Forest Ecology and Management 432 (2019) 189–199

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

A spatio-temporal analysis of canopy dynamics and intra-stand competition in a riparian forest, south-eastern Australia

E.J. Curtis[a,*], E.J. Gorrod[a,c], M.V. Ellis[a], L.A. Chisholm[b]

[a] New South Wales Office of Environment and Heritage, PO Box 1967, Hurstville, NSW 2220, Australia
[b] Centre for Sustainable Ecosystem Solutions, School of Earth and Environmental Sciences, University of Wollongong, NSW 2522, Australia
[c] School of Earth and Environmental Sciences, University of New South Wales, Sydney 2052, Australia

ARTICLE INFO

Keywords:
Eucalyptus camaldulensis
Canopy condition
Landsat
FPC
Foliage projective cover
Irregular timeseries
Resource competition
High density
Woody thickening

ABSTRACT

Widespread high stem density stands of riparian River Red Gum (*Eucalyptus camaldulensis* Dehnh.) (RRG) result from land management legacies in inland riverine ecosystems of Australia. These stands generally exhibit reduced structural complexity with many slender stems and few large trees. Higher competition for water among populations of RRG in dense stands may affect stand-level canopy condition, particularly when water is scarce. We investigated whether stem density and water availability affected canopy condition dynamics in RRG forests of Murray Valley National Park, New South Wales. We collected eight years of satellite derived Foliage Projective Cover (FPC) data (Landsat 5 TM (2008–2011) and Landsat 8 OLI (2013–2016)) encompassing some of the driest and wettest years on record in south-eastern Australia. We used Generalised Linear Mixed Effects Modelling to investigate the drivers of RRG canopy condition at the plot-level. Canopy condition dynamics were driven by different sets of variables under different climatic phases, with water availability at the plot and regional scale, as well as climate, being the primary drivers of trends in RRG canopy condition. Stem density was not found to be a significant predictor of overall RRG stand canopy condition, although results suggested that individuals in higher density stands have lower canopy condition on average. Live basal area (LBA) was positively correlated with FPC in all climatic phases, and stands with high LBA tended to have a greater abundance of large trees than low LBA stands. Research efforts should be made towards integrating site-specific tree size class distributions with remotely sensed metrics to guide management for biodiversity. Findings from this study provide a baseline understanding against which ecological restoration actions can be evaluated and a foundation upon which an ongoing monitoring program can be developed.

1. Introduction

Increases in stem density (also known as woody thickening) have been recently reported in arid and semi-arid vegetation across the world (Eamus and Palmer, 2007; Hoffman and Rohde, 2011; Saintilan and Rogers, 2014). High stem density, but low basal area, forest stands are characterised by abundant even-aged slender stems and few large trees (Mac Nally et al., 2011). Within high stem density forest stands, more trees compete for limited light, water, nutrient and space resources. We sought to investigate whether competition in high density forest stands affected the amount of photosynthetically active foliage contained in forest canopy (herein referred to as 'canopy condition'). With water availability considered to be a key resource, we anticipated that canopy condition would be particularly low in high stem density stands during times of water scarcity.

River Red Gum (*Eucalyptus camaldulensis* Dehnh.) (RRG) is a flood-dependent episodic recruiter that generally forms a mono-specific canopy and produces valuable hardwood timber (Dexter, 1978; di Stefano, 2002; Colloff, 2014). RRG forests provide ecosystem services through carbon retention, resource and habitat provision and water purification (Finlayson et al., 2005), and are key refuges for indigenous flora and fauna in landscapes otherwise dominated by agricultural activity (Lunt and Spooner, 2005). High stem density stands of RRG forest have become widespread on the upper Murray River in south-eastern Australia (Bowen et al., 2011; Mac Nally et al., 2011; Horner et al., 2010; McGregor et al., 2016). Widespread high stem density stands established following two key land-use changes associated with European settlement (Bowen et al., 2011; McGregor et al., 2016; Gorrod et al. 2017). Firstly, 150 years of commercial native timber harvesting removed and ringbarked a large proportion of the large trees (Eyre,

* Corresponding author.
E-mail addresses: evan.curtis@environment.nsw.gov.au (E.J. Curtis), emma.gorrod@environment.nsw.gov.au (E.J. Gorrod), murray.ellis@environment.nsw.gov.au (M.V. Ellis), lauriec@uow.edu.au (L.A. Chisholm).

https://doi.org/10.1016/j.foreco.2018.08.044
Received 24 May 2018; Received in revised form 21 August 2018; Accepted 24 August 2018

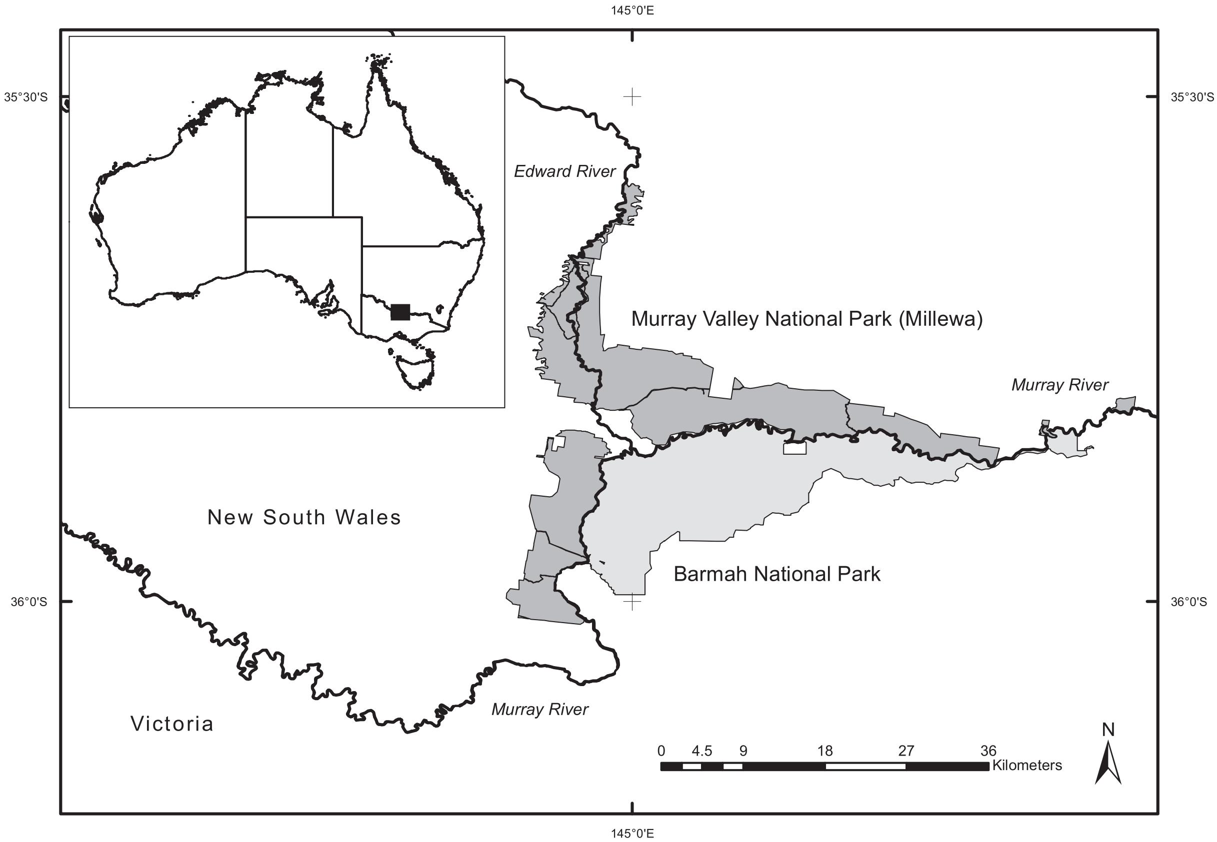

Fig. 1. Murray Valley National Park in southern inland New South Wales encompasses the north-eastern segment of the Barmah-Millewa River Red Gum (RRG) Forest, the world's largest continuous stand of RRG.

et al., 2010). Secondly, river regulation substantially altered flood regimes, reduced water availability and slowed tree growth (Bren, 1988; di Stefano, 2002).

The largest contiguous area of RRG forest is approximately 36 500 ha on the Murray River in New South Wales, known as Millewa. In 2010 the Millewa State Forest was gazetted as Murray Valley National Park (MVNP) (*NSW Riverina Red Gum Reservations Act, 2010*) with 33% of the RRG forest in the Park mapped as high stem density (> 400 stems ha^{-1}) (Bowen et al., 2011). Additionally, approximately 70% of the forests on the nearby Victorian Murray River floodplain were in a state of canopy dieback (Cunningham et al., 2007, 2009; NRC, 2009; van Dijk et al., 2013). The primary objectives of management shifted from mixed use and timber production to conserving biodiversity, maintaining ecological function and adhering to conservation principals outlined in the National Parks and Wildlife Act, 1974. Several conservation issues were associated with the presence of widespread, high density RRG stands, including canopy dieback. Canopy condition is an important factor in the provision of food, foraging habitat and shelter for canopy and ground dwelling flora and fauna. Lower canopy condition in high stem density stands during times of water scarcity may confer lower resilience in an ongoing drying climate in the Murray-Darling Basin (Kirono et al., 2011), and increase the likelihood of total stand death (Mac Nally et al., 2011).

Competitive superiority enables individuals or populations to capture enough resources to enhance their likelihood of survival. In populations with a high degree of niche overlap, resource demand is increasingly density dependent and individuals that most effectively and efficiently capture and use resources will likely be superior competitors. Competition in plant populations is driven by demand for light, nutrient and water resources (Grime, 1977). In arid and semi-arid Australia, where water availability is highly variable, plants typically gear carbon allocations towards promoting efficient water usage (Bernardo et al., 1998; Carter and White, 2009; McLean et al., 2014). Individual RRG trees produce and shed canopy foliage in response to fluctuating levels of water availability (Briggs and Maher, 1983; Bacon et al., 1993; Doody et al., 2014) this enables individuals to compete by regulating their own water use and suppressing the growth of nearby individuals that fall within a 'zone of influence' immediately beneath their canopy (Opie, 1968). It is also known that RRG trees can utilise water immediately as it becomes available (Heinrich, 1990; Akeroyd et al., 1998), with a rooting habit that enable high rates of hydraulic conductivity (Heinrich, 1990). Hence, RRG are expected to exhibit a response in their canopies in reaction to the level of water demand, water availability and dynamic inputs and outputs of water into the system.

Stand structure has been significantly associated with canopy decline within 100 000 ha of RRG forests and woodlands across the entire Victorian Murray River floodplain (Cunningham et al., 2010). Canopy condition was visually assessed, and all stems were counted, in 176×0.25 ha plots. Approximately 20 sites were in the upper Murray, in the vicinity of Millewa, including 3 sites with more than 600 stems ha^{-1}. In the upper Murray, the relationship between stem density and canopy condition was weakly positive. Results suggested that this was because both large and small trees were experiencing dieback, although the mechanism differed.

We sought to investigate the effect of stem density on canopy condition at the stand scale (< 10 ha) with interest in understanding spatio-temporal change in different hydro-climatic phases within a National Park management context. The longevity of the remotely-sensed data collected by the Landsat series of satellites is useful for monitoring canopy condition dynamics over this spatial extent (Wulder et al., 2012), with a 25–30 m^2 spatial resolution and 16-day repeat coverage (USGS, 2017). A metric of canopy condition that can be calculated from Landsat imagery is Foliage Projective Cover (FPC), which describes the proportional unit ground area obscured by live foliage.