SD Case Exercise: Soil Nutrient Dynamics in the Western Brazilian Amazon:

Introduction

The purpose of this exercise is to gain additional practice in thinking about system structure and behavior, based on previous research and observations about a particular situation. This exercise was inspired by the dissertation research of Bertha Rueda[1]. The structure of exercise will be for you to read a summary of the observed facts, then to work in groups to follow the first two steps of the SD modeling process proposed by Professor John Sterman[2], namely:

1) Problem articulation (e.g., reference mode)
2) Formulation of a dynamic hypothesis (a system structure that may explain it, along with two alternative "mappings" of the system structure, a ***Causal Loop Diagram*** and a ***Stock-Flow Diagram***.

At the end of the two exercises, I will share some thoughts about a proposed structure and its dynamic implications based on a simulation model programmed in Vensim® software.

Background

Cattle systems in the western Amazon of Brazil are based on pasture systems occupying land formerly in tropical rain forest. Nutrient dynamics in these systems are crucial. There is a wealth of experience from the eastern Amazon region that suggests that these systems are not sustainable (meaning that pastures degrade over time, pasture biomass production declines and the land must eventually be abandoned). There is concern by researchers and development agencies that cattle-pasture systems in the entire Amazon region are inherently unsustainable over short time frames, although there is limited evidence about the role that the choice of pasture species and management practices play in this process. Thus, there is a need to better understand the role that nutrient cycling (nutrient dynamics) plays in the process of generating the outcome of pasture degradation.

Observed Facts for the Western Amazon

Rueda collected data on three farms in the western Amazon region to examine pools of nutrients in soil, forages and cattle herds, and to determine the extractions of nutrients from the system through milk and cattle sales. The overall objective was to better document the nutrient dynamics so as to minimize the risk of pasture degradation through appropriate nutrient management practices. Rueda took numerous soil samples for land under forest, pasture, and crops at different times (0 to 20 years) since the land was cleared of trees. She took samples from the topsoil (0-10 cm depth) and examined the content of five nutrients (Ca, K, Mg, P, and C). She also estimated the amounts of these nutrients in pasture biomass, animal biomass and

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[1] Reuda Maldonado, Bertha. 2003. Nutrient Dynamics and Productivity Potentials of Pasture-based Cattle Systems of the Western Amazon of Brazil. Ph.D. dissertation, Cornell University.

[2] Sterman, J. D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* Boston: Irwin/McGraw-Hill.

pasture root biomass. She calculated the amount of nutrients extracted from the system via animal product (milk, beef) sales and periodic burning (once every two years).

Rueda observed the following:

- *Brachiaria* species with deep root systems are commonly used on these farms, and thus allow access to nutrients in the soil below 10 cm. Pasture biomass production declines only slightly with age of the pastures.
- In order to control weeds and other pests, pastures are burned every other year on average, which reduces standing pasture biomass and decaying plant material but returns some nutrients more quickly to the topsoil.
- Farmers rarely fertilize pastures, despite recommendations from the national extension service.
- Time since land was cleared of trees did not have a statistically significant negative impact on any of the nutrients examine (in fact, some effects were positive). This result was based on regression analysis.
- The average stocking rate was 2 AU (450 kg) per hectare. At this stocking rate, forage production exceeded consumption by cattle, leading to more mature (lower quality) forages and a large proportion of the nutrients in forage being returned to the topsoil through decay of senescent plant material.
- Cattle consume forage and excrete urine and feces. Some nutrients (e.g., ammonia) in manure are volatilized quickly and are lost, whereas others are returned to the topsoil as the manure decays.

Exercise

1) **Draw the reference mode behavior** over time for the amount of a “generic nutrient” in the topsoil for the pasture-cattle systems in the western Brazilian Amazon examined by Rueda. Be sure to include label both axes carefully. Justify the time horizon you choose to display the behavior of the system. You may also wish to contrast this behavior with that reported in the literature for the eastern Brazilian Amazon. What are the likely fundamental behavioral modes for these two systems?
2) Identify key variables that relate to the observed pattern of behavior of the quantity of the “generic nutrient” in the topsoil for western Brazilian pasture-cattle systems. Using these variables, **develop a Causal Loop Diagram** (CLD) to indicate your initial hypothesis about how the observed behavior arises (Remember: “Structure determines behavior.”) Follow the guidelines for CLD development from the preceding lecture: use causal links (these can be hypothesized, not necessarily proven), label link polarities, label important feedback loops and their polarities, and indicate relevant delays. You may develop the CLD using Vensim or by hand on a piece of paper.
3) There are at least six key stocks of nutrients (physical locations where nutrients are located) in this system:
    - Nutrients in topsoil*

- Nutrients in standing pasture biomass*
- Nutrients in plant litter biomass
- Nutrients in animal biomass*
- Nutrients in decaying manure
- Nutrients in the subsoil

A "*" indicates a stock for which Rueda collected information.

Some of the key flows of nutrients in this system are related to:

- Plant uptake of nutrients
- Pasture decay to plant litter
- Litter decay to topsoil
- Nutrient cycling from pasture biomass and litter to topsoil through burning, with potential nutrient losses
- Animal uptake through grazing
- Animal excretion (which may be spatially concentrated)
- Decay of manure (and losses due to volatilization in some cases)
- Export of nutrients through milk and beef sales

Develop a stock-flow diagram to link these stocks and flows of nutrients, assuming that an individual farm is the unit of observation. If you believe that other stocks or flows should be added, incorporate them into your diagram.

4) Use the diagram assess the future sustainability of this system based on the information presented, using the following questions as a guide:

   - What prevents the amount of nutrient in the topsoil from declining over time during the 20-year period observed by Rueda, despite the fact that there are nutrient extractions from the system due to burning, animal product sales and volatilization of manure nutrients?
   - What interventions, if any, do you think are necessary to ensure that the pastures do not degrade in the future?
   - Does the answer change if the stocking rate is increased as proposed by Rueda (i.e., if there is intensification of the system through greater production of milk and beef per unit land area?)