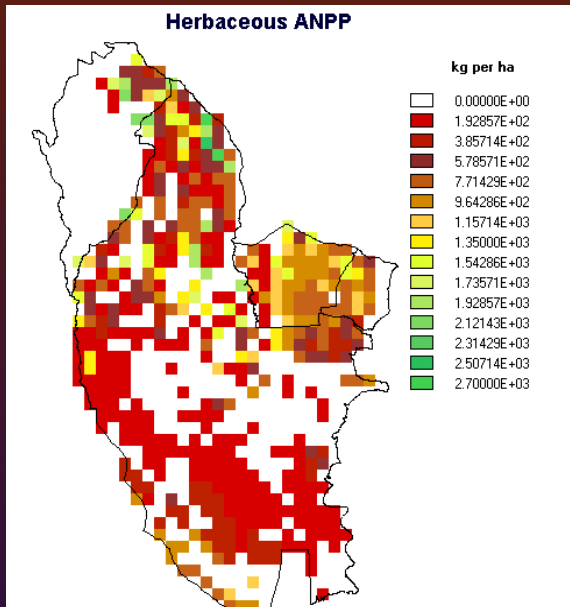
A Heterogeneous Landscape

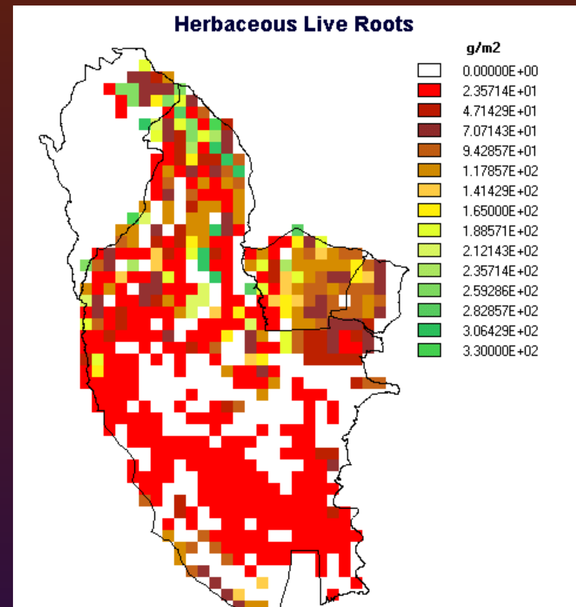


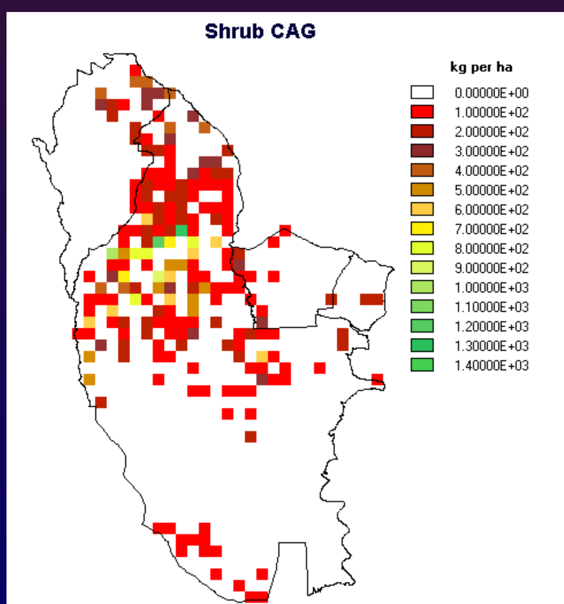
Effects on Herbivore Distribution -Distance from Water

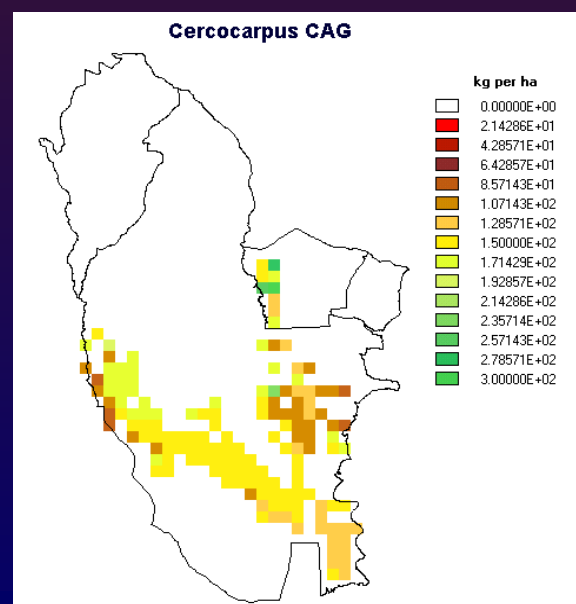


Distribution of forage production.

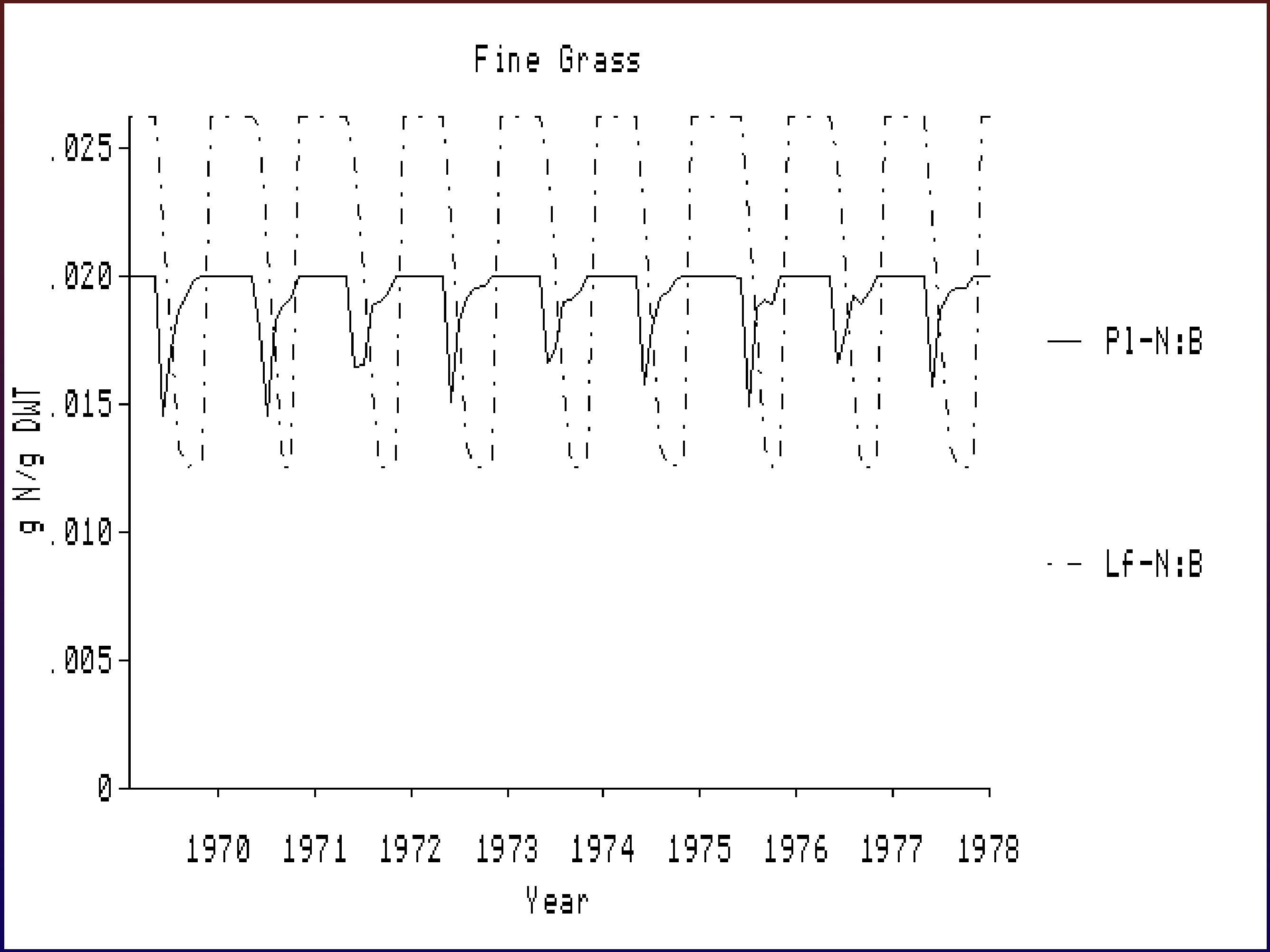




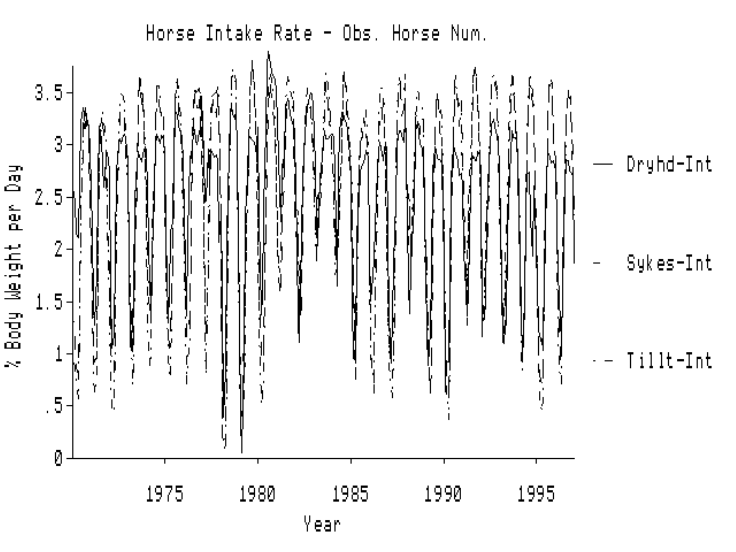


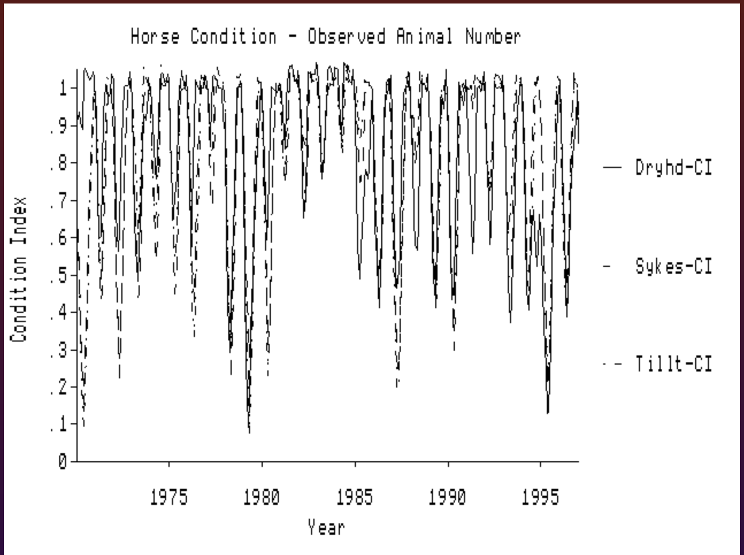


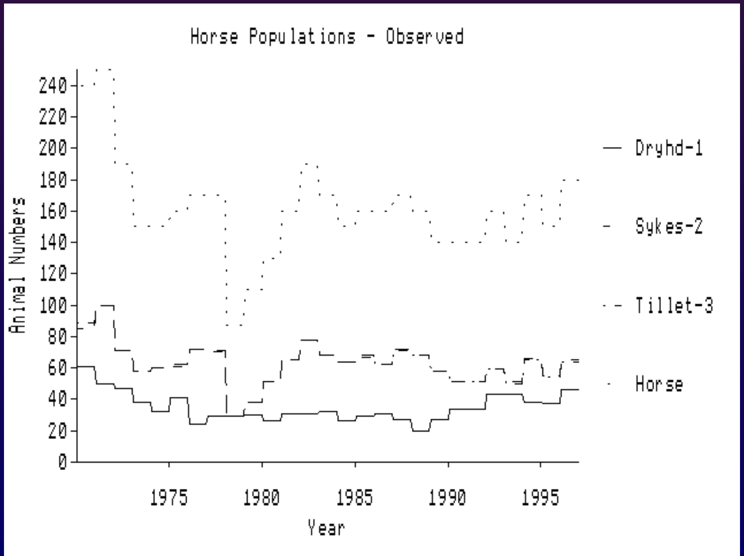
Seasonal Variations in Forage Quality

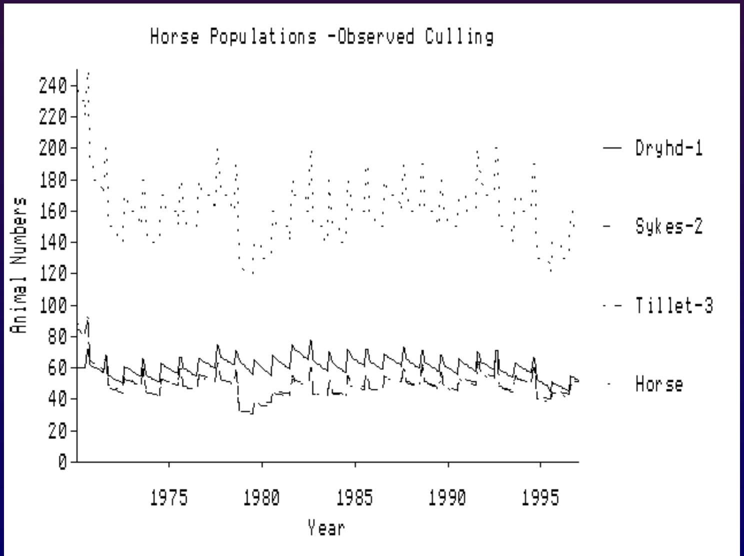


Example simulation output - horse intake, condition, and population size

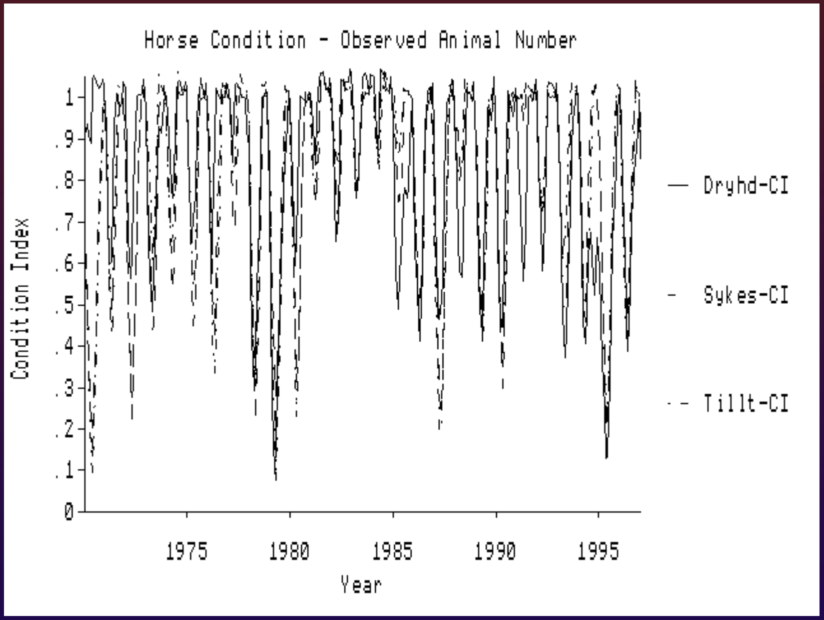


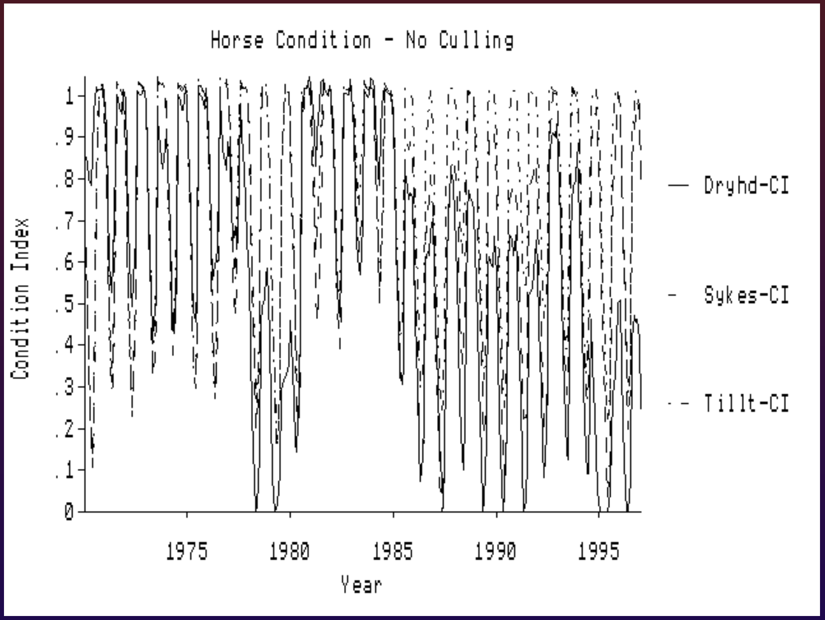






Without culling - horse condition declines to very low levels.



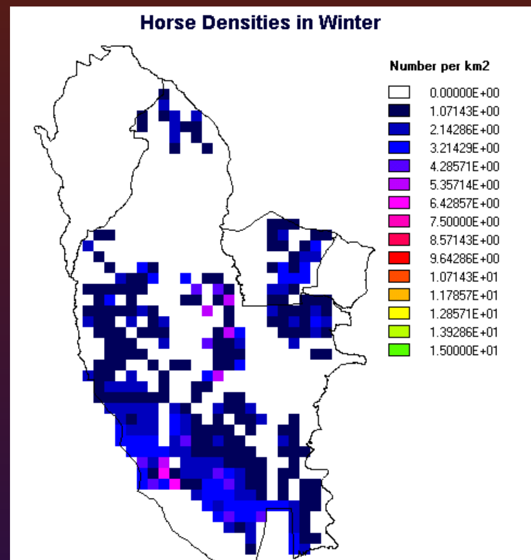


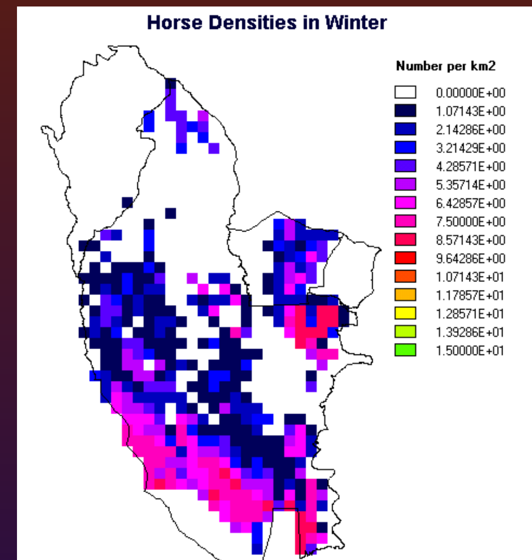
Horse densities

Observed number

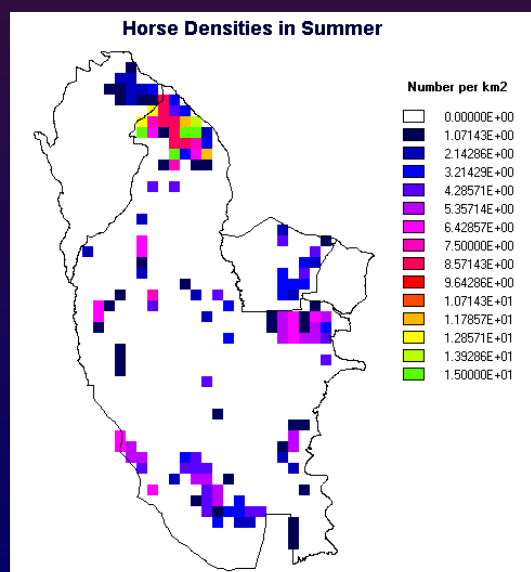
No culling

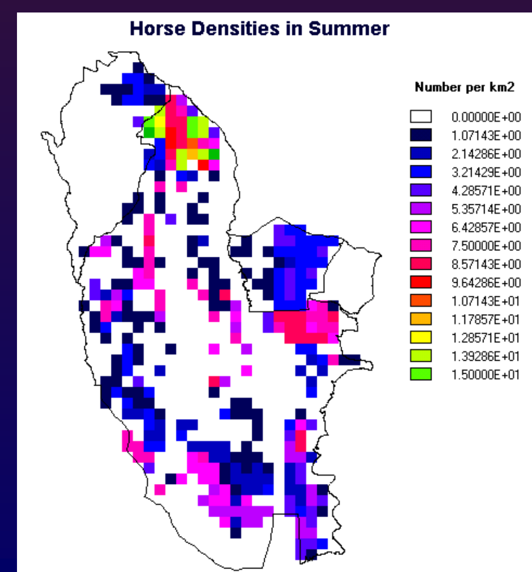
Winter





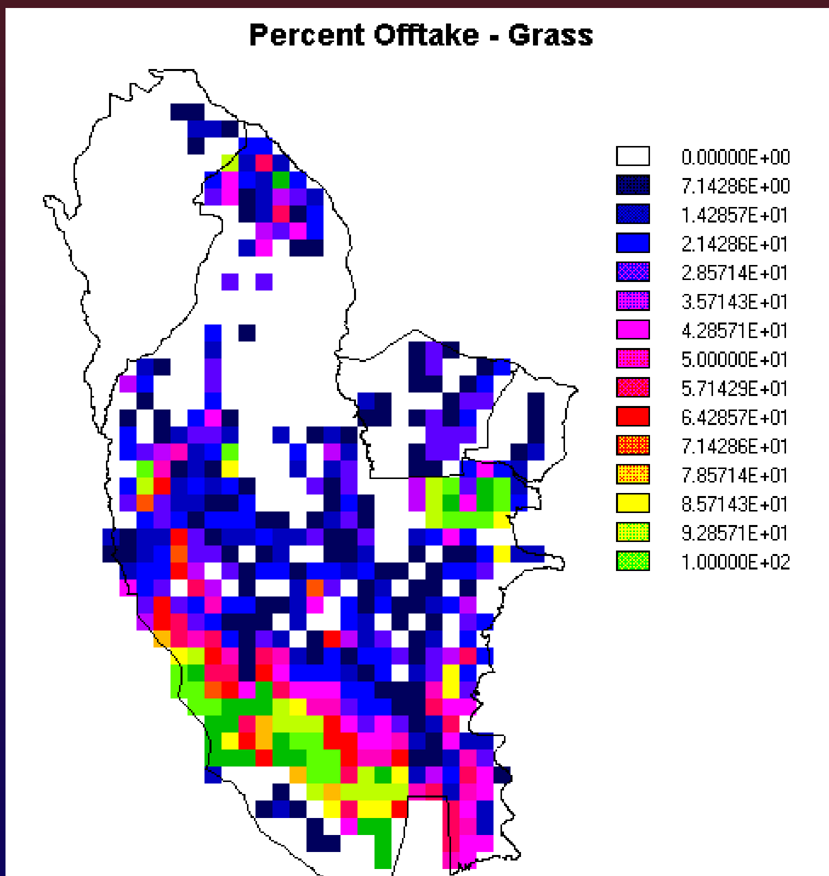
Summer



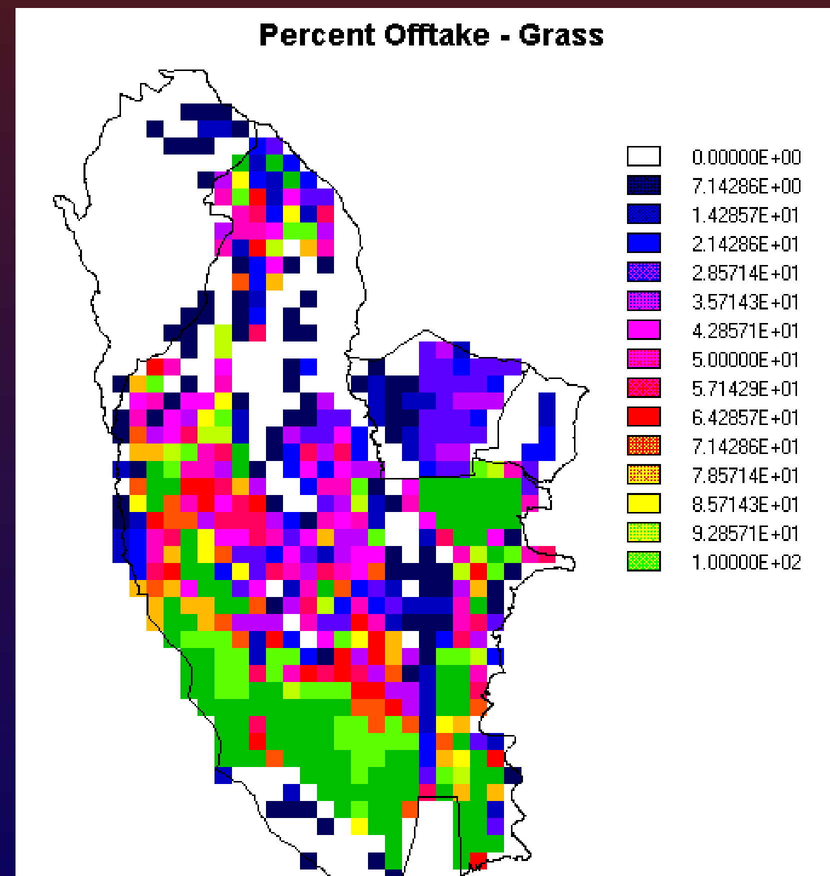


Distribution of horse grazing pressure - non-uniform.

Observed horse number

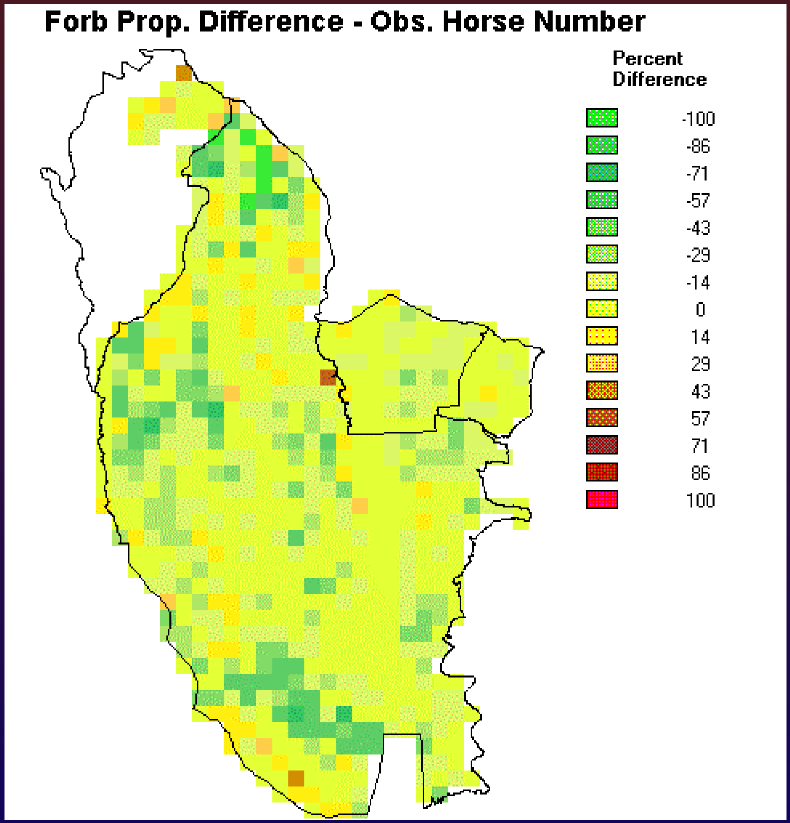


No culling

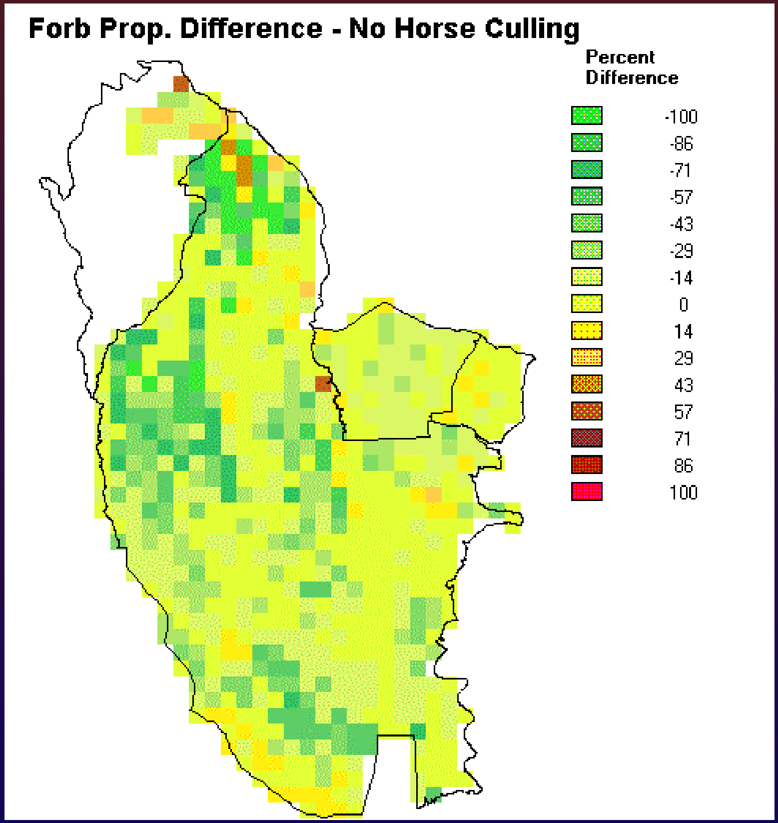


Impacts on plants are spatially heterogeneous. These are changes compared to no horses.

Observed horse number



No culling



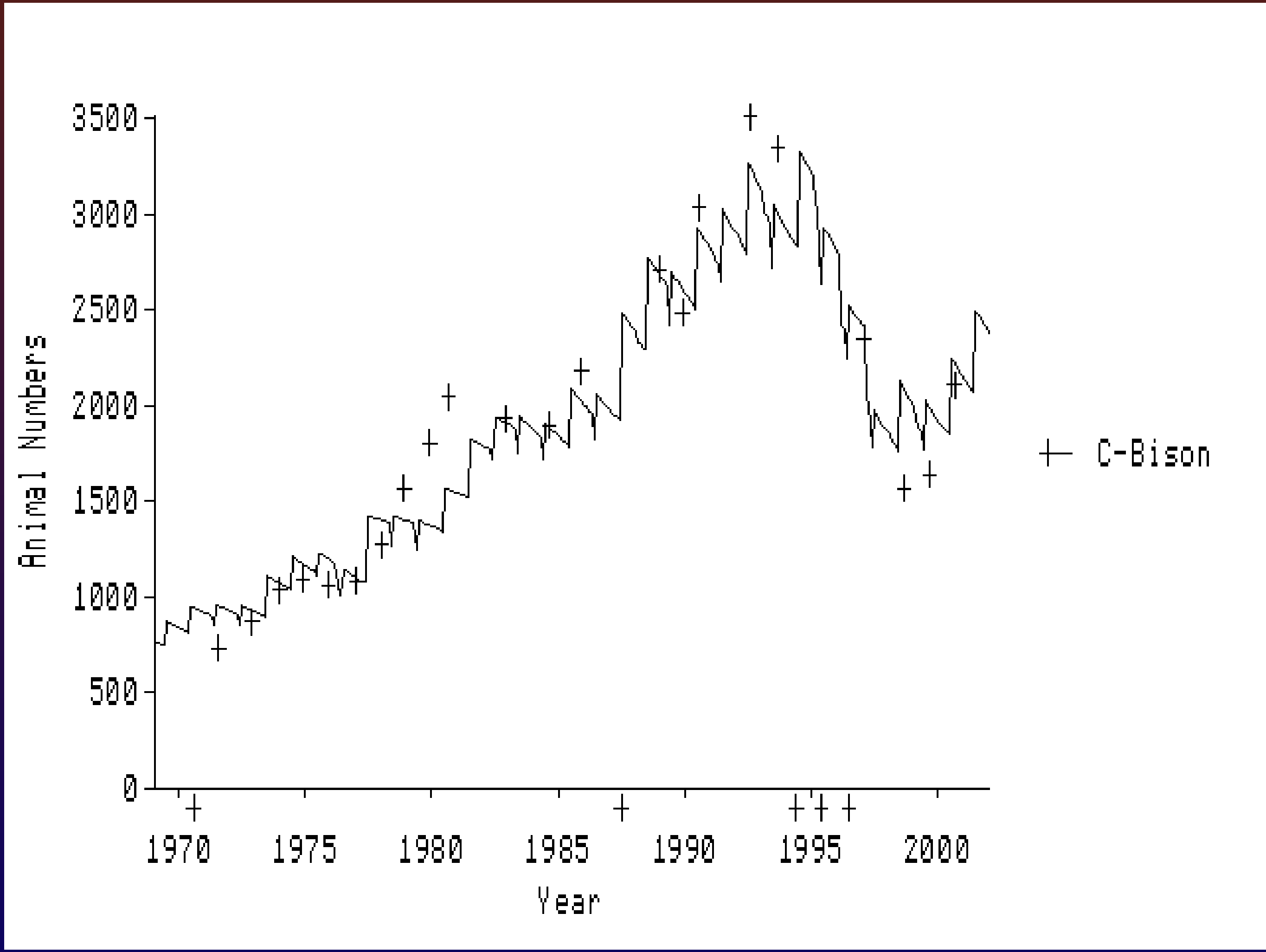
The Ecosystem Modeling Approach in National Parks

- What is "carrying capacity" due to "natural processes"?
- Approach
  - Apply a value-neutral ecosystem model to simulate historic and current scenarios of vegetation and herbivore management.
  - Use the model to estimate herbivory effects on vegetation and soils, and herbivore population responses to alternative management policies, including "natural regulation".
- Importantly – this requires fundamental understanding of ecosystem processes and dynamics

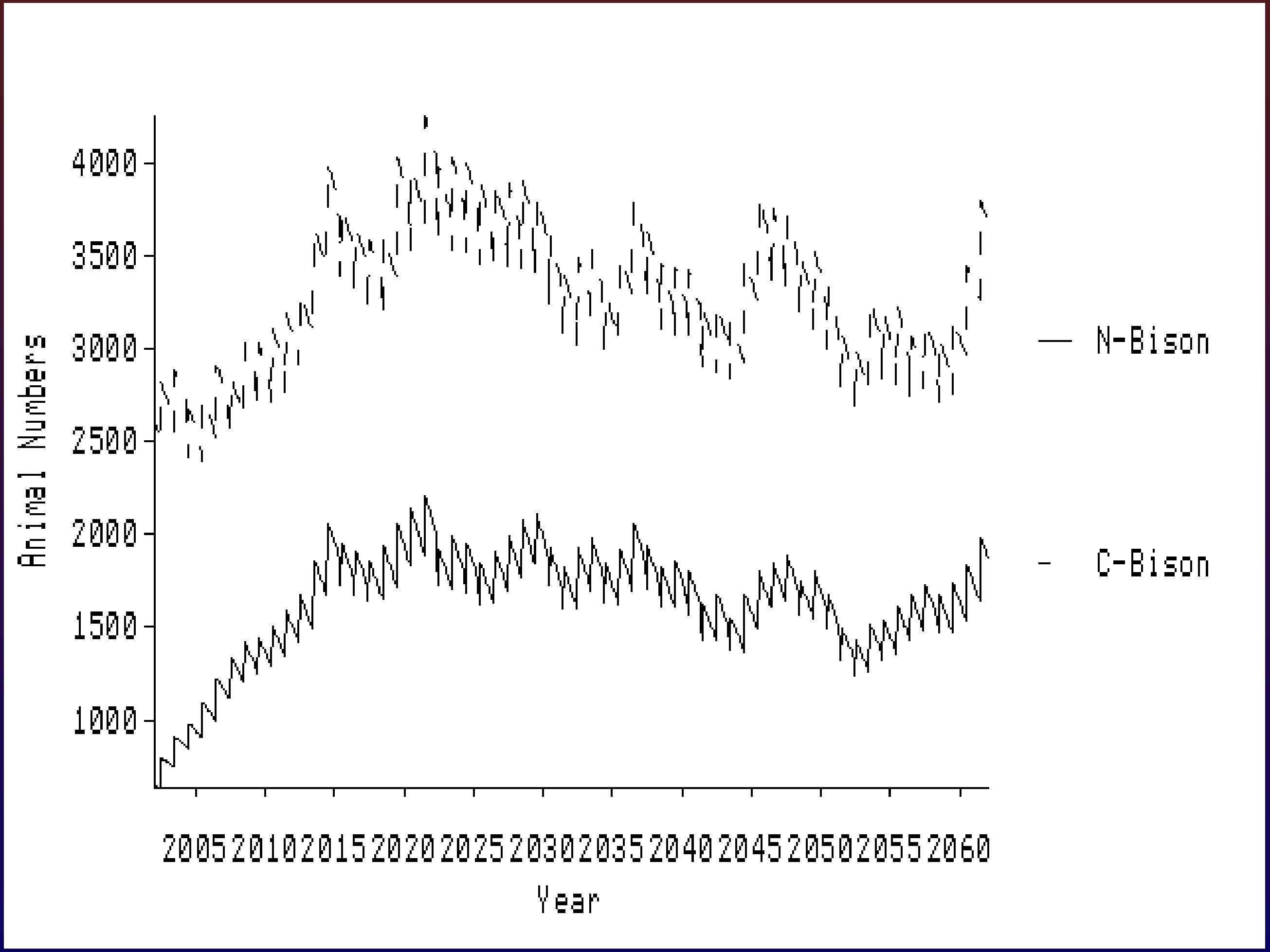
Yellowstone National Park

- Elk
  - What is “carrying capacity”?
  - Forage-limited or predator limited?
  - Is the winter range large enough?
  - What is the effect of hunting on elk and therefore plants and soils?
- Bison
  - What is “carrying capacity”?
  - How many bison can be expected to cross the boundaries and why?
  - Effects of removal/no removal on plants and soils?

Simulated and Observed – Central Bison Herd



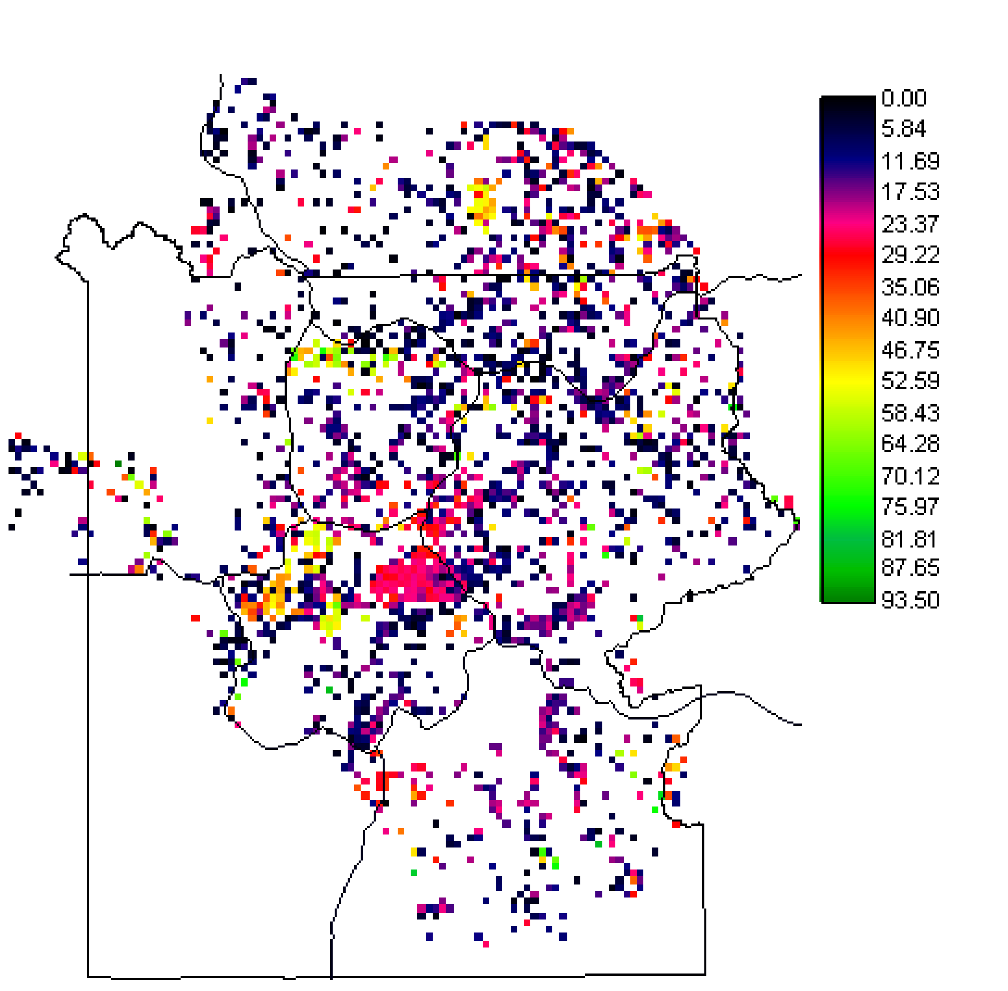
Bison Numbers with no Removals and Successful Hazing of All Animals Back into the Park for 50 Years



Percent Decreases in Herbaceous Root Biomass

-After 50 years of elk and bison at food-limited K

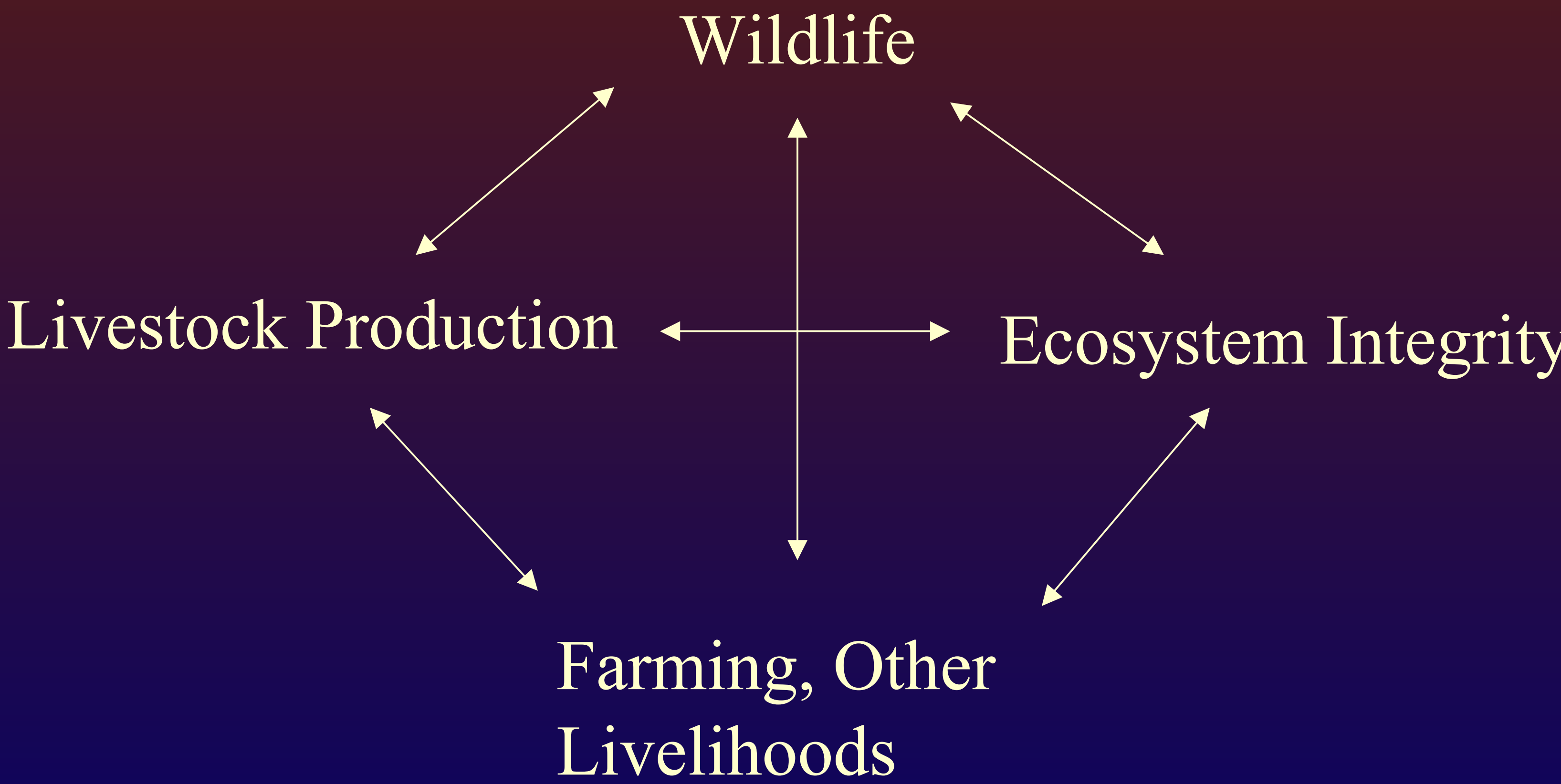
-Only areas with decreases are shown



Integrated Modeling and Assessment Systems for Balancing Food Security and Wildlife in East Africa

Funding Provided by the Global Livestock Collaborative Research Support Program of USAID

Assessing Ecosystem Interactions – Trade-Offs or Complementarities



Project Objectives

- Provide the information and understanding necessary to conserve biodiversity, wildlife, and ecosystem integrity while increasing pastoral food security.
- Quantify the impacts of livestock and wildlife on four objective functions: *livestock production, human well-being, wildlife, and ecosystem integrity*.
- Enable alternative policy and management strategies to be objectively explored, debated, implemented, and reassessed.

In Summary

How might this approach be useful for ensuring the sustainability of mixed grass-woody ecosystems that are used for livestock production?

Considerations for Assessing Grazing-Browsing Ecosystems

- Sustainability depends upon long term plant and soil responses
- Total forage is an overly simplistic basis. Quantity and quality vary seasonally as well as among species.
- Landscapes are heterogeneous, use is heterogeneous
- Carrying capacity varies - in response to precipitation and other factors
- Sustainability may involve interactions with wildlife
- Livestock production and herd dynamics are linked to ecosystem dynamics

Considerations for Carrying Out Integrated Assessments of Livestock Ecosystems

- Linkages between livestock and ecosystem dynamics
- Herbivory effects on vegetation, soils, water
- Interactions among species – livestock, wildlife
- Implications for people

Modeling for Ecological Forecasting

- Provide explicit, quantitative, justifiable basis for setting sustainable stocking rates, forage allocations
- Predict responses to climatic change
- Assess the likelihood of potential risks, to vegetation, livestock, biodiversity, humans