Ecological Informatics 39 (2017) 84–98

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Livestock Settlement Dynamics in Drylands: Model application in the Monte desert (Mendoza, Argentina)

Emmanuel N. Millán[a,b,*], Silvana Goirán[b,c], Julieta N. Aranibar[b,c], Eduardo M. Bringa[a,b,*]

[a] CONICET, Mendoza, Argentina
[b] Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Mendoza, Argentina
[c] Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CONICET, CCT-Mendoza, Argentina

ARTICLE INFO

Article history:
Received 18 November 2016
Received in revised form 14 February 2017
Accepted 29 March 2017
Available online 31 March 2017

Keywords:
Settlement Dynamics
Spatial Distribution
Monte Carlo simulations
Old river beds
Vegetation degradation
Water availability

ABSTRACT

Human settlements in arid environments are becoming widespread due to population growth, and without planning, they may alter vegetation and ecosystem processes, compromising sustainability. We hypothesize that in an arid region of the central Monte desert (Mendoza, Argentina), surface and groundwater availability are the primary factors controlling livestock settlements establishment and success as productive units, which affect patterns of degradation in the landscape. To evaluate this hypothesis we simulated settlement dynamics using a Monte Carlo based model of Settlement Dynamics in Drylands (SeDD), which calculates probabilities on a gridded region based on six environmental factors: groundwater depth, vegetation type, proximity to rivers, paved road, old river beds, and existing settlements. A parameter sweep, including millions of simulations, was run to identify the most relevant factors controlling settlements. Results indicate that distances to rivers and the presence of old river beds are critical to explain the current distribution of settlements, while vegetation, paved roads, and water table depth were not as relevant to explain settlement distribution. Far from surface water sources, most settlements were established at random, suggesting that pressures to settle in unfavorable places control settlement dynamics in those isolated areas. The simulated vegetation, which considers degradation around livestock settlements, generally matched the spatial distribution of remotely sensed vegetation classes, although with a higher cover of extreme vegetation classes. The model could be a useful tool to evaluate effects of land use changes, such as water provision or changes on river flows, on settlement distribution and vegetation degradation in arid environments.

1. Introduction

Livestock production, the largest land use sector on Earth, is experiencing changes related to climate change and anthropogenic pressures. Population and economic growth, urbanization, and consumption patterns are shaping livestock production, with impacts on societies and environments, such as greenhouse gas emissions, nutrient cycles, land demand and degradation, and protein supply (Herrero and Thornton, 2013). The challenge to feed the world sustainably partly depends on how we understand and manage the livestock sector. In drylands, which sustain a third of the world population and 78 % of livestock worldwide (Asner et al., 2004; Corvalan et al., 2005), livestock production is one of the main economic activities. Groundwater coupled ecosystems in the Monte desert (Argentina) are used for subsistence livestock production, which allows the coexistence of areas with high vegetation cover in most of the region (Goirán et al., 2012), and rural communities. However, changing land rights, water provision, infrastructure, and population growth may increase population density and grazing pressures, with increasing risks of ecosystem degradation. In order to predict future conditions of livestock production and ecosystems in the region, it is crucial to understand the feedbacks between natural resources and livestock settlements at present.

Several models have been used to understand and simulate settlement dynamics in different regions of the world. Settlement Dynamics has been simulated using Agent-based models (ABM) in Kohler et al. (2012) and Crabtree and Kohler (2012), also using Multi-Agents in Bura et al. (1996) and Le et al. (2008, 2010), using Knowledge-based simulations in Page et al. (2001) and with decision making rules for land cover changes in the Amazon in Evans et al. (2001). Dispersion of plants has been simulated with stochastic models based on environmental conditions relevant for their survival

* Corresponding authors at: FCEN, Universidad Nacional de Cuyo, Padre Jorge Contreras 1300, Parque General San Martín, CP M5502JMA Mendoza, Argentina.
E-mail addresses: emillan@itu.uncu.edu.ar (E.N. Millán), ebringa@yahoo.com (E.M. Bringa).

http://dx.doi.org/10.1016/j.ecoinf.2017.03.006
1574-9541/

in Fennell et al. (2012). In this work, we use a novel approach to simulate settlement dynamics (Millán et al., 2016), which allows to spatially consider vegetation-human interactions, with a probabilistic model.

Several factors may influence the dynamics of livestock settlements in arid environments, including environmental and socioeconomic drivers. Availability of forest resources, groundwater, and access roads may all affect settlement patterns, but their interactions or relative importance on settlements distribution and success are not known. Goirán et al. (2012) studied the spatial distribution of human settlements in North East (NE) Mendoza, finding a heterogeneous pattern, with spatial aggregations around rivers and other landscape features, indicating the importance of water availability for settlements. However, the relative importance of surface, groundwater, and old river beds is difficult to obtain from a simple observation of settlement distribution, because more than one factor may have opposing or multiplying effects on a given space. Goirán et al. (2012) also found a pattern of concentric vegetation reductions around settlements, given by the concentration of animals and higher pressures around water points, also observed in other deserts (Ringrose et al., 1996). The practice of night-time livestock accumulation, free grazing around settlements, and the scarcity of permanent fresh water sources generate concentric gradients of grazing pressure. Because environmental and economic changes may encourage or discourage settlement establishment and change their distribution in the landscape, we aim to identify the main drivers of landscape occupation in these arid groundwater-coupled ecosystems. We hypothesize that surface and groundwater availability are the most important factors for settlements in drylands, and forest resources and access roads have a minor effect.

In order to test this hypothesis for the Monte desert, we used a Monte Carlo based model of Settlement Dynamics in Drylands (SeDD) (Millán et al., 2016), which supports different types of environmental factors. We included six environmental drivers of settlements: surface and groundwater availability, vegetation type, existing settlements, access routes, and old river beds. These factors provide different services to settlers, such as water provision for humans and livestock, forest products for construction and forage, transport and communication with existing settlements and other regions, and initial labor, materials, and water during the construction period. The model assumes that places with higher availability of water and forest resources will be preferentially settled, independently of the social structure. The model assigns settlements in places where the aptitude (simulated as probabilities) is higher, with a number of settlements established stochastically. The model simulates the number and distribution of settlements from 1928 to 2015. The model also simulates the degradation of vegetation around settlements, gradually reducing the suitability of these spaces. Vegetation degradation around settlements is simulated up to 2 km, according to observed vegetation patterns in the region (Goirán et al., 2012). Our model differs from plant and animal dispersion models (i.e., Fennell et al., 2012) because it assumes that settlers have a prior knowledge of the environment in the entire region, simulating environmentally-based, human informed decisions. Millions of simulations with combinations of crucial parameters were run to find minimum residuals between simulated and observed spatial indexes of settlements in relation to other settlements, rivers, and roads. Combinations of parameter values that resulted in low residuals were interpreted to indicate the relative importance of each parameter.

The simulations performed suggest that environmental factors related to surface water availability (river and old river beds) are the most important to settlers. The presence of a paved road does not seem to influence the decision of establishing new settlements. Finally, groundwater and vegetation do not change settlement distribution considerably.

2. Materials and methods

2.1. Study area description

Our study area is located in the non irrigated lands of North East Mendoza, Argentina, where mean annual precipitation is below 200 mm. The region is framed by permanent and temporary rivers (San Juan, Desagüadero, Mendoza, and Tunuyán rivers). Groundwater is recharged in the Andes (100 km west) and reaches the area with a high salt and arsenic content, preventing its use for irrigation (Aranibar et al., 2011). The region has an aeolian plain with sand dune-interdune systems, old river beds, and lacustrine systems (Fig. 1), with varying access to surface and groundwater. Most of the region is occupied by the aeolian plain, and lacks surface water. One of the four old river beds of the region crosses the aeolian plain from West to East, providing an easier access to the territory, and localized patches of groundwater with a better quality (Aranibar et al., 2011; Jobbágy et al., 2011). The other old river beds are shorter, and interrupted by sand dunes. Historic documents suggest that river beds have been dried at least from 1778 (Prieto, 1997). The only paved road of the region (road Number 142) was built along the main old river bed for most of its length. People live in livestock settlements, which mostly hold 1 to 3 families (from 1 to 10 persons) and their livestock (mainly goats, but also cattle and horses) with an average size of 160 (Soria et al., 2011). At present, there are 577 settlements with a heterogeneous spatial distribution, aggregated at different scales (Goirán et al., 2012). Settlements located far from the paved road are accessed through dirt roads that cross the high sand dunes of the aeolian plain, decreasing the possibilities of communication, trade, and transportation between areas.

In interdune valleys where groundwater is near the surface (from 5 to 15 m depth), highly productive, phreatophyte, *Prosopis flexuosa* forests develop (Contreras et al., 2011; Jobbágy et al., 2011). These forests have been seasonally used by aboriginal groups since prehispanic times, providing them with hunting animals and *Prosopis pods* (Llorca and Cahiza, 2007). During colonial times, many aboriginal (Huarpe) individuals or groups used the area as a refuge, changing the previous seasonal and complementary occupation of the area to a more permanent pattern of occupation (Escolar, 2007; Prieto, 1997). During the 19th century, part of the forests were cut for railroad and vineyard construction in irrigated oases, but sand dunes prevented clear cutting in certain areas, where old *Prosopis flexuosa* individuals still remain (Alvarez et al., 2006; Villagra et al., 2005).

At present, local Huarpe descendants still inhabit these lands, mainly practicing subsistence livestock production in permanent livestock settlements, which rely exclusively on groundwater for most uses. Animals graze freely during the day around the settlement, but return at the end of the day to drink water, and they are kept in corrals during the night. In areas close to paved roads, people have access to drinking water, transported from irrigated oases by trucks, or a recently (2012) built aqueduct. The hydrogeology of the region, including a shallow aquifer and fine sediments (Aranibar et al., 2011), allows the construction of wells by independent individuals at a relatively low cost, without government assistance. Wells are constructed near the corral and housing area with wooden *Prosopis flexuosa* frames, and groundwater is extracted manually, or with the help of an animal. This relative independence of livestock owners from government assistance and planning allows settlers to establish in areas that they consider appropriate for their subsistence, probably basing their decisions on their knowledge of natural resources availability, as we simulate with our model.

The exclusive reliance of livestock on groundwater from their settlements causes a pattern of night-time animal concentration around wells and corrals, as also observed in Botswana, Patagonia and other arid areas. This causes higher pressures near wells, and consequent changes on soils, groundwater quality, and vegetation