

## FAST METHODS FOR FITTING LOG-GAUSSIAN COX PROCESS MODELS IN ECOLOGY

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Log-Gaussian Cox processes (LGCPs) offer a framework for modelling point patterns that can accommodate latent effects. These latent effects can be used to account for missing predictors or other sources of clustering that could not be explained by a Poisson process. Such models are important in ecology where point patterns arise in the form of presence-only data—records of species' locations—and are used to construct Species Distribution Models (SDMs) as a function of environmental variables. Fitting LGCP models can be difficult and time consuming and, as a result, limits the ability of researchers to flexibly analyse presence-only data. We develop novel methodology and software for fitting LGCP models, as well as demonstrating how to incorporate presence-only and other data sources jointly into SDMs.

Fitting LGCPs quickly is challenging due to their intractable marginal likelihood which involves a high dimensional integral to account for the latent Gaussian field and leads to large spatial variance-covariance matrices. We address these challenges using a novel combination of variational approximation and reduced rank interpolation. Additionally, we implement automatic differentiation that enables us to obtain exact gradient information rapidly for computationally efficient optimisation and inference. We demonstrate the method's performance through both simulations and a real data application, with promising results in terms of computational speed and accuracy compared to that of existing approaches.

We then extend our novel method to combine presence-only data with that obtained through scientific surveys to improve SDMs in what is called data integration. We demonstrate scenarios in which sharing both the latent influence and the species'

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response to the environment across each dataset can improve upon results achieved by modelling each individually, both via simulation and by using real data involving several species of flora in NSW, Australia.

We also illustrate the use of software developed to implement these advances via the freely available R package (<https://github.com/ElliottDovers/scampr>). The package allows users to fit likelihood-based LGCP to presence-only data swiftly and with a formula interface familiar to those in other regression-style modelling frameworks implemented on R.

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