Modelling macrophyte organic matter inputs to rivers under different flow conditions

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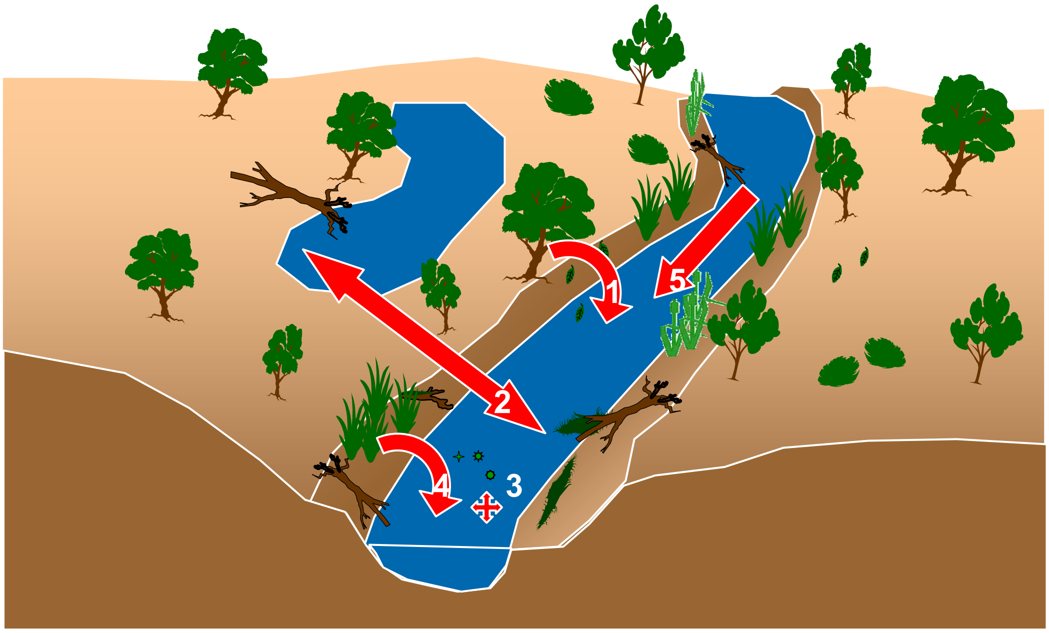
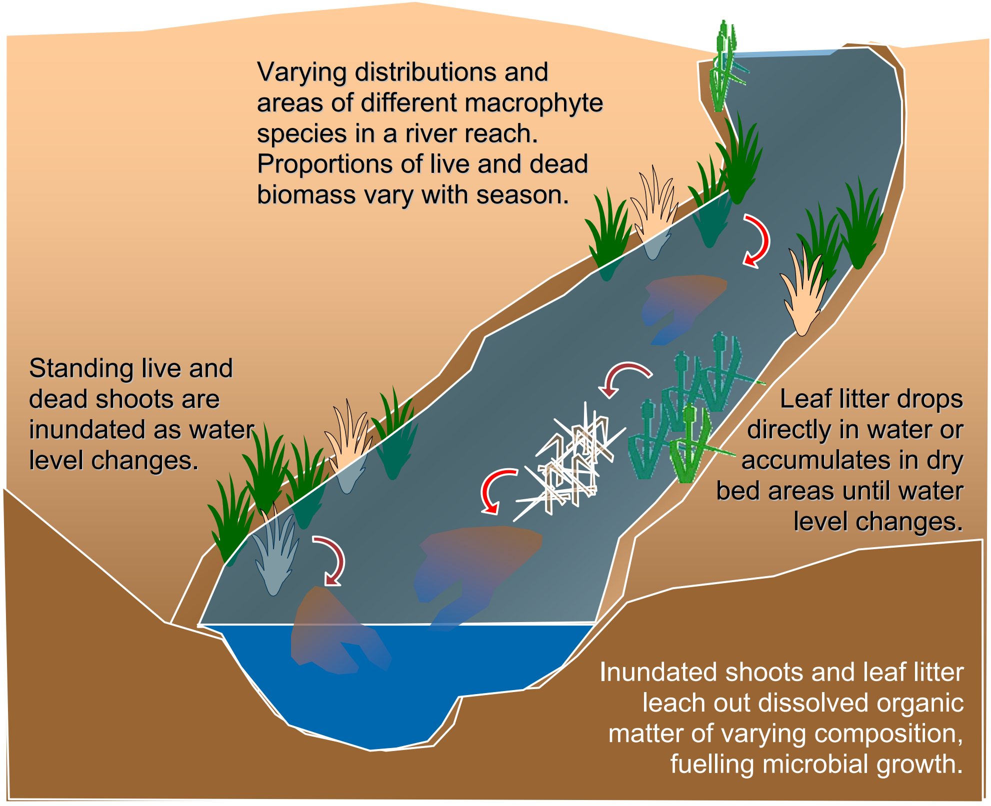
Understanding transfers and transformations of material produced by living organisms (organic matter) is important to understanding how different ecosystems function. In rivers, inputs of organic matter (OM) can come from a range of sources (Figure 1), including inputs from the riparian zone (1) and floodplain (2), in-stream phytoplankton production (3), aquatic plant (macrophyte) inputs (4) and material transported from upstream (5). River regulation and landscape management practices since European settlement have altered OM inputs to Australian rivers, including changes to river flow regimes, dam construction, clearing of native vegetation, altered turbidity and water nutrient levels and algal growth. Macrophytes can provide OM to lowland rivers, with inputs linked to flow. However, macrophyte OM inputs and in-stream processing in Australian lowland rivers are poorly understood. The aim of my study was to examine inputs and processing of macrophyte OM in Australian lowland rivers under different flows, and to develop a predictive computer model of these processes which would help to inform managers in decisions regarding flow releases in regulated rivers.

Figure 1. Sources of organic matter for Australian lowland rivers. See text for description.



The conceptual model of macrophyte OM inputs upon which my work was based is presented in Figure 2. It shows beds of macrophytes growing within a river channel, with varying proportions of live (green) and dead (brown) shoots present at a given time. Leaf litter may drop directly into the water column, or be inundated when water levels rise. Water level changes also affect the quantities of standing shoots which are inundated. Particulate organic matter (POM) leaches out dissolved organic matter (DOM) when wetted, with different tissue types and plant species leaching different quantities and types of DOM. Because of the limited occurrence of direct herbivory of macrophytes in Australian systems, the major pathway for entry of macrophyte OM into the food-web is through the microbial loop, that is, via break-down by bacteria and fungi which are then eaten by larger animals. The utilisation of macrophyte OM by microbes depends on its composition or bio-availability.

Figure 2. Conceptual model of macrophyte organic matter inputs to lowland rivers.



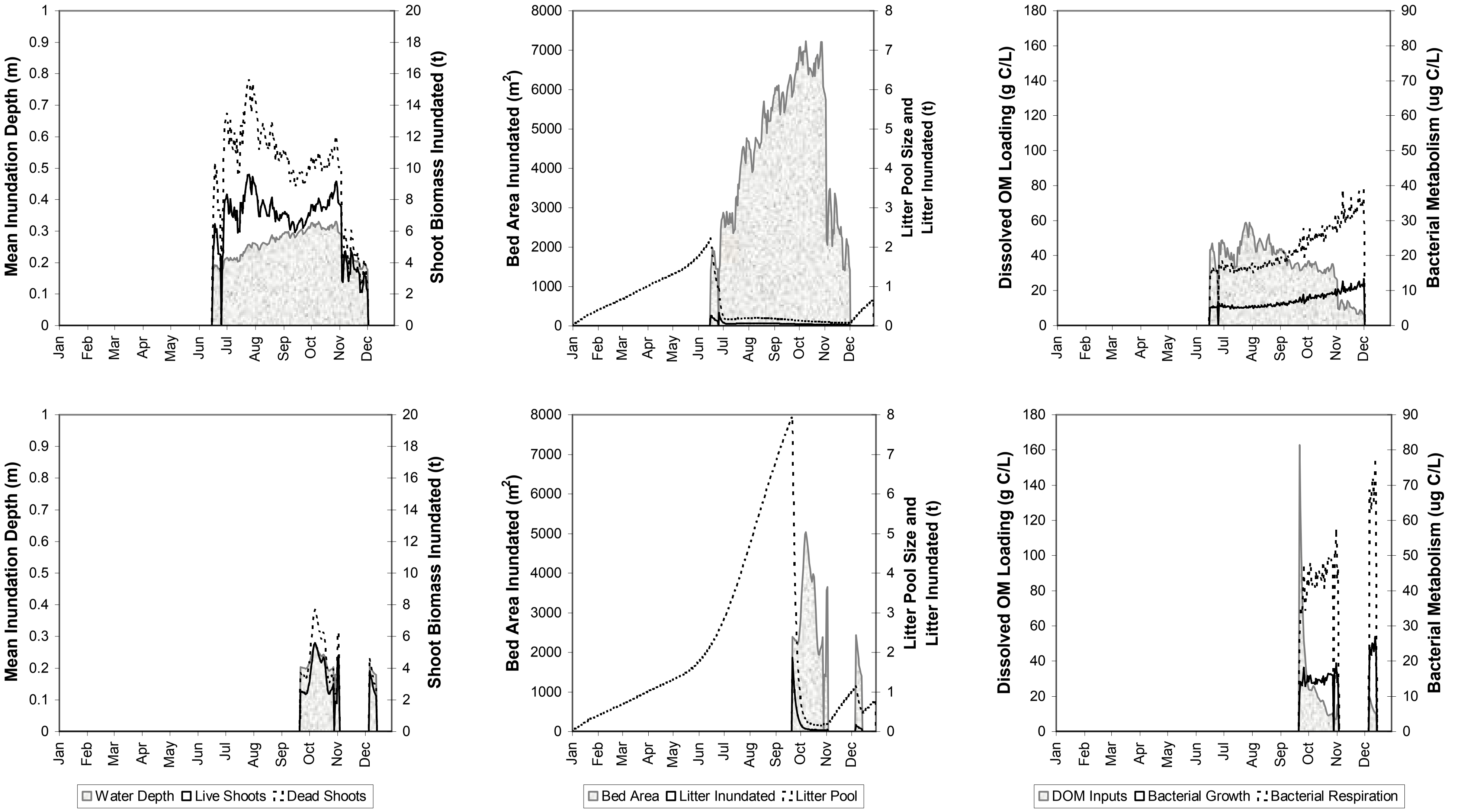
In order to develop a predictive model of macrophyte OM inputs and processing, each of the following parameters and processes identified in the conceptual model was measured in the field or laboratory or estimated from literature data:

- Macrophyte bed areas and inundation patterns;
- Live and dead shoot densities;
- Shoot biomass partitioning;
- Leaf litter production;
- Leaching rates and bio-availability of leachates.

Using differential GPS and standard surveying equipment, three dimensional maps of the channel were generated for each of three lowland river sites in south-eastern Australia, including the location and elevation of macrophyte beds. Integration with flow data in a geographical information system (GIS) allowed the determination of macrophyte inundation patterns under different flows. Plant resource allocation (biomass and nutrients), live and dead shoot densities and leaf litter production were monitored in the field over 18 months. DOM release from different macrophyte tissues was examined in the laboratory and leachate composition was assessed using nutrient and spectral analyses. Responses of riverine microbial communities to different OM sources were assessed from measurements of bacterial respiration and enzyme activities in the laboratory and field. Finally, all data were integrated into a computer model of microbial responses to macrophyte OM inputs induced by different flows.

Different flow scenarios were run through the model to determine macrophyte inputs and microbial activity induced by different flow management strategies, with the results from the regulated and historical (pre-regulation; “natural”) scenarios presented here. River regulation for summer irrigation flows had a major impact on OM inputs and microbial metabolism (example model output shown in Figure 3). Microbial metabolism and OM inputs occurred primarily in summer/autumn under regulated flows compared to a greater emphasis on winter/spring inputs and microbial activity under unregulated flows. Steady, continual OM inputs during winter and spring under natural flows would be expected to benefit large, slow-growing macro-invertebrates. River regulation resulted in a 4-fold reduction in annual OM inputs and these tended to occur as flashy pulses during spring/summer, potentially favouring riverine microbial and zooplankton production, although at low levels due to the overall reduction in OM inputs.

Figure 3. Modelled macrophyte (Common Reed, *Phragmites australis*) inputs and microbial metabolism for historic (top row) and regulated (bottom row) flows at the Murray River field site.



Comparisons were made of the major carbon sources available for riverine bacterial metabolism under current flow conditions at each of my study sites using output from the macrophyte computer model, my own calculations of riparian leaf litter inputs from previous work and algal production data provided by R. Oliver (Table 1). These showed that OM inputs from macrophytes represented a major food source for riverine microbial metabolism at some sites on an annual basis (seasonal variations in the relative importance of different OM sources were not assessed).

At the Murray River site, respiration on macrophyte OM accounted for only 7% of annual riverine microbial metabolism, with phytoplankton and riparian vegetation providing the bulk of carbon used by microbes at this site on a yearly basis (47% and 36%, respectively). In contrast, macrophytes represented the major driver of microbial metabolism in the Broken River, comprising 55% of annual riverine bacterial respiration. Riparian litter was the second highest contributor to microbial metabolism at this site (39%), with phytoplankton carbon responsible for only 13% of riverine bacterial respiration. In the Ovens River, only 66% of total annual bacterial respiration could be explained by metabolism of macrophyte, algal and riparian carbon, indicating that alternative carbon sources are contributing to microbial respiration at this site (e.g. ground-water inputs, leaching of large woody debris). Of the carbon sources assessed, riparian vegetation represented the major driver of microbial metabolism (43%) with macrophyte inputs responsible for 13% of bacterial respiration.

Table 1 Contributions of different riverine carbon sources to annual microbial respiration under current flow conditions (μg C/L/yr).

	Macrophytes	**Phytoplankton**	**Riparian Litter**	**Total Bacterial Respiration explained**
Murray R.	7%	47%	36%	90%
Broken R.	55%	13%	39%	107%
Ovens R.	13%	10%*	43%	66%

* assigned an arbitrary contribution of phytoplankton carbon to riverine microbial metabolism of 10% because net phytoplankton production appeared to be negative

Obviously, macrophyte inputs can represent a major source of OM in lowland Australian rivers. Macrophyte OM inputs and microbial metabolism can affect stream functioning at an ecosystem level through their contribution to food webs and competitive or complementary interactions with other biota. For example, particulate OM inputs provide a substrate or habitat for growth of biofilm and macro-invertebrates, and can also have a physical structuring role in the stream (affecting current speed and sediment deposition). Bacteria can out-compete algae for nutrients such as nitrogen and phosphorus where sufficient OM loads stimulate abundant growth, with biomass produced by microbes providing a food source for other stream organisms. Respiration by in-stream microbes affects water column gas concentrations, decreasing oxygen availability (possibly leading to black-water events) and increasing carbon dioxide, which can then be used by algae and submerged plants.

Understanding these interactions demonstrates the potential applications of my model in determining flow management strategies to achieve specific objectives regarding macrophyte-microbe interactions. For example, managers may wish to alter particulate OM inputs to a river reach at certain times of year to provide habitat for target macro-invertebrate species, or to stimulate microbial biomass production to increase food availability to other organisms. Management of microbial metabolism would also be useful to counteract imminent blooms of undesirable algae or minimise deleterious impacts of low-oxygen black-water events on resident fish populations.

This work represents a major step forward in our understanding of macrophyte-microbe interactions and our ability to manage our river systems. The computer model developed predicts inputs of macrophyte organic matter to rivers under different flow regimes and microbial utilisation of these inputs. This work has shown that flow manipulation can be used to influence macrophyte organic matter inputs to rivers and microbial responses, affecting whole stream metabolism and food web interactions. The computer model represents a tool that can be used by managers to predict the outcomes of proposed flow manipulations on macrophyte inputs to the study river reaches and can be adapted to be applicable to any site.