A Rule-Based System for Fire Management in the Brazilian Cerrado Vegetation

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Abstract

Fire has an important role on the dynamics, maintenance and evolution of savannas. Cerrado, a savannah like vegetation, complies many types of physiognomic forms along a gradient from open formations, dominated by a dense and continuous herbaceous layer, to closed formations, dominated by woody vegetation. Qualitative models have been used as an ecological tool to deal with situations where data are scarce and where there is a great amount of uncertainties. We used a qualitative simulator (GARP) to build an interactive qualitative model to represent the behaviour and impacts of fire in a "campo sujo" vegetation, an open savannah. The system guides the user to set the initial conditions of time since last burning, air temperature, wind direction and amount of biomass to start the simulation. The model is able to generate 144 different states in 18 different simulations based on theses initial conditions. Each state has a particular configuration of qualitative values for air moisture, precipitation, vegetation biomass, burning efficiency, fire risk, fire speed, fuel moisture, heat released, intensity, residence time, soil temperatures, and damage to woody vegetation. The model can be used for orientation of management practices and for understanding fire as an ecological factor in the Brazilian Cerrado.

Introduction

Fire is recognized as one of the best-described ecological disturbances (Christensen, 1995) to which the major part of world ecosystems is subjected.

Depending on frequency and the type of ecosystem, fire can damage the vegetation structure compromising biodiversity and ecological patterns of functioning and maintenance of ecological communities all around the world. Pyne (1992), states that no other technology has been influencing the planet for so long and in a so strong way, as fire in ecosystems.

The Cerrado is the second major Brazilian Ecosystem. It covers almost 25% of Brazilian territory. Some of its vegetation characteristics, as the presence of a grass layer ignitable during the dry season, make this vegetation extremely fire prone (Coutinho, 1990). Here fire can spread at higher speed and for large areas (Ramos-Neto, 2000, Ramos-Neto and Pivello 2000). Because of this common behaviour, fire is considered of high concern in defining management strategies of national parks and in the definition of policies for its use in large areas of native vegetation (Ramos-Neto, 2000, Ramos-Neto and Pivello 2000).

The development of research on fire ecology in recent years has allowed the building of qualitative models that considers fire as a relevant ecological factor to support management trade offs (Pivello and Norton, 1996, Pivello and Coutinho, 1996), and for better comprehension of the role of fire in Cerrado (Salles, 1977). The use of qualitative reasoning in these models has been essential to deal with parameters not yet sufficiently quantified and with causal relationships that are explicit in the descriptions of physical and biological process related to the fire factor (Salles, 1977).

This work presents a prototype of a rule-based expert system built to direct management decisions about fire in campo sujo vegetation, an open Cerrado, and to assist characterization of the behaviour and impacts of fire in Cerrado.

Fire Ecology, management practices and qualitative models in Brazilian Cerrado

Fire Ecology

Vegetation burnings are generally described in terms of some parameters like intensity, heat released, speed of fire, biomass consumption and flame heights (Pyne *et al.* 1996). All these variables together with other physical parameters such as velocity and direction of wind, air moisture and temperature, fuel moisture, type of fuel, and rain are important in determining the impacts of fire on the vegetation (Pyne *et al.* 1996).

These impacts can be evaluated in terms of tree and shrub mortality, rate of post-fire recovery and variations in the chemical and biological characteristics of soil and in vegetation structure.

Any kind of model with the aim of representing and making previsions on fire impacts on vegetation must also take into consideration the characteristics and fire history of the vegetation.

Qualitative models for Cerrado

There are three other models that use artificial intelligence to simulate and make previsions of the use and impacts of burnings on the Cerrado. Firetool (Pivello and Norton, 1996) is an expert system built on the commercial shell Knowledge-Pro that is able to estimate the fire risk, and to advice on the use of fire. The other two are qualitative sucessional models that take fire as an important factor controlling many stages of ecological succession. The first one (Pivello and Coutinho, 1996) takes a state transition approach (Westoby *et al.*, 1989) and is able to represent variations on the vegetation characteristics due to fire and to many other ecological factors. The second one (Salles, 1997; Salles and Bredeweg, 1997) uses the qualitative simulator GARP (Bredeweg, 1992) to represent qualitative states and transitions of a ecological succession based on a chain of causal relationships and parameters influences.

Management Practices in Brazil

Because of a lack of concluding studies related to the impact of burnings on Cerrado, Brazilian government agencies currently recommend total suppression of fire in Cerrado National Parks. Nevertheless, this regime is considered dangerous in many ecosystems of the world (Christensen, 1995), and it has been shown to be disastrous in Cerrado (Ramos-Neto 2000, Ramos-Neto and Pivello 2000). This is due to the fact that the burning suppression allows the accumulation of high loads of fuel, able to start and propagate fires, which provoke very great vegetation damage and are hard to be controlled. The problem is the lack of advice systems for fire management practices that could support management decisions and to generate hypothetic scenarios simulating the behaviour and effects of fire under different circumstances.

Rule-based Expert system for fire behaviour and fire impacts on Brazilian Savannas

Structure

The system is built on top of the qualitative simulator GARP (Bredeweg, 1992), and uses the modelling language for defining objects, values, quantity spaces, dependencies and relations. Domain knowledge is represented in Model Fragments, that contains the Conditions and Givens used to create IF-THEN rules.

Starting the expert system, user is introduced to an implemented in PROLOG (SWI-PROLOG) interface that ask some questions about weather conditions. The information given by user are translated into qualitative values, e. g. the temperature is above or below 25^{o}C. As the user answer the questions, the PROLOG interface select, an initial configuration for some pre-fire physical characteristics (air temperature, time since last burning and wind direction).

Once the pre-fire initial scenario is determined, the system opens GARP and runs the simulation. Inside the simulator, user defines an initial scenario based on the knowledge of the state of fuel load, in terms of qualitative quantities of green and dry biomass according to the distance from the dry or rainy season.

Conditions (If)	Givens (Then)
1. There is a parameter "Time without fire" that has a quantity space low-medium-hig and that is an instance of physical factors 2. There is a parameter "Vegetation damage" that has a quantity space low-medium-high and that is an instance of fire consequences 3. Parameter "Time without fire" has the quantity value high with derivate zero	1. Parameter "Vegetation damage" has the quantity value high with the derivate zero

Table 1. Example of a rule presented in a model fragment of the model library.

After the pre-fire conditions and the fuel load are determined, the user can see the qualitative values for all other parameters in the model for a given initial scenario and also, runs the simulation. The simulation shows how the system evolves representing time as a succession of qualitative states related to the growth of vegetation. Every qualitative state has a particular configuration of qualitative values for all variables considered in the model.

This model is not able to represent the evolution of the burning event. It can only determine the characteristics (intensity, heat released, fire speed, etc) and the effects on vegetation caused by fire at the specific configuration of fuel load told to the system by the user and in the future.

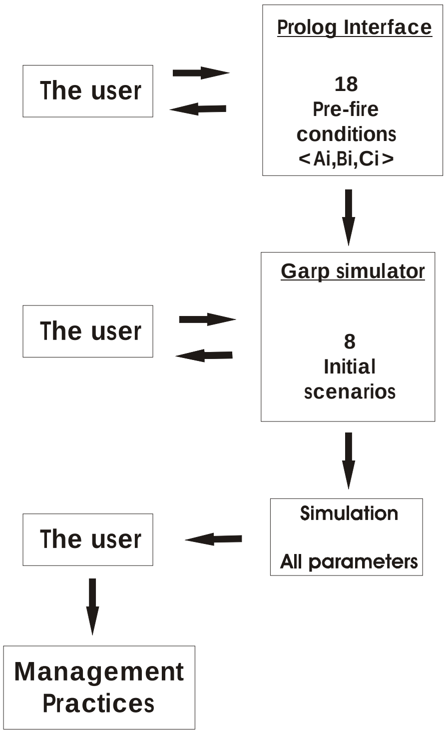

Figure 1 Graphic representation of the steps of this system and the moments in which the user interacts with the system

Reasoning

The reasoning used by this expert system is the same used by GARP simulator (see Bredeweg 1992), since this system uses this simulator as an inference engine.

As a rule-based system, this system does not use some possibilities of GARP as the reasoning of causal relationships between variables (proportionalities and influences), and qualitative values correspondences. Its knowledge base uses only inferences like if...then (conditions and givens). This inferences are in form of declarations of quantity values (if fire frequency is low.. then..) or relations of inequalities between variables (if fire frequency is lower than medium... then...). An example of the rules present in the model is in Table 1.

There is no direct influences and qualitative proportionalities representing processes and propagation of their effects to other variables (Forbus, 1984). Therefore, causality is not explicitly represented.

System variables

The model variables presented in the model are:

1. Pre-fire conditions variables: air moisture and temperature, amount of days since the last significant rain, woody biomass, green and dry herbaceous biomass, fuel moisture, mean precipitation, wind direction related to the direction of the fire, time since last burning and fire risk.
2. Variables that describe the burning characteristics when fire starts: fire efficiency, fire speed, intensity and heat released of fire and residence time.
3. Variables that describe the impacts burning: increase of temperature in the first centimetres of soil, increase of temperature bellow the first five centimetres

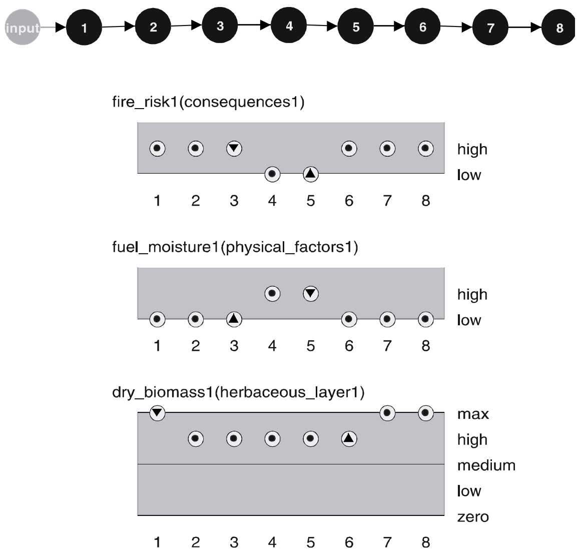

Figure 2. Initial situation (state 1) and system evolution (2-8) for three model variables: fire risk, fuel moisture and vegetation damage.

Main results and Model Validation

The model rules define the acceptable results and thus the model prediction. Theses rules were built based on consolidated and widely accepted literature on fire behaviour (Pyne *et al.* 1996 e Luke and McArthur 1986), and fire effects on the Cerrado (Miranda *et al.* 1996).

Based on these rules, the model predict that the most damaging fires for vegetation are those that occur after a long time of fire protection and at lower rates of spread (as in the case of high fuel moisture content and fires against the prevailing wind). In the case of headfire events (same direction as the wind), even with high intensity and high heat released, if the residence time of flames is low, the vegetation damages will not be considered great by the model (in the model the other choices are medium or low). This kind of result can only be observed in areas of vegetation adapted to fire events, as such as the Cerrado. In this ecosystem, the presence of thick barks and the regrowth ability of underground parts not damaged by fire, give to the vegetation the ability to withstand the direct effects of fire, even after high intensity fires (Guedes 1993).

The model also predicts that even in the case of high temperatures at soil surface, lower temperatures are maintained at lower depths. This is in agreement with field observations of fire effects in Cerrado (Miranda *et al.* 1996, Castro Neves and Miranda, 1996, Miranda *et al.* 1993).

Once the major part of the model was build in the form of rules based on empiric observations and measurements, the model predictions held an empiric reference beyond a merely theoretical construction. A whole model validation, which can only be done by using this system in the field, has not yet been possible.

Constraints

This model presents some constraints for use:

1. It considers as damage only the destructive effects of fire to the woody vegetation. It does not take into consideration the effects of repeated burnings to pools of nutrients and soil carbon.
2. User cannot easily alter the knowledge base of this model. It is essential for the user to know the structure of GARP as well as the PROLOG language;
3. User must have some computational systems skills to use this system efficiently, although there is a user-friendly version of Garp – the Visigarp. This constraint must be mentioned because many people in charge of fire management practices in Brazil do not have sufficient computational training;
4. Data in the knowledge base refers only to a particular type of Cerrado: a campo sujo, an open vegetation dominated by a herbaceous layer, with scattered trees and shrubs.

Concluding remarks

This model is a prototype and has not yet been tested by experts. To be a useful tool in fire management practices this system must be better evaluated by experts. Nevertheless, possible modifications are needed only for some rules and not for the functioning of the whole system.

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