2005 PREISM workshop – Washington, D.C.

Comparing Modeling Approaches for Invasive Species Management

Grant: Integrating Economics and Biology for Bioeconomic Risk Assessment / Management of Invasive Species in Agriculture

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Some Current Problems on Rangeland

- Perennials vs. Annuals
  - Buffalo Grass and Blue Grama
  - Cheat grass and Wheatgrass
- Grasses vs. Invasive Aliens
  - Leafy Spurge, Canada Thistle and Yellow Star Thistle
  - BLM estimates 14% growth rate
  - 140 million acres will be infested by 2010

What does leafy spurge look like?

Leasing Arrangements

- Lease Price Based on Total Potential Forage
- No Consideration of Species Composition

Previous Work

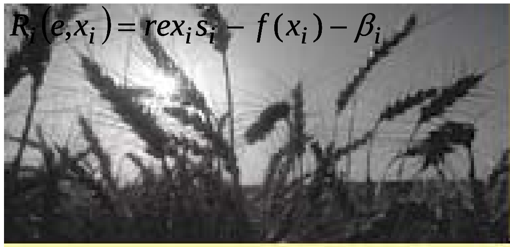
- Huffaker and Cooper, 1995
  - Social Optimum, dynamic, weed and grass only
- May et al., 2002
  - Role of lease length on productivity
- Tschirhart, 2000, 2002
  - GEEM, fish and plants
- Finnoff and Tschirhart, 2005
  - Physiological traits

Approach to the Problem

- Ecosystem Model
  - General Equilibrium Ecosystem Model
- Overlay Economy
  - Dynamically optimizing ranchers with differential lease lengths
- Overlay space
  - Interacting Agents

Ecosystem Model

- Begin with individuals rather than population level dynamics
- Each representative agent acts as if maximizing fitness net energy
- Within a trophic layer, species compete competitively with energy “prices” determined across trophic layers



Plants' Problem

- Plant objective function

$$R_i(x_i \mid SEL) = r(1 - SEL)x_i s_i - f(x_i) - \beta_i$$

- Two limiting resources, space and nitrogen

$$f_i(x_i, N) = \alpha_i x_i^2 \left((N - N_i)^2 + 1 \right)$$

- Determination of SEL

$$\sum_i n_i a_i x_i \le A \ \perp \ SEL \ge 0$$

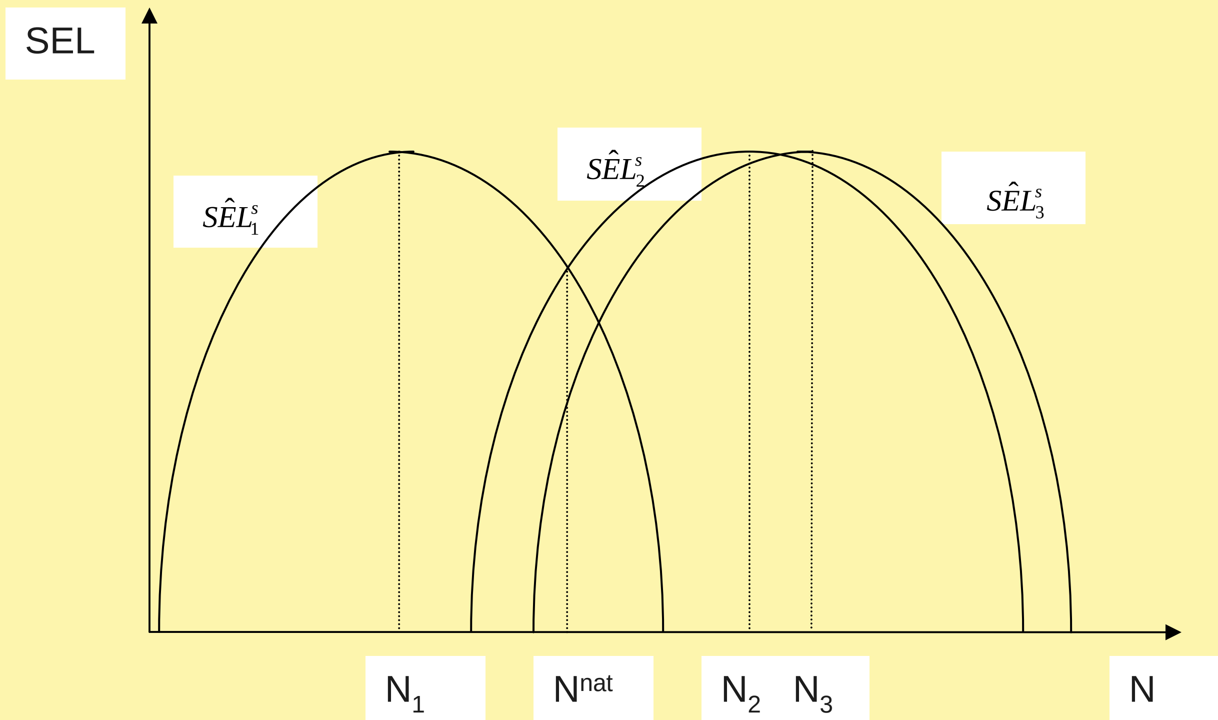
Plant Population Update

- Updating Equation

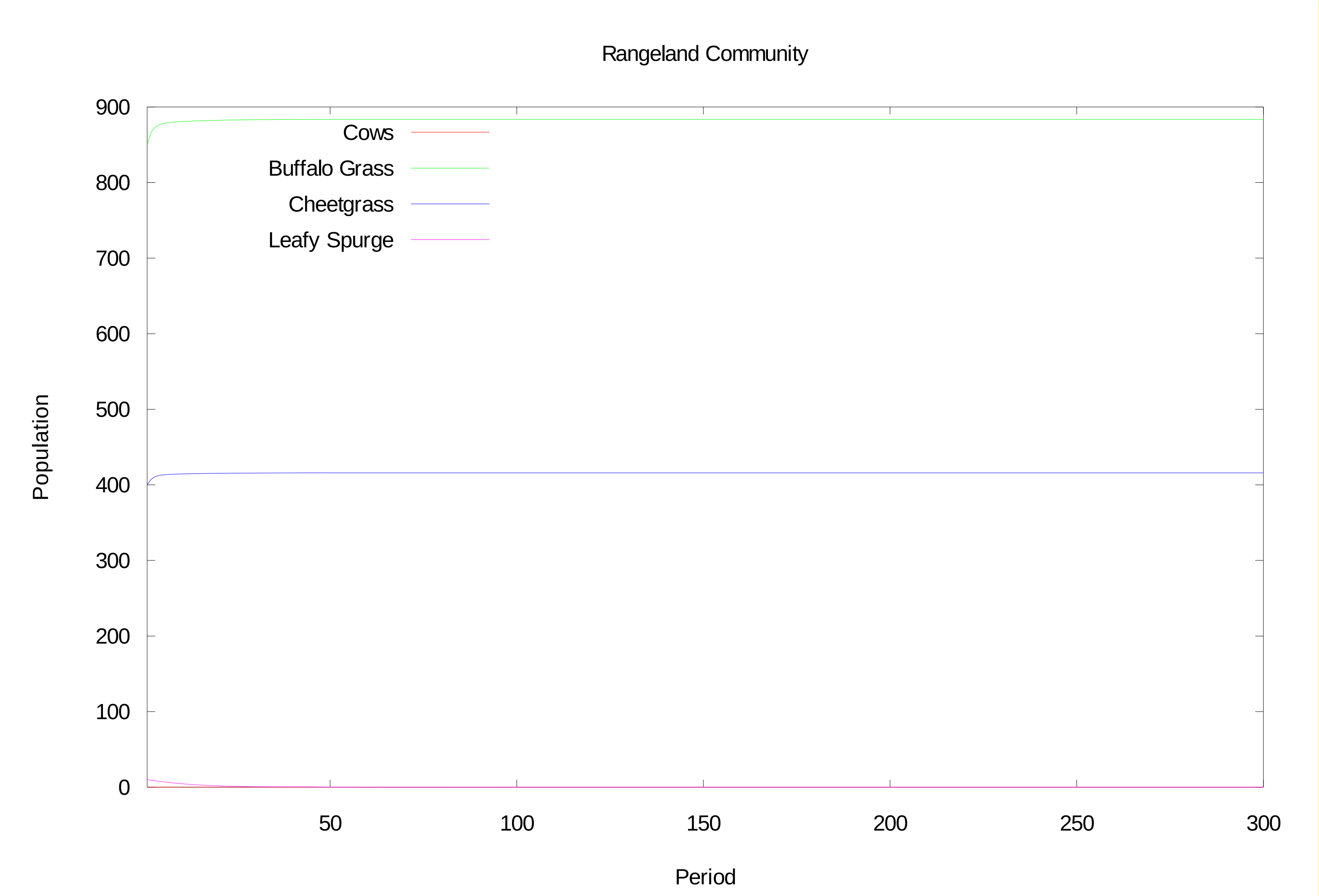
$$n_i^{t+1} = n_i^t + n_i^t \frac{1}{l_i}\left[\frac{\hat{R}_i(\cdot)+r_i}{r_i^{ss}} - 1\right]$$

- Coexistence

Relationship between space and nitrogen



Ecosystem composition without stocking



Cattle Introduction

- Cattle objective function

$$R_k\left((x_{k1}, x_{k2}) \mid (e_{k1}, e_{k2})\right) = \sum_{i=1}^{2}\left[e_i - e_{ki}\right]x_{ki} - f^k\left(\sum_{i=1}^{2} x_{ki}\right) - \beta_k$$

- Change in plant objective function

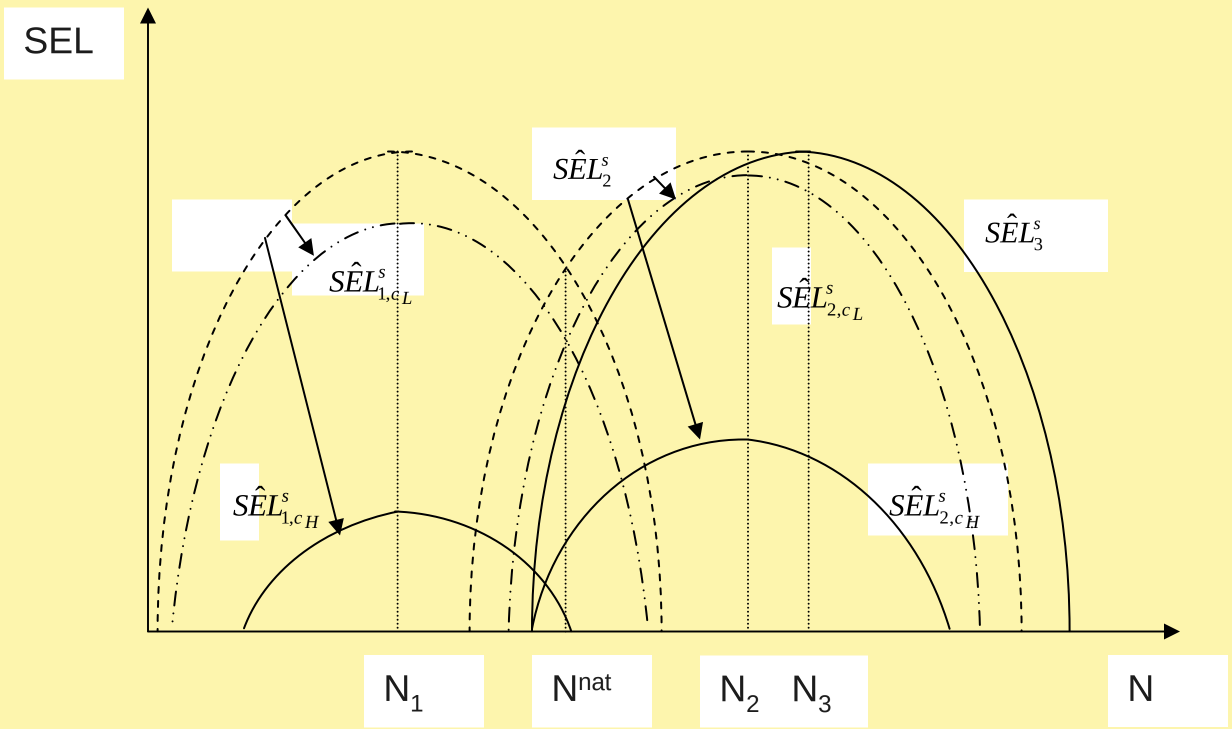
$$R_i\left(x_i \mid SEL\right) = r(1-SEL)x_i s_i - f(x_i) - \beta_i - e_i\left[1 + t_i e_{ki}\right]y_{ik}$$

$$y_{ik} = d_{ik}\left(n_k\right)x_i^{1/2}$$

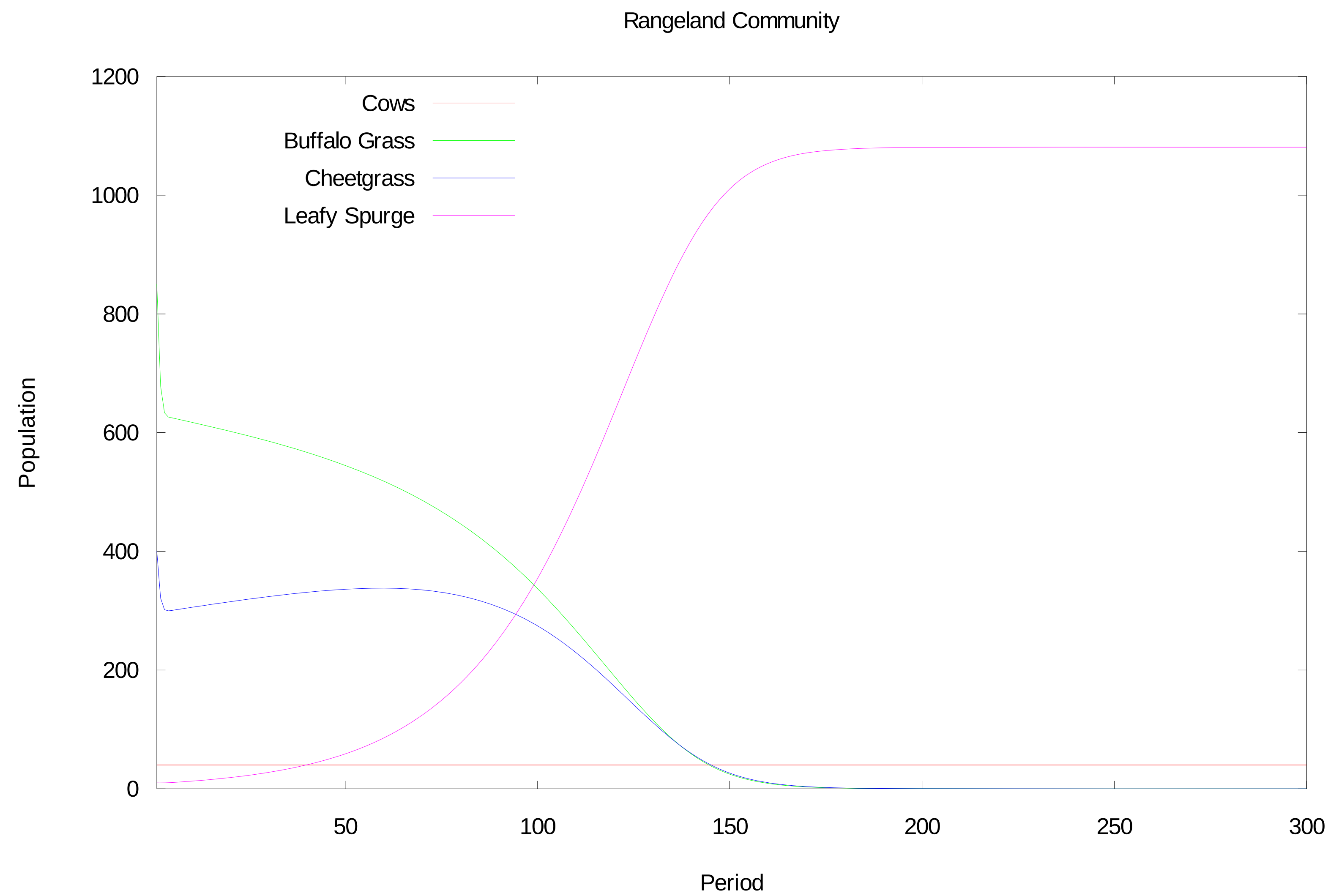
- Market Clearing

$$n_k x_{ki} \le n_i y_{ik} \perp e_{ki} \ge 0$$

Impact on space-nitrogen relationship



Ecosystem Composition with fixed stocking rates



Rancher Stocking Problem

- Maximize value added (weight gain) over planning horizon

$$\max_{n_k^t} \sum_{t=1}^{T} \delta^{t-1}\left(n_k^t\left[P^t \gamma_k R_k^t - C^t\right]\right)$$

$$s.t. \qquad \text{GEEM dynamics}, \quad n_1^1, n_2^1, n_3^1$$

Two Period Model

$$\max \quad n_k^1 P\gamma_k R_k^1 + n_k^2 P\gamma_k R_k^2$$

- FOC

$$P\gamma_k R_k^1 + n_k^1 P\gamma_k \frac{dR_k^1}{dn_k^1} + P\gamma_k R_k^2 \frac{dn_k^2}{dn_k^1} + n_k^2 P\gamma_k R_k^2 \frac{dR_k^2}{dn_k^1} = 0$$

- Expanding the second term

$$n_k^1 P\gamma_k \left(\begin{array}{l} \frac{\partial R_k^1}{\partial e_{k1}^1}\frac{\partial e_{k1}^1}{\partial n_k^1} + \frac{\partial R_k^1}{\partial e_{k1}^1}\frac{\partial e_{k1}^1}{\partial SEL}\frac{\partial SEL}{\partial n_k^1} + \\ \frac{\partial R_k^1}{\partial e_{k2}^1}\frac{\partial e_{k2}^1}{\partial n_k^1} + \frac{\partial R_k^1}{\partial e_{k2}^1}\frac{\partial e_{k2}^1}{\partial SEL}\frac{\partial SEL}{\partial n_k^1} \end{array} \right)$$

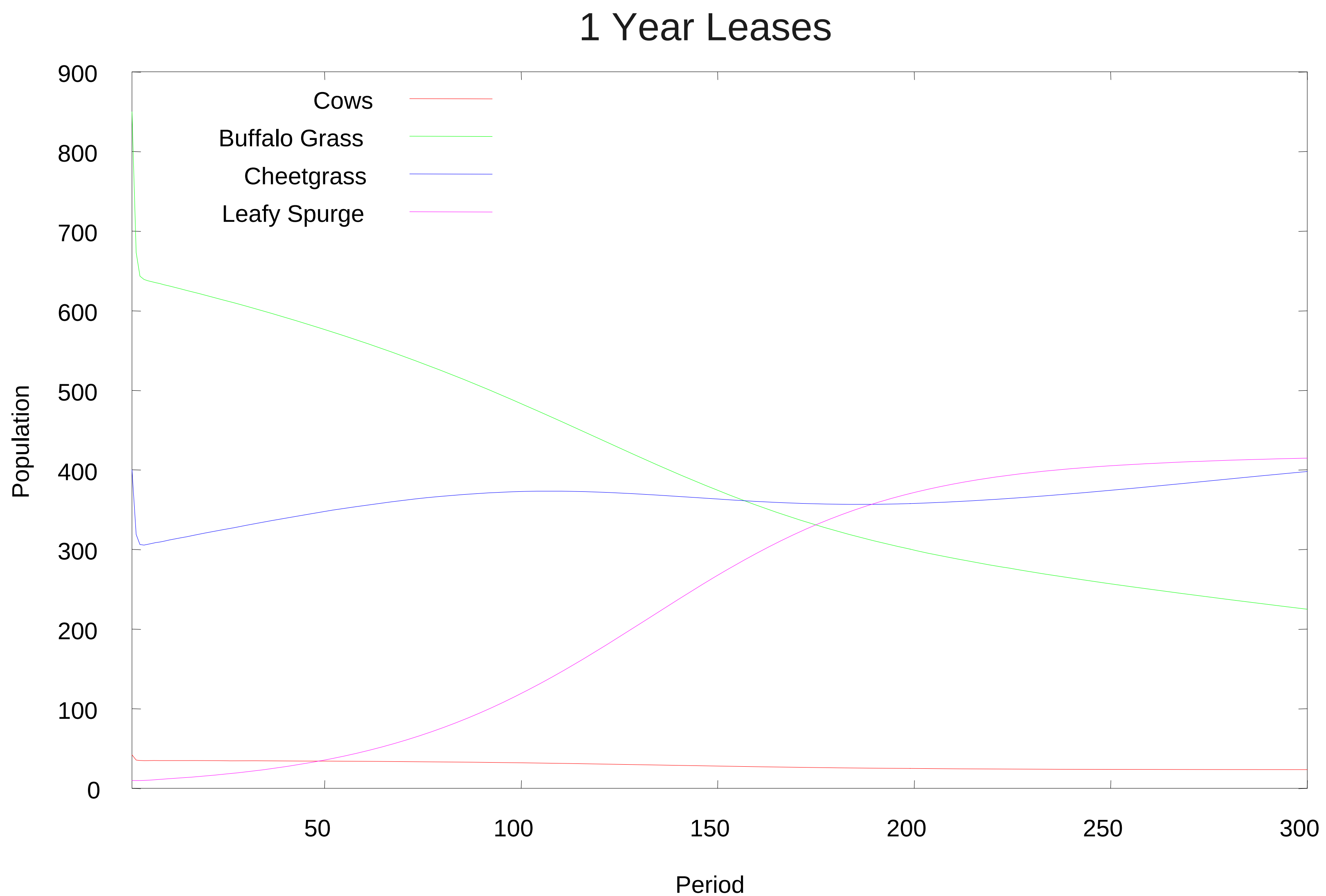
Two Period Model Cont

- Expand the fourth term

$$n_k^2 P \gamma_k R_k^2 *$$

$$\left(\frac{\partial R_k^2}{\partial \mathrm{e}^2} \left[\frac{\partial \mathrm{e}^2}{\partial n_1^2} \frac{\partial n_1^2}{\partial R_1^1(\mathrm{e}^1)} + \frac{\partial \mathrm{e}^2}{\partial n_2^2} \frac{\partial n_2^2}{\partial R_2^1(\mathrm{e}^1)} + \frac{\partial \mathrm{e}^2}{\partial n_3^2} \frac{\partial n_3^2}{\partial R_3^1(\mathrm{e}^1)} \right] \frac{\partial \mathrm{e}^1}{\partial n_k^1} \right)$$

Full Model



1 Year Leases
Cows
Buffalo Grass
Cheetgrass
Leafy Spurge
900
800
700
600
500
400
300
200
100
0
Population
50
100
150
200
250
300
Period

Growth and impacts of Leafy Spurge

Lease Length	Estimated Spread Rate	R^2	Terminal Biomass	% Change in Profits from Private
Private	0.0044	0.8412	45.19	-
100	0.0046	0.8602	46.97	-0.256
20	0.0056	0.913	56.44	-1.702
10	0.0067	0.943	69.18	-3.778
5	0.0085	0.9445	98.80	-8.132
3	0.0101	0.9441	147.89	-14.313
1	0.0119	0.8353	289.14	-39.110

Optimal Control Simulation Model

Figure 1: Native Grass and Leafy Spurge

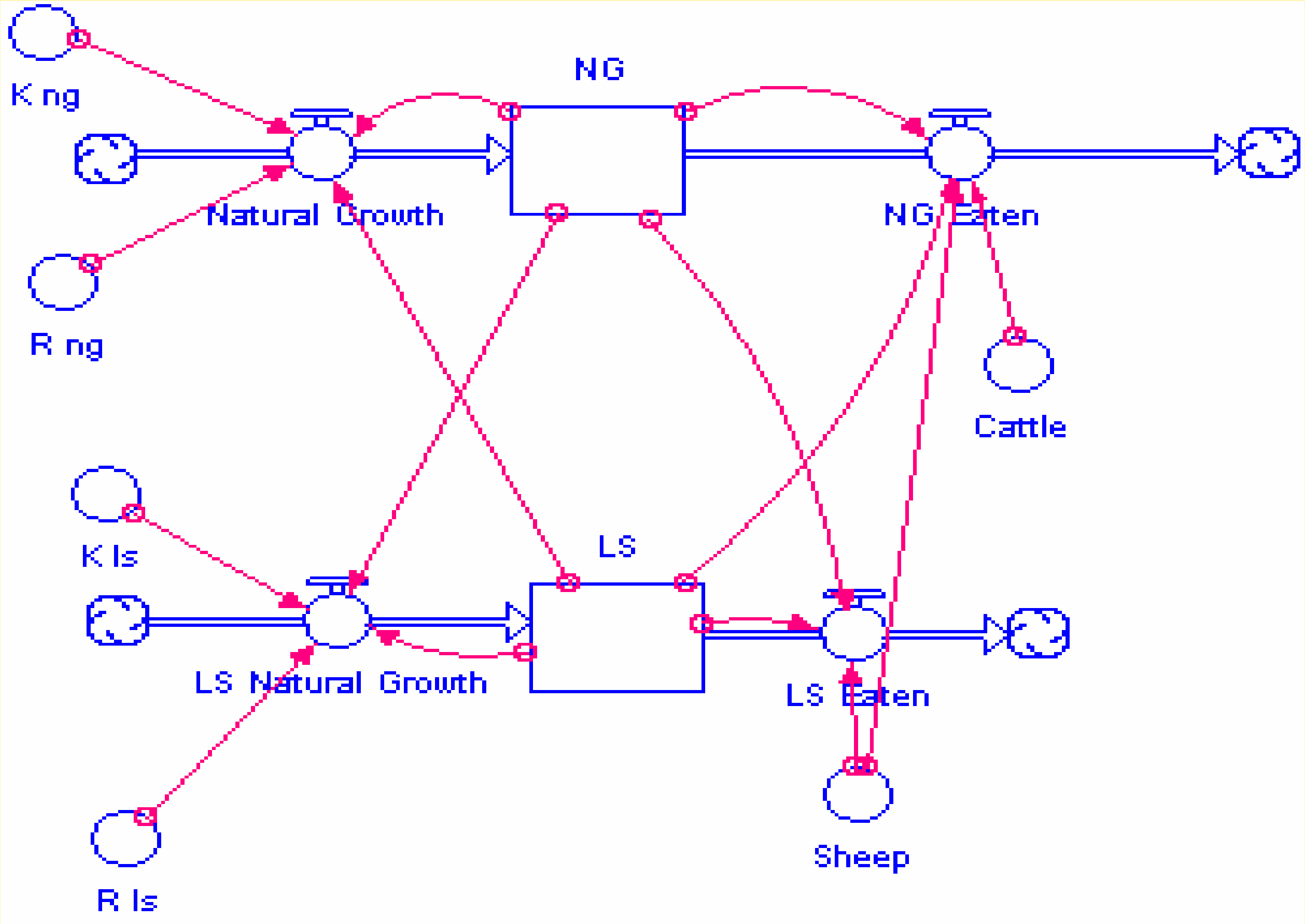


Figure 2: Carrying Capacity

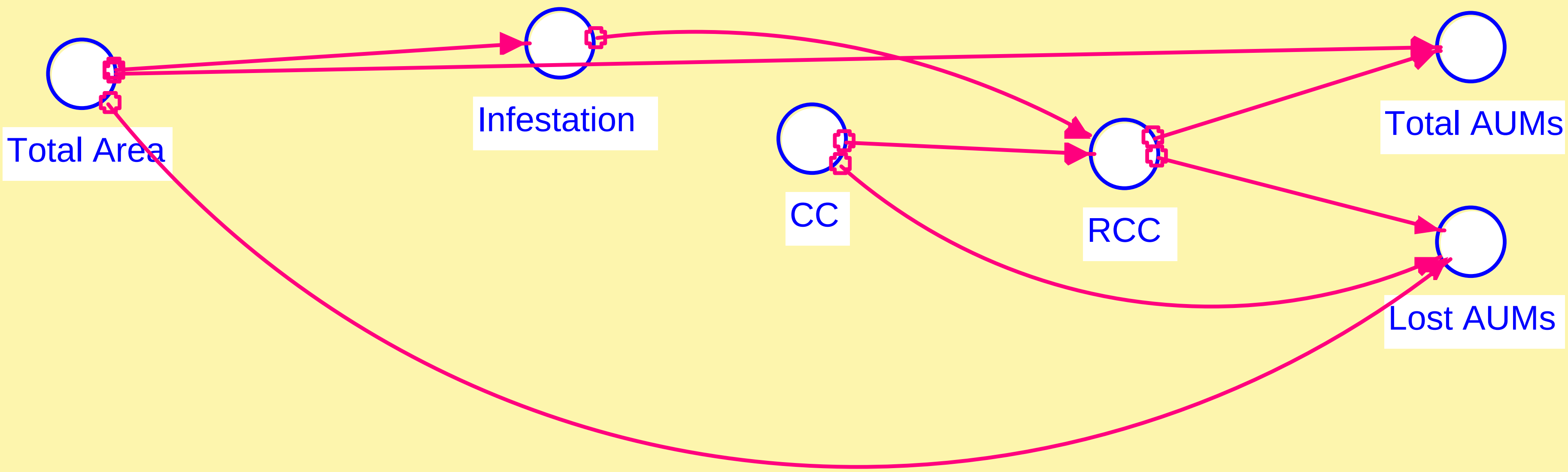


Figure 3: Thunder Basin Benefits

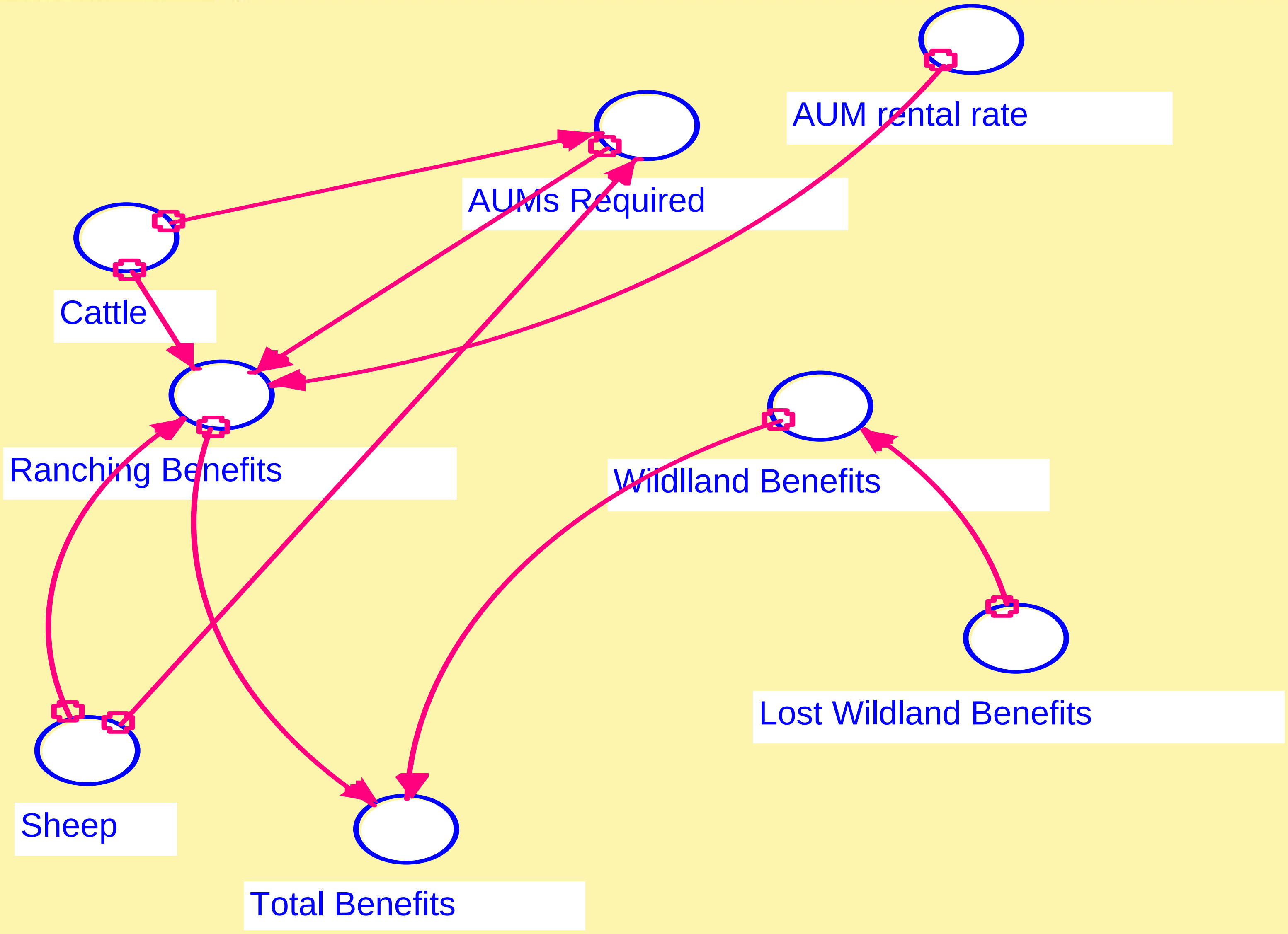


Figure 4: Full Simulation Model