# 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.

MacKenzie et al.’s 2002 paper, ‘Estimating site occupancy rates when detection probabilities are less than one,’ first defined what is now termed the ‘Dynamic occupancy’ model[[1]](#footnote-1) (henceforth DOMs - see ‘Box 1’ for details on the basic model structure). The model sits in the sweet spot for many applied ecologists: it requires only common presence/absence counts; albeit with revisits during each primary sampling occasion; yet provides valuable estimates of initial occupancy, colonisation, extinction, and detection probabilities.

Box 1: What are dynamic occupancy models?

**Model definition**

The basic structure of the model is simple, consisting of an occupancy module and an observation module. In the occupancy module, independent sites may exist in either occupied or unoccupied states; transitions between the two between time steps are termed colonisation and extinction. In the observation module, we account for imperfect detection by conducting multiple surveys within a single timestep.

**[GRAPHICAL REPRESENTATION HERE]**

**[Key formulas to go here]**

**Assumptions**

1. Sites are considered ‘closed’ between time-steps, with occupancy state presumed to be un-changed.
2. There are no false positive detections.
3. No unmodelled heterogeneity exists.

**Model extensions**

Beyond the basic form of the model, authors have contributed several other extensions to DOMs. Most popular are the multi-species extensions, valued for modelling interspecific relationships, and multi-state options with use for incorporating demography among other variations in what constitutes occupancy. Also available are variants accounting for false positive error.

Researchers in governmental agencies, academic institutions, and non-governmental organisations (NGOs) have implemented DOMs for a wide range of species and purposes, from estimating occupancy patterns of threatened species to monitoring the range expansion of invasive species. Since its publication, MacKenzie et al.’s 2002 model-defining paper has been cited 4962[[2]](#footnote-2) times increasing year-over year – a testament to their continued popularity within the applied modelling community.

DOMs do have their pitfalls, however. Their assumptions (see Box 1), while relatively straightforward, are also unlikely to be entirely fulfilled in natural systems. While a reasonable amount of work has been conducted on the importance of the closure assumption, comparatively little has been done with respect to the heterogeneity assumption. Heterogenous landscapes and patterns of occupancy are the norm in ecological systems and fully satisfying this assumption is not realistic in natural systems. The main option for users to mitigate this concern is via the inclusion of covariates to estimate parameters to describe how environmental variation may affect probabilities of occupancy or detection; however, implementation appears inconsistent across papers.

The matter in which models are implemented, including the data inputs, covariates considered, manner of final model selection, and evaluation of model fit are all important contributors to the reliability of model outputs. When conservation and management decisions are made based on model outputs, it is critical to ensure that all steps are fully considered to develop the best possible model.

This paper has two principal objectives:

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

1. Also variously termed ‘occupancy dynamics models’ and ‘multi-season occupancy models [↑](#footnote-ref-1)
2. Google scholar citation figure [↑](#footnote-ref-2)