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RIVERINE AND FLOODPLAIN INTERACTIONS
DURING HIGH FLOW

Principal Contact

DR. TERRY HILLMAN
Murray-Darling Freshwater Research Centre
PO Box 921, Albury NSW 2640
Phone: 060 582300 Fax: 060 431626

Project Team

ADRIENNE BURNS
ALISTAR ROBINSON
Johnstone Centre, Charles Sturt University

GERRY QUINN
Monash University, CRC Freshwater Ecology

TRISH BOWEN
HELEN GIGNEY
GARTH WATSON
Murray-Darling Freshwater Research Centre

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PROJECT OBJECTIVES
1. To measure changes to billabong and river ecosystems during high flow events which connect the two systems
2. To quantify the flux of materials (water, nutrients, carbon, invertebrates and fish) between river and billabongs during connections.
3. To interpret results in terms of river management strategies.
INTRODUCTION

As with all ecosystems, rivers are supported by primary production – the function whereby inorganic building blocks are turned into living (organic) material which forms the energy (carbon) supply for the rest of the biota. This is almost all achieved through photosynthesis and in river ecosystems it is carried out by organisms in the biofilm, free living algae, aquatic plants, riparian vegetation, and the floodplain ecosystem which includes terrestrial plants (e.g. Redgums, grass) and billabongs. Billabongs are known to be diverse and highly productive systems (Hillman 1986, Boon et al. 1992) and recent research has demonstrated a rapid reaction to inundation in experimental billabongs (Nielsen et al. 2000) leading to predictions that high productivity in billabongs during high flow events may provide strategic inputs to the river system (i).

This project set out to study the response of billabongs to connectivity and measure the exchanges between river and billabong during periods of high flow. Sites were chosen on the Murrumbidgee floodplain near Wagga Wagga with the aid of aerial surveys and historic flow records.

SUMMARY OF METHODS AND MODIFICATIONS

Study Area and Sampling Regime (Appendix I)

Following two Springs in which flows in the Murrumbidgee failed to reach a sufficient height to inundate the experimental billabongs, the Murrumbidgee Community Committee on Environmental Flows generously decided to combine two years of their discretionary contingency allocations to augment natural flow events and supply sufficient flows for the experiment. Consequently an Environmental Contingency Allowance release of 38 710 ML from Burrajunk and Blowing Dams was initiated between August 16th and 25th to augment natural flows at that time driven by mid-catchment discharge through Tarcutta Creek.

Two contiguous reaches of the Murrumbidgee River (200km by river) between Gundagai and Narrandera were studied: 1. between Gundagai and the confluence with Tarcutta Creek. 2. below Tarcutta Creek to above the confluence with Old Man Creek. The upstream reach contained one billabong that received water from dam releases. The downstream reach contained three billabongs and received significant tributary flow as well as dam releases.

Samples were collected between August 8 and September 8, 2000 in each billabong, on the main river channel (at sites within 100m upstream and downstream of the connecting channel), and within the billabongs connecting channel during high flows. Samples were collected twice prior to filling of the channels, and at a minimum of 3 occasions on inflow, 3 occasions on outflow, and 24h and 7 days after disconnection with the river. During this period, samples from the main river were collected at the furthest upstream and downstream locations, and at sites downstream of the confluence of Tarcutta Creek.
Billabong Hydrology during High Flow Period.

Physical descriptions of the experimental billabongs are provided in Appendix 1. They varied in volume, commence-to-fill height, and the degree to which they were empty prior to the high flow. These are summarized below:

<table>
<thead>
<tr>
<th>Billabong Number</th>
<th>Name</th>
<th>Commence-to-fill (ML/day - Wagga)</th>
<th>Volume pre-flood (ML)</th>
<th>Volume at 100% Full (ML)</th>
<th>Peak Volume during Flood (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eringoarrah</td>
<td>26000</td>
<td>1.4</td>
<td>11.5</td>
<td>16.4</td>
</tr>
<tr>
<td>2</td>
<td>Iris Park</td>
<td>24000</td>
<td>26</td>
<td>55</td>
<td>173</td>
</tr>
<tr>
<td>3</td>
<td>Berry Jerry</td>
<td>16000</td>
<td>40</td>
<td>46</td>
<td>58</td>
</tr>
<tr>
<td>4</td>
<td>Clarkes</td>
<td>24000</td>
<td>1.5</td>
<td>80</td>
<td>166</td>
</tr>
</tbody>
</table>

Carbon and Nutrients (Appendix 2)

To estimate fluxes of materials we made twice-daily simultaneous measurements of (1) the concentrations of particulate and dissolved organic carbon, particulate and dissolved nitrogen and total phosphorus in in-flowing and out-flowing waters in channels linking the river and four billabongs and (2) water volume changes in billabongs. By combining the two to give loads and knowing the directions of flow, we could calculate fluxes.

To calculate fluxes at the reach scale we combined daily measurements of dissolved and particulate carbon concentrations and flow at river sites downstream of the last major tributary stream Tarcutta Creek and downstream of Clarks Sandhill Lagoon (Billabong 4), some 100 river km apart. Differences between the loads of material between upstream and downstream sites represented fluxes on a reach scale.

Enzymes (Appendix 3)

Water samples were collected in two connected floodplain billabongs, three floodplain billabongs which remained disconnected, the main river channel and major tributaries of the Murrumbidgee River before, during and after high flows. Methylumbelliferyl (MUP) substrates were used as follows:

<table>
<thead>
<tr>
<th>ENZYME</th>
<th>SYMBOL</th>
<th>DECOMPOSITION ACTION CATALYSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty acid esterase</td>
<td>FAE</td>
<td>Esters</td>
</tr>
<tr>
<td>Alkaline phosphatase</td>
<td>AP</td>
<td>Organic phosphates</td>
</tr>
<tr>
<td>α-1,4-glucosidase</td>
<td>α-G</td>
<td>Polysaccharide</td>
</tr>
<tr>
<td>β-1,4-glucosidase</td>
<td>β-G</td>
<td>Polysaccharide</td>
</tr>
<tr>
<td>β-xylanidosidase</td>
<td>Xyl</td>
<td>Long-chain polysaccharide</td>
</tr>
<tr>
<td>Leucine amino-peptidase</td>
<td>LAP</td>
<td>Protein</td>
</tr>
</tbody>
</table>
These enzymes cover the microbial processing of a range of autochthonous and allochthonous organic matter sources common in river systems (Christ 1991). Activities were assayed by mixing 750 μL of each substrate with 750 μL of sample water. Fluorescence was read repeatedly over a 1-24 hour period at 365nm excitation and 450nm emission and enzyme activities were expressed as rate of substrate use in μmol/L/h. Individual samples were also corrected for substrate degradation and quenching.

Zooplankton (Appendix 4)

Three, 8L Schindler trap samples were taken at depth of around 20cm per site per occasion from each of four billabongs and their associated river connections. During hydrological connection, a channel site and both an upstream and downstream of inflow channel were included. Traps were taken as a cross-section of the billabong to reflect the gradient of habitats that exists from littoral to planktonic. Collections were subsampled and identified quantitatively for zooplankton abundance to at least genus level.

Macroinvertebrates and Fish

Macroinvertebrates were sampled using 30second dip-net trawls in available habitat types in the billabongs and river sites. During the period of connection between billabong and river, drift nets of equivalent mesh size were deployed to monitor movement of macroinvertebrates, larval and small fish. Very few fish were captured and there was no sign of organised fish movement. This may reflect the depauperate nature of the fish stocks in the Murrumbidgee, as predicted by Peter Gherke (see earlier progress report), that fish movement was not triggered by this flood (some of which resulted from reservoir release), or that movement to and from the floodplain under these conditions is not part of normal fish behaviour.

RESULTS

Hydrology

![Billabong Volume Graph]

The above figure summarises the hydrology of each billabong over the period of connection, relative to 100% full (after the recession of flood waters). There are
substantial differences in the starting point (relative volume before inundation) and the degree to which the high flows 'over-filled' the billabongs.

*Carbon and Nutrients (Appendix 2)*

The floodwaters entering the study reach were a mixture of water released from Blowering Dam and natural flood inputs from Tarcutta Creek. It was clear that Tarcutta Creek (the last major tributary to the river) contributed most of the particulate and organic carbon to the floodwaters.

When daily exchanges of carbon were summed over the duration of the flood there was significant net transport of particulate and dissolved organic carbon from the river into each of the four billabongs. The actual amount transported into each billabong, if it was all used to support biological production, would have fuelled respiration of the billabong biological community for some weeks.

At a larger scale, the floodplain is a source of dissolved organic matter to river channels during floods. Our findings from billabongs would suggest that they are not the source of dissolved organic carbon, since all imported carbon from the river channel during the flood. It appears that the small areas of the non-billabong floodplain that were wetted during the flood were the source of dissolved organic carbon. This conclusion is supported by previous work (O’Connell et al. 2000) and predictions regarding what might be exported from non-wetland parts of the floodplain during floods (Robertson et al. 1999). The tendency for billabongs to be a net user of dissolved carbon, despite the often substantial areas of dry sediment wetted by their inundation, may be indicative of rapid utilization of dissolved carbon (by microorganisms) in the billabongs.

*Enzymes (Appendix 3)*

High flows resulting in river-billabong connections did not change the billabong bacterial community composition.

High flows resulting in river-billabong connections altered the availability and composition of bacterial enzymes in the main river channel downstream of connected billabongs. Due to the rapid response of the dominant enzymes (FAE, LAP) sampling at a finer temporal scale of sampling may further elucidate the role of connection in delivering billabong bacterial communities to the river.

The major tributaries of the Murrumbidgee River in our study reach contributed little to the activity of the dominant enzymes in the main river channel. During high flows the contribution of high volumes of low activity water from the tributaries may result in a decrease in overall activity in the main river channel through dilution. Activities during the flood peak exceeded post-flood activities for all sites below Tarcutta Ck where there is an extensive network of floodplain and billabongs. It appears that the major sources of DOC used by microbial communities are derived partly from billabong outflow, but also from instream sources (sediments, biofilms and woody debris) and local runoff.
During the 2-3 day connection period there was a net increase in enzyme concentration in most cases – particularly in the most quickly responsive enzyme AP and LAP and β-GLU. Further, more frequent sampling may have provided more information on a possible succession of bacterial enzyme activity although this is likely to have been masked by rising grazing pressure from increasing zooplankton densities.

Zooplankton (Appendix 4)
The zooplankton communities showed the most unambiguous response to high flows. The responses in all four billabongs were remarkably similar in pattern given their significant hydrological differences. In general, the pattern of response was:

- Period of dilution following inundation
- Rapid increase in numbers – masked in several cases by reduction in volume during flow recession
- Continued increase in numbers after cut-off from river flows.
Detection of an effect on zooplankton populations in the river was made difficult by the short duration of the flood. The results indicate that, had the period of connection lasted for 1-2 weeks a greater impact could have been expected. However the data imply a shift in the species composition of riverine zooplankton communities towards that of the billabong communities during recession (see appendix 4). There also appeared to be a succession in body size of zooplankton following inundation probably indicating rapid recruitment of juveniles. This may be significant in terms of zooplankton as a food resource.

**DISCUSSION AND CONCLUSIONS**

This summary report concentrates primarily on outcomes of the research which are of direct significance to river managers. The following conclusions emphasise these outcomes.

The hypothesis that billabongs act as a significant source of dissolved carbon for the river during floods is not supported by the project. In total they appear to act as sinks (perhaps counter-intuitively?). How and in what form the carbon is sequestered in the billabong is not clear from this study. This requires further research – particularly how much is captured for increased billabong microbiological activity – as it changes part of our current conceptual model regarding movement of carbon through river ecosystems.

An hypothesised burst of microbiological activity in billabongs immediately following inundation again was not demonstrated clearly in our results. This outcome is less compelling because of the essential field scale of the operation, the large changes of volume, and the unknown but probably increasing grazing pressure from expanding zooplankton communities. The question needs to be investigated under intensive and better controlled conditions.

The predicted ‘bloom’ of zooplankton in billabongs following inundation was clearly observed at every experimental site, even though billabongs experienced increases in volume ranging from less than 100% to about 70-fold. In each case zooplankton biomass commenced increasing almost immediately on inundation and continued to do so for the 14+ subsequent days of observation. Because connection lasted only 2-3 days there was no clear influence of billabong outflow on the composition of the river zooplankton. Although the data showed a temporary shift towards the riverine community structure in the billabongs, while they were filling, the zooplankton of each billabong quickly regained a more characteristic composition as the biomass began to rise.

Insignificant numbers of fish were captured during the high flow in the river, the billabongs, or the connecting channel. This latter would seem to indicate that fish do not move into billabongs during high flows in response to increased larval food, although the fact that the native fishery was extremely depauperate may have resulted in its inability to respond in a natural way (Gehrke pers.com.).

Macroinvertebrate movement between billabong and river was very small and appears unlikely to contribute to a significant and systematic process related to connectivity. Longer term responses are currently being studied.
MANAGEMENT AND RESEARCH OUTCOMES

High flows result in two sets of outcomes: recharging of billabongs, and the opportunity for beneficial interaction between floodplain and main river channel. This experiment demonstrates that the first is an 'instantaneous' response which then progresses through its natural succession pattern regardless of continued connectivity. The second process, however, is time-dependent and the nature of the interaction is dependent on the duration of connection. For instance, the return of large volumes of zooplankton, a valued larval fish resource, is not likely to occur until 10-20 days after inundation. In terms of providing effective environmental flows a tactic of a short (recharging) release followed after about two weeks by a connecting/transfer high flow may produce effective inoculations of zooplankton to the river with maximum water economy. Experimentally, this could be achieved by pumping water to billabongs two weeks before high flows.

Carbon dynamics require further research. The results of this experiment seem, at least superficially, to be counter-intuitive as current conceptual models would have overbank flows as significant sources of dissolved carbon for the river system. It is quite possible that the time/space scale of this experiment did not allow us to track the movement of carbon accurately. Further research will be needed to identify the major sources of DOC, measure the quantity derived within billabongs from the inundation of previously dry sediments, and track its assimilation into the microbial community in the first hours/days of inundation.

Unfortunately, the value of zooplankton inoculation of the river as a fish resource remains an untested assertion which needs to be quantified if useful conceptual models of lowland river function in relation to flow are to be completed.

OUTPUTS

Components of this research have been incorporated into course work at CSU for both Science and Agriculture (irrigation) students. Four newsletters describing the rationale and progress of this project have been circulated to participating landholders and much of the latter has been incorporated into curriculum material prepared by Michael Copland*. Aspects are being presented in conference papers and prepared for refereed scientific publication (see below). The findings are also contributing significantly to the development of conceptual models for lowland river function (by Ben Gawne, Michael Stewardson, and Terry Hillman) and to the deliberations of the MDBC in reviewing the ‘Cap’ and developing environmental flow strategies.

Manuscripts to date:


Burns A. & Ryder D.S (2001), The emergence of biofilms as a monitoring tool in Australian riverine systems. Ecological Restoration and Management. 2, 53-63

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* This work has been curtailed by the cessation of Copland’s contract funded by MDBC.


Robertson, A. “Fluxes of organic matter between river and floodplain during a small flood.” School of Science and Technology, Charles Sturt University, Wagga Wagga, July 2001.

LIST OF APPENDICES:

1. Study Area and Sampling Regime
2. Transport of Carbon and Associated Elements during the Flood
3. The Response of Bacterial Extracellular Enzymes to River Floodplain Connections
4. The Response of Zooplankton to River Floodplain Connections
Appendix 1:
Study Area and Sampling Regime

Adrienne Burns and Helen Gigney

The Murrumbidgee River's catchments form part of the Murray-Darling Basin draining an area of approximately 82 000km². The River is around 1600km in length from its source in the Snowy Mountains to the confluence with the Murray River. It is the most regulated river in New South Wales with over 90% average annual discharge diverted for consumptive use. Most of the annual discharge is regulated by two storage reservoirs, Burragorang Dam on the Murrumbidgee River and Blowering Dam on the Tumut River a tributary that joins the Murrumbidgee upstream of Wagga Wagga (Figure 1A).

Prior to regulation, flows were highly variable, exhibiting winter maximums. Regulation for downstream agricultural irrigation has altered the flow to a summer dominated regime. The main impact has been a decrease in the frequency and duration of small to moderate flows derived from rainfall in the upper catchment.

The mid-catchment comprises the river reaches from Gundagai to Hay, with a widening of the alluvial floodplain and a reduction in gradient occurring from east to west. The low gradient in this zone results in a meandering river channel and the formation of numerous floodplain wetlands. The river flows in the mid-catchment are regulated by the upstream dams, but are also influenced by several tributaries between Gundagai and Wagga Wagga, the main one being Tarcutta Creek. Downstream of Wagga Wagga there are numerous distributaries, regulatory structures and off-take channels for the consumptive use of water.

Two adjoining reaches of the Murrumbidgee River (200km by river) between Gundagai and Narrandera were studied: 1. between Gundagai and the confluence with Tarcutta Creek. 2. below Tarcutta Creek to above the confluence with Old Man Creek. The upstream reach contained one billabong (cut-off meander, scroll) that received water from dam releases. The downstream reach contained three billabongs (ox-bow lakes) and received significant tributary flow as well as dam releases (Figure 1B). Onset of severe El Niño conditions in 1997 and early 1998 resulted in the wetlands having a mosaic of wetting and drying patterns prior to high flows in 2000 (Table 1). River flow over the whole period of the study (1997 – 2000) is shown in Figure 2A. During that time flows were sufficiently high to wet more than one of study billabongs during two events: firstly two brief pulses in August / September 1998 and secondly an extended pulse in August 2000.

Environmental Flows as part of the NSW Water Reforms were implemented in the Murrumbidgee River in August. During 2000, a total of 139 097 ML (13% of inflows) were released as translucent flows through Burragorang Dam, with the peak discharge of 7520 ML occurring on August 17th to 19th. An Environmental Contingency Allowance release of 38 710 ML from Burragorang and Blowering Dams was initiated between August 16th and 25th to extend the duration of a natural flow that was occurring in the river at that time and driven by mid-catchment discharge through Tarcutta Creek (Figure 2B). Of this total, 13 530 ML was released from Blowering Dam, as maintenance on Burragorang Dam limited releases to 10 000ML/day.
This report focuses on the 2000 high flow event, which due to its duration yielded a high number of samples (~1000 samples for each type of analysis). Samples were collected between August 8 and September 8, 2000 at locations within each billabong, on the main river channel at sites within 100m upstream and downstream of the connecting channel, and within the connecting channel during high flows. A subset of the samples collected was analysed. This included samples collected twice prior to filling of the channels, and at a minimum of 3 occasions on inflow, 3 occasions on outflow, 24h and 7 days after disconnection with the river. During this period, samples from the river were collected at the furthest upstream and downstream locations, and at sites downstream of the confluence of Tarcutta Creek.
<table>
<thead>
<tr>
<th>Property</th>
<th>Commence to fill flow (ML/day @ Wagga)</th>
<th>Previous drying of wetland basin</th>
<th>Previous river connections</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reach 1 (Upper)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Billabong 1</td>
<td>Eringoaarrah Station</td>
<td>26 000</td>
<td>Unknown</td>
<td>1998 – spring 1999 – summer</td>
</tr>
<tr>
<td><strong>Reach 2 (Lower)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Billabong 2</td>
<td>Iris Park Station</td>
<td>24 000</td>
<td>Summer 1997, Summer 1998, Winter 1999</td>
<td>1998 – spring 1999 – summer</td>
</tr>
<tr>
<td>Billabong 3</td>
<td>Berry Jerry State Forest</td>
<td>16 000</td>
<td>Unknown</td>
<td>1998 – spring 1999 – summer</td>
</tr>
<tr>
<td>Billabong 4</td>
<td>Bull’s Run Station (Clarkes Sandhill Lagoon)</td>
<td>24 000</td>
<td>Summer 1997, Summer 1998</td>
<td>1998 – spring 1999 – summer</td>
</tr>
</tbody>
</table>
Figure 1: The Murrumbidgee River. A) Murrumbidgee catchment including the two dams (●) in the upper Murrumbidgee and Tumut Rivers. B) The location of billabongs 1-4 and the unregulated tributary (Tarcutta Ck) on the studied reach near Wagga Wagga.
Figure 2: Murrumbidgee Flows. A) 1997-2000, two high flow periods (circled) and commence to fill flow requirements for billabongs (B1, B2, B3, and B4). B) August September 2000, contribution of dam discharge (Gundagai) and a major tributary flow (Tarcutta Ck) to the flow recorded at Wagga Wagga.
Appendix 2:

Transport of carbon and associated elements during the flood

Adrienne Burns and Alistar Robertson

Rationale

The carbon budgets of floodplain reaches of rivers are products of longitudinal transport of material from catchments, exchanges between the river channel and groundwater, lateral transport of materials between floodplain and river channels and transformations of carbon within all habitats that make up the river proper (eg Junk et al. 1989, Ritchey et al. 1990, Tockner et al. 1999). The relative roles of these various processes are determined by the interaction between elements of the flow regime and local geomorphology.

We know very little about the sources, sinks and transformations of carbon in Australian rivers, yet management efforts aimed at restoring river health depend on having appropriate models of river function (Robertson et al. 1999). A particular gap in our knowledge is the lateral transport of organic carbon between river channel and floodplain during floods.

This section of the report deals with two of the main questions posed in the project:
1. Billabong scale - what quantities of carbon materials are exchanged between the river channel and billabongs during a flood?
2. River reach scale - what are the effects of exchanges between billabongs and river during a flood on material transport in a large section of the river channel?

Based on the relatively scant understanding of carbon dynamics in floodplain rivers, and our pre-flood sampling, we would expect that since there are much greater concentrations of dissolved organic matter in billabongs than in the water of the river channel, a flood connection might mean there would be a net movement of carbon from billabongs to the river.

Methods

To estimate fluxes of materials we made twice-daily simultaneous measurements of (1) the concentrations of particulate and dissolved organic carbon, particulate and dissolved nitrogen and total phosphorus in inflowing and outflowing waters in channels linking the river and four billabongs and (2) water volume changes in billabongs. By combining the two to give loads and knowing the directions of flow, we could calculate fluxes.

To calculate fluxes at the reach scale we combined daily measurements of dissolved and particulate carbon concentrations and flow at river sites downstream of the last major tributary stream Tarcutta Creek and downstream of Clarks Sandhill Lagoon (Billabong 4), some 100 river km apart. Differences between the loads of material between upstream and downstream sites represented fluxes on a reach scale.

All water samples were collected in 1L acid-washed plastic bottles and returned to the laboratory within 3 hrs for processing. Water was filtered through pre-ashed and weighed GFF filters to obtain samples for analysis of particulate carbon and nitrogen (Leco CNS analyser) and water was then passed through a 0.45μM filter to obtain samples for DOC analysis (TOC analyser, Dohrman). Analysis for nitrogen and phosphorus followed standard techniques.
1. Billabong scale

Despite differences in the conditions in the four billabongs prior to flooding (one was almost dry, two had received a small flood one week prior to our measurements, one was half full), and different commence-to-fill heights (and hence periods of connection) there were similar patterns in the direction of fluxes of particulate and dissolved materials between wetlands and the river channel.

There were major influxes of particulate carbon and dissolved organic carbon into billabongs in the first two to three days of flood connection. The exception was Eringaarrar billabong (Billabong 1), where the total flood connection period was less than seven days. During the flood draw down period there were significant losses of particulate organic carbon and dissolved organic carbon from all billabongs to the river channel.

When daily exchanges of carbon were summed over the duration of the flood there was significant net transport of particulate and dissolved organic carbon from the river into each of the four billabongs (Table 1). The actual amount transported into each billabong, if it was all used to support biological production, would have fuelled respiration of the billabong biological community for some weeks.

Table 1. Summary of net material inputs to billabongs during the flood

<table>
<thead>
<tr>
<th>Billabong</th>
<th>POC kg</th>
<th>DOC Kg</th>
<th>DON kg</th>
<th>Total N kg</th>
<th>Total P kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billabong 1</td>
<td>87</td>
<td>213</td>
<td>6</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Billabong 2</td>
<td>279</td>
<td>4357</td>
<td>9</td>
<td>35</td>
<td>6</td>
</tr>
<tr>
<td>Billabong 3</td>
<td>525</td>
<td>36</td>
<td>&lt;1</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Billabong 4</td>
<td>185</td>
<td>280</td>
<td>7</td>
<td>36</td>
<td>3</td>
</tr>
</tbody>
</table>

There were no clear relationships between billabong size and the magnitude of carbon exchanges. For instance, dissolved organic carbon imports to billabong 1 and billabong 4 were similar, but they differed in size by a factor of five. Presumably antecedent conditions, amounts of organic debris and other factors such as the length of the connecting channel between billabong and river were responsible for these differences.

There were also significant inputs of particulate and dissolved nitrogen and phosphorus into billabongs during the flood event.

2. Reach Scale

The floodwaters entering the study reach were a mixture of water released from Blowering Dam and natural flood inputs from Tarcutta Creek. It was clear that Tarcutta Creek (the last major tributary to the river) contributed most of the particulate and organic carbon to the floodwaters.

During the transit of the flood through the reach between Tarcutta Creek and the confluence of Old Man Creek there was a net loss of 950 tonnes of particulate organic carbon from the river to the floodplain (Figure 1). In contrast to the flux of particulate organic carbon, there was a net input of 130 tonnes of dissolved organic carbon from the floodplain to river channel from the reach between Tarcutta Creek and the confluence of Old Man Creek (Figure 1).

Conclusions

In this flood all four billabongs received far more organic carbon and nitrogen and phosphorus than they delivered to the river channel. Based on these findings it appears that the prediction of billabongs being sources of organic carbon for the river channel was not supported.

At a larger scale than individual billabongs, the floodplain is a source of dissolved organic matter to river channels during floods. Our findings from billabongs would suggest that they are not the source of dissolved organic carbon, since all imported carbon to the river channel during the flood. It appears that the small areas of the non-billabong floodplain that were wetted during the flood were the source of dissolved organic carbon. This conclusion is supported by previous work we have done (O’Connell et al. 2000) and predictions we have made regarding what might be exported from non-wetland parts of the floodplain during floods (Robertson et al. 1999).
References


Figure 1.
Net accumulation or losses of POC (a), DOC (b), total N (c), total P (d) from the reach below Tarcutta Ck to downstream of Billabong 4.
Appendix 3: *The response of bacterial extracellular enzymes to river floodplain connections*

Adrienne Burns, Alistar Robertson and Trish Bowen

**Rationale**

Heterotrophic microorganisms (predominantly bacteria) form a key level in aquatic ecosystems, being supported by dissolved organic carbon (DOC). A technique has been developed which uses the activity of bacterial extracellular enzymes to link bacterial productivity to the concentrations and classes of available organic matter. Organic matter in aquatic systems occurs as carbohydrates, proteins, fatty acids and other compounds (Christ 1991; Findlay et al. 1997; Chappell & Gould 1995). Each class of organic matter requires a specific extracellular enzyme to be excreted from bacteria in order for the organic matter to be utilised. Bacteria can shift their composition of extracellular enzymes in response to changes in the classes of available organic matter. By monitoring these shifts in enzyme activity it is possible to examine the classes and quantity of organic matter available to these microbial communities. Therefore, by understanding the ecological role of high flows in fundamental processes such as bacterial use of DOC, we may predict the response of riverine food webs to different river flow regimes, within the main river channel or onto the floodplain. The main objective of this study was to assess the succession of bacterial enzyme response to high flows in floodplain billabongs and the main river channel.

We predict that high flows will result in higher enzyme activities in billabongs after connection resulting in increased activities in the river downstream of these billabongs. This should result in an overall increase in enzyme activity in the river with distance downstream.

**Aims**

- Did high flows, which resulted in river-billabong connections, reset billabong bacterial response to DOM availability and composition?
- Did high flows, which resulted in river-billabong connections, change the availability and composition of bacterial enzyme response to DOM availability and composition in the main river channel downstream of connected billabongs?
- To examine the contribution of major tributaries and floodplain wetlands to bacterial enzyme activity in the main river channel during and after a flood peak.

**Methods**

1. Enzyme Analysis

Water samples were collected in two connected floodplain billabongs, three floodplain billabongs which remained disconnected, the main river channel and major tributaries of the Murrumbidgee River before, during and after high flows. Methylumbelliferyl (MUF) substrates were used to determine extracellular enzyme activities of fatty acid esterase (FAE); alkaline phosphatase (AP); α-1,4-glucosidase (α-G); β-1,4-glucosidase (β-G); β-xylosidase (Xyl), leucine amino-peptidase (LAP). These enzymes cover a range of autochthonous and allochthonous organic matter sources common in river systems (Christ 1991).

Activities were assayed by mixing 750 µL of each substrate with 750 µL of sample water. Fluorescence was read repeatedly over a 1-24 hour period at 365nm excitation and 450nm emission and enzyme activities were expressed as rate of substrate use in µmol/L/h. Individual samples were also corrected for substrate degradation and quenching.

2. Data manipulations and analyses

Standard univariate statistical techniques (ANOVA) were employed to examine differences between the activity of individual enzymes between and within river and billabong sites during high flows. Multivariate statistical techniques (Multidimensional scaling) were used to examine activities of the suite of enzymes.

**Results**

Enzyme activities in this study were consistent with those from other river systems in North America (Sinsabaugh et al 1997), New Zealand (Findlay et al. 1997) and Great Britain (Chappell and Gould 1995). Highest activities in the Murrumbidgee River were from Fatty Acid Esterase, Leucine Amino Peptidase and Alkaline Phosphatase. These enzymes also dominated the bacterial communities in the majority of river systems where this technique has been applied (Sinsabaugh et al 1997; Findlay et al 1997; Chappell and Gould 1995).

1. Billabong response
   - After the flood peak there were no differences between the activities of the bacterial enzyme communities in billabongs which had been connected and those which had not been connected during high flows.
   - There were differences in the activities of the bacterial enzyme communities between all billabongs regardless of connection with the river.
   - There were no differences in the activities of the enzyme community over the course of the flood peak from pre flow, inflow, outflow and disconnection, in the two connected billabongs.

2. Local response in the river
   - There were differences in the enzyme community between the billabong and river site upstream of the connecting channel throughout the course of the study at the two connected billabong sites.
   - At the downstream river site of Billabong 1, there were differences in the enzyme community between pre connection, inflow and outflow, but no difference between inflow and disconnection and outflow and disconnection. At Billabong 1, the enzyme activities were lowest in the river prior to connection. Activities peaked at 10 hours (AP), 48 hours (FAE, βGI, LAP) and 336 hours (LAP) in both the upstream river site and in the billabong.
   - At Billabong 2, all enzyme activities were highest in the upstream river site during inflow. At the downstream river site, the enzyme community differed on outflow to pre connection, inflow and disconnection.
   - Highest activities were measured for FAE and LAP, together contributing between 60 – 75% of dissimilarity between all river and billabong sites.

3. River response – Reach scale
   - FAE and LAP were responsible for 60 – 75% of dissimilarity between sites along the river and major tributaries.
   - The two major tributaries the Tumut River and Tarcutta Ck had lower enzyme activities for the dominant enzymes (FAE, LAP and AP), than at sites downstream of their confluences in the main Murrumbidgee channel.
   - During peak flow, enzyme activities below Wagga Wagga at Iris Park exceed that of just below the confluence of Tarcutta Ck (FAE, LAP, βGI, αGI and Xyl).
   - There were significant interactions between location downstream and between peak and post flood for all enzyme activities (Fig 2).
   - Activities during the flood peak exceeded post flood activities for all sites below Tarcutta Ck where there is an extensive network of floodplain and billabongs.

Conclusions

High flows resulting in river-billabong connections did not change the billabong bacterial community composition.

High flows resulting in river-billabong connections altered the availability and composition of bacterial enzymes in the main river channel downstream of connected billabongs. Due to the rapid response of the dominant enzymes (FAE, LAP) sampling at a finer temporal scale of sampling may further elucidate the role of connection in delivering billabong bacterial communities to the river.

The major tributaries of the Murrumbidgee River in our study reach contributed little to the activity of the dominant enzymes in the main river channel. During high flows the contribution of high volumes of low activity water from the tributaries may result in a decrease in overall activity in the main river channel through dilution. Activities during the flood peak exceeded post flood activities for all sites below Tarcutta Ck where there is an extensive network of floodplain and billabongs. It appears that the major sources of DOC used by microbial communities are derived partly from billabong outflow, but also from instream sources (sediments, biofilms and woody debris) and local runoff.
Figure 1

Dominant enzyme activities in the Murrumbidgee River from Downstream of Burrajnuck Dam (D/S) to Below Billabong 4 during the flood peak on August 16/17 2000, and post flood (August 28-30, 2000). Note that during peak flow, enzyme activities below Wagga Wagga at Iris Park exceed that of just below the confluence of Tarcutta Ck.

References


Appendix 4:

The Response of Zooplankton to River Floodplain Connections

Terry Hillman, Garth Watson and Helen Gigney

Rationale

High flow events in floodplain rivers result in the river and at least some of its associated billabongs being temporarily joined. In addition to ‘topping up’ the billabongs, these events provide the opportunity for aquatic organisms to move between the two systems. The movement of water in and out of the billabongs may also result in passive movement of both biotic and abiotic material. It is likely that these events are significant to the function of floodplain river systems. Since control of flow patterns is a potential tool for the sustainable management of our river systems an understanding of the ecological significance of these interactions is necessary to maximise the effectiveness of environmental releases.

Recent and current research has added to our understanding of floodplain ecology. It has been known for sometime that billabongs and their parent streams are biologically quite different from each other - a factor contributing to the biodiversity of floodplain rivers (Hillman 1986). Recent research has shown that the presence of a mixture of temporary and permanent billabongs can further enhance biodiversity (Nielsen et al 1999, Hillman & Quinn, in press).

There is increasing evidence that inundation of billabongs results in a rapid increase of zooplankton numbers so that at least pre-flood densities are regained in a few days (Tan & Shiel 1993, Nielsen et al 1996). Because these organisms are a potential food resource for larval fish it is tempting to assume that this sudden flush of productivity could be important to breeding success for riverine fish which might gain access to the billabongs during high flow or at least obtain the food as the billabongs drain back into the river on the declining hydrograph.

Methods

Zooplankton in the water column was sampled quantitatively, to a depth of around 20cm, using a 4L Schindler trap. For each sample, two traps were collected and concentrated to 100mls through a 50 um mesh plankton net. This sample was washed down and preserved with 100% ethanol. Three samples were taken per site per occasion from each of four billabongs and their associated river sites. During hydrological connection, a channel sample and river samples both upstream and downstream of the connecting channel were collected. In the billabongs, traps were taken as a cross-section of the billabong to reflect the gradient of habitats from littoral to planktonic.

Two pre-flood samples were included in the analysis. The first, one week prior to connection and the second, one day prior, to establish baseline condition. During the flood, samples were collected at least daily until the billabongs were disconnected from the river, then sampled again seven days later. Collections were sub-sampled and identified quantitatively for zooplankton abundance to at least genus level.

Zooplankton abundance and billabong volume data was used to determine biomass or loads of animals and changes in species dominance and size class were assessed graphically for each billabong. Community structure was assessed for river and billabong samples at both species and genus level using Bray-Curtis Dissimilarity index interpreted by Non-parametric Multidimensional Scaling (MDS).
Results

Abundance and number of taxa are the primary differences between billabong and river samples as expected. The flood however did not result in a significant increase in either taxa or abundance of zooplankton in the river, despite its floodplain connections.

Site Analysis

Bong 1 ERI

**General:**
- Bong would be considered as completely dry but for one deep hole <1m deep at distal end to channel.
- Inundation fills bong while overlaying deep hole. Sampling occurred both in and around (20m periphery) this hole otherwise we would have been essentially sampling river water over this short event.

**Diversity:**
- Preflood/post flood spp ratio = 20:16.
- 6 spp in post flood samples not present in preflood. Species succession while diversity remains relatively unchanged.
- 11 spp (68%) of preflood spp comprise post flood samples.

**Spp dominance:**
- Small rotifer *Polyarthra* sp at 2% abundance preflood: but blooms at 47% postflood.

![Pre flood and Post flood graphs showing dominance of *Polyarthra* sp.]

**Size class:**
- Smaller spp (100-500um) dominate pre and post flood. Middle sized group increasing as with all other bongs at 14 days of inundation (except BER).

**Loads:**
- Increase in biomass and abundances. Biomass accelerates after 6 days of inundation at which time disconnection has occurred.
Bong 2 IRI

**Diversity:**

- Preflood/postflood spp ratio = 18:30.
- 17 spp in postflood samples not present in preflood. Increased diversity with significant succession of spp.
- 13 spp (43%) of preflood spp comprise post flood samples.
  
  **Size class**
  
  Smaller sized animals dominate post flood samples, which will be rotifers.

**Spp dominance:**

- Again small rotifer *Polyarthra* sp blooms. From 5% abundance preflood to 38% postflood.
- Another rotifer, *Epiphanes*, not present at all in preflood is second most dominant spp post flood with 19% abundance.
- Preflood dominance by nauplii of copepods (52%), all but disappear postflood (2%).

**Loads:**

- Initial lag with loads largely due to a diminished preflood standing stock (water had entered the billabong one week earlier). Biomass accelerates after 10 days at which time disconnection has occurred.

Bong 3 BER

**General:**

- Berry Jerry began quite differently from the above two sites as it registered a depth of 1.05m the day prior to inundation.

**Diversity:**

- Diversity remained unchanged although around 50% of postflood spp were not present in preflood samples. According to the size class graphs these new spp appear to be small (<500um) – basically rotifers.

**Spp dominance:**

- Dominance is shared among greater number of spp postflood.
- Postflood sample shares dominance between all three groups of taxa.
- There is 20 days between preflood and postflood sampling days.
Bong 4 CSL

**Diversity:**
- Preflood/postflood spp ratio = 18:20.
- 8 spp in postflood samples not present in preflood.
- 12 spp (66%) of preflood spp maintain their presence in post flood samples.

**Spp dominance:**
- Preflood abundance due to one species.
### Zooplankton Summary Sheet

<table>
<thead>
<tr>
<th></th>
<th>Billabong 1</th>
<th>Billabong 2</th>
<th>Billabong 3</th>
<th>Billabong 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>Mostly empty and dry prior to flooding. Resident zooplankton community in &lt;1m deep hole.</td>
<td>Flooding is the second inundation event within one week from dry billabong base. Resident zooplankton community very dilute, responding to initial pulse.</td>
<td>Not dry prior to inundation. Over-channel flows at flood peak meant distal end of billabong connected with inflow channel for a short time.</td>
<td>Not dry prior to inundation. Over-channel flows at flood peak meant distal end of billabong connected with inflow channel for a short time.</td>
</tr>
<tr>
<td><strong>Sampling period</strong></td>
<td>14 days</td>
<td>21 days</td>
<td>20 days</td>
<td>24 days</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Pre:post-flood spp ratio</td>
<td>20:16</td>
<td>18:30</td>
<td>18:19</td>
<td>18:20</td>
</tr>
<tr>
<td>(ii) Number of new taxa post flood</td>
<td>6</td>
<td>17</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>(iii) Pre flood taxa comprising post flood assemblage</td>
<td>68%</td>
<td>43%</td>
<td>42%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Post flood species dominance</strong></td>
<td>Dominant and small size class species <em>Polyarthra sp</em> blooms at 47% in post samples from a pre-flood abundance of 2% – see graph.</td>
<td>Dominant and small size class species <em>Polyarthra sp</em> blooms at 38% in post samples from a pre-flood abundance of 5% – see graph.</td>
<td>Dominant species is shared between developmental stages of copepod nauplii, two species of rotifer and a cladoceran. These were all present in pre-flood samples – see graph.</td>
<td>Dominant species is shared between developmental stages of copepod nauplii, two species of <em>Keratella spp</em> (rotifer). Pre-flood dominance is due to one species of <em>Keratella australis</em>.</td>
</tr>
<tr>
<td><strong>Size class</strong></td>
<td>Small sized taxa dominate pre &amp; post-flood, with medium size class increasing in abundance by day 14 – see graph.</td>
<td>Small and medium sized taxa share an even dominance pre-flood (in very low numbers). Post-flood dominated by small size class – see graph.</td>
<td>Small sized taxa dominate pre-flood but after 3 weeks the middle size class blooms to share dominance – see graph.</td>
<td>Small sized taxa dominate pre-flood but after 3 weeks the middle size class blooms to share dominance – see graph.</td>
</tr>
</tbody>
</table>
References


Hillman, T. J. and Quinn, G. P. in press. Temporal changes in macroinvertebrate assemblages of permanent and temporary wetlands in a floodplain forest. *Regulated Rivers*.


Example of MDS analysis of zooplankton community structure in billabong, connecting channel, and river (upstream and downstream) illustrating dissimilarity of billabong and river systems post-connection.

Berry Jerry (Top 20 taxa)