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MURRAY-DARLING BASIN ESSAY

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Restoring sustainability to Murray-Darling Basin freshwater fish and aquatic ecosystems

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Above: Menindee Lakes, New South Wales. JohnCarnemolla, iStock.

EXECUTIVE SUMMARY

Koehn describes the riverine ecosystems of the Basin and their health. They are generally in poor condition due to impacts from a range of threats, and many of these valuable ecological assets continue to decline. While much attention has been given to economic development and management in the MDB, investment in ecological management has lagged. The greatly diminished state of native fish populations (losses of > 90% in the past 150 years) together with massive fish kills in the Darling River and explosions in alien carp populations all provide clear wakeup calls to the ecological emergency occurring in MDB aquatic ecosystems. Comprehensive attention must be given to all biota, aquatic ecosystems, and the ecological services they provide. Reductions in the original amounts of environmental water recovered, pauses in Basin Plan implementation and neglecting to account for the consequences of climate change have postponed any major environmental improvements and threaten Basin Plan objectives.

In 50 years, Basin aquatic ecosystems and their biota can be sufficiently restored such that they are sustainable, resilient environments to provide for the socio-ecological and economic needs of future generations in the face of the challenges of climate change.

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Restoring sustainability to Murray-Darling Basin freshwater fish and aquatic ecosystems

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Abstract

Aquatic ecosystems of the Murray-Darling Basin (MDB or Basin) are generally in poor condition due to impacts from a range of threats, and many of these valuable ecological assets continue to decline. While much attention has been given to economic development and management in the MDB, investment in ecological management has lagged. This essay focuses on the native freshwater fish as an example of MDB aquatic biota in crisis. The greatly diminished state of native fish populations (losses of > 90% in the past 150 years) together with massive fish kills in the Darling River and explosions in alien carp populations all provide clear wakeup calls to the emergency occurring in MDB aquatic ecosystems. This situation requires urgent and decisive actions to avoid further declines, degradation, likely extinctions and an intergenerational ecological catastrophe, where avoidance passes the ecological costs on to the next generations. As well as fish, comprehensive attention must be given to all biota, aquatic ecosystems, and the ecological services they provide. This essay provides only a few pertinent examples for non-fish biota. The efforts undertaken for freshwater fish can, however, provide direction to improved holistic management. Considerable investment in socio-**ecological** management is sorely needed.

Through full implementation of Basin Plan and other recovery initiatives there is an opportunity to rebuild the resilience of ecological assets so they can recover from disturbance. However, under the regime of current management, this is doubtful. Indeed, under existing progress, the objectives of the Basin Plan (improved ecological health condition and no extinctions) will not be met. Reductions in the amounts of environmental water recovered, pauses in Basin Plan implementation and neglecting to account for the consequences of climate change have postponed any major environmental improvements. To build ecological resilience, there is a need to restore populations, habitats and ecosystems. To achieve this requires improved management of water for the environment including full implementation of stalled environmental water reforms, further potential changes to water policy, and a comprehensive program of additional measures to address the range of other threats impacting native fishes. Restoring ecological assets can be achieved by working together, across jurisdictions, communities and stakeholders. The challenge is to have the long-term vision, political will, commitment, and adequate resourcing to implement these necessary actions. As the decline of MDB native fish populations has occurred over more than a century, a long-term strategy is needed for recovery.

A 50-year vision for Murray-Darling Basin aquatic ecosystems and their biota is that they be sufficiently restored so they can be sustainable, resilient environments to provide for the socio-ecological and economic needs of future generations in the face of the challenges of climate change.

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Introduction

The Murray-Darling Basin (MDB or Basin) covers >1 million square kilometres (14% of Australia's land area), includes Australia's two longest, most iconic rivers (the Murray and Darling; Eastburn and Mackay1990; Breckwoldt et al. 2004) that each flow over 3,000 km across a range of habitats. Management involves water, natural resource and conservation agencies from six jurisdictions. Being about three times the area of the Great Barrier Reef, the MDB environments support unique biotic communities. For example, about a quarter of its native fish species are endemic to the MDB, not occurring anywhere else (Lintermans 2023). The Basin contains over 30,000 natural wetlands including sixteen listed under the Ramsar Convention (Zhang et al. 2024), along with their associated biota of plants, invertebrates, fish, waterbirds and other vertebrates. Despite having been greatly modified from their natural state (see below), these habitats and environments, even in their altered state, retain significant cultural, scientific, environmental/conservation, ecological, social/recreational, and commercial/economic values. These assets are recognised under the Basin Plan (MDBA 2011) and are owned and valued by all Australians, both regional and urban communities.

Much of the written history of the MDB reflects on the development of irrigation infrastructure and water management, which has resulted in considerable agricultural prosperity. Less has been recorded of the natural environments, the abundance of fish wildlife, their cultural (Ellis et al. 2022) and other values such as early commercial and current recreational fisheries (Rowland 2005). These are important perspectives. Water is the lifeblood of most regional towns, agriculture and industries. However, the prosperity and well-being of these communities is also dependent on the sustainable maintenance of MDB environments and their ecosystem services, especially rivers, wetlands, and their biota. While much attention has been given to economic development over time and management, less attention has been given to ecological management. Considerable investment in socio-ecological and ecosystem-based management (people and their ecological environments) (Woods et al. 2022) is sorely needed.

The MDB is often referred to as 'Australia's food bowl', contributing about 40% of the country's agricultural production (Koehn 2015; Bowland 2023). It accounts for more than 60% of the total water used for irrigated agriculture in Australia, with considerable associated irrigation infrastructure such as dams, weirs, channels, pipes and pumps that extract water from aquatic habitats. The MDB economy is currently worth around $230 billion per year, with agriculture contributing over $20 billion per year in gross value (since 2010), about 30% of which is from irrigated agriculture (Bowland 2023). While agriculture dominates land use and management (Hart et al. 2021a, b), mining, tourism and recreation also make valuable contributions to the economic and workforce diversity (Bowland 2023). Many of these industries, especially tourism (31,000 businesses in 2016; Hart et al. 2021a, b) rely on the natural environment and are particularly important for regional towns. Recreational angling is an important Australian pastime, and important to tourism, especially in regional areas (Henry and Lyle 2003). There is competition between water used for agriculture and to sustain these aquatic environments (Koehn 2015; Wheeler 2024) and demand for water in the MDB is increasing because of population and economic growth (Williams 2017). This demand is likely to be exacerbated by climate change (CSIRO 2008).

This essay uses fish as a basis for illustrating the condition and management of MDB riverine (and floodplain) aquatic ecosystems. Fish can be viewed as sentinel species for many issues impacting the requirements of the many other aquatic organisms present. It is recognised, however, that greater attention needs to be given to other biota, and that the rivers and floodplain ecosystems in particular, need to be addressed holistically. Mosley et al. (2024) provide an example of this for the Lower Lakes and Coorong, including estuarine fishes. Fish, however, are considered key assets of the MDB under the Basin Plan, are highly dependent on water, are mostly near the top of the food chain (and hence are reasonable overall ecological indicators), are highly valued by all stakeholders and communities, and have a high ecological knowledge base, with key threats and remedial options already considered in existing integrated restoration plans. The plans developed for freshwater fish may provide an example way forward for improved management of other ecological components. Within that context, the objectives of this essay are to:

1. Examine the key issues impacting freshwater fish and aquatic ecosystems.
2. In addition to fish, provide some similar examples for other key aquatic biota.
3. Indicate how populations and habitats have been affected by changes to flows and other threats.
4. Look at impediments and options for improved management.
5. Provide a 50- year vision with a way forward as to how it can be achieved.

Major changes to aquatic habitats, water and flows

To date, irrigation development has generally dominated management of the MDB, to the extent that it is one of the most regulated river basins in the world (Grill et al. 2019). Over-allocation of water, flow regulation and environmental damage have all been identified as issues that urgently need to be addressed (Walker 2006; Kingsford 2000; Lester et al. 2011; Walker 2019). Riverine aquatic habitats have been greatly impacted in many ways (also see Table 1):

- MDB now has 240 dams storing 29,893 GL of water (Kingsford et al. 2017).
- Only 40–50% of its main stem rivers remaining free-flowing (Liermann et al. 2012), and many of those having their hydrology altered to some degree by regulation or extraction.
- End-of-system flows are now zero for 40% of the time, compared with 1% of the time under natural flow conditions (CSIRO 2008).
- Extensive river reaches have been converted from lotic to lentic environments by weirs and reduced flows (Maheshwari et al. 1995; Walker 2006).
- Low water levels and critical no flow periods have increased significantly in previously naturally perennially flowing rivers (e.g. Darling River; Mallen-Cooper and Zampatti 2020).
- There are more than 5,000 barriers (Lintermans 2023) that cause disruption to river connectivity (Baumgartner et al. 2014).
- There has been a significant loss of off-stream lakes and wetlands that may provide waterbird and fish nursery habitats. While the quantum (e.g. area) is not readily available, only 11 of a potential 567 golden perch (*Macquaria ambigua*) larval nursery sites have been considered to be still operating in western NSW (Sharpe 2011).
- The effects of anthropogenic flow alterations were exacerbated during the 'Millennium Drought' (Murphy and Timbal 2008; van Dijk et al. 2013), as they will also be under projections for climate change (see below).

Predicted changes due to climate change

Climate change is projected to have a range of impacts on MDB aquatic habitats and their biota (Pittock et al. 2010; Pittock, and Finlayson 2011; Balcombe et al. 2011; Pratchett et al, 2011):

- The MDB will be hotter and drier under climate change (Grose et al. 2020, Chiew et al. 2023; Zhang et al. 2024), having already warmed by 1°C since 1910 and the warming will continue (Whetton and Chiew 2021). Changes to temperatures will impact fish metabolism and spawning, and may result in changes to their distributions (Bond et al. 2011).
- Water availability is decreasing (Prosser et al. 2021) and likely to reduce across the entire Basin with a greater reduction in the south of the Basin (CSIRO 2008).
- Average annual runoff is projected to decrease 9% by 2030 and 23% by 2070 (CSIRO 2008). There is high variability, however, with projected changes in mean annual runoff ranging from -40% to +10% in the southern MDB and -45% to +30% in the northern MDB (CSIRO 2008). The direction of change in summer rainfall is less certain with the magnitude of extreme high rainfalls expected to increase (Timbal et al. 2015).
- There will be large increases in frequency in the length and severity of multi-year droughts and hence low flow and zero flow periods (Zhang et al. 2020). Together with a decrease in freshes of up to 55% (Zhang et al. 2020) there is likely to be an increase associated events such as major cyanobacterial blooms, low dissolved oxygen concentrations and blackwater (Verhoeven et al. 2024).
- Severe drought conditions (Vertessy et al. 2019), together with increased fires and post-bushfire run-off will also cause increased fish kills (Legge et al. 2020).

Climate change has not been adequately addressed in the Basin Plan (Pittock et al. 2015; Prosser et al. 2021; Zhang et al. 2024) with future climate-induced flow reductions negating some of the benefits of projected environmental water allocations. The impacts of climate change reduction in MDB flows cannot be allowed to be borne by the environment as the median projected decline in annual runoff is similar to the volume of water returned to the environment under the Basin Plan (around 3,000 GL) (Whetton and Chiew 2021). For example, Kingsford et al. (2017) modelled the effects of returning water to riverine environments could improve waterbird abundances by 18% but projected climate change effects could reduce these benefits to only a 1% or 4% improvement, with annual recovery of environmental flows of 2,800 GL or 3,200 GL respectively. This is being further exacerbated by the fact that environmental water is now already being used for emergency events such as fish kills, rather than to promote population and general ecosystem recovery. Within the context of already reduced and much-delayed recovery of water for environmental purposes, the impact of climate change will be even greater and needs better consideration, especially as water management will become even more difficult (Neave et al. 2015).

While it is predicted that primary production in the MDB in 50 years' time will be substantially impacted by a changing climate (Boland et al. 2024), it is fair to say that aquatic ecosystems have already been impacted by far greater changes to flow regimes imposed by flow regulation and extraction. While climate change will impact water resources in the MDB, this impact will be less than that already caused by water extraction (Grafton et al. 2013). These further changes will greatly affect fish species and overall ecosystem services, with impacts differing among species (Chessman 2013).

Major changes to aquatic biota and ecosystems

Globally, freshwater biota and their ecosystems are under threat and in need of conservation and restoration (Malmqvist and Rundle 2002; Dudgeon et al. 2006; Flitcroft et al. 2019). The MDB is no exception and is now considered one of the most at-risk river systems in the world (Wong et al. 2007). There is no doubt that development of the MDB has caused great damage to natural aquatic ecosystems (Walker 2006; Kingsford 2000; Baumgartner et al. 2019; Koehn et al. 2020a), through impacts from a range of threats (see also Table 1). This is evidenced by monitoring that indicates that most MDB rivers and catchments are now in poor ecological condition (e.g. Davies et al. 2008, 2010).

Key documented changes for native freshwater fish include:

- Native fish populations have declined by >90 % over the past 150 years (MDBC 2004; Koehn and Lintermans 2012).
- Almost half the native species are now of conservation concern, being listed as rare or threatened under state or national legislation (Lintermans 2023).
- Many smaller fish species, especially wetland specialists, are at greatest risk (Lintermans et al. 2020) and Yarra pygmy perch (*Nannoperca obscura*) appear now to be extinct in the MDB.
- Several fish communities of the MDB have been listed as threatened under both State (Victorian and New South Wales) and Commonwealth legislation.
- There have been rapid declines in key, popular recreational and commercial 'flagship' species such as silver perch (*Bidyanus bidyanus*), freshwater catfish (*Tandanus tandanus*) and trout cod (*Maccullochella macquariensis*) (Cadwallader and Gooley 1984; Reid et al. 1997; Clunie and Koehn 2001a, b) with observed declines in recreational angling success.
- Almost all commercial fisheries have collapsed and are long closed (Rowland 1989, 2005).
- There is the likely loss of Murray cod and silver perch from the Paroo River (Sarac et al. 2011).
- Important traditional cultural practices of First Nations People have been weakened (Humphries and Winemiller 2009; Ellis et al. 2022).
- Fish kills are increasing in magnitude and becoming more frequent (see below) including from post-fire run-off (Lyon and O'Connor 2008; Legge et al. 2020).
- Cold water released from dams impacts spawning, recruitment and growth in over 3,000 km of MDB rivers (Lugg and Copeland 2014).
- Alien species (12) now comprise a quarter of MDB fishes with carp dominating fish biomass in many river reaches (Harris and Gehrke 1997; Stuart et al 2021).
- There has been damage to and loss of habitats for wetland species (Closs et al. 2006; Sharpe 2011).

In addition to riverine fish, there have been major impacts on other biota – here are some select examples for wetlands. Flow alterations have greatly reduced flows into wetlands reducing their number and area (Sharpe 2011), impacting vegetation and waterbird habitats (Kingsford and Thomas 1995; Kingsford et al. 2011) and changing their ecological character (Pittock et al. 2010). This has caused major ecosystem-wide impacts, including successional changes in aquatic vegetation; reduced vegetation health; declining numbers of waterbirds and nesting; declining native fish and invertebrate populations (Kingsford 2000) and changed organic-matter dynamics and physicochemistry (Watkins et al. 2010). Significant long-term declines in total waterbird abundances are associated with reductions in cumulative annual flow (Kingsford et al. 2017).

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The major threats to MDB fishes have long been identified (e.g. Cadwallader 1978) and urgent and effective remediation of them has been recognised as essential for the recovery of fishes (Baumgartner et al. 2019; Koehn et al. 2020a; Table 1). Given the poor and declining status of native fish populations in the MDB, it must be concluded that the MDB is not currently being managed in an ecologically sustainable manner. While there are a range of threats, it is evident that the footprint of irrigation and its infrastructure (in terms of area and extraction overall) on the aquatic biota of the MDB is very large (see shaded rows in Table 1). There is a need to recognise this current critical state and the urgent need for restorative policy, management and community actions; we can no longer just manage for the *status quo.* We need to build resilient populations able to withstand and recover from the unsustainable collective impacts and consequences of human-induced disturbances as well as the existential impact of climate change (currently not addressed by the Basin Plan).

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Table 1. A summary of key impacts on native freshwater fishes by various threat mechanisms, along with potential solutions (from key references such as MDBC 2004; Baumgartner et al. 2019; Koehn et al. 2020a, b; MDBA 2020 and references therein). Shaded rows indicate association with water extraction or infrastructure.

Threat mechanism (cause)	Detail of the threat	Impact on fish populations	Potential improvements
Water storage and delivery for consumption	Major reduced inflows through the river system	Loss of habitats and flow components vital to population growth (e.g. movement, spawning and recruitment cues)	Use environmental water and design irrigation water delivery to meet optimal flow components required by aquatic biotas Protect refuge habitats
	Altered flow regimes: Reduced winter flows; reduced overbank flows, very low base-flows	Loss of habitats, and flow components vital to population growth	See above; increase critical flow components in line with natural seasonal frequencies, Protect refuge habitats
	Altered flow regimes: Increased summer flows (seasonal flow reversal)	Loss of seasonal flow components vital to population growth	See above: increase critical flow components in line with natural seasonal frequencies
	More uniform flows	Reduced biological cues (e.g. spawning, movements)	Increase delivery variability in line with biological needs, including overbank flows
	Lack of flushing flows	Poor water quality; Fish kills; Reduced biological cues	Decrease no flow periods; better real time remote water quality monitoring for key parameters, informed, adaptive water management planning and actions
	Release of cold water from deep outlets	Prevention of spawning and recruitment, reduced growth	Install mechanisms such as curtains or variable level outlets

Water extraction	Reduced overall flows	Loss of habitats and spawning/recruitment cues and needs	Adequate environmental water allocations, altered water delivery, all extraction remotely monitored in real time
	Pumps	Loss of fish through extraction	Install pump screens
	Irrigation channels	Loss of fish through diversion	Install screens
Weirs and structures (barriers)	Reduced river connectivity	Inability to move, complete life-cycle requirements, recolonise or escape poor water quality	Install effective fishways for longitudinal upstream and downstream fish movements
		Accumulations below barriers- increased susceptibility to disease, predation, poor water quality and capture	See above- with adequate flow cues for movements
		Reduced connection to floodplain habitats	Install effective lateral fish passage
		Mortality of larval and juvenile fish passing weirs	Replace undershot weirs
		Conversion of flowing to still-water habitats, increased carp abundances	Remove unnecessary infrastructure or alter operations
	Floodplain regulators	High risk to native fish; increased carp abundances	Recognise risks to native fish and use sparingly
Habitat removal and destruction	De-snagging; originally for river boats, later for ‘improved’ water delivery	Woody habitats, aquatic vegetation, reduced population capacity	Habitat reinstatement and protection; protection of riparian vegetation; more natural flow regimes

	High irrigation flows	Aquatic vegetation loss	
	Riparian zones	Erosion and cattle grazing.	Vegetation reinstatement and protection e.g. from stock grazing
	Wetland drainage	Wetland loss	Habitat reinstatement and protection; connection and re-connection flows
Angling	Angler harvest	Reduced adult spawning stock, reduced populations	Harvest and stock management
	Hatchery stocking	May increase populations of some predators	See above
Alien fishes	Especially: Salmonid species, carp, redfin (*Perca fluviatilis*) Gambusia (*Gambusia holbrooki*), oriental weatherloach (*Misgurnus anguillicaudatus*	Increased predation and competition	Implement an effective alien species management Strategy

Two key events that have engaged (and enraged) the public and highlighted the critical status of MDB aquatic ecosystems are worthy of further comment.

Fish Kills

Fish kills are predictable (with adequate attention and monitoring) and very visible events, with high levels of public scrutiny and media attention. Significant, large-scale events in the lower Darling River In 2018-19 (estimated 2-4 Million fish killed) (Australian Academy of Science 2019; Vertessey et al. 2019) and 2023 (estimated 20-30 Million fish killed) (Office of the NSW Chief Scientist & Engineer (2023), created anger, despair and dismay within local communities and the broader Australian population. The losses included important cultural, threatened and popular, iconic and angling species that cannot be quickly regenerated. Such losses cannot be sustained, especially for long-lived species such as Murray cod (Thiem et al. 2017). These events and the publicity surrounding them (including international coverage) caused serious questions to be asked regarding the competence of the protection of fishes and of MDB water management. Numerous other fish kills have occurred but received less attention, especially during drought conditions and subsequent bushfires (e.g. Legge et al*.* 2020). Given the predicted increasing frequency and severity of fish kills under climate change, there is an imperative for greater dedication to this area of resource management (Koehn 2022).

Carp

There are estimated to be between 199.2 M ('average' hydrological scenario) and 357.5 M ('wet' hydrological scenario) carp across Australia, most being in the MDB (Stuart et al. 2021). Populations fluctuate with flows and there have been increases in carp recruits following the 2022-23 flooding (Stuart et al. 2023). Being a highly visible alien species, in very large numbers, this has also caused public concern. Managing carp is difficult (Koehn et al. 2000), even with potential widespread actions such as the proposed carp herpes virus (KHV) (Stuart et al. 2023). Consistent with most invasive species they take advantage of ecosystems in poor condition. Carp are often also favoured by current water management regimes; including still weir pools, use of floodplain regulators and the delivery of high-level annual irrigation flows that inundate low lying floodplains such as Barmah- Milawa (Koehn 2004; Koehn et al. 2016).

Declines of over 90% in natural populations, frequent and massive fish kills and explosions in carp populations must be seen as giant wake-up calls to the poor resilience of MDB ecosystems as a result of a century of inadequate management. There is a need to philosophically change our approach to more seriously address these and other ecological issues.

Challenges

A key challenge is to work together to ensure the sustainability and resilience of MDB ecosystems on which communities and industries rely. This includes redressing impacts and balancing the quantity of water extracted and used for irrigation with that which can be used to protect and restore ecosystems. We must work together to meet all interests and community values – e.g. for irrigation, to restore environmental assets and water to First Nations to preserve their cultures (Jackson and Moggridge 2019). There is also the need to recognise the damage that has been done by a range of factors and accept that there is the need to facilitate recovery so that ecosystems have the resilience to recover from future hits- including from climate change related events. Most impacts on aquatic ecosystems are well-known with potential solutions identified. Actions, however, require the undertaking of a wide range of identified non-water measures (e.g. provision of fish passage; MDBC 2004; Koehn and Lintermans 2012; Baumgartner et al. 2019) that need to be integrated with the water reforms in the Basin Plan (MDBA 2011).

There is the need for proper recognition of non-agricultural values and assets, and this will require extensive and timely changes in both attitudes, approaches and commitments. Water in the MDB is highly managed- because it is valuable. We need to apply similar levels of management and valuation to ecosystems, their biota and the services they provide as these are also important assets within this highly managed river system. MDB ecosystems are 'common property resources' belonging to, and valued by all Australians, both those within the MDB and also those outside it, including the capital cities. The public reaction by capital city population to the plight of farmers during the Millennium drought was one of great sympathy. The reaction of the same citizens to recent fish kills has been one of horror- 'what are we doing wrong out there?'

One of the most significant and impactful droughts recorded in the MDB (the 'Millenium' drought) provided a major wake-up call that resulted the development of extensive water policy reforms. The Basin Plan, however, has been controversial with considerable community outrage and significant public discourse (Pittock et al. 2015, Prosser et al. 2021; Zhang et al. 2024). There is opposition to any reductions of water available to agriculture, and equally, criticism of the lack of water projected to be returned to the environment (Chen et al. 2020), the limited amount of water actually returned to date and where is has been applied (Kirsch et al. 2021; Colloff and Pittock 2022). There have been several reductions to returns of environmental water following legislation of the Basin Plan, changes to the accounting and 'water savings' mechanisms utilised (e.g. Sustainable Diversion Limit Adjustment Mechanism projects (SDLAM), which along with other Federal and State government actions have been criticised (Walker 2019).

Some of the difficulties in Basin Plan implementation over the past two decades have been outlined in Wheeler (2024). Advice on Basin Plan implementation provided by the Murray-Darling Basin Authority on July 25, 2023, however, provides dismal reading. "Full implementation of the Basin Plan not possible by 2024 deadline. There will be a shortfall of water for the environment as set in the Basin Plan."

- Very little progress has been made in achieving the 450 GL/y efficiency target, and this water will not be recovered by 30 June 2024 as required under current settings.
- Only 5 of 20 water resource plans in New South Wales (NSW) have been accredited. These plans are more than 4 years behind schedule, and NSW still has 7 plans to submit for assessment by the MDBA.
- Critical measures for improving outcomes in the northern Basin will not be delivered on time. Only 2 of 6 are on track for delivery by 30 June 2024. The remaining 4 measures are expected to take longer, delaying the achievement of environmental outcomes.
- With 16 key SDLAM projects unlikely to be operable by 30 June 2024, the Authority estimates a shortfall in water recovery of between 190 and 315 GL.

(https://www.mdba.gov.au/news-and-events/newsroom/authority-advice-basin-plan-implementation#msdynttrid=6pgxvlfAP0fGPIJtmrREzpWRSOJjnXYnVd1DOnxXyS0, accessed on 8 March 2024)

There is little doubt that the negative changes to the original water reforms and the considerable delays in implementation of measures to redress the water imbalance between agriculture and the environment have delayed any major improvements to aquatic environments, and probably led to further declines (e.g. contributed to the increased scale and frequency of fish kills). Maintaining the current incremental approach to water policy and management reform will not address all the current impacts or those from climate change. Hence it is likely that further degradation will occur and further changes to water policy and management may be required (Boland et al. 2024; Verhoeven et al. 2024; Wheeler 2024).

The ecological effectiveness of SDLAM measures has been highly criticised (Colloff and Pittock 2019). SDLAM in effect, decreased the need to recover 605 GL for the southern MDB of water entitlements within the Basin Plan through 'an equivalent reduction in surface-water diversions' (mostly installing regulators or building levee banks or improving on and off-farm water infrastructure) (Wheeler 2024). In relation to native fish, they have been assessed as being of minimal benefit, generally causing great risks, but being of great benefit to increasing carp populations. They cause risks to native fishes and benefit carp (Mallen-Cooper et al. 2008, 2010; Koehn et al. 2016).

Opportunities

Many voices continue to show concern about the state of aquatic habitats and biota in the MDB (e.g. Australian Academy of Science 2019; Walker 2019) and researchers, stakeholders, communities, and natural resource agencies must coordinate their activities and act decisively to improve the dire state these ecosystems are in.

The actions required to restore MDB native fish populations can be categorised into: (1) Flow management; (2) Water infrastructure; (3) Other restoration (actions to be implemented in parallel with appropriate flow management); and (4) Support and engagement (Koehn et al. 2020a). This requires: (a) coordinated policy settings under which actions can be implemented; (b) sound supporting science; (c) prioritised actions; (d) commitment and investment; and (e) stakeholder and community support (MDBA 2020).

The good news is that there are two existing policy frameworks that can help achieve this. The Basin Plan (MDBA 2011), which has the objective of improving flows through increased delivery of water for the environment (Hart 2016a, b; Stewardson and Guarino 2018), is funded and needs full implementation. While the Basin Plan (MDBA 2011) provides a much-needed framework for water reform, including the recovery of water for the environment to support native fishes, there are many additional non-water-related threats that impact recovery. Hence the Basin Plan must be complemented with additional measures to address threats. The value of addressing additional threats through parallel restorative actions has been recognised (Koehn and Lintermans 2012; Baumgartner et al. 2019) and these have been included in the Native Fish Strategy (2003-2013) (MDBC 2004) which is currently not adequately funded or fully implemented (Koehn et al. 2014), nor its the subsequent the Native Fish Recovery Strategy (NFRS) (MDBA 2020).

These documents provide a whole-of-fish-community approach that address priority threats and aims to rehabilitate native fish populations to 60% of levels prior to European settlement (current populations are estimated to < 10%). The NFRS had a 50-year time frame and coordinated actions across jurisdictions, communities and stakeholders in an effective partnership model where central coordination, coupled with focused jurisdictional actions, can deliver benefits to all governments. This model can readily incorporate other State and regional plans (e.g. ACT Government 2018).

A key purpose of such restorative programs is to restore the ecological requirements of the biota that have been impacted by human-induced ecosystem alterations (Cooke et al. 2012; Baumgartner et al. 2019). Both the Basin Plan and the NFRS restoration programs recognise the requirement for policy setting and decision-making to have a strong foundation and to be guided by contemporary knowledge of the species' ecological requirements (MDBC 2004; Swirepik et al. 2016). In more good news, the past 20 years have seen significant advances in the scientific understanding of native fish ecology, the impacts of human-related activities and potential solutions. This includes the science for environmental water, which aims to re-establish critical components of flow regimes that have been lost to benefit biota (Bunn and Arthington

2002; King et al. 2016). This rapidly developing sphere of water management (Arthington 2012) requires a range of data and knowledge, and while some gaps remain, there is adequate knowledge to undertake robust restoration-enabling policies and actions for most key MDB fish species (Stoffels et al. 2018; Koehn et al. 2019, 2020b).

We can also take heart and build on some of the successes that have already been made by restoration actions. For example, the Sea to Lake Hume fishway program has allowed the passage of many fish along the Murray River and has benefited population of migratory species such as silver perch (Baumgartner et al. 2014). The partial recovery of trout cod populations through a dedicated recovery plan has also been promising (Koehn et al. 2013). The use of environmental flows has been shown to increase spawning and recruitment of some fish species (e.g. King et al. 2009) and reinstalment of woody habitats has increased populations of Murray cod (Lyon et al. 2019). The design of hydrographs and effective water strategies to enhance population growth is rapidly developing (Yen et al. 2013; Stuart and Sharpe 2020). Recent modelling of the proposed implementation of higher flows under the Constraints Management Strategy (MDBA 2013) in the Murray River indicates likely improvements to golden perch populations (Todd et al. 2023). These successes show some progress and provide proof of the success of such remedial actions that now need to be funded and greatly up-scaled to be undertaken at the Basin-scale.

The way forward

The challenge now is to have the long-term vision, political will, commitment, and adequate resourcing to implement the necessary actions. Providing a legacy of healthy fish populations in the MDB, rather than continuing the significant declines and likely extinctions, is our moral obligation. The need for further institutional change water policy has been suggested (Wheeler 2024) and the integration of biotic assets on a more equal footing with water utilisation (e.g. restoration of threatened species) would be a step forward. The efforts of futures thinking and management that has been applied to industry and water resources (Horne 2022; Boland et al. 2024) should also be applied to aquatic biota, predicting the impacts and forecasting likely outcomes. Hard choices will need to be made regarding water policy in the future, as well as many trade-offs between competing demands, especially with regard to climate change (Wheeler 2024) with increased value given to environmental and cultural values and uses of water (Moggridge et al. 2019; Ellis et al. 2022).

The word *Sustainability* is used in many essays in this collection, but this is currently not a reality for our aquatic ecological assets. *Status quo* management is no longer an option as it will only result in further degradation, extinctions and an intergenerational ecological catastrophe where avoidance of the situation passes the ecological costs on to the next generations (Bommier and Zuber 2008). The existing losses to MDB aquatic ecosystems outlined in this essay highlight the urgent need for both change and action. The current incremental, partisan political and self-interest, transactional management approach must evolve to equitably consider all interests with an approach toward ecosystem restoration and reducing risk of ecological collapse. This must focus on major issues such as the over allocation of water and other recognised threats and the objectives of the Basin Plan, with a holistic view that focusses on habitats, ecosystems and the services they provide to communities.

Two existing key policy frameworks in the Basin Plan and Native Fish Recovery Strategy provide a solid basis from which recovery can begin. The science and knowledge of MDB fishes is considerable and growing, and while additional information will help maximise outcomes, knowledge is not a constraint to species and ecosystem restoration. From an aquatic ecosystem point of view there is the need for long-term continuity in restoration and a whole of the MDB approach – not site by site. As the decline of MDB native fish populations has occurred over more than a century, a long-term strategy is needed for recovery (Koehn and Lintermans 2012). We need to commit and stay the course. What is now required is the political vision and commitment to support investment to drive this recovery.

Working across interest groups (rather than just opposing each other) can initiate some easy ecological wins. For example, while irrigation and ecological water needs may be different, they are not always incompatible. For example, designing consumptive water delivery to provide for the needs of fish species needing population restoration (e.g. Stuart et al. 2019). Screening of pumps (Baumgartner et al. 2009) or irrigation outlets (Boys et al. 2013) can not only save fishes from injury or death but also save maintenance costs for irrigators. We need agencies to help facilitate such mechanisms that can be mutually beneficial. The removal of redundant weirs, replacement of weirs (Baumgartner et al. 2006) or altered weir pool management (Bice et al. 2017; Mallen-Cooper and Zampatti 2018) may also have ecological benefits at minimal costs.

The 50-year vision for agriculture in the MDB proposed by (Boland et al. 2024) is for a highly profitable industry producing more from less through sustainable practices. Objectives of the Basin plan include Improvements to the health of rivers and no extinction of species. This includes not just fish but other aquatic biota, water birds and vegetation, which are also listed as key ecological assets under the Basin Plan. Existing management is unlikely to meet these objectives and cannot currently be considered to be ecologically sustainable given the assessment of the state of MBD fish populations and riverine health (Davies et al. 2008, 2010).

A 50-year vision for Murray-Darling Basin aquatic ecosystems and their biota is that they be sufficiently restored so they can be sustainable, resilient environments to provide for the socio-ecological and economic needs of future generations in the face of the challenges of climate change.

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