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Redressing the limnological imbalance: trends in aquatic ecology, management and conservation in Australia

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Introduction

Almost 20 years ago, Bill Williams wrote a provocative opinion paper (Williams, 1988) entitled 'Limnological imbalances: an antipodean viewpoint'. In his typical stimulating style, Bill Williams made a number of assertions about his personal perception of the global status of the discipline of limnology and some recommendations for future directions and ways to address the perceived 'imbalance'. In essence, he argued that modern limnology is excessively concerned with research and issues in the northern temperate region because that is where the majority of work published in English originates. Concepts and models such as the River Continuum Concept (Vannote et al., 1980) and the processes of stratification in dimictic lakes (reviewed in Hutchinson, 1967) were spawned and supported by examples from the northern temperate region, and through adoption into textbooks, became considered the 'norm'. Naturally, these models and concepts came to underpin management strategies, sometimes being misapplied to situations well beyond those intended by the original proponents. Williams (1988) concluded his paper with encouragement to 'consider alternatives' and to broaden the scope of modern limnology to include salt lakes (his personal favourite) and temporary waters because, as he argued, these may be more typical of world waterbodies than deep permanent lakes or hydrologically stable north temperate rivers.

So has this balance been redressed in the last 20 years, at least in Bill Williams' antipodean epicentre? Are trends in limnological research and management in Australia following trajectories advocated by Williams (1988) or are some aspects still lagging? Have there been new trends that were not foreshadowed by Williams (1988) and where might antipodean contributions to global limnology be likely to flourish in the next 20 years? In this synthesis, we begin by setting Australian limnology into a brief historical context, much of which derives directly from Bill Williams' papers. We then explore several trends in aquatic ecology, management, and conservation in Australia exemplified by papers in this Special Issue honouring Bill Williams' extraordinary contribution to global and Australian limnology. Virtually every aspect of modern Australian limnology has built on or been complemented by Bill Williams' prolific output, and this is also true for the papers in this Issue (Table 1). We conclude that, in general, Australian limnologists and aquatic managers are making valuable contributions to global limnology and water resource management, fulfilling Bill Williams' hopes. Some issues (e.g., salinisation) are more prevalent in Australia than in the northern temperate zone as Williams (1988) pointed out but problems of eutrophication and acidification are also becoming serious in parts of Australia. Critically, the management solutions to these problems must address causes not symptoms (Boulton & Brock, 1999) and understanding these causes must include assessing the geomorphological, hydrological, and ecological contexts unique to different parts of Australia.

Table 1. Since the opinion paper by Williams (1988), redressing the 'limnological imbalance' has followed several trends in Australia. These are listed below, matched with their authors in this Special Issue and a subset of papers by Bill Williams that exemplifies or complements each general topic

Topic	Special Issue author	Bill Williams' examples
Trends in salt lake ecology and management	Timms; Strehlow et al. Halse & Massenbauer	Williams & Kokkinn (1988); Williams (1999a, 2001, 2002).
Trends in dryland river ecology and management	Sheldon; Jenkins et al.	Williams (1975, 1985, 1998).
Trends in water resource management and conservation	Hancock & Boulton Fitzsimmons & Robertson Hillman et al.	Williams (1980, 1983, 1998b, 2003).
Repairing spaceship Earth	Lake; Miller & Boulton Brookes et al. Ryder & Miller	Williams, 1976; Williams, 1988; Williams, 1999b; Williams, 2003.

The Australian context

Although Australia is hailed as the world's driest inhabited continent, it spans tropical to alpine areas, boasting a diversity of river and wetland types that rivals those found among the other larger continents. Admittedly, much of the continent is arid or semi-arid (Comín & Williams, 1994) and large, deep lakes or rivers with substantial permanent discharge are rare. Most of Australia's natural surface waterbodies are saline and/or temporary, and the continent is prone to frequent and protracted supra-seasonal droughts (Lake, 2003). In a continent blessed with an abundance of many other natural resources, fresh water is often the limiting resource. Paradoxically, the scarcity of Australia's water supply and the impacts of the last 200 years of human population expansion on surface and groundwater quality have not been reflected in an emphasis on the scientific study of our water resources, despite constant encouragement for nearly 30 years from Williams (1976, 1980, 1993, 1998, 1999a, 1999b, 2001, 2002, 2003).

Modern limnological research in Australia has had a relatively short history, and much of it has drawn from Bill Williams' contributions. Understandably, most of the early work was taxonomic as scientists, usually immigrating from the northern temperate zone, came to take up university or museum curatorial positions, and began to describe the (to them) unusual and distinctive aquatic flora and fauna (e.g., platypus, black swan). For the aquatic invertebrates, a group of special interest to Bill Williams, this taxonomic focus was evident in the first half of the 20th century (e.g., Tillyard, 1916; Nicholls, 1943), culminating in texts on entire orders (Mosely & Kimmins, 1953; Harker, 1954) and the first edition of 'Australian Freshwater Life' (Williams, 1968) that drew together keys for many of these groups. New families of aquatic insects continued to be discovered (e.g., Neboiss, 1978), and a second edition of Bill Williams' popular book of keys was produced (Williams, 1983). This proved invaluable to the next generation of limnologists who began working in the 1960s and 1970s as public awareness grew regarding the severe environmental degradation of Australia's waters. In the last decade or so, his lead has been followed by annual taxonomic workshops for professionals as well as the popular book by Gooderham & Tsyrlin (2002).

In 1961, Bill Williams co-founded the Australian Society for Limnology, a society that now boasts over 650 researchers, managers, and students, and has held well-attended annual meetings since its origins. Over the 45 or so years since its foundation, research papers have increasingly focused on management of aquatic ecosystems in Australia although fundamental research, particularly ecology, continues to be reported. This has paralleled the change in preoccupation with 'water quantity' to 'water quality' (Boulton & Brock, 1999), and the increasing role played by biologists in aquatic management, another of Bill William's central messages (Williams, 1980). In 1973, Ian Bayly, another influential Australian limnologist, and Bill Williams wrote the first textbook of Australian (and New Zealand) limnology (Bayly & Williams, 1973). It had a strong focus on physical and chemical limnology, reflecting the majority of work that had been done in Australia to that time, and more significantly, identified the scarcity of research on Australian flowing waters. In the last few decades, this has also changed (Lake, 1995), and Australian limnologists have made valuable global contributions to lotic ecology (e.g., Bunn & Davies, 1999; Lake 2001, 2003).

A snapshot of Australian limnology in the 1980s was captured by De Deckker & Williams (1986). Their edited book, 'Limnology in Australia', contains a series of essays on those areas of limnology where Australian scientists had most impact and topics regarded as interesting to the international limnological community. The book demonstrates how Australian limnology at that time had advanced both conceptually and in global awareness of management issues, with equal numbers of chapters covering pure sciences, ecosystems, and processes and management. Later, Bill Williams would go on to edit further collections of papers that focused increasingly on management and conservation issues (Williams, 1998), and his awareness of the importance of applying rigorous scientific research to management issues in a global context is the topic of his ultimate paper (Williams, 2003).

Trends in salt lake ecology and management

Bill Williams had a special interest in salt lakes. He insisted that limnology was not exclusively a 'freshwater' domain and that much could be learned from comparative ecology spanning different types of wetlands (Williams, 1988). Initial research in these environments was directed towards describing their distinctive faunal features (e.g., Williams, 1972; Walker, 1973) but there was soon the realisation that salt lakes were a common wetland globally (Williams, 1976) and secondary salinisation was a major environmental threat across much of the world outside the northern temperate zone (Williams, 1987). It is now widely accepted that secondary salinisation has destroyed or currently threatens numerous fresh and saline wetlands, and has impaired agricultural productivity in many areas (Crabb, 1997). The severity of this impact in Australia is reviewed by Timms (2005) who also identifies the grim future for wetlands from global trends in climate change and further extinctions from salinisation. This prediction may provide a stimulus for research in salt lake ecology to identify linkages among salinisation, ecological processes, and landscapes.

Strehlow et al. (2005) provide an example of applied research that builds on the knowledge of salt lake fauna and their ecology from early limnological work including that by Bill Williams (Table 1). Their study is based on the model of alternate stable states (Scheffer, 1989), and provides conceptual links between salinity, productivity, and macroinvertebrate communities. The study concludes with a classification of 'ecological regimes' that provide a link between management actions and wetland health, suggesting this approach may more useful in protecting the structure and function of salt lake ecosystems than managing salinity in isolation.

With a better understanding of landscape linkages, there is a trend in saline lake management towards addressing the causes rather than symptoms of salinisation, and increasing the effectiveness of wetland management through improved communication with research scientists. This is the central message of Halse & Massenbauer (2005) who draw on examples from south-western Australia (where secondary salinisation is most severe) to highlight the importance of understanding physical and chemical linkages within catchments. They conclude that effective aquatic conservation will rely on informed management actions in terrestrial landscapes. This recognition of landscape–waterscape linkages has led to the recent proliferation of inter-disciplinary research involving geomorphologists, hydrologists, and ecologists to tackle management problems.

Trends in dryland river ecology and management

Williams (1988) identified temporary waters as more typical of world water bodies than deep permanent lakes or north temperate rivers, and he foreshadowed how our increased scientific understanding of these wetlands would inform management of water allocations and the effects of extractive use (Williams, 1998). Conceptual insights have also emerged from studies of temporary waters (e.g., Fisher, 1983; Stanley et al., 1997; Boulton, 2003; Lake, 2003). Williams (1988) also bemoaned the lack of coverage of temporary waters in many textbooks but this situation is changing (Boulton & Brock, 1999; Dodds, 2002). In Australia, wetlands in arid and semi-arid areas face intensifying pressure for their water resources, yet harbour unique biota and ecological processes that rely on the 'boom and bust' regime of alternating flood and drought (Williams, 1998; Kingsford, 1999).

As Williams (1988) noted, this variable water regime is a contrast to conditions in many areas where 'conventional' models of ecosystem function have been developed, and this also applies to techniques for assessing river condition or 'health' where many standard field methods are confounded by variable flows (Boulton et al., 2000). Sheldon (2005) tackles this dilemma by proposing a 'trend approach' in which the use of common macroinvertebrate-based indicators for river health could be adapted for use in naturally variable systems. Wetlands in Australia's arid-zone face many threats (reviewed in Jenkins et al., 2005) and there is urgent need for reliable indicators of condition. Also required is more interactive and collaborative research rather than the more common reactive approaches, and this needs to be conducted at relevant spatial and temporal scales, and with full recognition of the fundamental role of hydrologic variability (Jenkins et al., 2005).

Trends in water resource management and conservation

As described above, early ecological limnology in Australia was preoccupied with the taxonomy of the often-distinctive aquatic biota. Globally and in Australia, research has broadened to include the ecological roles of this biota, recognising the benefits of functional approaches (e.g., Cummins & Klug, 1979; Brock & Casanova, 1997). One significant limnological advance since Williams (1988) has been the greater global appreciation of the ecological implications of the tight linkages between surface and groundwaters (Gibert et al., 1994; Jones & Mulholland, 2000). This linkage has important implications for how we manage surface waters (Boulton, 2000) and groundwater dependent ecosystems (Murray et al., 2003). Environmental flow releases have been seen as a valuable management tool in helping to restore altered flow regimes (Ladson & Finlayson, 2002) but most studies of the ecological effects of environmental flow releases have focused on surface riverine biota and processes (e.g., Gore et al., 2001; Arthington & Pusey, 2003). Hancock & Boulton (2005) describe responses of the surface–subsurface linkages in a river subject to an experimental environmental flow release. Not only does this provide useful information for managers about the benefits of 'flushing flows', it is an example of the application of experimental manipulations in field studies to help elucidate causes of ecological patterns and processes.

River regulation and groundwater abstraction, the development of agriculture, declining water quality, isolation from catchment processes, and degradation of riparian areas are persistent threats to aquatic ecosystems in Australia (Williams, 1980, 1998; Kingsford, 2000; Boulton et al., 2003). Although there are efforts to address some of these issues (Brock et al., 1999; Arthington & Pusey, 2003), equivalent attention to the conservation of freshwater ecosystems through protected areas has lagged far behind. Australia currently lacks an adequate freshwater reserve system (Georges & Cottingham, 2002; Nevill & Phillips, 2004) and their establishment is one of the highest priorities for biodiversity conservation research (Fitzsimmons & Robertson, 2005). One of the major impediments to the identification and designation of freshwater reserves relates directly to the Australian landscape that incorporates aquatic habitats that are highly diverse both spatially and temporally, and the subsequent inability to ascribe representativeness or 'health' to these habitats (e.g., Sheldon, 2005).

While the delineation of a reserve boundary that incorporates the full range of water levels and flow regimes for an aquatic system may be desirable, it may be unlikely given the competing interests of economies, communities and natural resource management.

Williams (1993) drew attention to the importance of social issues such as population growth in Australia, and likely effects on water resources. This linkage between aquatic systems and their catchments, the economy based on them, and the human societies and cultures connected to them has led Hillman et al. (2005) to propose that one way in which change in natural resource management is best managed is with the cooperation of those most affected. They suggest that identifying and engaging the community and the development of analytical techniques to support inter-disciplinary research projects are two major areas in which new knowledge is urgently needed. This, in turn, implies the need for greater understanding and a broader knowledge base than is likely to be found in any one discipline or any one group in the community.

Repairing spaceship earth

Given Bill Williams' devoted efforts advocating the sustainable use and conservation of Australia's inland waters, it is fitting that one of the major advances in limnology has been in the field of rehabilitation and restoration. Williams (1988) argued that limnology in Australia is much less distinctive and more generally applicable on a global basis than had been fully realized. The development and application of restoration ecology theory to Australian rivers and wetlands (e.g., Lake, 2003) provides a global commonality for the assessment of Australian inland aquatic ecosystems. In examining restoration as an ecological enterprise, Lake (2005) sets the scene for the remaining papers in this Special Issue by emphasizing the need for restoration to be set at the catchment scale, for clear goals to be set, and for effective monitoring to determine progress.

There is a clear trend evident from the papers in this Issue that the restoration and management of Australian inland aquatic ecosystems is moving towards an approach integrating ecosystem structure and functions for designing restoration projects, and measuring restoration success (reviewed in Ryder & Miller, 2005). Miller & Boulton (2005) use urban streams as a template to demonstrate that an understanding of the interactions of catchment scale processes such as hydrology, drainage pattern, leaf input, and biological attributes of a stream is crucial for managers trying to restore stream ecosystem services. Bill Williams was one of the earliest Australian researchers to recognise the inherent importance of urban streams for research and management (Williams, 1999b) and he would be pleased to see the advances currently being made in urban stream research in this country (e.g., Walsh, 2004).

Brookes et al. (2005) postulate that anthropogenic disturbances to catchments have decreased the structural complexity of such ecosystems, and in doing so have reduced their resilience to further environmental change. They suggest that the effective management of water resources requires a catchment scale restoration of biogeochemical pathways. As a result, increased biodiversity of aquatic and terrestrial habitats, and ecological functions will promote ecosystem resilience. However, the use of ecosystem functions as measures of ecosystem health or restoration success is still in its infancy, providing an opportunity for Australian limnologists that was not foreseen by Williams (1988). Ryder & Miller (2005) suggest one way forward is undertaking research into where, and under what circumstances the structure and function of aquatic systems are linked. Restoration of streams and wetlands may be furthered by an appreciation of the functional role of biological communities, and from targeting some restoration towards the re-establishment of structurally significant species and functionally significant processes (Ryder & Miller, 2005). This approach provides an integrated, long-term measure of ecosystem function with knowledge of structural attributes facilitating historical comparisons. Restoration projects with a well-founded scientific base, and defined scientific and management goals and outcomes (Lake, 2005), will expand our knowledge of aquatic ecosystem function, and contribute to the effective conservation and management of water resources, ensuring the sustainability of 'Spaceship Earth'.

Conclusion

In our Introduction, we asked whether Bill Williams' perceived limnological imbalances had been redressed in the last 20 years. Efforts by Australian and other antipodean limnologists, and the papers from this Special Issue indicate the balance has been redressed, although perhaps there are still some aspects lagging. These aspects would include research and management of temporary waters and groundwaters, freshwater protected areas, and assessments of functional as well as structural aspects of freshwater ecosystems. Limnological research and management directions have taken different trajectories beyond those forecasted in Williams (1988). For example, there is more emphasis on social aspects and community involvement in water resource management, a greater amount of work on assessment of waterbody condition and 'health', cutting-edge research on aquatic rehabilitation and restoration, and some excellent examples of experimental field ecology. Australian limnologists are already recognised as international leaders in some of these 'new trends', and Bill Williams would be proud of his legacy. Perhaps the most encouraging aspect is that there is probably no need to consider an antipodean viewpoint because the global contributions from Australia are just that – global. The papers in this Special Issue are not so much uniquely Australian as internationally relevant, and many of their messages apply equally across the globe, perhaps even in those deep permanent lakes and rivers of the north temperate zone. Most importantly, there is a greater awareness of the vulnerability of the aquatic life support systems of Spaceship Earth (Williams, 2003), and recognition of the value of the science reported in this Special Issue to tackling the water resource issues of the next 20 years.

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