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LANDSCAPE 2018

Landscape 2018

Frontiers of agricultural landscape research

Book of Abstracts

Leibniz Centre for Agricultural Landscape Research (ZALF)

Leibniz Association

Landscape 2018

Frontiers of agricultural landscape research

12–16 March 2018

Berlin, Germany, Adlershof con.vent

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Agent-based modelling of a synthetic pastoral landscape

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Introduction

This model allows the spatial dynamics stemming from the interactions between mobile agents (herbivores) and their environment (rangeland) to be simulated. It features a herd grazing on a pasture. With a sustainability aim a dynamic balance must be found between grass intake by the animals and herbage growth. However, two behaviours may threaten this equilibrium: overgrazing, leading to desertification; under-grazing, leading to excessive vegetation and landscape "closure" by invasive shrubs (issue dealt with in Anselme *et al.*, 2010). Both processes may lead the herd, considered as free-grazers, to extinction by starving. This model's aim is not to mimic real specific rangelands but to offer a generic simple synthetic ecosystem to check ecological hypotheses.

Materials and Methods

The model has been implemented with the agent-based simulation NetLogo platform (Wilensky, 1999). It comprises two types of agents: spatial cells, called "patches" in NetLogo, representing the landscape as a grid, and mobile agents, called "turtles", standing for herbivores. Vegetation on patches are characterized by their color ranging from very light to very dark shades of green: darker the shade, higher the grass biomass and lower its quality. Herbivore attributes are their birth date, age, sex, previous location, destination, pathway, travelled distance, ingested feed, live-weight, calving dates. At each simulation time-step each individual iterates the following actions: stay on the current patch or move to another, graze, gain and lose weight, age and, possibly, reproduce or die. Although deliberately naive, the model was parameterized with real rangeland data borrowed from various authors (Bayer and Waters-Bayer, 1999; INRA, 1988; Vayssières *et al.*, 2009). Based on a reference landscape comprising 1,225 patches (1 ha each) and 1,225 cattle heads (1 head/ha), simulations have been made to check variants of the ecosystem's structure and animal behaviours (see below). The main criteria of simulation assessment are animal and vegetal productions, herd demography, landscape fragmentation over temporal horizons spanning up to 55 years. Whereas the focus was put on comparing animal walks, the emphasis is now on challenging ecological theories (optimal foraging, ideal free distribution, marginal value theorem).

Results and Discussion

Heterogeneity of landscape at initialization: starting with patches uniformly green or with different greens in a narrow range makes little difference. However, with higher heterogeneity the system's performances quickly decrease in terms of population size, pasture and shrub extensions. Whatever their initial state, all landscapes converge eventually towards a similar heterogeneity degree.

Heterogeneity of spatial distribution of animals at initialization: starting with all cattle on the same patch leads to a quick resource depletion radiating in concentric circles around the origin with huge mortality. The remnants colonize a few peripheral patches where they stabilize at very low level, abandoning the rest of space to shrub invasion.

Should I stay or should I go? The best strategy for turtles proved to be: if grass on the current patch is above a certain biomass*quality value, then keep on grazing, otherwise move to another patch.

Walk types: a directed walk like moving to patches with maximum herbage tends to create too high local animal density, inducing overgrazing, high mortality and bush extension. However, keeping the same rule within a limited perception range of animals may lead on the long run to sustainable rangelands with low-biomass but high-productivity pastures supporting a huge animal stock above 8 times the initial one; this emerging phenomenon, known as "grazing lawns" (Bonnet *et al.*, 2010), is illustrated on Figure 1.

Move length: short moves lead to better animal and herbage production than long ones.

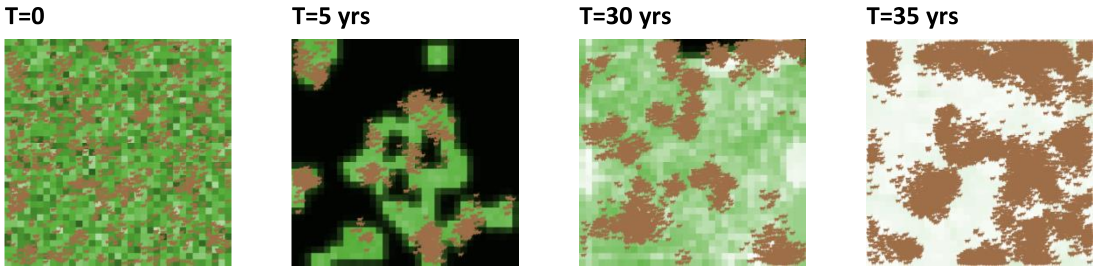

***Figure 1.* Example of a simulated 1,225ha landscape over 30 years. T=0, randomly generated rangeland with 1.12 heads/ha free-grazing cattle; T= 5 yrs, closing landscape, 0.76 heads/ha; T=30 yrs re-opening landscape, 3.36 heads/ha; T=35 yrs, stable "grazing lawn", 8.48 heads/ha.**

Conclusions

The most sustainable foraging strategies were found to be those fostering space occupation, local foraging, short walk steps and anticipating resource exhaustion. Animal movement proved to be crucial in shaping the system. The model also was used for testing theoretical hypotheses like "Ideal Free Distribution". Simulations made on a long run allow the emergence of interesting succession of extreme phenomena also found in real cattle farming systems or natural ecosystems (e.g. grazing lawns).

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