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DEATH AND LIFE OF THE BILLABONG

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ABSTRACT

Billabongs, cut-off meanders of the Murray-Darling rivers, South-east Australia, were the main standing (fresh) waters prior to colonisation by Europeans. There were few natural freshwater lakes. In the 200 years of European settlement >100 dams and weirs have been built on the rivers, limiting flooding and reducing regular replenishment of billabong waters. Floodplains have been used extensively for agriculture and grazing; many billabongs have been drained or filled to provide more arable land. Extensive clearing of river redgums (*Eucalyptus camaldulensis*) led to rising water tables and increased salinization. All of these pressures are reflected in reduced biodiversity in the floodplain ecosystems, some of which are only beginning to be understood. Mention is made of the remarkable diversity at all levels of the billabong ecosystem – complex food webs dependent on a flood-drought regime. Belated recognition of the need to preserve billabongs and wetlands in general has come only in the last few years. The recognition that there are problems and the allocation of funds for wetland research are the most promising steps to date.

INTRODUCTION

To an Australian limnologist accustomed to the dry, dusty plains and turbid rivers of the Murray-Darling Basin, the myriad lakes and rivers of New Zealand seem to be a limnologist's paradise. Despite the contrasts, it is evident that both Australia and New Zealand share the problems of two centuries of injudicious use of the country's natural resources, and are now reaping the legacy of the "taming" of our respective islands. Celtic-European farming practices, extensive modifications of hydrologic regimes, deforestation, introductions of exotic plants and animals – these are a few of the shared features.

The Basin is significant because it is one of Australia's most productive agricultural areas, and the major irrigation region. Ever-increasing productivity has long been the goal. In economic terms, annual production of $A10,000 million, or 30-40% of Australia's resource-based production, derives from the Basin. Some 1.8 million inhabitants within, and more than one million people outside the Basin (in South Australia), depend on its rivers for water supplies. The demands on its land and water have been, and are, immense, and are clearly beyond the capacity of the environment to provide. However, the problems summarised here are not specific to the Murray-Darling Basin, nor, indeed, to Australia.

Figure 1 The Murray-Darling Basin showing major rivers, Eildon, Dartmouth and Hume Dams on upper River Murray tributaries, and locked weirs on the lower river. New Zealand is superimposed at approximately the same scale.

In preparing this paper for a New Zealand audience, the most obvious contrast to explore was one of scale. Figure 1 compares the $>1x10^6$ km^2 area of the Basin with that of New Zealand. The two major rivers, the south-flowing Darling River and the west-flowing River Murray, have a combined length of ca. 5300 km. The difference in scale is relevant when considering the practicalities of restoration.

A further contrast is in the age of the Basin – it was in its present location in Gondwana, i.e. at least 60 million years B.P., and the R. Murray has been in its present channel for >2 million years. Low gradients and slow flows are now a feature of the catchments. With declivities as low as 1 cm km^{-1}, travel times from headwaters to the Southern Ocean may be 2-3 months. The temperate location of the Murray catchment brings winter-spring rains, while the tropical location of the Darling headwaters brings monsoonal (summer) rains. Superimposed on this seasonality is extreme variability of rainfall. Much of the Basin (98%) is arid to semi-arid, providing little or no runoff to rivers, and in consequence, overall runoff (10,035 Gl) is low by global standards. 70% of the flow in the R. Murray derives from the South-east corner of the Basin (the area bounded by Eildon, Dartmouth and Hume Dams in Figure 1).

There are no large natural freshwater lakes comparable to the glacial lakes of New Zealand, although there are five small "alpine" lakes in the Mt Kosciusko region at the south-eastern corner of the Basin. The most abundant standing freshwaters prior to European settlement were on floodplains, formed as rivers meandered across floodplains up to 25 km wide. Many of these waters in the middle reaches of Murray-Darling rivers are in the form of cut-off meanders (ox-bows or, colloquially, billabongs). It is these waters which provided refuges for aquatic biota as continental aridity increased, the most recent phase commencing 36,000 years ago (Bowler 1990). Notably, aboriginals had gathered food from Murray-Darling billabongs for more than 40,000 years. It is also these waters and their inhabitants which were profoundly affected by the activities of Europeans after settlement of the Basin began in the 1820s.

These introductory remarks are necessarily a brief overview of the Murray-Darling Basin. For more detailed information on the Basin, see O'Brien *et al.* (1983), Walker (1986), Murray-Darling Basin Ministerial Council (MDBMC) (1987), Eastburn (1990a) and Mackay and Eastburn (1990), or for Australian wetlands generally, McComb and Lake (1990). Degradation of the continent is reviewed in Beale and Fray (1990). In the context of this symposium, the rest of this paper considers the "death" of billabongs, i.e. deleterious impacts on floodplain ecology caused by river regulation and inappropriate landuse. A brief review of the present understanding of the life of billabongs follows. In conclusion, recent research effort is reviewed, particularly experimental flooding of river red gum forests, and prospects for restoration of Murray-Darling floodplain communities are considered. It should be noted that very little research data exist. Billabongs, indeed most of the Murray-Darling floodplains, are distant from long-established research centres, most of which are coastal (cf. Green and Shiel 1992).

"DEATH" OF THE BILLABONG

On a geological time scale, billabongs are ephemeral. Meandering rivers move back and forth across their floodplains, leaving scrolls, swales and cut-off meanders. In southern Australia the latter are specifically termed billabongs, although elsewhere on the continent the term applies to a wide range of standing waters. The abundance of standing waters relative to the mainstream river can be seen in Figure 2, which is sketched from an aerial photograph of the R. Murray floodplain 60 km downstream of Hume Dam (cf. Fig. 1). In some reaches the off-river waters provide >60% of available water surface. This is significant for animals which require sheltered, still waters, or abundant supplies of food in "nursery" areas for juvenile development. These are not attributes of the main channel.

Figure 2 Section of River Murray floodplain showing main channel, billabongs/abandoned channel and swales, filled loops, remnants of banks, etc. 2170/2175 indicates river distance (km) from Murray mouth. Hume Dam is at ca. 2230 km. (Orig. from MDBC aerial photograph).

The rate of billabong formation in the natural system is not known, however Rutherfurd (1990) noted for the regulated R. Murray that 20 meanders, representing 65 km of channel, had been cut off between Albury and the Darling Junction in the previous 100 years. His study further indicated that the Murray is one of the most stable rivers in the world, i.e. billabongs are still being formed under the present flow regime, but meander formation is an extremely slow process.

Over time, natural cycles of vegetation growth, death and decomposition, including riparian vegetation, fringing Eucalypts *inter alia*, sedimentation of dead zooplankton and macroinvertebrates, and siltation from soil surface erosion during floods, gradually fill the billabong. As most billabongs reflect the morphology of the parent river, their depths are usually <5 m, more often <2 m. There is little information on the rate of sedimentation; cores from billabongs on the R. Murray near Wodonga, Victoria. (Fig. 3), at present with 2 m water depth over ca. 6 m sediments, have been dated at 4-5000 yrs B.P., and a sedimentation rate of 1-2 mm yr^{-1} has been estimated (R. Ogden, Australian National University, pers. comm.). Billabongs thus have a finite existence at a particular point on the floodplain, i.e. the process leading to "death" is natural.

Human activities inexorably speed up the process, e.g. one person with a back-hoe needs only a couple of afternoon's work to drain a 10,000 year-old billabong to provide more arable land for agriculture. Such draining, use as garbage dumps, filling, etc., are the major cause of complete loss of billabongs, but there are few available estimates of such loss since settlement. In Victoria, for example, losses of wetlands in general have been reported at 30%, with losses on some of the more severely degraded floodplains approaching 50% (Anon 1988, Scott and Christoff 1988). Losses in other areas of the Basin may be as high as 60% (Murray-Darling Basin Commission 1993).

For much of the Basin there are no accurate records of how many billabongs are extant. Some idea of their present abundance can be gained from the work of Pressey (1986, 1990), who identified some 7000 **remaining** wetlands on 2500 km of R. Murray floodplain downstream of Albury. If 30-60% of R. Murray wetlands also have been lost or severely degraded (cf. the Victorian ranges cited above), by implication 3-10,000 wetlands may have been lost along the Murray alone. Regardless of the validity of such extrapolation, the loss of biological diversity with even a fraction of this number may have been profound. The significance of such losses, in the biological context, is considered later.

Figure 3 Ryan's Billabongs, #1 centre, #2 foreground, on the Murray floodplain below Lake Hume. Ryan's #2 is ca. 1.3 km long, 2 m deep.

Of the surviving wetlands, few, if any, have escaped the effects of deforestation, changes in hydrology, eutrophication, inappropriate land use practices, particularly uncontrolled irrigation, pollution, introduction of exotic plants and animals, and destructive recreational activities. How these events impinge on billabongs is considered briefly below.

Deforestation

A priority of the early settlers was to clear the trees, and this process has continued to the present. More than 20 **billion** trees have been cleared by felling, ringbarking, poisoning and blowing up vast areas of native woodland for wheat cultivation, grazing or other development (Beale and Fray 1990). Introduced stock subsequently selectively or differentially grazed, promoting changes in species composition of the vegetation, and encouraging exotics, primarily weeds (Frith and Sawer 1974). Enormous plagues of introduced rabbits further removed seedlings and ringbarked mature trees, and their

Figure 4 Drowned river red gums in the weir pool of Lake Mulwala, formed behind Yarrawonga Weir at ca. 2028 river km.

Figure 5 Changes in storage capacity in the Murray-Darling Basin, reflecting dam construction, since 1922, and diversions over the same period (gigalitres (GL) × 10^3; 1 GL = 1,000,000,000 l) (redrawn from Close 1990).

burrowing activities degraded highly erodible soils (Smith and Smith 1990). More than two-thirds of Australia's vegetation has been severely or moderately degraded, an extraordinary feat for a small population on such a large continent.

In the Murray-Darling Basin, over 335,000 ha. (30%) of the floodplain have been cleared, with >18,000 ha. "severely degraded" (Margules *et al.* 1990). The proportions are likely to be higher on more intensively farmed floodplains, e.g. all of the Goulburn R. floodplain (downstream of Eildon Dam in Fig. 1) is regarded as "severely degraded" (Anon 1988). Murray and Goulburn billabongs pre-settlement were surrounded by either mixed woodland, i.e. trees, shrubs and understorey at various stages of development, or almost-pure stands of river red gum (e.g. as in the extant Barmah/Millewa Forest) with a grass understorey. On the Murray floodplain today (cf. Fig. 3), billabongs on grazing lands may be fringed by solitary old red gums, the only survivors of 150 years of overgrazing, and introduced pest species such as scotch thistle (*Onopordium acanthum*) or patterson's curse (*Echium lycopsis*).

The rivers became major transport corridors for early settlers and their produce. Several hundred riverboats plied the rivers in the late-1800s, using riparian vegetation for fuel. Some paddle-boats burned a tonne of wood per hour. Locked weirs were built to facilitate riverboat activity, and weir pools flooded and subsequently drowned large areas of red gum forest (Fig. 4). Development of the railways created a heavy demand for red gum as sleepers. Loss of trees resulted in rising water tables, exacerbated by use of flood irrigation (see below). Flood irrigation, in combination with extensive underlying marine sediments, has caused large scale salinisation, to the further detriment of native vegetation. Surviving vegetation in these areas was replaced by a depauperate salt-tolerant flora (Margules *et al.* 1990).

Figure 6 Regulated and unregulated mean monthly flows at Albury (GL = gigalitres) (redrawn from Close 1990).

These are only some of the effects of logging and clearing the native vegetation, however the effects specifically on billabongs are not documented. It is likely that reduced diversity of floodplain vegetation had significant impacts on billabong heterogeneity, e.g. in reducing availability and/or diversity of leaf fall or wood for colonisation and eventual breakdown. Salinisation clearly has had profound effects on the biota of downstream billabongs, particularly those of the middle and lower Murray, with reduced species richness, and replacement with more tolerant, in some cases halophile, species.

River Regulation

Subsequent to construction of locks and weirs on the lower Murray, >100 headwater dams were built to provide assured water supplies for irrigation, stock and domestic supply. An indeterminate number of floodplain waters drowned with the filling of these reservoirs. The "lakes" so formed did not provide many of the previous residents with appropriate living conditions, hence a different, if not reduced, biota survives there. Figure 5 shows the growth in storage capacity, and also diversions, over the last 75 years. Environmental impact assessment was not required when most of these dams were built, i.e. the long-term effects of reducing flood heights and changing the flow regime were not considered.

The change in flow regime immediately below Hume Dam is shown in Figure 6. A winter-spring peak in the unregulated system has been replaced by a summer-autumn peak, not conducive for a flood-cued biota which evolved nesting/breeding/feeding responses to a spring spill over the floodplain. The variability of the Basin's rainfall is such that large floods cannot be contained by the storages, and overbank flows still occur, but less frequently. The floodplain is thus effectively alienated from the river for longer periods, often further isolated by construction of levees to protect riverside towns and farms. Recent evidence suggests also that floods do not persist as long as they did previously, further mitigating against fish and other flood-cued biota (Walker and Thoms 1993)

Other effects of dams include depression of downstream water temperatures. Most dams in the Basin use hypolimnetic release, with no provision for multi-level offtakes, and the lowered temperatures of the outflows affect fish spawning, macro- and microinvertebrate life cycles in the rivers. Anoxic releases with poisonous levels of H_2S are inimical to the biota in general. Dams impede fish migration (most have no fishways). Downstream weirs may exacerbate salinity problems by increasing pressures on aquifers. Permanent flooding of red gum communities by weir pools drowns them. Declines (i.e. reductions in distribution or range) attributed to regulation have been reported for waterbirds, most native fish species, freshwater crayfish (*Euastacus*), and various mollusc species. For further details see reviews in Walker (1983, 1985, 1986), Close (1990), Walker and Thoms (1993).

Eutrophication

Eutrophication is another process which occurs naturally in billabongs, but over a much greater time frame than occurs with "cultural" eutrophication. The same symptoms signalling excessive nutrient inflows to rivers are seen in billabongs, but the latter are less in the public eye, and have received little attention. Cyanobacterial (blue-green algal) blooms are of increasing occurrence in billabongs in heavily grazed catchments. Faecal material from sheep and cattle may be a significant source of phosphorus and nitrates. Heavy "top-dressing" with superphosphates over many years may lead to similarly heavy nutrient inflows to billabongs. Some billabongs are used as stabilization ponds in sewage treatment, or are recipients of organic pollution from abbatoirs, wool scours, or paper mills. With declining numbers of wetlands for water birds, increasing concentrations of birds in surviving habitats add to the nutrient pollution. All of these factors contribute to decline in "amenity" or water quality for the inhabitants or users, and hasten eutrophication. More frequent flooding in the past would have replaced standing waters, flushed nutrients to the main stream, and reduced or ameliorated nutrient accumulation, effectively exchanging resources (cf. Walker and Thoms 1993).

Land Use

Much of the early settlement led to overgrazing and overcropping of the land. Increased erosion resulted. Increased sediment loads to billabongs speed the in-filling process, and increase turbidity. Large-scale irrigation exacerbated land and water degradation. Much of the southern Basin lies over buried marine sediments, and flood irrigation has brought saline groundwater to the surface, increasing salt loads to the rivers, and often to floodplain waters. Billabong waters have been variously polluted by agricultural runoff, including fertilizers, pesticides and herbicides, but the effects on the biota are undocumented. The problems brought about by inefficient or inappropriate land use practices are detailed in the reports cited earlier.

Exotics

Both plant and animal exotics have degraded floodplains. One third of at least 767 plant species on the the Murray floodplain are exotics and are "one of the most pervasive effects of European settlement" (Margules *et al.* 1990). Willows have crowded out native riparian species, and several aquatic weed species are well-established in the Basin. Some thrive in the sheltered waters of billabongs, e.g. *Alternanthera, Eichhornia, Elodea, Hydrilla,* and *Salvinia*.

The devastating effects of rabbits, cattle and sheep on floodplain vegetation and soils have been well-documented, but their effects specifically on billabongs have not. They graze to the water's edge, destabilising banks, contributing to erosion and siltation, and devegetating riparian areas. Cattle are more invasive to the extent that they wade in and crop emergent (and submerged!) vegetation. All contribute to eutrophication by direct input of faeces, or by nutrient runoff from heavily grazed catchments.

Native fish have been displaced by introduced species (e.g. European carp, *Cyprinis carpio*) or have been eaten by them (e.g. redfin, *Perca fluviatilis*, and trout, *Oncrhynchus mykiss* and *Salmo trutta*). There is also some evidence for carp increasing turbidity by their bottom-feeding activities, and devegetating by eating or uprooting submerged plants. The predation effects of introduced planktivores are undocumented, however >100 years of massive stocking rates must surely have depleted the indigenous fauna of micro/macroinvertebrates.

Recreation

There is less pressure on the Basin's billabongs from some recreational activities, e.g. power-boating, fishing, tourism, etc., than there is on the rivers and reservoirs. Other activities such as shooting and off-road vehicle use, are more likely to affect billabongs. Impacts on billabong ecology include: overfishing contributing to the decline of native species; recreational shooting endangering some waterbird species; damage to floodplain areas by recreational vehicles. Health risks associated with faecal or chemical contamination have been noted for recreational users of inland waters (cf. O'Brien *et al.* 1983).

LIFE OF BILLABONGS

On a biological time scale, billabongs are relatively permanent, i.e. they are "predictably permanent" enough for their biota to have evolved a range of survival strategies to persist through periods of drying. Notably, the physical and chemical environment of billabongs is particularly heterogeneous, such that they form an "environmental mosaic" (Hillman 1986). For details of the characteristics of billabongs, see Boon *et al.* (1990), suffice to note here that the environmental heterogeneity is mirrored by biological heterogeneity. As most of my own research is on microbiota, the following observations refer to this group.

Figure 7 Population density of selected rotifer species demonstrating specifically different responses to intrusion of river water (indicated by a vertical broken line March 17, 1990) in Ryan's #1 Billabong, Wodonga. Taxa figured are (L-R from top) *Brachionus lyratus, Filinia pejleri, Lecane bulla, Brachionus falcatus, Filinia opoliensis, Proalides tentaculatus.* ind = no. of individuals (adapted from Tan and Shiel 1993).

The floodplain contains resting stages of some (if not all) of the extant microfauna (protozoans, rotifers, microcrustaceans). When a particular section of the floodplain is inundated, germination or hatching of the assemblage, or a part of it, will follow. There is preliminary evidence that only a portion of the available biota emerges at any time (cf. Boulton and Lloyd 1992), and that response time to inundation may be very rapid (Tan and Shiel 1993) (Fig. 7). Germination or hatching time varies between organisms, e.g. short-duration floods may be enough to trigger emergence of microcrustacea, but be inadequate for germination of river red gum seedlings. There appears to be a critical flooding frequency beyond which resting or resistant stages do not survive (cf. Boulton and Lloyd 1992).

Figure 8 Simplified food web showing some of the interactions in a billabong and a nearby river. Many of the families occur in both habitats, but the species composition is different (figure by R. J. Shiel, from Boon et al. 1990).

Timing of inundation also is significant. Water "quality" may differ with natural seasonal variation, and hence provide different sets of cues to be "perceived" by the dormant biota. Whether the same assemblage would emerge from "unnatural" flood events remains to be investigated. Interestingly, even in an extant, i.e. wet, billabong, rapid and marked changes occur in the microfaunal community soon after intrusion of river water (cf. Fig. 7). In this study of a billabong rotifer community, there were reproductive-rate changes, resting egg hatching, and specific population crashes within days of inundation. The post-flooding community was quite distinct from the pre-flooding community, although species diversity or richness had not changed.

Clearly, the inhabitants of any billabong can be seen as two broad components. Firstly, there is the assemblage that has resting stages in, and has emerged directly from, its sediments, cued by habitat conditions at any particular time (i.e. the autochthonous biota); secondly, an allochthonous biota, which arrived as propagules or alive from elsewhere by wind, water or "under their own steam" and can either be established or transient. A simplified representation of a billabong food web prepared for the review by Mackay and Eastburn (1990) is shown in Figure 8. Interestingly, slower-flowing reaches of nearby rivers also may have diverse micro- and macroinvertebrate communities, but their species composition differs.

Little is known about these communities Basin-wide, but preliminary evidence indicates that Murray and Goulburn floodplains have characteristic and distinct microfaunal assemblages (Boon *et al.*, 1990, Hillman and Shiel 1991, Shiel and Green unpublished data). A small proportion (<10%) of the microfauna (rotifers and microcrustaceans) are indigenous, known only from single billabongs. Whether this is a real phenomenon, or a reflection of the small number of sites sampled (ca. 100) remains to be determined. It is possible that isolated populations may be subject to genetic drift or selective pressures in billabongs, promoting speciation, however the genetics of billabong faunas have yet to be studied. If local endemism in billabongs is real, loss of 30-60% of billabongs implies loss of a great deal of genetic diversity.

Observations on some of the billabong inhabitants are given below. In view of the poor level of taxonomic discrimination of phytoplankton, protozoans, and other groups of invertebrates in Australia, comments are only general. Reasons for the lack of research were considered by Hillman (1986) and Green and Shiel (1992).

Bacteria

In a comparison of seven paired billabong/river sites in the Murray catchment, billabongs were found to support larger bacterial populations (1-157 x 10^9 cells l^{-1}; 11-10,270 µg C l^{-1}) than did nearby rivers (1-10 x 10^9 cells l^{-1}; 6-143 µg C l^{-1}), with bacterial productivity at least an order of magnitude greater than that of temperate eutrophic lakes. Bacterial dynamics were shown to be closely linked to phytoplankton production (Boon 1991).

Algae

There is little published information on Murray-Darling billabong algal communities, although data for the rivers have been collected by water authorities (cf. Sullivan 1990). Chlorophyll-a concentrations (which reflect algal biomass) of 1500 µg l^{-1} have been recorded from Ryan's 2 Billabong (Fig. 3), whereas the nearby R. Murray rarely exceeded 10 µg l^{-1} (Boon *et al.* 1990). Species diversity may be similar to that recorded from Magela Creek billabongs (Northern Territory), where >800 algal taxa have been identified (Ling and Tyler 1986, Thomasson 1986).

Microfauna

The major microfaunal groups in billabongs (Protozoa, Rotifera, Cladocera, Copepoda) are considerably more diverse and abundant than in either the nearby rivers, or in-stream reservoirs. For example, a species list of rotifer and microcrustacean zooplankton collected over one year from oligotrophic Dartmouth Reservoir (Fig. 1) may contain 50 taxa. Downstream, Hume Reservoir (mesotrophic) for the same period might have 100 taxa. Either of Ryan's Billabongs (eutrophic) may have 100 taxa in a single collection (Shiel 1990). Microfaunal diversity in billabongs of the temperate Murray floodplains is at least as rich as those of the tropics (Shiel and Williams 1990).

A "guesstimate" of total billabong microfaunal species, including protozoans, would be in the order of hundreds to >1000 over a year. More than 230 rotifer species alone have been recorded to date from Ryan's #1, with species dominants changing as rapidly as every 3-4 days (Hillman and Shiel 1991). Rotifer densities of >25,000-75,000 individuals l^{-1} have been recorded from billabongs, including both bacteriovorous and algivorous taxa. Such diversity and density reflects the range of available niches and vast food supply, particularly for bacteria. The majority of rotifer species in Ryan's Billabongs are bacteriovores (cf. Boon and Shiel 1990).

Effects of habitat degradation on the microfauna are seen as reduced species diversity or altered species composition. For example, the calanoid copepods of upper Murray billabongs commonly include two or three species from *Boeckella fluvialis*, *B. symmetrica, B. triarticulata, Calamoecia ampulla,* and *C. lucasi*. In the highly salinized billabongs of the middle reaches of the Murray, these genera are represented only by the halophiles *Calamoecia clitellata* or *C. salina*. Similarly, the brachionid rotifers of upper Murray billabongs are a diverse array, with five or six species of *Brachionus* and three to five of *Keratella* common in any one billabong. In the salinized downstream habitats the sole representative of the family is *Brachionus plicatilis*, which is present at very high densities. Thus, biomass may be comparable, but diversity is lower.

Macroinvertebrates

General observations on macroinvertebrate communities from Upper Murray billabongs were given by Boon *et al.* (1990) and Hillman and Shiel (1991). Of some 288 macroinvertebrate species collected between 1980-1988 from adjacent river and billabong sites, more than half occurred only in billabongs. Groups which preferred macrophyte beds were more abundant in billabongs. In general many of the macroinvertebrates were opportunists using the rich billabong resources as they were available. There was considerable temporal and spatial variation within and between billabongs.

Macroinvertebrates assemblages from floodplains of the lower R. Murray were analysed by Boulton and Lloyd (1991). They found 95 taxa, predominantly insects, with the greatest species richness and abundance of individuals in temporary and permanent billabongs. There was little faunal overlap between billabongs and the main river. In a second study the same authors examined emergence of invertebrates from wetted floodplain sediments (Boulton and Lloyd 1992). They selected sediments from floodplains of different average flood recurrence frequencies. The greatest biomass and numbers of invertebrates emerged from annually flooded sods, with a marked decline in less frequently flooded sods. They concluded that reducing flood frequency probably severely reduces the reserve of resting stages of invertebrates. Deleterious effects on larger macroinvertebrates, i.e. crayfish and mussels, are described by Geddes (1990) and Walker (1990).

Vertebrates

Flooding is the stimulus for breeding of many of the larger inhabitants of floodplain waters, and the billabongs the source of their food. More than 100 bird species have been recorded around billabongs on Upper Murray floodplain at Wodonga. Two hundred and six bird species have been recorded from the Barmah-Millewa River red gum forest, including terrestrial species using the flooded forest. Also 25 native mammal, 27 reptile, and 10 species of amphibians have been recorded (Eastburn 1990b). Declines in range and abundance of many of these species are clearly attributable to changes in availability of these resources. Deleterious impacts of reduced flooding on waterbird breeding were detailed by Briggs (1990).

Native fish have been profoundly affected by, *inter alia*, river regulation and the introduction of exotics, with dramatic declines in range and distribution reported for most of the native species. Of the 50 fish species recorded from the Murray-Darling system, 26 are indigenous, and have evolved in the Basin's flood-drought environment. Some, e.g. Macquarie golden and silver perch (*Macquaria australasica, M. ambigua* and *Bidyanus bidyanus*) are cued by rising floods, and migrate upstream to spawn. Golden perch, for example, may travel more than 1000 km upstream (Reynolds 1983). Spawning in these and other species takes advantage of the production of zooplankton and littoral micro- and macroinvertebrates stimulated by flooding of billabongs. Indeed, the dry floodplain is an enormous "seedbank" of resting stages of all these food items, in turn cued to emerge by flood events (cf. Boulton and Lloyd 1992, Tan and Shiel 1993). Notably, most native fish species are carnivorous, taking microfauna and macroinvertebrates, with the larger species, e.g. golden perch and Murray cod (*Maccullochella peeli*) also piscivorous (Cadwallader and Lawrence 1990).

For species which utilise food-rich billabongs as nursery areas, regulation of rivers and concomitant reduction of flooding frequency and flood height has limited access to this resource. Altered seasonality of high flows does not correspond with the reproductive cycles of native species. Both reduction of rising flows and depression of water temperatures downstream of large dams remove cues to migration and spawning. Dams and weirs impede migration. De-snagging and channel straightening have removed significant cover and spawning sites for some species. Siltation, pollution, overfishing, and predation by introduced exotic species have all been implicated in the demise of the native fish fauna. For full details, see Cadwallader and Lawrence (1990).

WHAT HOPE FOR RESTORATION?

How do we set about repairing 180 years of damage to 1 million km^2? Even acknowledgment of the problems has been slow in coming, although recognition of some, for example salinization, came at the turn of the century. The scale, as mentioned at the outset, is enormous, and the research base too small. Most of the country's population (70%, or 12.3 million people) occupies only a narrow coastal strip and is far removed from the Basin. It is probable that the taxpayers would be disinclined to bear the cost of restoration in the form of increased taxation or water charges. The "average" Australian is profligate with water use, but may not be so if water was priced realistically.

It is evident from the reports cited herein that most attention has been focussed on the environmental problems only in the past decade. The *Water-2000* series (e.g. O'Brien *et al.* 1983) comprised thirteen volumes detailing Australia's water resources, the first comprehensive treatment of its kind. The Murray-Darling Basin Environmental Resources Study (MDBMC 1987) similarly was the first detailed review of the extent and severity of resource degradation in the Basin. Some of the recommendations from this and other reports include special zoning of the entire floodplain, controls on further clearing, incentives for landholders to preserve areas of high conservation value, ensuring protection and adequate regeneration of riparian vegetation, encouragement and support for experimental studies of manipulation of grazing levels, watering trials, and rehabilitating identified degraded sites.

To achieve these ends, the Natural Resources Management Strategy (NRMS) was set up to provide for coordinated action, to identify responsibilities of government and community, to provide funds for the community to implement action, etc. The aims of the Strategy are to prevent further degradation, restore degraded resources, ensure use of resources within their capability, minimise adverse effects of resource use, ensure self-maintaining populations of native species, ensure appropriate planning and management, and preserve cultural heritage (MDBMC 1989).

NRMS (and also the Land and Water Resources Research and Development Corporation and CSIRO) is funding and providing research direction. A number of community projects have been supported, with liaison between management, community, and researchers. Considerable effort has gone to educating the water users: NRMS-funded community videos, total catchment awareness projects for schools, teacher education, fact sheets, publications, television updates on Landcare projects, and Saltwatch activities for schools – all are promoting community awareness. Many of the Basin's problems stem from basic ignorance of interactions or ramifications of a specific action. Education is resolving this ignorance, from the community through to management.

What of the billabong? Much of the recent surge of research is on the mainstream rivers and the problems that beset them. Relatively little attention has been paid to the floodplain. There are exceptions, e.g. trial flooding of the largest remaining extensive river red gum Forest at Barmah/Millewa also flooded the billabongs within the Forest (MDBC 1992). The study was prompted by poor tree health and regrowth, changes to the understorey, and a general reduction of species diversity of plants and animals. Research data from this study is being processed, but preliminary evidence suggests that only small changes in management practices may be necessary to sustain the forest (MDBC 1992). More frequent minor flooding would also rejuvenate forest billabongs.

Notably, in several of the reports cited here, billabongs specifically, and wetlands generally, have not been targetted for restoration or rehabilitation. A recent report on the state of Australia's rivers (CSIRO 1992) identifies the riparian zone as the most neglected ecosystem in Australia, but gives passing mention to the floodplain, and virtually ignores billabongs. Clearly, considerable education has yet to be achieved before the perception of floodplains is improved. Whether this is feasible in the light of increasing population pressure is of some doubt.

In the context of the lower River Murray in South Australia, Walker and Thoms (1993: 117) noted, "*Given the requirements of irrigators and other water consumers, and the political and economic constraints that abound, it is doubtful whether proposals to restore a more nearly natural distribution of flows...would be seriously regarded, although this may be the only option for restoring some elements of the natural ecosystem*". They considered the lower Murray to be a river in crisis, but so too are the other rivers of the Basin.

FUTURE DIRECTIONS

Given the reliance of the floodplain on activities in the catchment, it is not possible to treat the disappearing billabong ecosystems in isolation from the surrounding environment. The needs summarised below are general to the Basin and continental Australia; they must be met before appreciation of the present plight of the floodplain environment becomes widespread at the community level.

Although "sustainable economic development" is now the catch-phrase of the authorities, there remains an appalling ignorance of the environmental processes of Australia's land and water ecosystems on which our continued livelihood depends. Significant economic leverage continues to be applied to the administration to permit, for example, vast mining projects, clear-felling of old-growth forests for wood-chipping or increased extraction of water for commercial irrigation projects. These activities certainly are **economic**, but they cannot be **sustainable**, and whether they are **development** is debatable. At administrative through to community levels there appears to be little vision that such activities are the bases of our present problems. Apathy may be a contributing factor. It would seem, therefore, that the most critical and urgent future direction is in improved education.

Who to educate? Critically, the administrators, particularly those who push for increased immigration or more resource development – those who hold the view that more people will produce more and extract more wealth. Not only are the resources finite, and becoming more so, but this short-sighted perception completely overlooks the costs of the present overpopulation, in providing housing, services, waste disposal, and so on, all of which are *now* costly problems. For example, 143,000 immigrants in 1989 brought $2 billion capital, yet cost $11 billion in housing and infrastructure (Beale and Frey 1990). Noted ecologists (e.g. Paul Ehrlich, David Suzuki) have already suggested that Australia's carrying capacity is around 10 million people (cf. 18 million at present). Reality has to be imposed upon the administrators.

Urgently, the minority of landholders are unaware (or dismissive) of the long-term repercussions of their actions. They are less informed or "dollar-driven" and continue to clear and further degrade the environment. Continued degradation of the Murray-Darling Basin, for example, ultimately will force relocation of at least some of its population as the land becomes eroded or salinized and unusable......but relocate where? The majority of landholders are already aware of the enormity of environmental degradation in the Murray-Darling Basin, indeed in continental Australia as a whole. In most cases they do what they can with limited means: by forming landcare groups they provide a regional approach, increase skills and diversity by pooling, contribute more time and resources than could individuals, utilise limited resources more efficiently, and are more likely to receive government support and/or resources than are individuals (Beale and Frey 1990).

Urgently too, the urban majority, many of whom perceive their food, furniture, houses and motor cars as deriving from supermarkets and suburban suppliers, with little or no appreciation of the cost to the land from which they are isolated. The future may indeed be greener, but the environmental costs of supporting our present standard of living suggest that it will indeed be leaner.

Research direction? To provide better education implies a sound research base, yet for billabong and other ecosystems there are profound gaps in our understanding of what is (or was!) there, of ecological interactions, and of responses to human interference. Development of sound management strategies also depend on a sound research base. There has clearly been an enormous loss of genetic diversity and untold numbers of plants and animals, yet conservation of the survivors does not figure high in the priorities of the present government . For example, there is limited funding for taxonomic and ecological studies of the flora and fauna, particularly the lower systematic groups (see Green and Shiel 1992). Only in the last few years has there been any effort to document Australia's indigenous flora and fauna in any systematic way, yet the Australian Biological Resources Study (ABRS) is severely handicapped by limited federal funding. There has been little comment from the Australian scientific community regarding this dearth of research funding. When an ecological disaster occurs, such as the enormous blue-green algal blooms of summer 1990-91 in the Murray-Darling system, funds can be found immediately to "fix" the problem. Interestingly, there had been predictions for at least 50 years that such blooms were inevitable. A little foresight by the relevant authorities in the form of research funding would have been better preventative medicine than the band-aid approach subsequently followed.

Integrated management? Considerable planning and research duplication and resistance to integration have resulted from imposition of state and federal boundaries. Impediments to resolving problems on a Basin or continental level include territorial "jealousies" between state water authorities, universities and research facilities, and, particularly by the former group, effectively "locking-up" research data in internal reports. By overcoming the inertia and fragmentation implicit in Australia's state and federal bureaucracy an integrated approach to restoration and conservation is facilitated. Clearly, programmes such as the ABRS and NRMS go some way to overcoming these constraints, but they are notoriously under-funded. Similarly, the recent establishment of state and federal Environment Protection Authorities requires considerably more support and integrated management. Most important is the need for effective legislation with deterrent "teeth" in the form of realistic penalities to discourage further environmental degradation – for many large companies a $5000 fine is petty cash, whereas a $5,000,000 fine might induce pause for thought!

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