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The response of dryland floodplain vegetation productivity to flooding and drying

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ABSTRACT

Dryland floodplains are characterized by highly variable flooding and drying. This variability plays a key role in the productivity of dryland floodplain vegetation. The Normalized Difference Vegetation Index, a surrogate for vegetation productivity, has been extensively used to examine floodplain vegetation productivity responses to flood inundation but generally focuses on inundation alone, or at a single scale thereby potentially omitting important elements of dryland variability. This study used fine resolution satellite imagery, through sequences of flood and dry resource states, at multiple scales of observation and with consideration of the relative influence of rainfall and flow to examine floodplain vegetation productivity in the dryland floodplain. There were marked differences in floodplain vegetation productivity between wet and dry resource states. Overall, response patterns were complex and varied among vegetation communities and in different resource states. The findings suggest that vegetation productivity in the Narran floodplain does not correspond well with the boom and bust model of floodplain ecosystem productivity. Rather, understanding vegetation productivity in a highly variable floodplain requires an enhanced understanding of the nature of variability in space and time. Conceptual models that can better convey the complexity of vegetation productivity responses to floodplain wetting and drying are suggested.

1. Introduction

The importance of hydrological variability for sustaining riverine ecosystems is well-recognized (e.g. Poff and Ward, 1989; Thoms, 2006). Dryland rivers are characterized by high hydrological variability (McMahon, 1979). Australia's dryland rivers have some of the most variable flow regimes in the world (Puckridge et al., 1998) and are characterized by long periods of low or no flow followed by periods of extreme flooding (Thoms, 2006). Flow varies in duration, frequency, magnitude and timing over the time periods associated with a flow pulse, flow history and flow regime and flow is comparatively unpredictable in all time periods. Flow variability and unpredictability also translates to variability in floodplain inundation and influences the distribution and productivity of floodplain vegetation. Floods create an irregular mosaic of floodplain inundation in space and time in relation to the timing, magnitude and duration of overbank flows, and the interplay between flow and floodplain topography (Murray et al., 2006). Patterns of floodplain inundation in space and time influence the distribution of vegetation communities (Townsend, 2001; Nakamura et al., 2007; Barrett et al., 2010; Reid et al., 2011) and the productivity of floodplain vegetation (Clowsen et al., 2001; Parsons and Thoms, 2013).

The relationship between dryland floodplain inundation and vegetation productivity has typically been examined at small scales (sites or plots) and results up-scaled (e.g. Capon, 2003; Reid et al., 2011). Rarely is the whole floodplain – which may be hundreds of square kilometres in area and contain a complex imprint of inundation variability – considered as a unit of study. Remote sensing provides a tool to examine floodplain vegetation productivity at large scales. The Normalized Difference Vegetation Index (Rouse et al., 1973) measures vegetation greenness and can be used as a surrogate for vegetation productivity (Lillesand and Kiefer, 2000). Several studies have used the Normalized Difference Vegetation Index (NDVI) to examine floodplain vegetation productivity responses to flood inundation in Australian dryland floodplains. Flow was shown to be the primary driver of spatial variation in the NDVI across 10 semi-arid floodplain wetlands in the Macquarie Marshes, although rainfall and minimum temperature modified spatial

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variation in the NDVI, particularly among different vegetation communities (Wen et al., 2012). Sims and Colloff (2012) calculated that a single flood, which inundated more than 50% of a semi-arid floodplain along the Paroo River increased the NDVI by up to 19% above non-flood levels, and that these elevated values of the NDVI continued for up to 13 months following flood recession. Parsons and Thoms (2013) examined the NDVI in flood, rain and dry states in the Lower Balonne floodplain and found higher values of NDVI in the flood state, although trees situated in the riparian area also maintained high values of NDVI in the dry and rain states. Flooding was also shown to create a heterogeneous inundation mosaic in the lower Murrumbidgee River floodplain and this resulted in a non-uniform, spatially complex response in NDVI and vegetation biomass within the inundated mosaic (Shilpakar, 2013). The united view emerging from these studies appears to be that flooding increases vegetation productivity in dryland floodplains, measured through the NDVI, but these productivity responses can be modified by rainfall, temperature, lack of surface water, the mosaic of floodplain inundation and vegetation community type.

Despite these successful uses of the NDVI to examine floodplain vegetation productivity in dryland floodplains, these studies have four limitations that may obscure signals of vegetation productivity response to hydrological variability. First, the resolution of satellite sensors and techniques used to compute NDVI varied from 250 m MODIS NDVI (Wen et al., 2012; Sims and Colloff, 2012) to NDVI calculated using Landsat TM 5 or 7 bands and resampled to 25 m (Parsons and Thoms, 2013; Shilpakar, 2013). Coarser resolution MODIS NDVI images are unable to capture the detail of responses in semi-arid landscapes where vegetation communities are often spatially fragmented (Munyati and Mboweni, 2012). Second, most of these studies focus on floodplain inundation only (Wen et al., 2012; Shilpakar, 2013; Sims and Colloff, 2012), omitting to examine NDVI during the characteristic and often long dry periods that occur between floods. As dryland floodplains have been conceptualized as boom-bust systems (Walker et al., 1995), vegetation productivity in both flood (the boom) and dry (the bust) states should be considered. Third, some studies examined the NDVI at one scale in the floodplain (Sims and Coloff, 2012) while others examined vegetation response at multiple scales by considering the whole floodplain and in component vegetation types (Wen et al., 2012; Shilpakar, 2013; Parsons and Thoms, 2013) or in geomorphic units (Parsons and Thoms, 2013). The interaction between pattern and process occurs at multiple scales in complex systems and the interplay of flood inundation and vegetation response may therefore occur at different scales within the floodplain (Wiens, 1989). Examining floodplain vegetation responses to inundation and rainfall at scales of the whole of floodplain and component vegetation communities is important for advancing a systems understanding of floodplains. Fourth, only Wen et al. (2012) considered the influence of rainfall and temperature on the NDVI of floodplain vegetation in concert with flooding. An integrated study using fine resolution satellite imagery, through sequences of flood and dry states, at multiple scales of observation and with consideration of the role of climatic variables is needed to better understand the responses of floodplain vegetation in highly variable dryland floodplains.

This study examines vegetation productivity in a dryland floodplain using a sequence of 75 high resolution remotely sensed images captured through a series of dry and wet resource states to determine if differences in NDVI are consistent between resource states at the entire Narran floodplain landscape scale and the vegetation community scale. It also seeks to identify what drives differences in NDVI at the landscape scale and between vegetation communities in terms of climate and flow.

2. Study area

The Narran floodplain is a terminal floodplain wetland complex located in the lower Condamine Balonne Catchment, in the northern Murray Darling Basin, Australia (Fig. 1). The floodplain covers an area of 296 km^2 and its landscape is geomorphologically complex, with four major lakes, distributary channel networks and dissected floodplain surfaces. Quaternary alluvial sediments, the dominant geology of the region, are composed of moderately to highly weathered sedimentary rocks. The main soil types are hard setting red-brown earth (*red and brown Chromosols*), pellitised clays (*Lunettes*) along with deep grey (*Grey Vertosols*), brown (*Brown Vertosols*) and black self-mulching cracking clays. The climate of the Narran floodplain is semi-arid with an average long-term (1940–2009) annual rainfall of 448 mm at Collarenebri (Station 048038) and an average annual evaporation of 2250 mm. Rainfall is also highly variable over time; with annual rainfall ranging between 144 mm (2002) and 957 mm (1950). Thus, this ecosystem experiences significant periods of moisture deficit. Most rainfall in the Condamine-Balonne River catchment occurs in the well-watered uplands in the summer months (November–February) associated with tropical monsoonal activity. As a consequence, flows to the Narran floodplain are also highly variable. The long term mean annual discharge (1965–2009) of the Narran River at Wilby Wilby, just upstream of the Narran floodplain, is 128,717 ML with a range of 690,000 ML to 1003 ML and a coefficient of variation of 307 percent. Average mean summer and winter temperatures for the region are 36 °C and 19 °C respectively.

Flows in excess of 13,000 MLD in the Narran River at Wilby Wilby result in inundation of the Narran floodplain. The Northern floodplain inundates first and fills in sequence through Clear Lake, Back Lake and Long Arm (Fig. 1). Water continues along the main Narran River or flows overland to Narran Lake, in the southern part of the floodplain (Fig. 1). These floodplain lakes can retain water for approximately 12–15 months following inflows to the system. However, given the highly variable and unpredictable nature of the flow regime of the Narran River there are periodic dry and flood (wet) states in the Narran floodplain (Murray et al., 2006). The Narran floodplain remains dry approximately 60% of the time (Rayburg and Thoms, 2009). The drying and wetting of the Narran floodplain has been significantly impacted by water resource development in the upper catchment (Thoms, 2003). Water extraction has reduced the median annual flow in the Narran River by approximately 30%, significantly reducing moderate-sized floods to the Narran floodplain (Thoms, 2003).

The Narran floodplain was gazetted as a National Park in 1988 and listed as a Ramsar wetland of international importance in 1999. The floodplain serves as a critical habitat for colonial water birds and has been identified as one of nine significant refugia for biological diversity in semi-arid areas of NSW (Kingsford, 2000). The Narran floodplain contains several vegetation communities but is dominated by four major vegetation community types (Fig. 2). Extensive areas of the floodplain are dominated by the perennial shrub lignum (*Duma florulenta*). Lignum shrubland occupies 11,242 ha (38%) of the floodplain area and can also feature a very sparse overstorey of woodland species such as coolibah (*Eucalyptus coolabah*), river red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*), poplar box (Eucalyptus *populnea*), leopardwood (Flindersia *maculosa*), gidgee (Acacia *cambagei*), white cypress pine (Callitris *glaucophyll)*, and smaller shrub/tree species such as river cooba (*Acacia stenophylla*) and eurah (*Eremophila bignoniiflora*). Grassland covers 4163 ha (14%) of the floodplain area. Grassland consists of Mitchell grass (*Astrebla spp*), neverfail (*Eragrostis setifolia*), box grass (*Paspalidium constrictum*), kangaroo grass (*Themeda triandra*) and Warrego summer grass (*Paspalidium