A review of dynamic occupancy models and guide to building them for applied ecology

Target Journal: Ecography

# Abstract

# Introduction

## Overview

Capturing patterns of species occupancy over space and time is a common goal for ecologists, particularly those focused on conservation and wildlife management. Advances in recent decades have provided numerous options for methods and statistical models, with sub-fields such as species distribution modelling and metapopulation modelling contributing increasingly sophisticated tools to support on-ground practitioners. No matter the method, ecologists must balance data input requirements and analyst skillsets against inferential power and suitability to purpose when determining how best to analyse data from natural systems.

Dynamic occupancy models[[1]](#footnote-1) (henceforth DOMs) balance ease of use, realistic data requirements, and assumptions with analytical capabilities suitable for answering many types of questions common in ecology and conservation science. MacKenzie et al.’s 2002 paper defining the model has been cited [XXXX] times, reflecting their importance in applied ecological modelling.

This paper has two principal objectives:

1. To review the history of DOMs development and their use in applied ecological research, including for what practitioners used these models and how they implemented them.
2. To provide practical recommendations for how to use these models to ensure outputs and predictions are as robust as possible, with a practical workflow for development to incorporate key considerations.

## Model development and history

The standard form of the dynamic occupancy models was initially described by MacKenzie et al. 2002 in their Ecology paper ‘Estimating site occupancy, colonisation, and local extinction when a species is detected imperfectly’. This title highlights one of the key benefits of the model - the ability to account for imperfect detection is a ubiquitous problem in surveying wildlife, and the subject of a great deal of discussion in this field.

Give a basic definition of the model structure, with a visualisation and directions to other key resources with further information?

Multi-species and multi-state versions?

Bayesian implementation?

Additional extensions

- elephant dispersal paper

- other imperfect detection formulations

# Review methods

## Paper elicitation

This review was focused only on papers which model occupancy across space and time using real data. To quality for inclusion, papers were required to fulfil each of these criteria:

* Multiple sites capable of exhibiting two or more occupancy states; including an occupied and unoccupied state.
* Multiple time-steps between which occupancy states can change, with transitions between states modelled as a Markovian process.
* Data must be collected from a natural system, not theorical or simulated. The data need not have been explicitly collected for the given paper.

Following internal discussions, four search terms[[2]](#footnote-2) were used to generate the initial pool of papers:

* Dynamic occupancy model
* Occupancy dynamics model
* Multi-season occupancy model
* Stochastic patch occupancy model

Each term was searched on Google Scholar (Appendix I). The first 100 results (if available) for each term were considered for inclusions, although non-English papers, those clearly outside the field of ecology, or those not accessible via Google Scholar or the University of Melbourne library were immediately discarded. 287 papers remained for consideration at this stage.

## Preliminary and formal reviews

The pool of papers was stratified by search term and publication period[[3]](#footnote-3) and randomly ranked within their strata. Papers in the lowest 25% or lowest 5 (whichever was larger) were marked for inclusion in review. In cases where papers did not meet qualification criteria, they were replaced by the next lowest paper in their strata if available.

Authors developed a structured spreadsheet with categories for study metadata, objectives, taxa, location, survey methods, detection, covariates, modelling, and outputs. Findings were systematically noted as each paper was read; 75 papers were included at this stage.

Study questions were further refined after the preliminary review, and a revised spreadsheet with better articulated parameters was generated (Appendix II). The authors also determined that ‘Stochastic patch occupancy models’ represented a distinct model form from the other three search queries, with a unique history and distinct qualities. Therefore, we decided to exclude these papers (n = 21) from the formal review.

For the formal review, all remaining papers were re-read and their results logged in the spreadsheet. The final count of qualified papers was n = 54. All analysis was conducted in R.

# Results

# Discussion

# Conclusions

1. Also variously termed ‘occupancy dynamics models’ and ‘multi-season occupancy models’ [↑](#footnote-ref-1)
2. Plus grammatic variation, e.g. ‘Occupancy dynamic model’ [↑](#footnote-ref-2)
3. 2000-2005, 2006-2010, 2010-2015, 2015-2021 [↑](#footnote-ref-3)