Influence of remotely-sensed vegetation productivity indices and fine-scale landscape characteristics on Malleefowl (*Leipoa ocellata)* breeding activity

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Abstract

Distributed in the semi-arid regions of southern Australia, the iconic Malleefowl (*Leipoa ocellata*) is listed as nationally vulnerable due to contractions in the species' range and numbers since European invasion. Therefore, understanding the drivers of Malleefowl population dynamics is essential for conservation of the species. Recent studies have shown the important impact of winter rainfall on breeding activity. Rainfall is thought to play a key role in the breeding cycle because it directly begins the decaying process inside mounds and is indirectly linked to food and organic matter availability. However, the studies linking rainfall with breeding activity use low resolution estimates of rainfall at monitoring sites. Alternatively, vegetation productivity might better predict Malleefowl breeding activity as it reflects the localised effect of rainfall. A variety of remotely-sensed vegetation productivity indices, such as Normalised Difference Vegetation Index (NDVI), have been used globally to predict bird abundance and breeding dynamics. In this project, I aim to explore whether remotely-sensed vegetation indices are better predictors of Malleefowl breeding activity than rainfall. I will also investigate the effect of small-scale site characteristics, such as aspect, soil composition and soil moisture. This research is the first to quantitatively study the effect of vegetation and local landscape attributes on Malleefowl. It will provide insight into where and when Malleefowl are likely to breed in response to vegetation productivity rather than interpolated rainfall, which may deepen our understanding of the species' requirements and help direct conservation resources.

Background

Distributed in the mallee regions of southern Australia, the iconic Malleefowl (*Leipoa ocellata*) is a large, ground-dwelling bird renowned for its unusual nesting habits. Although formally abundant across the nation, long term population studies have shown Malleefowl numbers are decreasing; in Western Australia (Benshemesh *et al.,* 2007; Parsons *et al.,* 2009), South Australia (Gates, 2004; Benshemesh *et al.,* 2007; Priddel *et al.,* 2007), New South Wales (Frith, 1962; Priddel and Wheeler, 2003; Priddel *et al.,* 2007) and are possibly extinct in the Northern Territory (Benshemesh, 2007). The reduction in population numbers and spatial extent has prompted research into the environmental drivers of this decline.

Recent analysis of monitoring data by Benshemesh *et al*. (2007) suggested the importance of winter rainfall on breeding activity. Winter rainfall is positively correlated with the number of active mounds (Booth and Seymour 1984; Benshemesh *et al.,* 2007), as well as extended laying periods and larger clutch sizes (Priddel and Wheeler, 2005). Correspondingly, Malleefowl breeding activity noticeably decreases in times of lower than average rainfall and many individuals abandon breeding in years with low winter rainfall (Frith, 1956; Frith, 1959; Booth and Seymour, 1984) or high summer heat. Those Malleefowl which continue to breed produce fewer and smaller eggs, and reduced rate of egg production (Frith, 1959; Priddel and Wheeler, 1999).

Rainfall is suggested to be important for Malleefowl populations through both direct and indirect pathways. Firstly, rainfall directly influences the decomposition within mounds (Frith, 1959).

Sufficient moisture levels are essential to begin the breakdown of organic matter within the mounds, which produces heat to incubate eggs (Booth and Seymour, 1984). The exothermic reaction of decomposition is vital because it allows the commencement of the Malleefowl laying period earlier in the year and the eggs to be incubated at suitable temperatures (Frith, 1959) before the solar radiation input is sufficient to warm the mound. However, excessive levels of rain may also cause the temperature of mounds to decrease, as observed by Frith (1959) and Priddel and Wheeler (2005). Frith (1959) noted the nearby mounds situated in sandy, and hence well drained, soil continued to lay. Malleefowl favour sandy substrate for mounds (Frith, 1959; Benshemesh, 2007; Parsons *et al.,* 2009; Gillam, 2008), likely because good drainage allows the mounds to reach higher temperatures (Frith, 1959). This highlights the importance of other small-scale landscape characteristics, such as soil composition, which may interact with rainfall (Brereton *et al.,* 1994).

Secondly, rainfall indirectly affects Malleefowl through the influence of vegetation. In times of high rainfall, vegetation health and growth also improve (Booth and Seymour, 1984; Bradstock, 1989). Green-pick, flowers and seeds from herbs or shrubs are essential for Malleefowl foraging. Booth (1987) suggest the home-rage size of Malleefowl is driven by the vegetation productivity to fulfil the energy requirements of breeding. Malleefowl eggs usually weigh c. 10% of the female’s body weight, with a full clutch weighing 2 to 3 times the female’s body weight (Frith, 1959). High vegetation productivity may also facilitate Malleefowl breeding by promoting high amounts of biomass available for nest building. Furthermore, vegetation quality may also reduce predation rates through increase canopy cover affecting raptors, and undergrowth visibility affecting ground-dwelling predators. However, these association are relatively poorly understood within the current literature.

Despite the high ecological importance of rain, current studies linking water availability with breeding activity use low resolution estimates of rainfall. In the trend analysis by Benshemesh *et al.* (2007), rainfall was interpolated from weather stations a distance away from the actual site. Alternatively, vegetation productivity may predict Malleefowl breeding activity more accurately as it reflects the localised effect of rainfall at a small spatial scale. Moreover, vegetation productivity may provide a more accurate estimate of the food resources available at a specific location, compared to interpolated rainfall estimates. Quantifying the vegetation condition would also reflect other small-scale variables such as soil qualities, as vegetation growth is strongly related to local climate (Pettorelli *et al.,* 2005).

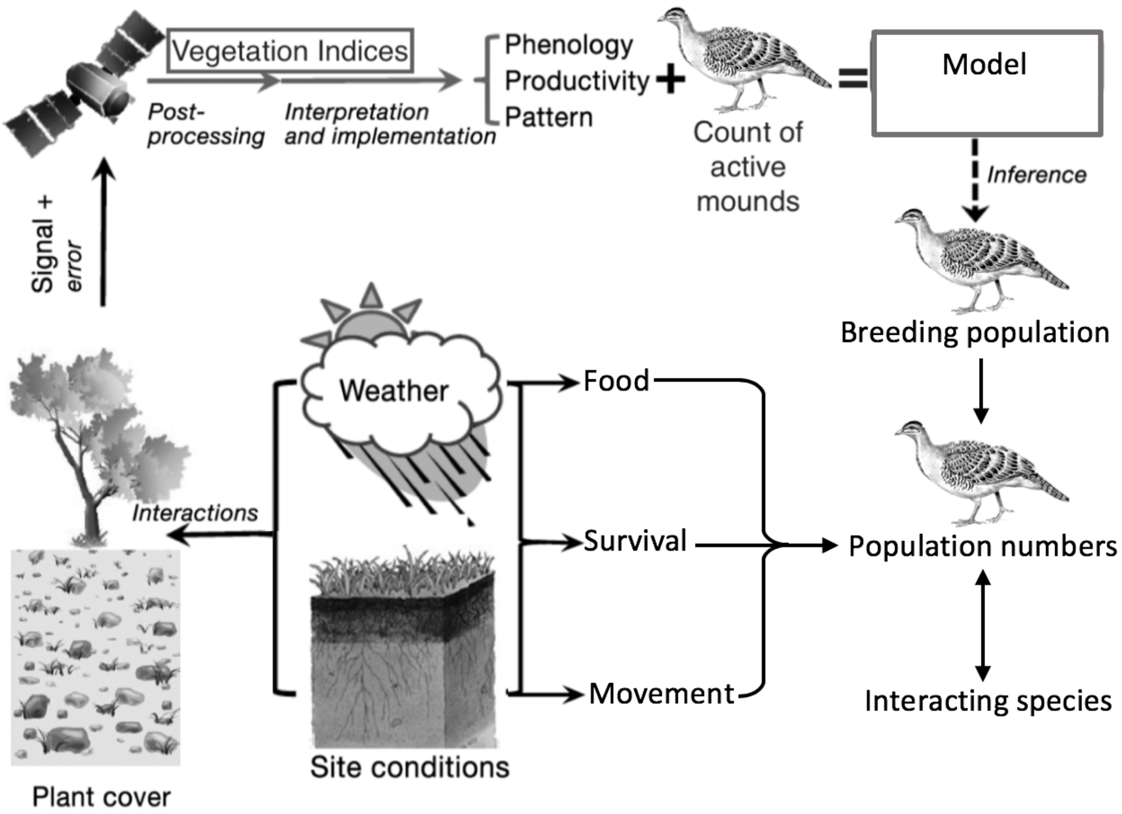

Figure 1. Schematic of the effect of vegetation on Malleefowl breeding activity and the measurement of vegetation productivity through remotely sensed indices. Adapted from Pettorelli *et al.,* (2011).

Unlike rainfall data, Vegetation condition can be quantified from remotely-sensed satellite imagery such as Landsat at specific locations in the landscape. The image processing can be completed using a variety of methods to create a range of remotely-sensed vegetation indices (VI). One such VI is the Normalised Difference Vegetation Index (NDVI). Popular because it is easily derived from online data (Bradley and Fleishman, 2008), NDVI reflects visible and infrared light as a proxy for photosynthetic activity and is strongly correlated to vegetation productivity (Pettorelli *et al.,* 2005), net primary productivity (Kerr and Ostrovsky, 2003; Turner *et al.,* 2003), soil moisture (Gandi *et al.,* 2015) and hence resource availability (Hurlbert and Haskell, 2003). Other VI include Leaf Area Index (LAI) which is correlated to NDVI (Pettorelli *et al.,* 2011), Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI) for arid regions.

NDVI has been used recently to model a variety of species distributions and abundances (Pettorelli *et al.,* 2005; Pettorelli, *et al.,* 2011), including avian species. Saino et al. (2004) found that swallows had earlier breeding seasons, larger clutch sizes and greater breeding activity in high NDVI years. These same attributes were related Malleefowl to rainfall by Priddel and Wheeler (2005). NDVI has also been found to be the strongest predictor of drought resistance in bird assemblages within Australia (Selwood *et al.,* 2018). Despite the importance of NDVI at explaining bird richness and breeding behaviour globally, and the ecological importance of vegetation condition for Malleefowl, surprisingly no studies have explored the effect of NDVI on Malleefowl breeding dynamics.

In this project, I aim to explore whether remotely-sensed VI are better predictors of Malleefowl breeding activity than rainfall. I will then explore the influence of other fine-scale habitat characteristics, such as soil moisture, aspect and topography, on Malleefowl breeding activity. There is also scope to explore these questions during years of drought, to determine if the variables change in importance in years with extremely low rainfall, or under the predicted rainfall patterns of climate change.

Method

After beginning regular monitoring at 4 sites in 1989, the Malleefowl monitoring program has now extended to 144 sites across Australia; 14 in New South Wales, 47 in Victoria, 43 in South Australia and 40 in Western Australia. The annual trends of active mound counts will be used to indicate the breeding activity of the Malleefowl population at a specific site.

Remotely-sensed environmental parameters and Global Information System (GIS) derived elevation models will be used to describe the vegetation productivity and fine-scale site characteristics. The free, open access to these layers provides an invaluable resource, spanning the entire temporal extent of the monitoring program. The spatial and temporal scale to be used for the environmental predictors is currently under discussion. A single value can be taken for the variables that are constant across time such as elevation, aspect and slope. A piolet study will be used to investigate the homogeneity within an individual site in the mallee regions, to inform the scale appropriate for the environmental predictors. If the variation is minimal, a single value for the constant predictors will be taken from the centroid. For variables that change temporally such as vegetation productivity, soil moisture and rainfall, an average will be taken over a period that is ecologically relevant to Malleefowl. Winter rainfall has been used previously (Benshemesh *et al*. 2007) as an average from May-August to represent that period of greatest importance to Malleefowl leading up to the breeding period. Therefore, I will also use a winter average for soil moisture and VI. The winter rainfall period will also be compared to annual averages as well.

Regression models will relate site trends of active mound counts from 1989 to 2017 to the remotely-sensed environmental variables to determine the best predictors of Malleefowl breeding activity. To validate the final model, I will predict the breeding activity of Malleefowl at monitoring sites in 2018 and compare these predictions with field observations of actual mound activity. Depending on the predictor variables found to be important, I may then subset the mound count data to focus on drought periods, such as the Millennium drought which affected south eastern Australia from 1996 to 2010. Another path would be to explore the predicted rainfall under different climate change scenarios and investigate the possible effect of climate change on Malleefowl breeding activity in the future.

Conclusion

We aim to explore remotely-sensed environmental variables across Australia and highlight the key predictors of Malleefowl breeding activity. We hope this research will inform managers of consistently high and low performing sites across Australia to aid decision making. It will also highlight key environmental factors that influence the number of active mounds and how a change in these factors, such as a reduction in rainfall during drought periods, will translate into Malleefowl breeding activity. It will provide insight into where and when Malleefowl are likely to breed in the coming year in response to rainfall events and vegetation condition, which can help direct the scarce conservation resources across Australia. Depending on the predictors of importance to Malleefowl, my research may also convey patterns and predictions for the breeding activity into the future under a changing climate.

Acknowledgements

This project is generously funded by Park Victoria and I am grateful to John Wright for his support. I am also greatly appreciative to my supervisors Darren and Kat who have dedicated their time to help me learn. I would like to thank Joe Benshemesh, Tim Burnard and Liz Kington for their willingness to share their knowledge and ongoing assistance. Finally, I thank all volunteers over the many years which have been involved in data collection and providing an extensive source of knowledge upon which I have based this project.

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