Twenty years of dynamic occupancy modelling – what’s been done, and where to next?

2024-03-25

Abstract

In the twenty years since their introduction, the dynamic occupancy model has become an important tool for describing trends in species occupancy across landscapes and throughout time while accounting for imperfect detection.

We present a retrospective of the first two decades of dynamic occupancy modelling based on the results of a systematic review of models fit to field data. We describe how authors have used these models to describe patterns of occupancy for a diverse range of study systems and focal taxa, dedicating particular emphasis to how authors engaged with modelling decisions such as covariate selection and model evaluation. Modelling approaches vary considerably within the literature, and objective metrics of model performance are rarely estimated.

From these results we consider what the future of dynamic occupancy modelling may hold. Key questions remain on how the modelling process influences parameter estimates and model performance. Considerably more emphasis must be placed on evaluating models via processes such as out-of-sample validation. Further opportunities also abound; newly proliferating data types such as bioacoustics and camera traps present new questions around model design as well as new ways to study occupancy at scales which have not been historically possible. The suitability of dynamic occupancy models to generating predictions, as an alternative to static models, is another area which has been historically under-emphasised.

# Introduction

The dynamic implementation of the occupancy model was introduced two decades ago in MacKenzie et al. (2003). Since then, the model has become a popular tool for ecologists seeking to describe occupancy dynamics while accounting for imperfect detection, generating hundreds of articles describing model uses and inspiring popular software tools for their implementation (Kery and Chandler 2016).

The dynamic occupancy model (DOM) fills an important niche in the ecological modelling landscape as an approachable midpoint between purely correlative species distributions models and more complex process-based models. Data input requirements are achievable for many research programs, and estimates of occupancy dynamic parameters (i.e., colonisation and extinction) are of use in addressing many key ecological questions. Furthermore, the capacity to control for imperfect detection addresses a ubiquitous source of bias and uncertainty in field ecological data. A description of the basic model form is presented in **Box 1.**

## How are they used

Outputs of dynamic occupancy model may be put to many uses. In many cases, simple estimates of the ecological parameters (i.e. occupancy, colonisation, or extinction) can aid in describing understanding changes in range dynamics. In other cases, estimates of covariates relating to these parameters are used to test hypotheses, for example, the influence of forest fire on the probability of local extinction. Less frequently, DOMs are used to make predictions of site occupancy either across unsurveyed sites or into the future under predictions of future conditions or management actions.

These models are particularly well-suited to non-equilibrium situations such as recovering, declining, or invasives species, where assumptions of conventional species distribution models cannot be met.

## What does this article do

We present a comprehensive overview of how the dynamic occupancy model has been applied in its first two decades, with a look to the key questions which remain on how DOM can best be used to address ecological questions.

# History of the dynamic occupancy model

## Precursors

Dynamic occupancy models originate in the mask-recapture model literature with roots in the robust sampling design, which is also used in the Jolly-Seber and other related models. In the case of the dynamic occupancy model the unit of inference is the site, not the individual.

DOMs bear similarities to the Incidence-Function or Hanksi models frequently used in the study of island biogeography, with similar probabilities of colonisation and extinction; DOMs are typically not spatially-explicit, however.

## Variants

Various parameterisations of the standard dynamic occupancy have been described, the most frequent being those described by MacKenzie and Nichols. The former estimates probabilities of initial occupancy, colonisation, extinction, and detection and derives probabilities of yearly occupancy. The latter directly estimates probabilities of occupancy, local extinction, and detection; colonisation is then estimated as a derived parameter.

The Bayesian implementation of the dynamic occupancy model was described by Nichols.

## Model extensions

The dynamic occupancy model has been extended numerous times, to make it suitable for multiple scales, multiple species, and to accommodate for false positives. An in-depth discussion of model extensions is presented in Bailey 2014.

# Review of published implementations

## Systematic review methodology

## Study systems

## Data collection

## Objectives and authorship

## Model development and evaluation

# Future priorities for dynamic occupancy models

## Model selection and evaluation

## Continuous detection data

## Predictions

Kery, Marc, and Richard Chandler. 2016. “Dynamic Occupancy Models in Unmarked,” 24.

MacKenzie, Darryl I., James D. Nichols, James E. Hines, Melinda G. Knutson, and Alan B. Franklin. 2003. “Estimating Site Occupancy, Colonization, and Local Extinction When a Species Is Detected Imperfectly.” *Ecology* 84 (8): 2200–2207. <https://doi.org/10.1890/02-3090>.