Population Viability Analysis of Endangered Plant Species: An Evaluation of Stochastic Methods and an Application to a Rare Prairie Plant

by
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CONTRIBUTION OF AUTHORS

Dr. J. Boone Kauffman was involved in the design of the prairie burning experiment with *Lomatium bradshawii* presented in Chapter 2. Kathy Pendergrass and Karen Finley collected data and also assisted with the analysis conducted in Chapter 2. David A. Pyke provided guidance in the implementation of the analyses and writing of chapters 3 and 4.

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Chapter 1. Introduction

STOCHASTIC POPULATION MODELS IN ECOLOGY AND CONSERVATION BIOLOGY

Rare organisms that inhabit variable environments appear to be at the greatest risk of extinction. Computer simulations illustrate that increases in environmental variation cause a corresponding increase in extinction probability (Menges 1992). In the *Origin of Species*, Darwin (1859:153) noted that "any form represented by few individuals will, during fluctuations in the season or in the number of its enemies, run a good chance of utter extinction." It is this chance of extinction and decline in viability of populations that forms the focus of this dissertation.

A key goal of conservation biology is to maintain viable populations of rare species (Soulé 1987). This dissertation utilizes knowledge of environmental variation to estimate extinction risk or stochastic population growth rate for populations of rare plant species. My approach centers on transition matrix modeling, using demographic information from structured populations to project their growth or decline. Because matrix models can incorporate observed levels of environmental stochasticity to simulate population dynamics through time, they can be used to calculate the chance of population loss under various conditions. Land stewards can use this information to determine whether a management action should be taken to benefit a species of concern (Schemske et al. 1994). This type of analysis, therefore, is directly applicable to management and conservation of natural populations.

Transition matrix models are recommended widely as an effective method for evaluating demographic data, especially for calculating population growth rate, extinction probability, and sensitivities (e.g., Menges 1986, Burgman et al. 1993, Schemske et al. 1994, Caswell 2001). Such matrices are based on the Leslie matrix format (Leslie 1945), as modified by Lefkovitch to fit the more general form of a size or stage-structured population (Lefkovitch 1965).

Transition matrices have been used extensively to evaluate population dynamics of plants with various life histories, including trees (Hartshorn 1975, Namkoong and Roberds 1974, Enright and Ogden 1979, Pinero et al. 1984, Burns and Ogden 1985), herbaceous perennials (Sarukhan and Gadgil 1974, Bierzychudek 1982, Meagher 1982, Fiedler 1987, de Kroon et al. 1987, Kaye 1992, Menges 1986 and 1990, Gregg 1991), biennials (Caswell 2001), and annuals (Schmidt and Lawlor 1983). However, significant theoretical and practical issues pertaining to matrix models have not been resolved in the literature, thus limiting their application by managers and technicians. First, environmental stochasticity can be incorporated into matrix models through matrix selection (Menges 1990) or element selection (Ferson 1991; see also Burgman et al. 1993), but these methods may yield substantially different results (Greenlee and Kaye 1997). A formal comparison of stochastic methods is currently lacking in the published literature. Second, little attention has been given to the problem of constraining stage specific survival to 100%, a problem that arises in element selection for stage (but not age) structured models. Lastly, the effect of correlation among vital rates under theoretical conditions has been discussed by a few authors (e.g., Tuljapurkar 1982, Orzack 1993 and 1997, Ferson in prep.), but formal tests of the effect of correlation on multiple species are lacking.

A NOTE ON TRANSITION MATRIX METHODS

In this dissertation, transition matrix models will be constructed for each species by calculating the proportion of individuals that make the transition from one stage to another between years, and the fecundity of each stage (based on fruit production and seedling recruitment measurements). Separate matrices will be built for each pair of years available, e.g. 1992-93, 1993-94, etc. See Caswell (2001) for a complete description of matrix population models and their implementation. Extinction probabilities (calculated in Chapter 2) will be defined as the likelihood that a population will drop below 10 individuals in a 100-yr period, and stochastic growth (Chapters 2-4) rate will be approximated via long-run simulation (Caswell 2001).

Two methods of incorporating environmental stochasticity (and thus calculating extinction probability and stochastic growth rate) will be utilized in this dissertation: matrix selection and element selection. Burgman et al. (1993) review some matrix and element selection procedures. Matrix selection involves randomly selecting a whole matrix (from among a collection of matrices available from a series of years of observation) at each time-step in the model simulation (Figure 1.1) (e.g., Menges 1992). In contrast, element selection is implemented by building a new matrix at each time step with each new element drawn from a distribution with a specified mean and variance (calculated from the collection of individual matrices) (Figure 1.1). This procedure can employ various statistical distributions.

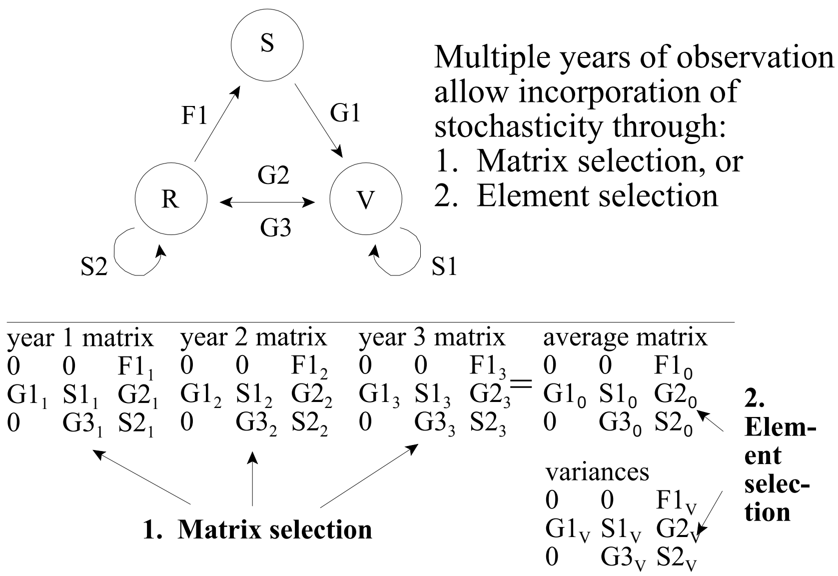

Figure 1.1. A transition matrix model. Matrix selection involves randomly selecting whole matrices (e.g., year 1, 2 or 3) at each time step of the simulation, while element selection generally involves building a new matrix from the mean and variances of each element.

DISSERTATION SCOPE

In Chapter 2 of this dissertation, I present an in-depth evaluation of the effects of prairie burning on an endangered plant of Willamette Valley wetlands, *Lomatium bradshawii*, a near-endemic that appears to be declining due, in part, to fire suppression. Specifically, the impact of fire is evaluated in terms of its effect on extinction probability and stochastic growth rate of wild populations subjected to different fire frequencies. This chapter demonstrates the utility of the matrix model approach for assessing the impact of alternative management practices on population viability, and compares two methods of stochastic modeling.

Chapter 3 broadens the scope of the dissertation to a consideration of methodological issues, utilizing empirical data from 27 populations of five perennial plant species collected over periods ranging from 5 to 10 years. The effects of different methods of incorporating stochasticity are evaluated with stochastic growth rate as the response variable. These methods include matrix selection (also known as whole-matrix bootstrapping) and six statistical distributions for element selection (beta, truncated gamma, truncated normal, triangular, uniform, and observed/discontinuous). This evaluation also considers the effects of two different methods of constraining stage-specific survival to 100%, and tests for interactions between stochastic and survival constraint methods.

The issue of correlation among vital rates is considered in Chapter 4, along with an examination of interactions with species and stochastic methods. Correlation among matrix elements is a significant issue because it can increase or decrease estimates of population viability, such as stochastic growth rate, depending on whether the correlations are positive or negative (Orzack 1997). This creates some uncertainty in viability estimates and the need for including correlation structure, which can be an analytically cumbersome process. Even so, correlation structure has rarely been included in stochastic matrix models (Table 4.2). I use a method of generating correlated random numbers that employs a normal copula, a technique of specifying dependencies of variables that has been overlooked in the ecological literature.

Each successive component of this dissertation seeks to build on the last. A pervading goal among the chapters is to explore applications of ecological theory to some of the practical needs in conservation biology. These needs include improvements in management of endangered species and refinement of tools available to the practitioner of population viability analysis. By exploring both a specific case study and general methodological issues, I hope to contribute in some form to the advancement of the fields of ecology and conservation biology.