Hydrobiologia (2005) 552:147–158
D. Ryder, A. Boulton & P. De Deckker (eds), Conservation and Management of Australia's Water Resources:
20/20 Vision or Blind Faith – A Tribute to the late Bill Williams
DOI 10.1007/s10750-005-1512-7

Setting goals and measuring success: linking patterns and processes in stream restoration

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Key words: restoration, ecosystem structure, ecosystem function, river, biofilm, DOC

Abstract

Successful stream restoration requires the setting of appropriate goals and an ability to measure restoration success using quantitative ecological indicators. At present, a dichotomy exists between the setting of restoration goals to enhance ecosystem 'processes' or 'functions' such as sustainability, and measuring the success of these goals using 'patterns' or 'structural' ecosystem attributes. The presence of a structural facade may be no indication of a viable ecosystem as this requires evaluation of whether key ecosystem processes have been restored and whether the system is ecologically sustainable. We briefly discuss the benefits and drawbacks associated with setting restoration goals and measuring their success based on ecosystem patterns and processes. Two case studies are provided based on measurements of biofilm chlorophyll *a* and Dissolved Organic Carbon (DOC) to debunk the myth that these structural variables can be used as surrogates for ecosystem processes of productivity and respiration in rivers. We suggest that the discipline of restoration ecology will benefit and grow from a greater appreciation of the functional role of biological communities within stream ecosystems, and from targeting some restoration towards the re-establishment of structurally significant species and functionally significant processes. This approach to stream restoration with a well-founded conceptual base and defined scientific and management goals should expand our knowledge of stream function and contribute to the effective restoration of stream systems.

Introduction

The conservation of aquatic systems was a central theme throughout the career of Bill Williams, with works such as 'An ecological basis for water resource management' (Williams, 1980), 'Water as a limiting resource: Conservation and management' (Williams & Sládecková, 1997) and 'Spaceship Earth' (Williams, 2003) advocating the sustainable use of our water resources. Despite this call for sustainable management of water resources, streams represent some of the most altered of Earth's ecosystems because they have been diverted and dammed and their floodplains developed for agriculture and flood control (Dynesius & Nilsson, 1994; Ward et al., 2001). Changes to the natural disturbance regime provided by flow regulation and the introduction of exotic taxa and landuse practices have all suppressed the natural environmental heterogeneity in riverine landscapes, resulting in dramatic impacts on biodiversity and ecological processes in rivers (Ward, 1998). The extent of human-induced change and damage to the riverine habitats has meant that the restoration of these ecosystems is now widely recognised as essential for both nature conservation and sustainable production (Hobbs & Norton, 1996; Wilkins et al., 2003). Such an approach requires the setting of appropriate restoration goals and sufficient knowledge that the ecological indicators used to monitor restoration initiatives are suitable for assessing the success of the stated goals (Karr, 1999; Watts & Ryder, 2001; Pedroli et al., 2002).

There is broad consensus among restoration ecologists that measuring success using ecologically based criteria is an essential ingredient for all ecological restoration projects (Hobbs & Harris, 2001; Hobbs, 2003; Lake, 2005). Yet many authors (Grayson et al.,1999; Hackney, 2000; Wilkins et al., 2003) suggest that the success of many restoration projects is often unknown or rarely appropriately and systematically determined. Through not knowing whether these projects are successful or not, either because attempts at measuring success were never made or success was measured using inappropriate criteria or indicators, resources will be wasted, ecosystems remain degraded, and restoration efforts are not assessed and disseminated for use in future restoration programs.

Yet, despite the consensus among restoration ecologists on the need for goal setting, the search for a universal statement of goals for ecological restoration continues to generate controversy. Debate centres on the appropriate level of organisation at which goals should be specified and their success measured (Cairns, 2000; Ehrenfeld, 2000; Kentula, 2000). At present, there is a dichotomy that exists in many restoration projects between the setting of restoration goals to enhance ecosystem *processes* or *functions* such as sustainability, and measuring the success of these goals using *patterns* or *structural* ecosystem attributes (Grayson et al., 1999). Historically, structural measures of restoration success have dominated the literature as it is often assumed that if the pattern or structure of an ecosystem has been reinstated, then so too will the processes pivotal to ecosystem sustainability (Simenstad & Thom, 1996; Kentula, 2000). However, the presence of a structural facade may be no indication of ecosystem viability, as this will require the evaluation of whether key ecological processes of the ecosystem have been restored and whether the system is biologically viable and sustainable.

In this paper, we discuss the benefits and drawbacks associated with setting restoration goals and measuring their success based on the *patterns* of structural attributes and the *processes* present within restored ecosystems. Using stream ecosystems, we present two case studies to demonstrate the advantages of using an integrated approach, measuring both patterns of ecosystem structure and ecosystem processes. We believe this approach to stream restoration will ensure that appropriate goals are set and, more importantly, that their success can be measured.

Definitions

While we acknowledge the ongoing debate surrounding the definition and interpretation of the term 'restoration', for this paper we concur with Lake (2005) and adopt the most recent definition from the Society of Ecosystem Restoration (SER) which states restoration is the processes of assisting the recovery and management of ecological integrity including the critical range of variability in biodiversity, ecological processes and structure (SER, 2002). Similarly, there is debate regarding the rubric of terms used by restoration ecologists that describe structural and functional attributes of an ecosystem. Examples of vagueness and circularity in defining these terms abound in the literature (see review in Goldstein, 1999). Commonalities can be drawn, with a structural attribute usually taken to mean measures of species composition (abundance, richness, diversity) and the patterns or structuring of these communities within physical habitats (Hobbs & Norton, 1996; Duffy, 2002), however definitions are rarely this explicit. Commonalities can also be drawn among references to ecosystem functions or processes, with most ecologists considering functions to be the flow of matter and energy, and are concerned with an heuristic approach comprising interactions among biological organisms and their abiotic environment (Loreau, 2000; Ehrenfeld, 2000; Claret et al., 2001). In this paper, we adopt these definitions, adding that a structural variable is estimated from an instantaneous measurement (e.g., macroinvertebrate abundance, nutrient concentration) and a functional variable is one that estimates a rate or potential of an ecological process over time (e.g., production or respiration rate, nutrient turnover).

Patterns and processes in stream restoration

The intimate link between streams and their catchments leads to the restoration of stream ecosystems becoming a complex and difficult task. Stream restoration projects often aim to restore systems to a predetermined state that resembles a reference condition or represents the most desirable outcome in relation to available resources. Goals and strategies are often formed in an attempt to ensure success of restoration projects (Ladson et al., 1999). To do this, a suite of indicators is typically used to assess the current 'health' of the river (Boulton, 1999). These indicators provide managers with a template on which efforts should be focused for the best possible restoration outcome, ecologically, socially and financially. Due to constraints on time and funding during the restoration process, rapid assessments using 'river health indicators' are often performed over a relatively short period of time using simple, structural attributes of the physical, biological and chemical environments (Bunn & Davies, 2000).

Although conditions that allow the replacement of plants, animals and even specific habitats can be created and maintained, the restored system may still not perform the critical ecosystem functions required for ecosystem sustainability. A more important implication for the measurement of restoration success is that the return of key processes may lag behind that of the reinstatement of ecosystem structure (e.g., Simenstad & Thom, 1996; Zedler, 1996; Findlay et al., 2002). Patterns and processes in ecosystem attributes are, however, not the same, and restoration of one does not necessarily equate to the restoration of the other (Grayson et al., 1999; Cairns, 2000; Kentula, 2000). The result is that stream restoration, founded on the conceptual basis that a restored site should be self-sustaining (i.e., require no input of materials and energy) might not occur. Therefore, one of the most important issues in restoration ecology is the relationship between the structure and function of ecosystems. Analysis of this relationship has significant management implications because measuring processes rather than patterns may provide better indicators of ecological integrity (*sensu* Karr, 1996) for assessing river 'health' (Bunn et al., 1999). By combining these two types of variables, our understanding of inputs, storage, transformations, and exports of material and energy in ecosystems is enhanced considerably (Bott & Kaplan, 1985; Dahm et al., 1998).

The structure of biological communities, in particular, is often used as the basis on which to set restoration goals, and for measuring their failure or success (Bunn et al., 1999). The restoration of ecosystem structure is based on an understanding of the biology (e.g., genetic structure, population dynamics) of an organism or population and their habitat requirements. A major problem associated with goals focusing on a particular ecosystem structure is the implicit knowledge needed of ecosystem or landscape level interactions and processes influencing the organisms or population (Ehrenfeld, 2000). This approach is somewhat more complicated in streams, as fluxes of water, transported components and organisms occur between different geomorphic features and results in a mosaic of interdependent habitats, each one suitable for different species and communities (Pedroli et al., 2002). Any attempt to restore streams in favour of biodiversity needs to focus on these pre-conditions intrinsic to flowing waters.

Many stream restoration projects focus on improving habitat complexity by manipulating in stream habitat or riparian vegetation (Walsh & Breen, 1999), with the aim of improving biological diversity. However, the creation of a structurally complex habitat for plants and animals is not always successful as this may not be the limiting factor influencing their distribution and abundance. Measuring attributes such as habitat complexity and biological diversity are popular as these surveys are quick and easy to perform, and data are simple to analyse and communicate, particularly when using predictive models (e.g., AusRivAS, RIVPACS; Boulton, 1999). Unfortunately, there is little evidence to link patterns of diversity in the biological community with ecological processes (Bunn & Davies, 2000). Similarly, the restoration of ecosystem structural components presupposes that a restoration project should attempt to recreate the habitat of the target species without necessarily considering the habitat requirements of co-occurring species and dependent processes that constitute an ecosystem (Ehrenfeld, 2000).

The relative ease of measurement and interpretation of structural ecosystem attributes is perhaps the major advantage for their use in setting restoration goals and evaluating success. Keddy (1999) suggests desirable properties of such structural variables include ease of sampling and processing, relative low cost, lack of ambiguity such as taxonomic uncertainty, high sensitivity to restoration measures, and direct relevance to the hypothesis being tested. This facilitates an historical comparison among outcomes from previous restoration projects, and is an imperative process if we are to learn from our mistakes. As a result, many studies of stream systems have inferred prevalent ecological processes from instantaneous collections of physical, chemical, and biological data (e.g., Dole-Olivier et al., 1994; Tockner & Bretschko, 1996). This is a perilous undertaking when the spatial or temporal scale of measurement does not coincide with the relevant process (McKee & Faulkner, 2000; French McCay et al., 2003). This dilemma is evident in many aspects of river ecology (Minshall, 1988; Palmer & Poff, 1997).

The production of organic matter, establishment of food webs, and movement of carbon and energy are important functional aspects of stream ecosystems. The changing relationships over time among biomass, productivity, respiration and nutrient turnover have formed the basis for the theory of ecosystem function (*sensu* Odum, 1969). It is the changes in these patterns over space and time that can be used by restoration ecologists to evaluate project success. The use of ecosystem processes as an approach to setting goals and measuring success in restoration projects recognises that the viability of populations of all species, including rare and endangered species, depends on the maintenance of both large and small-scale ecological processes, the presence of a characteristic mosaic of community types over a broad area, and the movement of individuals and populations over large areas (Ehrenfeld, 2000). Similarly, the use of functional indicators to set and assess restoration goals recognises the dynamic and interconnected nature of ecological entities (Kentula, 2000). Thus, the problems associated with ancillary damage caused to non-target organisms or other parts of an ecosystem, which may result from focusing restoration efforts on structural ecosystem components such as biodiversity, are overcome by recognising the existence of ecological complexities and underlying interconnected processes, and setting restoration goals based on this knowledge.

The use of process-based attributes in restoration has been strongly criticised, centred largely on the use of methods and equipment that are still in their infancy (Bunn et al., 1999) and a poor definition of the key concepts and terms used in setting process-based goals (see Goldstein, 1999; Walker, 1995). However, dismissing the validity of ecosystem processes as a focus for restoration founded on a lack of an historical dataset and an explicit definition ignores the critical importance of the interconnected nature and the integrated function of ecosystems. Many reviews critique structural and functional attributes in restoration ecology (e.g., Walker, 1995; Hobbs & Norton, 1996; Ehrenfeld, 2000; Gessner et al., 2004), yet few base their critiques on ecological data. Furthermore, studies that aim to elucidate relationships through correlative evidence among ecological patterns and processes are rare (e.g., McKee & Faulkner, 2000).

To illustrate our thesis and provide a critique based on ecological data, we describe two case studies that highlight the benefits to stream restoration of understanding changes in system structure, and enhancing this by understanding the underlying processes that influence ecosystem structure. The first case study uses measures of benthic biofilm algal biomass and metabolism to assess the ecological effectiveness of environmental flow releases, and the second examines the effects of deciduous leaf litter on the biogeochemistry of dissolved organic carbon in an urban stream.

Do patterns of biofilm structure reflect processes in cobble streams?

Submerged surfaces in lakes and rivers are colonised by assemblages of algae, fungi and bacteria in a mucilaginous matrix of algal and bacterial exudates and detritus. These are the biofilms that cover rocks, wood, sediment particles and other surfaces in aquatic systems (Burns & Ryder, 2001a). Biofilms are central to fundamental biogeochemical processes in streams such as nutrient and carbon turnover, and therefore can provide an indication of the restoration or otherwise of underlying processes upon which stream organisms rely. Their short generation time, sessile nature, responsiveness to environmental condition and the availability of sound, quantitative methodologies makes them ideally suited as ecological indicators to measure both ecosystem structure and function (Burns & Ryder, 2001a), as they may respond to restoration efforts before effects on higher organisms are detected. Structural attributes such as algal biomass or taxonomic composition of biofilms can be obtained rapidly and cheaply. Biofilm functional measures integrate diverse communities into a few attributes that can be measured using techniques such as metabolic chambers, extracellular enzyme activity and nutrient turnover. The combination of structural and functional information from biofilms at population, community and ecosystem levels offers even greater potential for ecologically meaningful analysis (Burns & Ryder, 2001a).

In this case study, we compare the response of biofilm chlorophyll *a*, a structural attribute that is commonly measured to infer ecosystem production, and rates of Net Primary Productivity (NPP), a direct measure of an ecosystem function, to the implementation of environmental flow releases in the Mitta Mitta River, south eastern Australia. Prolonged low flows (300 ML day^{-1}, 0.2 m s^{-1}) from an upstream impoundment resulted in large mats of *Stigeoclonium*, a late successional filamentous green algae, comprising up to 97% of the total biofilm's biovolume for 40 km downstream of the impoundment (Sutherland et al., 2002). An environmental flow release comprising two peaks (4800 ML day^{-1}, 1.2 m s^{-1}) released 14 days apart, aimed to reduce algal biomass by scouring biofilms and restoring algal biodiversity on cobble substrata along the entire impacted reach. It was hypothesised that the initial flow release would significantly reduce biofilm chlorophyll *a* concentrations and rates of NPP while the second release would further reduce biofilm algal biomass and NPP to negligible levels.

Biofilms from eight individual cobbles that remained permanently inundated throughout the variable flow releases were sampled on nine occasions from an upstream site immediately downstream of the impoundment and a downstream site approximately 40 km from the dam. Detailed field and laboratory methods are outlined in Sutherland et al. (2002) and Ryder (2004). Briefly, biofilm NPP was measured by placing individual colonised rocks within separate light and dark sealed Perspex chambers (~4 L volume; 8 replicates of each) and measuring changes in dissolved oxygen (DO) concentration over 8 h. At the end of each incubation, individual rocks were removed and scrubbed for analysis of chlorophyll *a* concentration using the methods of Tett et al. (1975).

Rates of biofilm productivity responded rapidly to the variable flow releases. Dramatic reductions of up to 300% in biofilm NPP during peak flows (Fig. 1(a)) at both upstream and downstream sites support the hypothesis that both flow releases would substantially reduce biofilm productivity. After the cessation of environmental flows and a return to low flow releases from the impoundment, biofilm NPP declined until the NPP of biofilms at the downstream site was negative just six weeks after the major flooding events (Fig. 1(a)). In extreme contrast to the response in biofilm function, there were no significant differences in biofilm chlorophyll *a* concentrations throughout the entire period of variable flow releases and subsequent low flow periods in either site (Fig. 1(b)).

The scouring of biofilms is an important process in resetting biofilm structure (Peterson, 1996; Mosisch & Bunn, 1997) and function (Bunn et al., 1999), with the balance between autotrophy and heterotrophy often determined by physical disturbances (Peterson, 1996). The dramatic reduction in NPP during peak flows is a result of a substantial decrease in Gross Primary Production (GPP) and concomitant increases in respiration caused by the physical abrasion and damage of algal cells along the entire study reach. This would lead to an increase in heterotrophic microbial productivity within the biofilm but potentially negligible changes to chlorophyll *a* concentration due to the lack of wholesale scouring of biofilms (Sutherland et al., 2002).

If this assessment of the success of variable flow releases to restore biofilm biomass and biodiversity to sections of the Mitta Mitta River was based solely on the response of biofilm chlorophyll *a* concentration, a structural variable, then we would infer that the system had changed little over the course of the study and the restoration was unsuccessful. However, the functional response of biofilm productivity showed otherwise. By

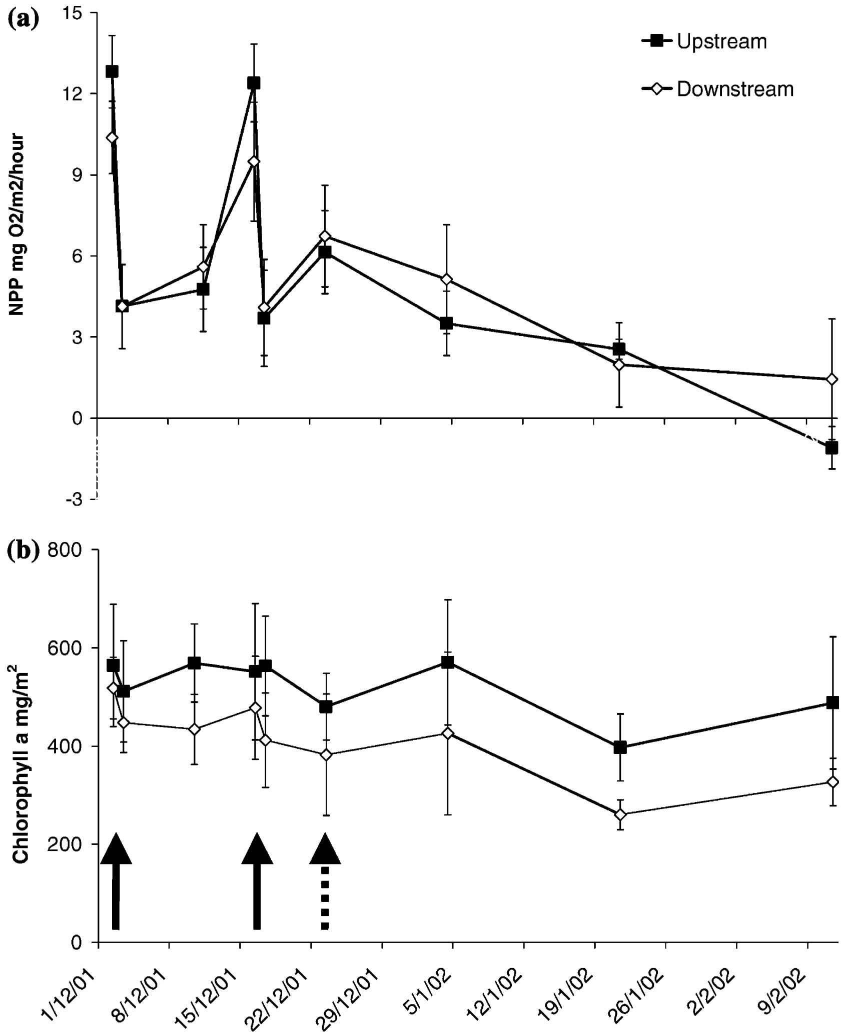

Figure 1. Mean ± S.E. (a) benthic algal Net Primary Productivity (NPP) in mg O_2 m^{-2} h^{-1} and (b) benthic algal chlorophyll *a* concentration in mg m^{-2} measured from 2nd December 2001 to 11th February 2002. Solid arrows indicate dates of peak flow releases, and the dashed arrow indicates the cessation of variable flow releases and the return to low flow conditions.

including NPP as a measure of an ecosystem process, we were able to demonstrate a short-term system-level response to peak flows and an integrated response to prolonged periods of low flows. This would have remained unnoticed based solely on the structural attribute of chlorophyll *a*.

To further illustrate our point, we examined the relationship among biofilm chlorophyll *a* concentration and NPP based on changes in biofilm dissolved oxygen concentration from a number of streams in south-eastern Australia (Ryder, unpublished data; Fig. 2). The poor relationship between these two attributes that are often used synonymously does not bode well for researchers who continue to use chlorophyll *a* as a surrogate for benthic algal productivity.

Do patterns of DOC concentration reflect microbial processes in urban streams?

If restoration efforts in urban stream ecosystems are focussed on the reinstatement of endemic riparian vegetation and removal of exotic species, we need to better understand the implications of such actions on stream biogeochemical functions. Ecosystem processes, such as the processing of organic matter and transformation and retention

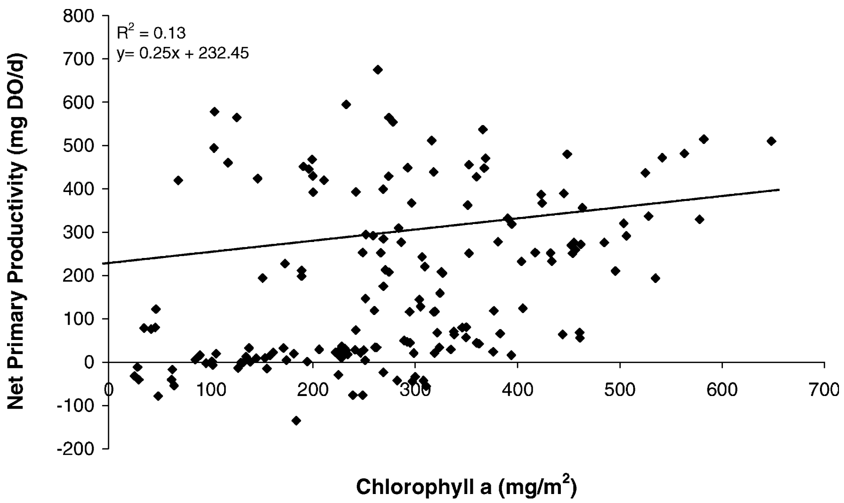

Figure 2. Relationship between chlorophyll *a* concentration in mg m^{-2} and Net Primary Productivity (NPP) in mg O_2 m^{-2} h^{-1} for benthic algal samples for a range of rivers in south-eastern NSW, Australia.

of nutrients have been largely ignored in urban stream research until recently (Paul & Meyer, 2001). Many urban streams in temperate Australia have experienced a proliferation of exotic, deciduous trees within their catchments and along waterways (Miller & Boulton, 2005). Leaves from exotic deciduous trees represent not only a potential 'unnatural' source of DOC, but also a many-fold increase in the total volume of litterfall within a short period relative to native riparian species (Miller, unpublished data). As DOC leached from leaf litter is often the major source of carbon for stream food webs (Findlay & Sinsabaugh, 1999), an alteration to the quantity and quality of litter entering the stream can have profound effects on ecosystem productivity and trophic dynamics (Miller & Boulton, 2005). A technique has been developed which uses the activity of bacterial extracellular enzymes to link bacterial productivity to the concentrations and classes of available DOC. Organic matter in aquatic systems occurs as carbohydrates, proteins, fatty acids and other compounds (Chròst, 1991). Different enzymes are responsible for assimilation of each class of carbon, so the suites of enzymes present reflect the class and fraction of DOC available for assimilation (Findlay et al., 1997). By monitoring these shifts in enzyme activity, it is possible to identify the classes and quantity of organic matter available to these microbial communities.

Understanding the functional role of DOC in urban stream ecosystems is necessary to provide an indication of whether the underlying processes upon which stream organisms and populations are reliant have been restored. In this case study, we compare the response of DOC concentration, and rates of respiration and extracellular enzyme activity (EEA), to the experimental introduction of exotic and native leaf packs to an urban (Armidale) and two non-urban streams in northern New South Wales. We hypothesised that DOC, DO, and EEA would differ between native and exotic leaf type and that among-stream responses would reflect the degree of urbanisation and riparian condition.

Three sites (upstream of urban, urban and reference), and two species of riparian trees (*Pistacia chinensis* Bunge – exotic, deciduous and *Eucalyptus nicholii* Maiden & Blakely – native, evergreen) were used as they are common in urban areas of northern NSW. Detailed field and laboratory methods for metabolism are outlined in Ryder (2004). Briefly, the respiration rate of leaf packs was measured by placing one of four replicate leaf packs of each species (each containing 15 g of senescent, dried leaf material) into sealed Perspex chambers (~4 L volume) and measuring changes in dissolved oxygen (DO) concentration over 5 h. The chambers were equipped with recirculation and bilge pumps, allowing the venting and renewal of water within each chamber at hourly intervals. Water samples from within each chamber were collected during each hourly venting via a non-return valve fitted to the chambers and analysed for DOC and EEA. DOC concentration was analysed using a Dorhmann TOC analyser and extracellular enzyme activity was assessed using the methods described by Burns & Ryder (2001b). Five Methylumbelliferyl (MUF) labelled enzymes (β-xylosidase and fatty acid esterase [carbohydrates], α- and β-glucosidase [polysaccharides] and peptidase [proteins]) were used to analyse samples for the presence of carbon sources commonly found in aquatic ecosystems.

An analysis of the DOC concentration for each species revealed a significant difference between leaf type ($F_{1,36}$ = 10.91, p = 0.0021,) with *Eucalyptus* leaves leaching significantly more DOC than the exotic *Pistacia* (Fig. 3(a)). If we were to use these concentrations as surrogates for ecosystem processes such as microbial metabolism, we would conclude the DOC from the native eucalypt would support more instream heterotrophic activity. However, when functional attributes were measured, there was a significant difference between leaf types ($F_{1,76}$ = 11.94, p = 0.0039) with respiration rates significantly higher in the exotic *Pistacia* treatment despite the lower concentrations of DOC in the leachate (Fig. 3(b)). This pattern is confirmed by a significant difference between leaf type ($F_{1,18}$ = 16.83, p = 0.0008, Fig. 3(c)) for EEA, with highest activities associated with increased respiration rates and corresponding lower concentrations of DOC of the exotic *Pistacia* leaf packs (Fig. 3(b)). These patterns are based on peptidase activity which was the dominant substrate responsible for the discrimination between leaf species based on SIMPER analyses (Clarke & Warwick, 2001).

The quality of DOC being delivered to streams and its effect on ecosystem function are rarely studied (McArthur & Richardson, 2002). This case study has demonstrated that the composition of riparian and catchment vegetation can influence fundamental in stream processes such as carbon turnover by microorganisms. Although the concentration of DOC leached from the exotic *Pistacia* leaf packs was lower than the native eucalypt, the leachate from the exotic leaves supported higher levels of heterotrophic metabolism. Supporting evidence from enzyme activity leads us to hypothesise that the *Pistacia* leachate had a higher relative proportion of bioavailable DOC compared to the eucalypt that was dominated by refractory DOC not readily assimilated by bacteria. Simply measuring DOC concentrations and loadings in a stream may not indicate its availability or its effect on ecosystem metabolism. By including respiration as a measure of an ecosystem process, we were able to clearly demonstrate an ecosystem response that could not be assessed solely on knowledge of DOC concentration, a structural attribute. More widely, this case study has highlighted the need for stream restoration projects to not only focus on improving the structural integrity of the riparian zone but also to take into account the functional importance of its species composition.

Assessing stream restoration into the future

What does the future hold for the setting of restoration goals and measuring their success in stream ecosystems? As proposed by Hobbs (2003), the process of setting restoration goals through scientific, management, and community forums is paramount to ensuring that there are clear endpoints, each with a timeframe for achievement. The choice of indicators to measure restoration success depends on identifying stressors on river systems and which components and processes within rivers are likely to be affected by disturbance (Pratt & Cairns, 1996). Structural variables can be processed quickly at low cost using sound, standardised and repeatable methodologies based on an excellent historical literature base from their extensive use in assessing restoration projects. However, the two case studies presented above have demonstrated that patterns of ecosystem structure do not always concur with ecosystem processes, and in some cases may lead to incorrect conclusions being drawn.

Ecosystem-level processes such as the transformations of matter and fate of energy and matter can be ideal measures of the ecological condition of rivers because they provide an integrated response to a broad range of disturbances (Poff et al., 1997; Bunn et al., 1999; Watts & Ryder, 2001; Ryder, 2004). Researchers are beginning to move beyond the rhetoric of

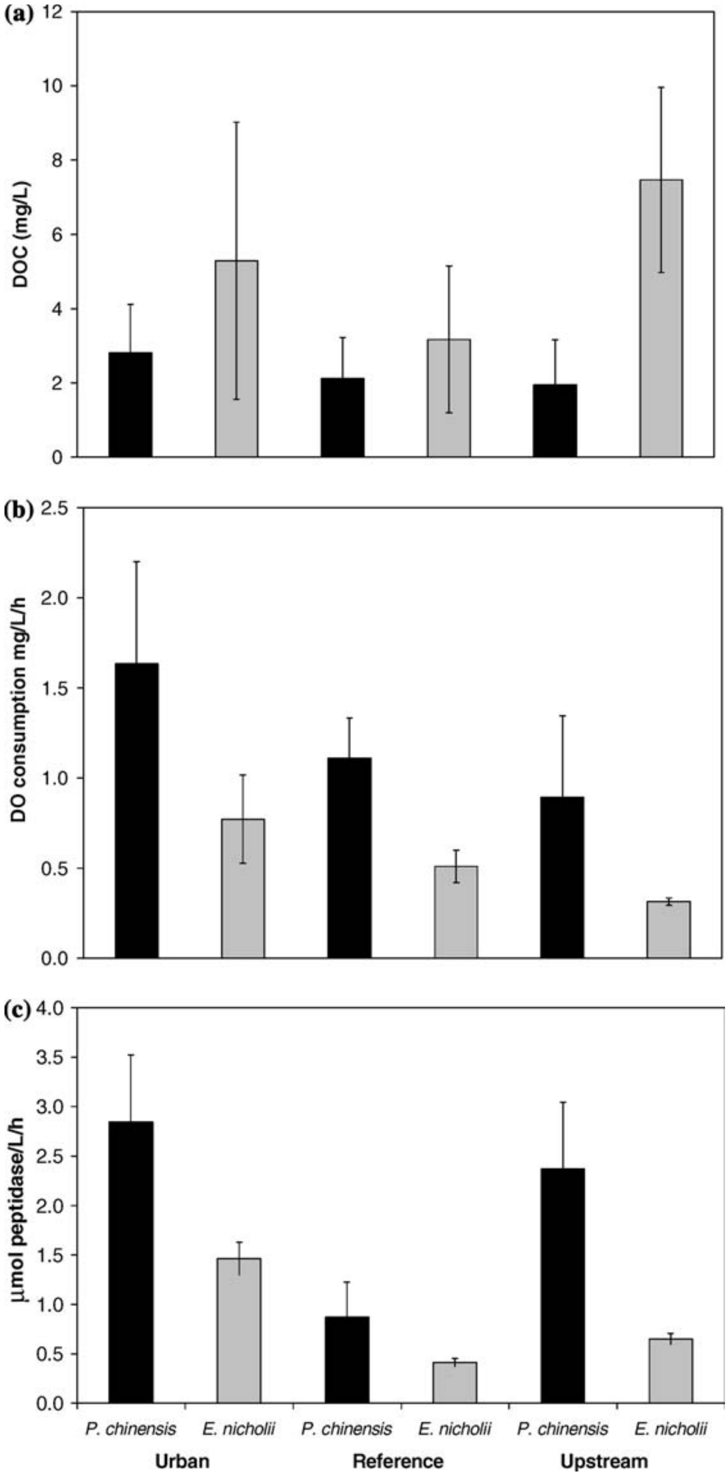

Figure 3. (a) Concentration of dissolved organic carbon (DOC) in mg L^{-1}, (b) rate of dissolved oxygen (DO) consumption in mg O_2 L^{-1} h^{-1} and (c) rate of peptidase extracellular enzyme activity (EEA) in μmol L^{-1} h^{-1} for leachates of *P. chinensis* (exotic) and *E. nicholii* (native) in urban, reference, and upstream of urban stream locations.

advocating the use of process-based ecological indicators to quantitatively assessing measures such as biogeochemical cycles (McKee & Faulkner, 2000), primary production (French-McCay et al., 2003), and organic matter breakdown (Gessner & Chauvet, 2002) as ecological indicators of restoration success. Use of these processes facilitates the examination of long-term and cumulative impacts on aquatic communities from the base of the food web. This approach is still in its infancy, with methods under development and researchers divided as to what constitutes an ecosystem function. At present, this hinders the use and implementation of functional attributes in setting restoration goals and measuring success. However, the measurement of functional variables does provide an insight into ecosystem processes fundamental to river health and to the sustainability of organisms and populations within the restored ecosystem. This insight is not always available through structural attributes.

Chapman & Underwood (2000) suggest that if measurements of structure are to be used to set goals and provide information on the success of projects, then there is value in undertaking research into where and under what circumstances structure and function are linked. Recent attempts to link measures of ecosystem structure to function are reviewed in Giller et al. (2004) and Gessner et al. (2004). As demonstrated in the case studies, these relationships are not always clear or intuitive. Any relationships that may facilitate links between structure and function, or the development of surrogate measures for ecosystem function will require substantial development. Despite the current lack of knowledge of such relationships, the discipline of restoration ecology will benefit and grow from a greater appreciation of the functional role of biological communities within stream ecosystems, and from targeting some restoration towards the re-establishment of structurally significant species and functionally significant processes. This approach provides an integrated, long-term measure of ecosystem function, with structural attributes such as biomass and diversity allowing historical comparisons from an excellent literature base. Stream restoration projects with a well-founded scientific base, and defined scientific and management goals and outcomes, will expand our knowledge of stream function, and contribute to the effective conservation and management of water resources, ensuring the sustainability of 'Spaceship Earth'.

Acknowledgements

The benthic productivity research was supported by grants from the Australian Research Council SPIRT program and the Land and Water Australia/Murray Darling Basin Commission National River Contaminants program. The urban DOC research was supported by an Australian Postgraduate Award awarded to Wendy Miller. We thank the editor Andrew Boulton, and two anonymous referees for comments on earlier drafts of this manuscript.

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