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# Phenology of epigeous macrofungi found in red gum woodlands

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ABSTRACT

The timing of fruiting body production by epigeous macrofungi is thought to be mostly determined by substrate moisture and temperature. Understanding the environmental cues that influence fruiting can help when designing surveys, interpreting results, and predicting effects of an altered climate. Species fruiting in 22 river red gum (*Eucalyptus camaldulensis*) woodland sites in southeastern Australia was recorded at regular intervals over 2 y. Models were constructed to explain the phenology of 25 of the most common species, as well as the total number of species found fruiting on each survey occasion. We found that rainfall minus evaporation and the time of year each influenced fruiting of the common fungi, but to varying degrees depending on species. Using these same variables, the model predictions for the total number of species expected to be found on each survey occasion fit the observations reasonably well ($R^2 = 0.49$). The models could be used to estimate the probability of presence for species of conservation interest, to optimise survey timing, or to predict effects of climate change on fruiting.



## Introduction

Surveying fruiting bodies is a standard method for assessing fungal diversity. Despite recent advances in molecular survey techniques, and their relative efficiency at detecting species, fruiting body surveys are still used because they may find species missed with molecular methods. Although not all fungi will fruit during a survey and thus be detected, fruiting body surveys can produce results that are indicative of environmental conditions, sometimes more so than molecular methods (Peter *et al.* 2001; Lilleskov *et al.* 2002; Newbound 2009).

An understanding of fungal phenology is important to guide the design of fruiting body surveys and to interpret their results. If the cues that trigger fruiting are known then the timing and intensity of surveys can be planned (Salerni *et al.* 2002). Survey frequency may need to be increased when most species are fruiting, as sporocarps are short lived, usually lasting only between a few days to a few weeks, and may easily be missed (Vogt *et al.* 1992; Salerni *et al.* 2002). Knowledge of phenology can also support the analysis of observations. For example, if we know how likely a species is to be seen in particular conditions, we can infer its presence or absence at sites if it was not found (Mackenzie & Royle 2005). In addition, if the relationship between phenology and climate can be reliably estimated, then the effects of climate change on fruiting patterns can be predicted (Gange *et al.* 2007). As the presence of fruiting bodies indicates an active

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mycelium, then changes to the number of species found with climate change may reflect environmental processes.

A number of environmental factors important for triggering primordia formation and the production of fruiting bodies have been identified from experiments in culture, from work with cultivated edible mushrooms and through field studies of phenology. The culture and edible fungi research has studied a relatively small number of saprotrophic species. This work has identified factors including the need for high substrate moisture, sudden drops in temperature to initiate primordia, and light and dark periods of specific length for both initiation and development of mature fruiting bodies (Elliot 1994; Ohga 1999; Kues 2000; Kues & Liu 2000).

The results from studies of phenology in the field provide more general information on how the environment influences fruit body production of macrofungi. This research has mostly focussed on the effects of rainfall and temperature. Some of this work has looked specifically at epigeous fungi (*e.g.* Eveling *et al.* 1990; Straatsma *et al.* 2001; de Aragon *et al.* 2007), and some at hypogeous species (*e.g.* Hunt & Trappe 1987; Johnson 1994; Claridge *et al.* 2000; Abell *et al.* 2006). Others have singled out particular common fungi or harvestable species (Chacón & Guzmán 1995; Munguia *et al.* 2003; de Aragon *et al.* 2007). In a few cases the number of species found, or the abundance of sporocarps, have been described by models using rainfall and temperature as explanatory variables (Eveling *et al.* 1990; Johnson 1994; Straatsma *et al.* 2001; Salerni *et al.* 2002; de Aragon *et al.* 2007). These analyses typically investigate the influence of climate by considering how well discrete periods of rainfall or temperature explain variation in phenology. Usually a combination of rainfall and temperature effects has been influential, with emphasis on one or the other for particular time periods. Soil moisture has also been investigated, either directly measured, or by considering both rainfall and evapotranspiration (Claridge *et al.* 1993; Swaty *et al.* 1998; de Aragon *et al.* 2007).

The research presented here has built on this previous phenology research by using the results of 2 y of surveys within Bayesian models that consider rainfall, evaporation and the time of year as factors for fruiting. The aim was to understand how environmental conditions influence fruiting body production of epigeous macrofungi, in the relatively dry environment of river red gum woodlands in southern Victoria. The probability of detection for particular species using fruiting body surveys under different conditions, and the site occupancy for common species were predicted. As an application of the model, the effect of various climate change scenarios on fruiting was estimated for our region, which is expected to become warmer and drier.

## Materials and methods

### *Study area*

Fruiting body samples were collected from 22 sites of river red gum woodlands in and around Melbourne (38°S, 145°E) (see Appendix A for details), a city of three and a half million people located on the coast of south eastern Australia. The woodlands are remnants that resemble the vegetation structure that existed before European settlement. The size of the woodlands ranged from small parks of less than 1 ha to a large 800 ha reserve. The open canopy of all sites is dominated by *Eucalyptus camaldulensis* (river red gum), an iconic tree with an open spreading canopy that grows to 50 m. The understorey is sparsely populated with smaller trees, mostly acacias, and occasional shrubs. Long-term average annual rainfall at the sites is between 618 and 772 mm. Although fairly homogenous, there were some differences between sites that could potentially influence substrate moisture, such as variations in topography, aspect and the level of canopy cover (Newbound 2009).

### *Sporocarp sampling*

Individual plots of 1000 $m^2$ were surveyed regularly for epigeous macrofungi from the end of May 2006 to the end of Oct. 2007. There was one survey plot at each site. Plot dimensions were $50 \times 20$ m, with the exception of two plots that were $40 \times 25$ m and one of $200 \times 5$ m. Plots were searched by slowly walking over the entire area and collecting fruiting bodies for later identification. Not all fruiting bodies were removed; those remaining *in situ* that persisted until the next survey were counted again. The number of sites visited and the number of surveys per site were higher during the fruiting season, which was from Apr. to May until late Aug. for the 2 y. Throughout the fruiting season each site was usually visited once every three weeks. During the out of season months, a subset of six sites was surveyed once per month.

### *Climate data*

Rainfall and evaporation records were sourced from weather station data supplied by the Bureau of Meteorology (www.bom.gov.au) (Appendix B). Daily data for both rainfall and evaporation over the study period, as well as long-term averages, came from an automated station at Bundoora (LaTrobe University, 37.72°S, 145.05°E), which was the closest station to most sites. All but three of the sites were within a 15 km radius of the station; the furthest site was 21 km away. Missing data were occasionally replaced by records from the nearby Viewbank station (Arpansa, −37.74°S, 145.10°E). Daily rainfall values were supplied as precipitation in the 24 h before 9 am on the recorded date, measured in millimetres. Evaporation figures used ''Class A'' pan evaporation for the same 24 h as rainfall, also measured in millimetres.

Rainfall minus evaporation ($R - E$) was used as a distal measure of substrate moisture. The suitability of this measure was verified by examining the relationship between $R - E$ and measurements of soil moisture obtained from sites. An evaluation of various models using $R - E$ over different time periods to explain variation in soil moisture found that using the previous 28 d $R - E$ best accounted for the variation (see Appendix C). Hence, this time period was used in the phenology models.

### *Bayesian model for common species*

Both site occupancy and detection probability for common species found during the survey were analysed. Only species