



Software data news

Sensitivity Analysis of Range Dynamics Models (SARDM): Quantifying the influence of parameter uncertainty on forecasts of extinction risk from global change



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ABSTRACT

Spatially explicit demographic models are increasingly being used to forecast the effect of global change on the range dynamics of species. These models are typically complex, with the structure and parameter values often estimated with considerable uncertainty. If not properly accounted, this can lead to bias or false precision in projections of changes to species range dynamics and extinction risk. Here we present a new open-source freeware tool, “Sensitivity Analysis of Range Dynamics Models” (SARDM) that provides an all-in-one approach for: (i) determining the implications of integrating complex and often uncertain information into spatially explicit demographic models compiled in RAMAS GIS, and (ii) identifying and ranking the relative importance of different sources of parameter uncertainty. The sensitivity and uncertainty analysis techniques built into SARDM will facilitate ecologists and conservation scientists in better establishing confidence in forecasts of range movement and abundance.

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Software availability

Name of software: SARDM

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Available since: 2016

Software required: RAMAS GIS (Akçakaya and Root, 2005; www.ramas.com)

Availability: <https://github.com/GlobalEcologyLab/SARDM>

Cost: Free

Program language: Python

Program Size: 25 mb

1. Introduction

Stochastic demographic models are a commonly used method for forecasting the effect of global change on species' range dynamics (Lurgi et al., 2015) and to establish ecological and evolutionary responses to past climate change (Fordham et al., 2014a;

Prowse et al., 2013). Their principal advantages are the capacity to capture a wide range of ecological mechanisms simultaneously and to provide direct predictions of spatio-temporal patterns of abundance and extinction risk (Fordham et al., 2013a). However, all models of species' range dynamics must make simplifying assumptions to minimize the complexity of interactions between biotic and landscape processes (Fordham et al., 2014b). These assumptions can lead to uncertainty in model structure, and in combination with vagueness in parameter estimates, can cause bias in forecasts of species range dynamics.

Sensitivity analysis has been an integral part of stochastic risk-assessment modelling since the inception of the disciplines of conservation biology and global change. Early work demonstrated how model predictions could be influenced by uncertainty in input parameters (Mills et al., 1996), and methods were developed subsequently to allow for the systematic ranking of input values according to their relative influence on risk and abundance metrics (e.g., Brook et al., 2002; Drechsler, 1998; McCarthy et al., 1995). Yet comprehensive sensitivity analyses on population viability analysis (PVA) models are still not routine, perhaps because they are difficult and time-consuming to implement and analyse.

Integrating complex and often uncertain information into range-dynamics models obliges the practitioner to use sensitivity

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analyses to explore the influence of parameters on model predictions (Naujokaitis-Lewis et al., 2013). Doing so can improve a model's value in theoretical and applied contexts (Conlisk et al., 2013). For example, sensitivity analysis can be used to determine which parameters: (i) require additional research to most effectively reduce uncertainty in predictions; (ii) are unimportant and can be eliminated from the final model, or at least not varied; and (iii) contribute most to output variability (Hamby, 1994). More recently, sensitivity analysis has been used in combination with field data to calibrate individual-based demographic models (Wells et al., 2015); and to develop conservation protocols for mitigating extinction risk due to climate change (Stanton et al., 2015).

Models used to study and predict species' range dynamics are sensitive to input parameters in two ways: uncertainty associated with a sensitive parameter estimate can propagate through the model resulting in a large contribution to variability in predictions; and input parameters can be strongly correlated with model results, meaning only small changes in the input value result in changes that alter recommendations (Hamby, 1994). The former represents parameter importance, which is what underpins uncertainty analysis; while the latter represents parameter uncertainty, which underpins sensitivity analysis. The point of contrast is that a sensitive parameter is not necessarily important if it is known precisely, thereby contributing little to variability in the model output.

A key criticism of forecasts of range movement and extinction risk from stochastic demographic models is that they are seldom examined for sensitivity to input parameters, and rarely using global-type approaches (i.e., varying all parameters over the plausible range of parameter space; Naujokaitis-Lewis et al., 2009). Where sensitivity analyses have been done, these analyses have tended to develop a sensitivity ranking – a list of input parameters sorted by the amount of influence each has on the model output – usually using one-at-a-time sensitivity measures (e.g., Anderson et al., 2009). This technique involves generating a sensitivity ranking by increasing each parameter by a given percentage (i.e. $\pm 10\%$) while leaving others constant, and quantifying the change in the model output. The disadvantage of this simple one-at-a-time approach is that it does not address the interaction and influence of all parameters (Norton, 2015; Saltelli and Annoni, 2010). This is important, since parameter interactions are known to influence estimates of extinction risk from demographic models (Pearson et al., 2014). An alternative is to run a factorial analysis, which involves choosing a number of alternative states (e.g. low, medium and high values) for each parameter and running the model for all possible combinations; however, this can quickly result in a substantial number of model runs (Conroy and Brook, 2003). Recently, Latin-hypercube sampling procedures have been used for sensitivity and uncertainty analysis of species' range dynamics models used in climate change impact studies (Fordham et al., 2013b; Harris et al., 2012). The approach generates a stratified random subset of parameter input values for simulation, by assigning a plausible range for each parameter and sampling all portions of its distribution (Norton, 2015). The procedure is superior to factorial analysis because it allows model parameters to be varied concurrently, permitting interactions, typically with far fewer iterations (Conroy and Brook, 2003). However, Latin-hypercube sampling (like factorial analysis) is time consuming to implement without automation (e.g., using the Latin Hypercube Sample (lhs) package for Program R [<http://lhs.r-forge.r-project.org>] or the Uncertainty Quantification Python Laboratory [<http://www.uq-pyl.com/>], etc.) and, as such, the method is not commonly implemented in research done by the ecological community (Saltelli and Annoni, 2010).

Moving from model predictions to effective climate-adaptation strategies will require methods for improving the understanding of model uncertainty and parameter sensitivity in forecasts of range dynamics and extinction risk. Some population viability analysis software packages, like Vortex v10, have recently developed 'built in' sensitivity analysis (Lacy et al., 2013), but this is missing from most applications for population dynamics modelling and so a generic tool is badly needed. The required software must have the capacity to: automate a subset of parameter values for simulation; draw these parameter values from different types of sampling distributions; and generate and analyse output from multiple simulations.

2. Novelties of SARDM

SARDM is a new software tool we have developed to provide an all-in-one approach for accounting for uncertainty in population viability analysis and associated range-dynamics model predictions, and for identifying sources of this uncertainty (Fig. 1). It features three automated sampling procedures, drawing parameters from a choice of five different sampling distribution types. It then compiles output from multiple simulations and provides the user with the option of analysing output using built-in statistical tools. The software is written and compiled in the open-source language Python (www.python.org), and has been targeted towards the sensitivity analysis of spatially explicit demographic models, but can facilitate global sensitivity analysis for non-spatial demographic models. More specifically, SARDM parses information for range-dynamics models compiled using RAMAS GIS, www.ramas.com, because it is the most widely used software for metapopulation conservation and is used extensively to investigate the influence of climate change on range movement and extinction risk. Furthermore, RAMAS GIS models spatio-temporal change as well or better than most other range dynamics software and is user friendly (see a recent review of software options by Lurgi et al., 2015), but does not yet have a built in global sensitivity module.

Although SARDM was developed and tested using RAMAS GIS, the Python source code can be adapted to parse information from other software used to model species range movement and extinction risk (e.g., Vortex [www.vortex10.org], HexSim [www.hexsim.net], RangeShifter [Bocedi et al., 2014]). The Python code is available for use and modification under a Creative Commons licence. The source-code and pre-compiled .EXE versions of SARDM are available from: <https://github.com/GlobalEcologyLab/SARDM>. Any required changes to the software will be logged at the site of the software repository and users will be alerted.

Three sensitivity analysis techniques are built into SARDM: Latin hypercube, random and full factorial. The Latin hypercube and factorial approaches are described above. The random sampling technique selects input parameter values from plausible ranges without stratification and, as such, the distribution of the parameter might not be fully sampled. Results from sensitivity analysis with Latin hypercube or with random sampling can potentially be similar, especially if samples are numerous and the parameter space is small (Helton and Davis, 2003). However, given the relative ease with which SARDM can implement the more complex but theoretically superior Latin-hypercube methods, we can imagine few instances where random sampling would be preferred.

SARDM allows parameter values to be sampled flexibly from five distribution types: uniform, Gaussian, triangular, lognormal or Beta. Parameters include key demographic processes known to have a strong effect on estimates of range movement and extinction risk (e.g., population growth rate, carrying capacity, survival rates) and parameters which are difficult to estimate with high precision

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