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A STAGE-STRUCTURED PROJECTION MODEL INCORPORATING THE EFFECTS OF GRAZING MANAGEMENT AND RAINFALL ON POPULATIONS OF SHRUBS AND TREES IN THE AUSTRALIAN RANGELANDS

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ABSTRACT

We present a new stage-structured model activated in Excel to project potential impacts of grazing and rainfall (drought) over up to 500 years on population numbers of trees and shrubs in the Australian chenopod rangelands. The model is based on functional types rather than species so that it can be used on any species of tree or shrub, and includes the effects of grazing pressure of four herbivore species: sheep, rabbits, goats or kangaroos. Rainfall (either modelled or real rainfall records) is then included as another variable. The model can be set to run in stages with different herbivore intensities to model the effects of management interventions such as spelling of paddocks and control of feral herbivores. Users may also create various climate-change scenarios by editing the rainfall file.

INTRODUCTION

Previous research shows that grazing has reduced levels of regeneration of a number of species of native trees and shrubs in the arid lands of southern Australia since European settlement (Crisp & Lange 1976; Crisp 1978; Tiver & Andrew 1997). The reduced levels of regeneration reported in some species mean that their populations are declining whilst others are being maintained or are even increasing, hence gradually altering the composition and/or overall cover of vegetation. In the long term, this could result in loss of some species, and/or the dominance of large areas by undesirable "woody weed" species, with unknown effects on overall sustainability of biodiversity and productivity. There could be a corresponding loss of opportunity for marketing Australian rangeland products as being produced by ecologically sustainable industries, so there is a need to predict long-term impacts of herbivory on rangeland tree and shrub populations.

Ecological processes commonly operate on time-scales of decades or longer (Tyre *et al.* 2000). Because of the long life-spans of woody trees and shrubs compared to humans, there has tended to be very little research to follow the progress of plant cohorts compared to animals. Consequently, the field of mathematical modelling of plant populations has also been somewhat limited (Czaran 1997). Yet mathematical modelling is a useful tool that can be used to predict a range of population outcomes over 100s of years. Individual-oriented matrix population models (Leslie 1945) are widely used to study the long-term growth of populations (Caswell 2001). Two examples of the use of such models for arid zone shrubs are Grice et al. (1994) and Watson et al. (1997).

METHODS: MATHEMATICAL STRUCTURE OF THE MODEL

McArthur *et al.* (2006 in press) gives a full description of the mathematical structure of the model. In brief, a projection matrix is used, consisting of entries that represent the vital rates (fecundity and survivorship) of individuals of different stage classes. Most matrix-models use age-classes, but there is insufficient knowledge to determine the ages of most Australian trees and shrubs, so we adopted stage-classes. During each iteration of the matrix (representing a time-step – which can be any interval, but we assumed years) a proportion of the individuals move up one stage-class. Thus, for each time-step, each individual either remains in the same stage or proceeds to the next.

RESULTS: INPUT DATA & CAPABILITIES OF THE MODEL

Firstly, the user selects from among seven functional types the one that most suits their study species (Table 1). Each functional type is linked to a data-file containing parameters (probabilities) of fertility and survivorship, and how these are affected by grazing and rainfall, derived from literature sources and experimental data of the authors. Parameter files for any type can be edited to more closely represent the study species in question. Alternatively the user may select a generic type and enter their own parameters.

As a starting point (representing time-step zero), the user enters the frequency of individuals in each of seven stage-classes. The stage-classes are those of Tiver and Andrew (1997) where I = single-stemmed juvenile, II = branching juvenile, III = juvenile with central leader becoming dominant, IV = young mature (reproductive but canopy not full-sized), V = mature (full canopy size), VI = < 50% senescent and VII = > 50% senescent. Not all users wish to use all seven stage-classes, and Functional Types 5 and 7 use five stages only. The model can easily be adjusted to use fewer stages, by setting all survivorship probabilities in the earlier stages to 100% so that these stages are "skipped through" without affecting the matrix output.

In the traditional Leslie (1945) models, the stable state is defined as Lambda = 1 i.e. the resulting population is neither increasing nor decreasing, and fecundity levels are adjusted to achieve Lambda = 1. However, through reproduction, all populations have an intrinsic exponential growth rate (Begon *et al.* 2006) which is usually suppressed by variables we include in the model such as grazing or drought. To allow for intrinsic growth rate, users may alter Lambda by adjusting "Doubling Time" – the longer the doubling time, the higher the value of Lambda (intrinsic growth rate) of the population.

The effects of one to four herbivore species (sheep, rabbits, goats or kangaroos) may be added, at the five levels of grazing intensity of Tiver & Andrew (1997). The grazing variables act on the model matrix by reducing survivorship probabilities. The model can be set to run the same grazing parameters for every year (non-varying management regime), or alternatively the grazing regime can be altered at intervals to model management strategies such as the control of rabbits and spelling or grazing rotations.

Table 1: Functional groups represented in the Model (type species in bold)

Funct. Group	Representative Species	Height	Palatability	Longevity	Defoliation Recovery
1	*Callitris glaucophylla* ***Myoporum platycarpum***	>2m	High (decreaser)	Long (> 200 yrs)	Low
2	***Acacia aneura*** *Acacia oswaldii*	> 2 m	High (decreaser)	Long (> 200 yrs)	Low
3	***Acacia ligulata*** *Acacia victoriae* *Cassia chatelaniana* *Dodonaea viscosa* *Eremophila sturtii* *Senna artemisioides*	2 m	Low (increaser)	Short/Med 20-50 yrs	High
4	*Maireana polypteryga* ***Maireana sedifolia*** *Maireana pyramidata* *Rhagodia parabolica* *R. eremaea* *R. spinescens*	< 2m	Low (increaser)	Long (>600 yrs)	High
5	***Atriplex vesicaria*** *Maireana georgei* *Maireana platycarpa* *Maireana trichoptera*	< 1m	High (decreaser)	Short (c. 20 yrs)	Low
6	*Eremophila forrestii* *E duttonii* *E. alternifolia* *E. maitlandii*	2m	Low	Long (>200 years)	Unknown
7	***Acacia carnei*** *Acacia loderi* *Alectryon oleifolius* *Casuarina pauper* *Exocarpos aphyllus* *Pittosporum phylliraeoides*	> 2m	Variable	Long (>200 years)	High

The first option for rainfall is to use a file of historical data for which the default option is 116 years of Koonamore (SA) records. Users may enter their own regional historical rainfall data, and may also edit rainfall data sets to create various climate-change scenarios such as increased or decreased summer rainfall or drought frequency. Alternatively, rainfall can be generated using the rainfall sub-model, which uses the historical data set to create 1-199 years of synthetic rainfall. In the Australian arid zone, it is actually lack of rainfall (drought) that has the most significant impact on ecosystems (Stafford-Smith & Morton 1990; Denham & Auld 2004). Hence, rather than using rainfall totals for each time-step, plant response parameters are set to be sensitive to droughts, defined as months without effective rainfall. Effective rainfall varies with stage-class: juvenile individuals requiring less effective rainfall but only able to survive short periods of drought, whereas older individuals require larger effective rainfalls for maintenance, but are able to tolerate much longer periods of drought.

DISCUSSION: MODEL OUTPUT

The output is a plot of numbers of individuals in each stage-class, as well as the total population number (sum of all the stage-classes) at each annual time-step. Once parameters are set, the model can be run with grazing and rainfall, either separately or together. Some examples of model output for various management and rainfall scenarios are given in Palisetty *et al.* (this volume). The aim of the model is not necessarily to produce accurate predictions, but to provide users with an indication of the magnitude of variation of various management and climate scenarios as a risk-management tool. The identification of variables to which plant populations have high sensitivity also provides focus for future research that, by providing greater accuracy on plant responses to variables, would in turn allow greater predictive power of the model.

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