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Statistical description of wetland hydrological connectivity to the River Murray in South Australia under both natural and regulated conditions

Sean J. Robinson [a], Nicholas J. Souter [b], Nigel G. Bean [a,c], Joshua V. Ross [a], Richard M. Thompson [d], Kjartan T. Bjornsson [d,*]

[a] School of Mathematical Sciences, University of Adelaide, Adelaide, Australia
[b] Fauna & Flora International, Phnom Penh, Cambodia
[c] ARC Centre of Excellence for Mathematical and Statistical Frontiers, Australia
[d] Department of Environment, Water and Natural Resources, Government of South Australia, Adelaide, Australia

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SUMMARY

The effect of river regulation on the connectivity of the South Australian River Murray to its floodplain wetlands was examined using unregulated 'natural' and 'regulated' river flow data simulated between the years 1895 to 2009. A sample of 185 wetlands was used to calculate a range of connectivity statistics under both simulation scenarios. These statistics summarised the timing and duration of both connection and disconnection, as well as inundated area. Wetlands ranged from being permanently inundated, connected multiple times per year due to both small fluctuations in river level and the annual flood pulse, to flooded with diminishing frequency depending on the size of the annual flood pulse and their position on the floodplain. Under the natural scenario a wide range of wetland connectivity profiles were recorded whereas under the regulated scenario wetlands tended to be either permanently inundated or infrequently flooded. Under natural conditions wetlands that required higher flow before connecting were less frequently connected and for shorter periods. Under regulated conditions a larger proportion of wetland area was permanently connected than under natural conditions, however the annual flood pulse connected a larger area of wetlands under natural conditions. The information derived from this analysis can be used to design wetland management plans for individual wetlands within a river-wide management regime restoring lost hydrological variability.

1. Introduction

Floodplain wetlands are an integral part of many lowland rivers. They are naturally productive (Junk et al., 1989; Mitsch et al., 1991; Tockner and Stanford, 2002), provide feeding grounds, spawning habitat and nurseries for a diverse flora and fauna (Junk et al., 1989; Kingsford, 2000; Tockner and Stanford, 2002). Floodplain wetlands also provide a range of ecosystem services including flood control (Mauchamp et al., 2002), waste treatment (Tockner et al., 2008), fisheries (Thomas, 1995; Tockner et al., 2008), agriculture and livestock products (Thomas, 1995). The flood pulse, the predictable advance and retraction of water between the river and its floodplain (Bayley, 1995), maintains the productivity and diversity of floodplain wetlands.

To increase the reliability of river flow for human use, river regulation reduces variability (Kingsford, 2006), especially limiting inter-annual flow variability (Thoms and Sheldon, 2000). This alters the flood pulse and can reduce biological productivity, biodiversity, and connectivity between the river and its floodplain wetlands (Tockner and Stanford, 2002). The River Murray in south eastern Australia is intensively regulated to provide water for irrigated agriculture. Extractions of water for human consumption have seen the total flow at the mouth of the River Murray reduced by up to 61 percent (CSIRO, 2008) and during the droughts in the early 1980s and mid 2000s, flow to the sea ceased. Regulated by upstream dams and in-channel weirs, the River Murray in South Australia (SA River Murray) has been significantly altered, with average annual flows halved and median annual flows reduced by two thirds (Davies et al., 2008). Although the seasonal pattern of flow has largely been preserved (high flows in spring; low flows in late summer/early autumn; Maheshwari et al. (1995), Souter and Schultz (2014)), high flows are no longer as high or prolonged whilst low flows are lower and more prolonged (Souter and Schultz, 2014). Furthermore, flow variability has increased during times of high flow and decreased during times of low flow

* Corresponding author.
E-mail address: tumi.bjornsson@sa.gov.au (K.T. Bjornsson).

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(Souter and Schultz, 2014). A major consequence of this is a reduction in flood mediated connectivity between the river and its floodplain. The SA River Murray's in-channel weirs are used to keep the river level constant, further reducing hydrologic variability. Reduced flooding and static water levels have caused the natural ecology of the floodplain to decline with broad areas subject to salinisation and vegetation die back (Jolly et al., 1993; Jolly, 1996; Overton et al., 2006).

There are 1348 wetlands on the SA River Murray floodplain, ranging in size from small shallow ephemeral depressions to large permanent lakes (Jones and Miles, 2009). Prior to regulation, these wetlands would have had a wide variety of flooding and drying regimes according to their position on the floodplain, connection to the river and size. This is believed to have resulted in a complex and diverse floodplain ecosystem (Brock, 2003; Walker, 2006). However the combination of reduced overbank flooding frequency and management of stable river levels has polarised wetland water regimes. Wetlands at elevations lower than the operational river level are permanently flooded, whilst those at higher elevations are flooded less frequently. The permanently flooded wetlands are characterised by low productivity, a generalist fish fauna (Smith et al., 2009), a climax macroinvertebrate community (Walker et al., 2009), and a vegetation community structured by the static water regime (Blanch et al., 2000). No longer able to dry and refill, these permanent wetlands do not experience nutrient pulses (Scholz et al., 2002) and the associated productivity increase. This contrasts to the infrequently flooded wetlands which are often salinised and have macroinvertebrate communities distinct from permanent wetlands when flooded (Goonan et al., 1992). Infrequently flooded parts of the floodplain are dominated by bare soil, desiccation tolerant and salt tolerant vegetation (Gehrig et al., 2013).

In order to redress the ecological consequences of regulation, the Australian Government and the Government of South Australia are implementing the Riverine Recovery Project (RRP).[1] The RRP contributes to projects that seek to promote ecological resilience and river health through active management including weir pool water level manipulation (Siebentritt et al., 2004; Souter and Walter, 2014), wetland regulator construction and operation, pumping water to wetlands (Holland et al., 2009), and levee and bank construction or removal. The RRP takes the natural flow paradigm approach to river restoration as it seeks to restore attributes of the natural hydrological regime, altered due to regulation, that are critical in sustaining native aquatic ecosystems (Richter et al., 1997). The RRP aims to establish a more natural mosaic of diverse wetland communities through introducing greater diversity in wetland connectivity and flooding regimes along the river. Water management will seek to increase flooding frequency in high elevation wetlands, whilst variable water level regimes will be re-introduced to a number of now permanent wetlands. This will be achieved through the construction and operation of regulators which will be used to disconnect wetlands from the river, allowing them to dry. It is believed that these actions will create a greater diversity of aquatic habitats, increasing productivity and species diversity.

Wetland connectivity profiles need to be understood in order to get any benefit, ecologically or otherwise, from management (Arthington et al., 2006). In order to increase the diversity of wetland flooding regimes we need to understand the difference in wetland connectivity under both natural and regulated conditions. However, one of the major river-floodplain restoration challenges is determining the natural variability in flow, particularly in temperate countries with a long history of regulation and lack of undisturbed sites (Bayley, 1995). A number of methods have been employed to reconstruct the natural hydrological regime including simulation models (DWLC, 1995; US Army Corps Engineers, 1998), time-series analysis (Wen, 2009; Wen et al., 2011), historical data (Souter, 2005) and statistical analysis (Ganf et al., 2010). In this paper we extend upon the work of Ganf et al. (2010) and statistically describe the connectivity of the wetlands along the SA River Murray under simulated natural conditions, and compare this to wetland connectivity under simulated regulated conditions. We quantify the effect of river regulation on wetland connectivity and show how this has changed. In describing characteristics such as frequency and duration of connection for individual wetlands, as well as considering overall wetland connectivity across the entire river reach, we obtain information that can be used to develop wetland management plans.

2. Methods

2.1. Study site

The Murray–Darling Basin covers approximately 1,000,000 km^2 or one-seventh of Australia (Wohl, 2007). The basin contains Australia's three longest rivers: the Darling, Murrumbidgee and Murray. The SA River Murray (below the South Australian/Victorian state border; Fig. 1) is a dry-land river flowing for 650 km through a predominantly semi-arid environment which contributes little surface water. It is distinctive for its low gradient (mean 5.5 cm/km) and highly variable, but generally low flows (Walker, 2006). The SA River Murray terminates in the Lower Lakes (Lake Alexandrina and Lake Albert) before flowing to the Coorong and the Southern Ocean. The Lower Lakes do not feature in our analysis as we only consider wetlands along the river channel.

The SA River Murray is regulated by six locks and weirs that came into operation in the 1920–1930s, and five barrages that separate the Lower Lakes and the Murray mouth. As the locks and weirs were originally built for navigation, they have been situated so that water pooled behind one weir extends almost to the next upstream structure (Walker, 2006). Thus the river is now more often a series of cascading pools than a flowing river (Walker, 2006). The weirs are managed to maintain a constant 'pool-level' (to within ± 5 cm) in each reach for navigation and to allow irrigators to extract water. The weirs are operated up to flows of around 60,000 ML/d, above which they are removed (Table 1). We used 'lock site' to indicate a particular position along the river, even when discussing natural conditions when the lock structures were not present.

We determined the connectivity to the river of 185 of the 1348 SA River Murray wetlands under simulated natural and simulated regulated conditions. A representative sample of wetlands was obtained so that we could interpolate our conclusions to all wetlands along the river.

2.2. Flow data

The BIGMOD hydrological model (Close, 1996; MDBC, 1996) simulates daily flow and salinity in the River Murray system and supports the planning and management of water resources in the Murray–Darling Basin (MDBC, 2002; MDBA, 2012). Within South Australia, the BIGMOD model simulates River Murray flow by dividing the system into weir reaches. Since there are no major diversions in SA, under the model, water moves down the river with only minor hydraulic losses and evaporation between each reach.

We used data simulated from BIGMOD under both unregulated 'natural' and current 'regulated' conditions. Both simulations ran

[1] http://www.naturalresources.sa.gov.au/samurraydarlingbasin/water/river-murray/restoration-programs.