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The survey and modelling of small plant populations as a basis for developing conservation strategies

Abstract

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Surveying kinds of approach, working techniques, and the application of models for the study of small plant populations are discussed in the context of the design of conservation strategies. Surveys should start with the precise localization and delimitation of the population and include analyses of its demography and dynamics, genetic structure, and interactions with the environment. Modelling, especially when stage-structured, stochastic population models are used, depends on reliable data from surveys. It can help calculating extinction probabilities and minimum viable population sizes under stable or changing conditions, and predicting the effect of environmental changes and conservational management.

Introduction

The approach to the problem of how to conserve a particular threatened plant species subsisting as a small population often leads to questions such as: is population size actually declining? is preservation of the site in itself enough to maintain the population, or is active intervention required? in the case of such intervention, which is the best mode of management? how much plant material should be collected for ex-situ conservation? is there a risk that collecting will interfere with the dynamics of the population?

In order to answer these questions, and many others that may arise, a maximum of data must be gathered through surveys of the natural population. These data, then, may also be used in models that are able to predict the future of the population.

Kinds and techniques of surveying

A high proportion of autecological plant studies so far completed have been conducted in habitats where individual plants may be identified, measured, manipulated and mapped with relative ease. However, the scientist concerned with the conservation

of rare species cannot choose the species to be studied and may have to operate in communities that have a structure which hinders or prevents the detailed recording of data.

The fact that a species is very scarce in an area poses additional problems when field data are being collected. One such problem is to know whether the population can be studied without causing irreparable damage. Restrictions will almost certainly have to be imposed on experimental manipulation of the ecosystem and on the collection of plant material for detailed laboratory study.

Bearing such limitations in mind, one may discern three main fields of study in surveying a small plant population for conservation purposes, as follows:

– demographic structure and population dynamics:
– – delimitation of populations,
– – population size and geographical distribution,
– – survival, growth and reproductive output,
– – population structure based on plant size category and/or life-history stage,
– – seed bank composition and dynamics;
– genetic structure:
– – genetic variation within and among populations;
– environmental interactions:
– – habitat studies (topography, geology, soil and climate),
– – biotic interactions (predation, competition, symbiosis, and parasitism).

Demographic structure and population dynamics.

The first step in this type of study should always be the geographic delimitation of the population. It is important to explore the surroundings of the site where the population is known to exist in search for more individuals, subpopulations or populations of the same species. Aerial photographs, along with knowledge of the habitat, can be of great help in this search.

The area covered by the population can be delimited using standard topographic techniques. However, when it is of a certain magnitude, a global positioning system (GPS) technique may be helpful. This technique, based on the reception of satellite signals, enables a fast and accurate détermination of the population's location and boundaries.

Counting the number of plants can be a formidable task if the population is large, if the plants are very small, or if they reproduce vegetatively by off-shoots . When possible it is best to count the entire population. If this is not feasible, the population should be sampled and the numbers estimated. It is important to develop a practical and reproducible method that accurately characterizes the number of plants and their geographical distribution, so that the data can be used as a baseline for future monitoring of the population.

Next, individuals sampled in the field must be marked and/or mapped. Detailed mapping of individuals, based on an orthogonal grid system, can be accomplished using frames with graduated cross-bars. Hence, the fate of each individual sampled, its survival, growth and reproductive output, can be regularly followed.

Seed production can be estimated by determining of the mean number of inflorescences per plant, of seed-bearing fruits per inflorescence, and of viable seeds per fruit, in a sample of individuals of varying sizes, followed by allometric regressions of seed number on plant dimensions.

As the individuals of a population do not all behave in the same way, in terms of the parameters mentioned – survival, growth and reproductive output –, the population must be structured in groups. The criterion followed for such classification is normally plant size or life history stage. Stages should be so defined as to minimize the inner class variation in regard to the three before-mentioned parameters.

Knowledge of seed bank composition and dynamics requires estimating the quantity and longevity of viable seeds in the soil through soil sampling and germination, plus viability tests. Thereby, the basic information needed for the study of the dynamics of the population is completed.

Genetic structure of the population

An estimate of the genetic diversity of a small population can be made on the basis of a proper sampling of plant material and subsequent analysis in the laboratory. Traditionally, such estimates have been based on electrophoretic studies of isozymes. Nowadays, DNA analysis by new techniques using RAPD (random amplified polymorphic DNA) may allow for better estimates with a lower impact on the population, since less plant material is required.

A good knowledge of the genetic structure of a population can be of great help in conservation management. With regard to seed collection, it can help determine the sample size required to capture a representative share of the genetic diversity of the population. It is also relevant when planning introductions, reintroductions or reinforcement operations.

Environmental interactions

The study of the habitat of a population may consist of a geological description of the site, measurement of the slope and its orientation, analysis of soil samples, and compilation of climatic data from the nearest station. Further information may be obtained from the study of the biotic interactions of the population, including evidence of predation, competition, symbiosis or parasitism.

As a result, key factors responsible for the low number of individuals in the population (strong competition, absence of adequate pollinators, etc.) can be inferred Similarly, optimal culture conditions for ex-situ conservation may be devised.

Modelling populations

When modelling a population, all relevant demographic data obtained in surveys are put together and synthesized in a series of mathematical formulae. Their main purpose is to predict the future development of a population under current conditions or when one or several factors are altered.

There are several population models which follow different approaches. Methods based on discrete-time stage-structured models are probably the most flexible and the easiest to fit with available data (Menges 1986).

In these models, the projections begin with the structure of a population at a given time (e.g. , N_1 seedlings, N_2 juveniles, N_3 subadults and N_4 adults). Over one time step, some individuals will remain at the same stage, some will grow to another stage and others will die, changing the initial population structure. In fact, stage-specific survival, fecundy, and growth rates project the future of the population (Fig. 1). Each is an element in a square matrix (projection matrix) whose value can be empirically measured for a given population (Menges 1986).

The "finite rate of increase of the population" (L) is an important parameter in plant population dynamics, that can be calculated from the projection matrix. It represents the actual rate of population growth for a population characterized by a given set of survival and fecundity records.

When one maintains the life history components constant, one obtains a deterministic model which simulates a population tending asymptotically toward a stable-stage distribution (constant percent of individuals in each stage) with a total size that is either constant (L = 1), or growing (L > 1), or declining (L < 1) at a steady exponential rate.

A major limitation of deterministic models is their assumption of unchanging conditions. The use of stochastic models, allowing life-history components to vary over time and/or among individuals of the same stage, yields more realistic predictions.

Stage-structured, stochastic population models can be based on computer simulation. Such computer simulation models are quite flexible, being able to incorporate compensatory mechanisms and systematic pressures on a species or its habitat (Menges 1986). These models, even though not entirely accurate in their predictions, can be most effective in representing ideas and relationships. They can be used to estimate the effects

Projection matrix   Population   Population
structure   structure
t(n)   t(n+1)

$$
\begin{bmatrix}
a.11 & a.12 & a.13 & a.14 \\
a.21 & a.22 & a.23 & a.24 \\
a.31 & a.32 & a.33 & a.34 \\
a.41 & a.42 & a.43 & a.44
\end{bmatrix}
\times
\begin{bmatrix}
N1 \\
N2 \\
N3 \\
N4
\end{bmatrix}
=
\begin{bmatrix}
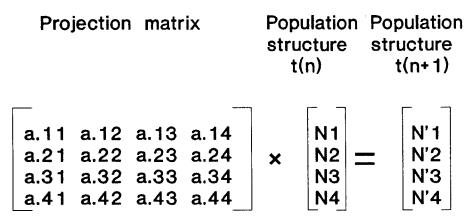N'1 \\
N'2 \\
N'3 \\
N'4
\end{bmatrix}
$$

Fig. 1. Discrete model where the population is structured in categories (Leslie 1945, Lefkovitch 1965). The projection matrix contains stage-specific information on transfer rates to other stages, reproductive output and survival rate.

of rare species cannot choose the species to be studied and may have to operate in communities that have a structure which hinders or prevents the detailed recording of data.

The fact that a species is very scarce in an area poses additional problems when field data are being collected. One such problem is to know whether the population can be studied without causing irreparable damage. Restrictions will almost certainly have to be imposed on experimental manipulation of the ecosystem and on the collection of plant material for detailed laboratory study.

Bearing such limitations in mind, one may discern three main fields of study in

of different types of management or of directional changes in environmental conditions. Thus, they can provide information to natural area managers and environmental agencies and help them make decisions.

Another practical application of stochastic models is the assessment of extinction probabilities and minimum viable population sizes with respect to environmental stochasticity.

Extinction probability and minimum viable population. sizes

Two major goals in the conservation of small and threatened plant populations are predicting the probability of extinction over a defined period of time and estimating the minimum population size necessary to keep extinction risk acceptably low. Population size is related to extinction probability because larger populations are better able than smaller ones to counter stochastic events that threaten populations with extinction (Menges 1991). Among such stochastic events, one can discern environmental, demographic, and genetic stochasticity, and natural catastrophes (Shaffer 1981).

Environmental stochasticity takes into account variations in the physical and biotic environment over time. Natural catastrophes can be considered to be an extreme form of environmental stochasticity. In models that reflect environmental stochasticity, life-history components of the projection matrix vary randomly within certain values from one time step to another. Hence, repetitions of the same simulation with the same starting data yield different prediction. Extinction probability can then be estimated as the number of simulations that end in extinction over the total number of simulations run. By starting from a wide range of population sizes, one can obtain the size of a minimum viable population (MVP).

Demographic stochasticity refers to chance events that affect the survival and reproductive success of individuals, not related to the environment. The effects of demographic stochasticity are usually important only in populations of 50 or less individuals (Keiding 1975).

Finally, genetic stochasticity considers the possibility that small populations may lose genetic variation, causing inbreeding depression and loss of evolutionary flexibility (Hamrick & al. 1979, Levin 1984). To counter these two negative effects MVP of 50 and 500 individuals respectively have been recommended (Franklin 1980). These numbers have been widely used in management considerations.

Since MVP to buffer environmental stochasticity and natural catastrophes in wild populations are of the order of 10^3-10^6 individuals (Shaffer 1987), genetic considerations may be considered as secondary to environmental stochasticity in formulating MVP for plant species. However, for ex-situ seed storage, where environmental variation is irrelevant, population-size considerations should focus on sampling genetic variation and attaining MVP based on genetics (Menges 1991).

At present, the most important restraint to practical application of population models is the availability of appropriate data from the populations. As previously observed, the required data can be quite easily obtained. However, the population must be monitored for several years, if variation in life-history components is to be taken into account.

Conservation strategies

The different strategies to adopt in a conservation programme can be classified under three categories: regenerative, biotic and adaptive (Table 1).

Table 1. Main strategies that can be adopted in the conservation of small populations.

Strategy:	Actions:	Knowlegde required:
Regenerative	propagation, culture, storage, introductions, reintroductions, reinforcements, etc.	reproductive biology, demographic and genetic structures
Biotic	stimulation of symbiotic interactions; inhibition of predative, competitive and parasitic interactions	biotic interactions
Adaptive	preservation of original habitat, prevention of habitat degradation (soil erosion, soil/water/air pollution, etc.)	physical environment

Regenerative strategies are based on a rapid increase in the number of individuals using ex-situ propagation techniques. Biotic strategies seek changes in the current biotic interactions that may benefit the targeted population. Finally, adaptive strategies aim at the maintenance of the population's optimal habitat.

The development of all these strategies requires specific information that, as shown before, can be provided by the survey and modelling of the population.

Conclusion

The success of a conservation programme for a small plant population heavily depends on the information available regarding the demographic status and the genetic structure of the population, the reproductive biology of the species, and its biotic and abiotic interactions.

This type of information, which is gathered through surveys of the natural population, is crucial for assessing the current situation of the population, for grasping the factors that promote its extinction, and for devising the type of direct or indirect interventions that may be necessary to assure the persistence of the population.

Modelling is another interesting tool in conservation, especially in the case of small populations where one cannot afford direct experimentation. It may help identify the threats to the population, anticipate future population changes, estimate the probability of extinction from measurable population parameters, and calculate the effects of various management policies and different environmental conditions.

Hence, both the survey and the modelling of populations comprise critical keystones to the design and implementation of conservation programmes for plant species with small populations.

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