



Spatial statistical analysis of tree deaths using airborne digital imagery

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ABSTRACT

High resolution digital airborne imagery offers unprecedented opportunities for observation and monitoring of vegetation, providing the potential to identify, locate and track individual vegetation objects over time. Analytical tools are required to quantify relevant information. In this paper, locations of trees over a large area of native woodland vegetation were identified using morphological image analysis techniques. Methods of spatial point process statistics were then applied to estimate the spatially-varying tree death risk, and to show that it is significantly non-uniform. [Tree deaths over the area were detected in our previous work (Wallace et al., 2008).] The study area is a major source of ground water for the city of Perth, and the work was motivated by the need to understand and quantify vegetation changes in the context of water extraction and drying climate. The influence of hydrological variables on tree death risk was investigated using spatial statistics (graphical exploratory methods, spatial point pattern modelling and diagnostics).

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1. Introduction

In recent years the availability of high-resolution digital aerial imagery has made it possible to recognise individual trees and shrubs over extensive areas (Caccetta et al., 2011). This opens up new opportunities for ecological metrics and monitoring based on the spatial arrangement of individual trees. Metrics relevant to structure and habitat may be derived from spatial arrangement and height of vegetation objects. Spatial patterns of change may indicate ecological processes or effects of management and so are of particular interest to vegetation managers. In particular spatial patterning in the deaths of trees over a period may indicate the location of threatening processes and vulnerability to these processes.

This study was conducted using imagery of native vegetation over a major urban groundwater supply area (Gnangara Mound, Western Australia). The Mound is both a significant biodiversity asset (Mitchell et al., 2003; Wilson and Valentine, 2009) and the major water supply area for the city of Perth – in 2006 it supplied 65% of the city's water (Government of Western Australia, 2009). There is major interest from the water supply agency (Water

Corporation of Western Australia) and the regulators in quantifying the impact of groundwater extraction on vegetation.

The reopening in 2005 of the Pinjar bore field in the Gnangara Mound provided an opportunity and an imperative for detailed vegetation monitoring (Wallace et al., 2008). When the bore field was first used, severe vegetation deaths were observed near bores during a very hot period in summer 1990/1991 and the field was consequently shut down (Groom et al., 2000; Water Authority of Western Australia, 1992). The Water Corporation acquired high spatial resolution airborne imagery of native woodland vegetation in the vicinity of the bores in summer 2005 before pumping recommenced, and in summer 2006. Annual image acquisitions over the area have continued, to provide ongoing monitoring. The deaths of trees occurring between two anniversary dates in 2005 and 2006, and any spatial association of tree deaths with the bore locations, were the questions of interest in the initial study. Tree deaths were identified using a thresholding approach applied to the two dates of imagery and manually digitised when confirmed by image interpretation. Ground validation visits were conducted. Tree death locations were compiled into a spatial map, which was smoothed by a kernel technique to obtain a colour map of the spatially varying density of tree deaths per square km, shown in Figure 5 of Wallace et al. (2008), which also shows the locations of the water supply bores. The density of tree deaths is spatially non-uniform with higher values in the southern and north-eastern areas.

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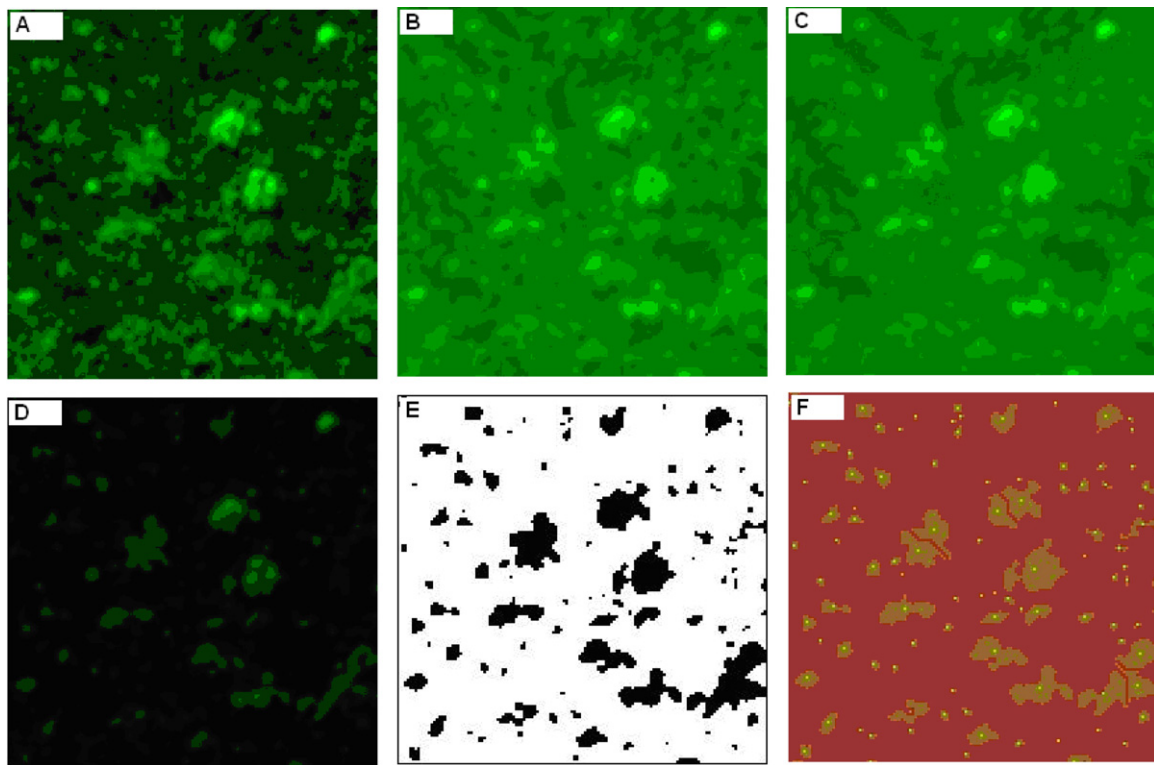


Fig. 1. Detection of live trees. (A) Raw green proportion image; (B) smoothed; (C) shadow removed; (D) background level subtracted; (E) thresholded; (F) de-clumped and centroids found.

Preliminary analysis using spatial point process residuals by Wallace et al. (2008) suggested that there was no significant association of bore locations and tree deaths in this annual period.

A potential criticism of the analysis of Wallace et al. (2008) is that tree deaths were not referred to the underlying population of live trees. Their analysis used the frequency of tree deaths per unit area, rather than deaths per thousand live trees. Observed spatial variation in the frequency of tree deaths could simply be attributable to spatial variation in the underlying density of live trees in the woodland. A more detailed analysis requires data on the reference population of trees that were alive in 2005. The aim of this paper is to demonstrate techniques for identifying the locations of live trees from high-resolution aerial imagery, and statistical methodology for analysing spatial trends and patterns in tree death rate. Manual identification of hundreds of thousands of tree locations would be prohibitively time-consuming. Therefore, an automatic or semi-automatic algorithm is needed for efficient detection of locations from digital imagery.

The spatial arrangement of the population of living trees is of interest in itself as a potential indicator of environmental conditions and may be examined using spatial point process methods. However in this paper we focus on the analysis of tree death rates.

Key questions are firstly whether the spatial pattern of tree death is random with a constant death rate, and subsequently whether there is evidence that water extraction from bores may have had an effect on tree death. To address these questions, we must first determine whether any observed spatial pattern is attributable to natural hydro-geological processes as measured by other variables.

To resolve this, we use methods of spatial statistics for spatial point patterns (Illian et al., 2008). These techniques have been widely applied to ecological data (Fortin and Dale, 2005; Perry et al., 2002; Stoyan and Penttinen, 2000). In this paper, we analyse the tree data using a combination of well-established,

recently-published, and currently unpublished techniques in spatial point process statistics.

The paper is organized as follows. Section 2 briefly describes the study area and data used. Section 3 shows the morphological procedure for detecting tree locations. The statistical methods used to analyse the tree death risk are also described in Section 3. Section 4 presents the results of our analyses. We end with a discussion in Section 5.

2. Study area and materials

2.1. Background

The study area for this paper, designated as Pinjar Study Block 1 in Wallace et al. (2008), is located in the Gngangara Mound, Western Australia. The area covers approximately 2100 ha on Perth's northern urban fringe, with several water bore sites along its western boundary.

The Gngangara Mound is of great importance to Perth's water supply and retains substantial biodiversity values. Effective monitoring of vegetation changes is a priority for multiple agencies. The Gngangara Sustainability Strategy, headed by Department of Environment and Conservation, was established to improve knowledge and management of the region (Wilson and Valentine, 2009). Native vegetation on the Gngangara Mound is taxonomically diverse, with a highly variable understorey (0.4–2 m tall). The overstorey (up to 10 m tall) in the Pinjar Study Blocks is dominated by *Banksia* species, notably the slender banksia (*B. attenuata*). It is open woodland with overstorey trees typically separated from each other and clearly visible as distinct crowns in high resolution imagery. Occasionally such crowns or objects may be formed of more than one tree growing together (see Fig. 1A). Information on the vegetation and hydrology of the Gngangara mound can be found in Davidson

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