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Supplementary material

Restoring dissolved organic carbon subsidies from floodplains to lowland river food webs: a role for environmental flows?

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Modelling

Koondrook–Pericoota Forest

Koondrook–Perricoota Forest is a large (~32 000 ha) river red gum (*Eucalyptus camaldulensis*) forest adjacent to the Murray River. Flows into the forest commence when flows in the Murray channel (measured at Torrumbarry) exceed ~18 000 ML day^{-1}. Flows in the Murray River at this site are regulated by two large headwater storages (Lakes Hume and Dartmouth), as well as a major irrigation infrastructure (Yarrawonga Weir and Mulwala Canal) just upstream of the forest. In the period 1980–1996, inflows into the Murray River were approximately average (Fig. S1). The period 1997–2009 was characterised by substantially below-average inflows to the Murray as a result of prolonged drought period in south-eastern Australia (the Millennium Drought).

Dissolved organic carbon (DOC) modelling

Dissolved organic carbon export from Koondrook–Pericoota Forest was modelled using the blackwater risk-assessment tool (BRAT; Whitworth and Baldwin 2016) on each individual overbank flow for the period from 1 January 1980 to 30 June 2009. BRAT is a generic, desktop risk-assessment tool that can be used to predict the likelihood of hypoxic blackwater during inundation of an idealised floodplain, but can be adapted to fit the hydraulic characteristics of a particular floodplain. In BRAT, water is routed onto a floodplain with a defined maximum input volume, inflow duration and inundation area. Carbon leached from the inundated litter on the floodplain, and carbon and oxygen consumption from the water column are calculated on daily time-steps, as are dissolved oxygen and carbon concentrations in the outflow.

Area of forest inundation during each flood event was based on flow–inundation curves for the forest supplied by the Murray–Darling Basin Authority (MDBA, see Baldwin *et al*. 2011). The flows used to estimate the area of inundation were based on natural (no river regulation) and current flow regimes (regulated flows) modelled at Torrumbarry by the MDBA using MSM-BigMod (MSM-BigMod Models for Murray River and Lower Darling system, see http://www.mdba.gov.au/kid/kid-view.php?key=EAbncKuQI1QRjInx/K60OTWeuuuG4JcWhiHxflpPapo=, accessed 31 August 2015) (Fig. S1). Commencement date of each flood event, flood duration and flood interval were based on the modelled hydrographs and extracted manually; if the modelled flow dropped below the commence-to-flow threshold for the forest (18 0000 ML day^{-1}) for fewer than 10 days (the approximate transit time for water through the forest), it was assumed to be the same flood event; if for longer, it was assumed to be a new flood event. Maximum flood extent was based on modelled peak flows. Daily changes in area of inundation during each flood event were based on the default normal distribution used in the BRAT model. Litter loading was estimated on the period-since-last-flood module in BRAT.

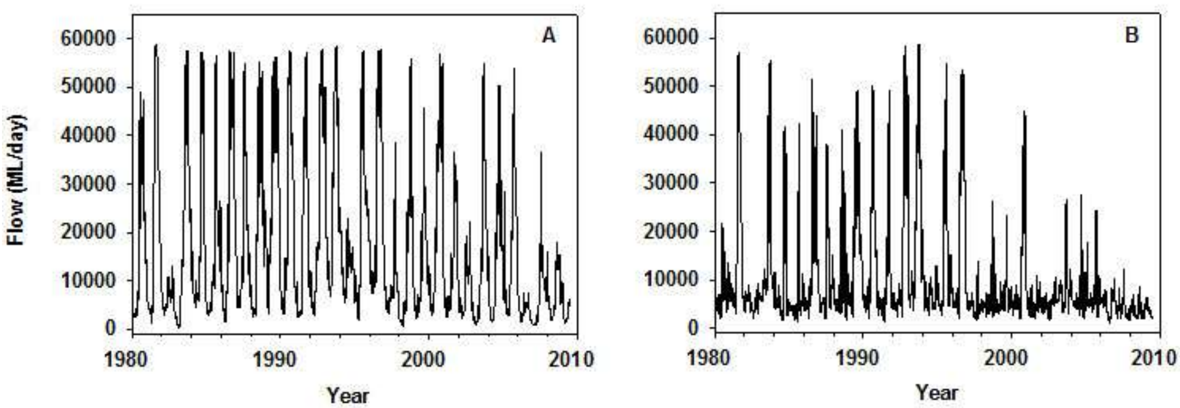

Fig. S1. Modelled daily flows at Torrumbarry on the Murray River under (*a*) natural (unregulated) and (*b*) current (regulated conditions) for the period 1980–2009. Data were supplied by the Murray–Darling Basin Authority.

Flow paths and DOC

Litter fall (Pathway 1)

Ostensibly, direct litter fall (including tree fall) into a river channel would appear to be unimportant for DOC transport into lowland rivers (essentially the thinking behind the river-continuum concept).

The narrower the channel, the more influential will be the flux of litter, which, on wetting, through either fluctuating discharge or as leaf fall directly into the water, will release DOC. The exception is the ephemeral channels that can be found across many floodplains (Hladyz *et al*. 2011). These channels serve to move water to and from the floodplain and can be filled either from overland flow from the catchment (Pathway 2) or from overbank flows. Because they are low points in the landscape, they tend to fill first, and, in small overbank flows, may be the only part of the floodplain that fills. Because they are the first to fill, they are also the part of the floodplain that is flooded most often (i.e both during small, medium and large events) and, hence, unlike other parts of the floodplain, may be flooded multiple times in the same year. Because they are low points in the landscape, litter, mostly from fringing vegetation, accumulates in the dry channel or any remnant pools (Hladyz *et al*. 2011). On rewetting, DOC is released from the accumulated litter, which in turn can enter the riverine food web on return. Therefore, when considering whether, historically, DOC may have been important to riverine food webs before human modification, the extent of the channel networks on the floodplain should be taken into consideration, especially the surface area of the total channel network compared with the size of the receiving channel. The food web in a small river connected to a floodplain with an extensive network of channels would more likely be supported by DOC than a very large river channel, with a floodplain with few, if any, channels.

Other things to take into consideration include how often the channels would have flooded on an annual basis, the nature of the natural floodplain vegetation, and the mechanisms of litter fall and accumulation. Litter accumulation in channels would more likely occur in floodplains dominated by trees rather than grasses. In floodplains dominated by deciduous trees, because litter fall occurs only once in a year, DOC export from the floodplain channels to the main river will mostly occur during the first inundation event following leaf fall. Therefore, DOC export from the floodplain will, at best, occur only once a year. In such a case, the importance of DOC export from the floodplain to the riverine food web will depend on the ability of the riverine biota to capture and store the DOC, which in turn will depend on the sites of transformation in the river system (see above). In floodplains dominated by evergreens such as *Eucalyptus* species, even though leaf fall may occur predominantly in one season, it occurs throughout the year. For floodplain eucalypts such as the river red gum, litter fall is a normal physiological response to drought stress and major declines (≥90%) and subsequent recovery in leaf-area index are common (Doody *et al*. 2015). Multiple flooding of river channels will lead to multiple pulses of DOC back to the river channel, although terrestrial ageing of fallen leaves means that the timing of inundation will play a role in the magnitude of DOC released (Watkins *et al*. 2010) and, possibly, its lability.

Flows from rain events (Pathways 2 and 3)

Rainfall events can mobilise DOC either from surficial litter and other plant material during overland flows or from the soil profile during subsurface flows. The importance of this pathway will depend on

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the width and gradient of the floodplain, the extent of channelisation on the floodplain and the intensity of a rain event. Unlike upland streams, lowland river floodplains tend to be wide (many tens of kilometres), flat and often a long distance from their upland and headwater streams. Therefore, runoff from rain events does not have the necessary hydraulic energy to produce sufficient overland flows for DOC, leached from the litter or soil, to reach the river channel; the exception would be channelised floodplains, where channels could intercept overland and surface flows (discussed above). Where rainfall events may play a role in DOC dynamics in floodplains is through the filling of low points on the floodplain, including oxbows, depressions and other types of wetlands. Litter that has accumulated in these types of features, will release DOC on inundation. And litter fall into the depressions post-inundation from fringing vegetation will add to the DOC pool. Some of this DOC will then be utilised by aquatic organisms that have evolved to utilise such ephemeral pool. Both the DOC in these pools, and the aquatic organisms that have developed in these pools, can be entrained in subsequent floodwaters and, hence, enter riverine food webs.

Subsurface flows from the river to the floodplain (Pathway 4)

Subsurface flows away from a river channel are not uncommon in lowland rivers. The extent of these flows will depend on several factors, including soil type and the extent of opposing hydraulic gradients (for example, Pathway 3). These flows can influence riverine food webs in two ways. The first is the mobilisation of riparian soil carbon that can make its way back to the floodplain. The second is through the filling of depressions such as oxbows (see above).

Lateral flow from the River to the floodplain during overbank flows (Pathway 5)

Floodwater will bring with it carbon from upstream sources, as well as aquatic organisms that can utilise floodplain resources. Although upstream sources probably affect the importance of DOC only as a basal resource to food webs within a channel, floodplain resources can be quite important for fishes, waterbirds, invertebrates and other aquatic heterotrophs living in floodplain wetlands and lakes, some of which will be based on food webs with DOC as a basal resource.

Return flows from overbank flows (Pathways 6 and 7)

Overbank flows will initially flood channels and depressions on the floodplain (see above) and then higher, shedding parts of the floodplain. During inundation, DOC will be mobilised from any litter and other dead plant material on the floodplain, from the soil and from standing water bodies on the floodplain (Kerr *et al*. 2013). On the basis of the few mass-balance studies available (e.g. Nielsen *et al*. 2015), it would appear that overbank flows are the most important source of DOC (by weight) than any of the other processes (noting the importance of litter fall into channels and standing water bodies discussed above). The amount of DOC that is mobilised will depend, in a large part, on the areal extent of flooding, as well as the vegetation type, amount of litter accumulation and the amount of DOC stored in standing waters on the floodplain (Kerr *et al*. 2013). For DOC from allochthonous sources to be an important component of riverine food webs, the annualised load of readily bioavailable DOC mobilised from the floodplain must be at least approximately the same as the amount of carbon fixed in the river channel. Therefore, food webs in rivers with highly productive floodplains (with respect to sources of DOC such as leaf litter) are more likely to be supported by allochthonous DOC, than they are in rivers with floodplains of low productivity, or rivers where lateral connectivity has been severed.

Flows downstream (Pathway 8)

As DOC moves downstream, it undergoes a series of biotic and abiotic reactions that serve to reduce its concentration. Furthermore, because the most readily bioavailable components of DOC are consumed first, the further away from the source of the DOC, the more likely the remaining DOC will be more recalcitrant. Therefore, both the quantity and quality of DOC will diminish from the distance from its source, and, therefore, the less likely allochthonous DOC will be an important basal resource supporting riverine food webs.

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