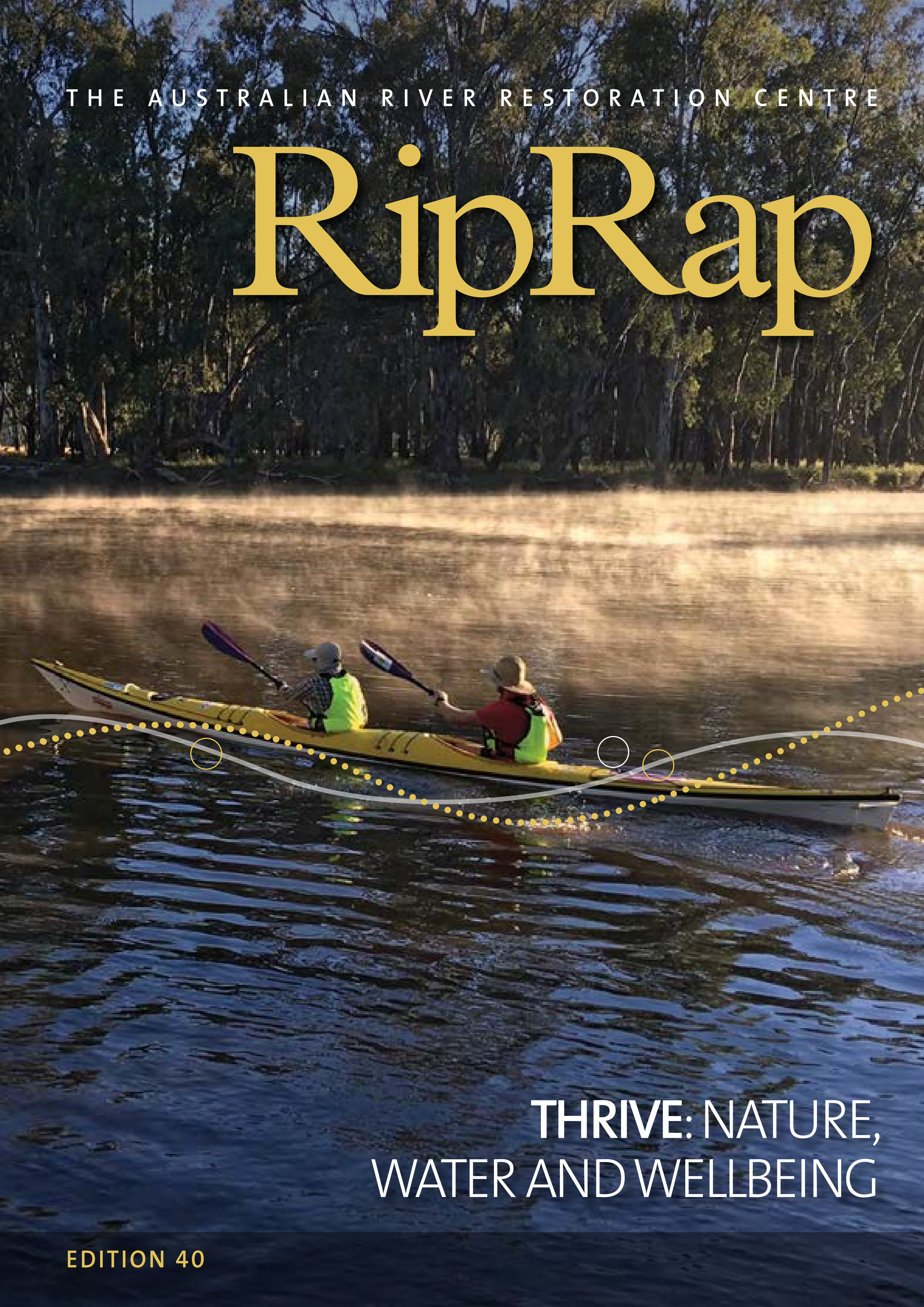
THE AUSTRALIAN RIVER RESTORATION CENTRE

RipRap



THRIVE: NATURE, WATER AND WELLBEING

EDITION 40

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Editorial

Bringing this edition of *RipRap* together celebrates the amazing amount of work and capacity we are developing in managing water for the environment. We are leading the world in our efforts to protect and restore the riverine ecosystems upon which we depend. We hope you enjoy these organisational snapshots, and encourage you to share the edition widely so that others can connect with and appreciate our efforts.

Thrive: nature, water and wellbeing

BEN GAWNE STARTS OFF THIS EDITION WITH A FLOURISH.

Our rivers, wetlands and floodplains have long supported our way of life, providing fresh water, fertile soils and food, as well as spiritual connection and recreation. As we developed the many opportunities created by rivers, it gradually became apparent that our management was having unexpected negative environmental consequences, and that if we were to sustain all of their values, we would need to manage for multiple objectives. This meant we needed to consider how to achieve the delicate balance between the values dependent on the extraction of resources, and the values delivered by a healthy system.

At first, efforts to achieve sustainable management were recognised and initiated at the site scale with local managers, supported by state and Commonwealth governments initiating actions designed to ensure iconic wetland values were protected. The limitations of this approach slowly became apparent, particularly during the Millennium Drought, when it was realised that sites needed to be managed for connectivity and not in isolation. There was also a recognition that flow modification was affecting rivers, wetlands and floodplains across the Murray–Darling Basin, and that Basin-scale management was required to sustain values from individual wetlands to the whole Basin.

Our response was to develop the Basin Plan, and the associated purchase of water to protect and restore the Basin's rivers, wetlands and floodplains. The implementation of the Basin Plan means that there is now an integrated management framework operating at a range of scales from individual wetlands and river valleys, to the Basin as a whole, and from individual flows to long-term flow regimes. This nested management hierarchy is important for two reasons:

1. The Plan's broad environmental, social and economic objectives need to be addressed at a variety of scales, as they are each influenced by drivers and stressors that act at different spatial and temporal scales.
2. In order to plan, implement and evaluate management actions at different scales, the engagement of a wide variety of individuals and institutions is required, each playing a role in protecting or restoring the values of the Basin's aquatic ecosystems.

PHOTOS IN THIS ARTICLE BEN GAWNE.

Learning by doing

The management of aquatic ecosystems is, however, always associated with uncertainty, and the only way to deal with this uncertainty is adaptive management, or 'learning by doing'. Wherever possible, we need to learn not just from our own experiences, but from the experiences of others. This is vital for a number of reasons:

1. It accelerates the sharing and accumulation of knowledge.
2. Comparisons of outcomes across sites can provide valuable insights into how systems function.
3. There is the potential for large-scale management to influence local management and vice versa.

Collaboration is key

Within this adaptive management context, collaboration across the many different parties involved in the Basin is essential. Without it, there is a risk that projects will work at cross-purposes, limiting or potentially undermining expected outcomes. Several articles in this edition of *RipRap* demonstrate the productive and collaborative partnerships that are underway between researchers, government agencies and diverse community groups, all working together for the health of the Basin.

Successful collaboration relies on a number of factors—shared vision, clarity of purpose, trust, knowledge and communication.

The Basin Plan and the associated Basin Watering Strategy provide a high level vision for the management of aquatic ecosystems. This provides a frame of reference for people to identify how management of their region or assets can contribute to achievement of the Basin Plan objectives, thereby providing a purpose. *RipRap* articles contributed by key Commonwealth and state institutions illustrate the roles they play in implementing the Basin Plan, and show how partnerships are critical to their success.

RipRap also has articles about knowledge-generating activities, including research and intervention monitoring. Knowledge is crucial in the planning, design, implementation and evaluation of management actions. The adaptive management approach relies on new knowledge to improve system understanding and implement new practices. We have fascinating articles on Congolli, waterbird flight paths in the Macquarie Marshes and Lower Darling, and Moira Grass in Barmah, all using monitoring to inform management practice. In other instances, research offers a more effective, timely and efficient means of generating new information, as is shared in the Murray–Darling Basin Environmental Water and Knowledge Research stories on waterbirds, vegetation, fish and food webs.

Sharing what we know

Collaboration is also critically dependent on communication which underpins coordination, capacity building, identification of opportunities and the development of new knowledge. We have several stories that show how working with local communities can reap great benefits, whether it be paddling down the Murray, tracking waterbirds or counting seeds. It is the networks that we build between and within institutions and community groups that enable us to motivate and achieve on-ground change, and we have several articles focusing on these human elements of river restoration and management.

We hope that in reading this edition of *RipRap* you will be inspired to collaborate and continue your efforts to protect and restore the Basin's fabulous aquatic ecosystems. It is very clear when reading these great stories that the Basin Plan, while large and complex, creates many and varied opportunities to influence the condition of our rivers and wetlands. Acknowledging and celebrating the work being done to bring nature, water and community wellbeing together, enables us all to 'thrive'.

Phil Palmer's photo of the Scottsdale Mothers Day planting.

To thrive—it's local, social and emotional

SIWAN LOVETT SHARES WHAT SHE HAS LEARNT AFTER MANY YEARS WORKING IN RIVER MANAGEMENT, SHINING A LIGHT ON WHY THE RIVERS OF CARBON PROGRAM IS CAPTURING THE HEARTS AND MINDS OF PEOPLE WANTING TO DO THEIR BIT IN RESPONSE TO CLIMATE CHANGE.

When I decided to go to university, after sampling a range of careers including stable-hand, waitress, secretary and telemarketer, I never thought I would end up running the Australian River Restoration Centre. My degree majored in sociology, organisational theory and administration—how on earth did I get to where I am now! Well, although it might seem strange, I use these skills every day working to make science relevant, meaningful and accessible to people from many different backgrounds, and with a wide range of interests.

What I have learnt over 20 years (and counting) of working in river management, is that rivers need people, and people need rivers, but that our approaches have tended to focus on the health of the river as being separate, rather than integral to the health of the communities that live, work and play along those riverbanks. This approach never sat well with me, as I don't feel separate from my environment, and it is only when I have a strong personal connection to place and people, that I get motivated to act.

"If you feel like there's something out there that you're supposed to be doing, if you have a passion for it, then stop wishing and just do it." (Wanda Sykes)

Fortunately, I was given opportunities during my time coordinating the National Riparian Lands Research and Development Program for Land & Water Australia, to combine biophysical and social disciplines, and to work with scientists, landholders and practitioners to try out different ways of doing this. Today, I am putting into practice what I have learnt, and it is really very simple—we need to tailor our expertise so that it becomes local, social and emotional. I will use our Rivers of Carbon (RoC) Program to demonstrate …

Rivers of Carbon

The idea for RoC came from a conversation I had on the side of a road at Tuross Heads on the south coast of New South Wales, where I was holidaying. Friend and colleague Lori Gould (then at Greening Australia) called to say there was an opportunity to apply for funding through the Biodiversity Fund, and why didn't we give it a go. Lori and I had always wanted to work together, our skills complement each other, with her many years working with local communities to restore riparian areas, and my connections with scientists and communicators, a perfect fit.

Like many women, Lori and I had both worked in teams managed by men with strong biophysical skills, but with little appreciation for the emotional antennae and social science expertise that makes technical knowledge relevant to people. This situation is common worldwide, across most river management institutions, with women under represented in senior leadership positions. RoC presented us with an opportunity to 'run the show', and we were delighted when we secured funding to do just that.

Go local

We started by looking locally at the issues people were concerned about, the successes of the past, and what was already underway in the region. From the very start, we wanted RoC to support and add value to existing initiatives, fully cognisant of the efforts and work that had gone before. Too often as we move on to the next project, we forget to look back at what has been done, and to reflect on what we have learnt, to take forward. We also wanted to work with local groups, as it is their knowledge, expertise and connections that open the door to developing collaborative relationships that inspire action.

When we 'tuned in' to our local area, as well as drawing on our own concerns, climate change was clearly the number one issue, with people finding the facts, figures and temperature graphs alarming, but with very little in the way of practical information about what they could do in response. We know our planet is in trouble, and the slow pace of reform is heart breaking to watch, but we can act locally to mitigate climate change impacts, and this is where we decided to focus RoC's efforts.

For us, going local meant being invited to work with local communities, and the Landcare network was a natural fit, with dedicated volunteers knowledgeable about their region and with a passion to get things done. Every RoC project works with a Landcare or equivalent volunteer group, to develop an idea, apply for funding and implement outcomes. This means that every investment made is on the basis of a negotiation with a local Landcare group about their priorities, and how RoC can help them to achieve their goals.

Angela Calliess' photo of the RoC team with landholder Margie Fitzpatrick (centre) at her property 'Australind'.

We also expanded our team to have local coordinators as our 'stars', people who live and work in the communities where RoC projects are underway. In addition, Greening Australia, as RoC's on-ground delivery partner, is well known and respected across our region, with low staff turnover and long-term and enduring local relationships.

Make it social

When we talk about making it social, we are referring to investing in and building 'social capital'. We often talk about 'natural capital' in the form of rivers, vegetation, soils etc but social capital is just as important. The idea of social capital grew out of the study of communities which showed that mutual reliance, an underlying sense of connectedness that builds trust, was what enabled communities to survive and flourish in times of stress. Social capital is the relationships, networks, interactions and people who make up the communities within which we work.

Using the work of Margaret Heffernan, RoC invests in social capital because it makes us more productive and creative. How? Because high levels of trust create a climate of safety and honesty, and this makes us more efficient, productive and able to help our communities. Why is being helpful important? Helpful teams of people accelerate the sharing of knowledge and expertise; we don't let one another stay stuck or confused, and we try to prevent problems before they arise. Her quote explains:

"Social capital compounds even as we spend it. And the longer groups work together— the more social capital they accrue— the more these benefits grow. Trust, helpfulness, practice and courage become the simple renewables that power our working lives." (Margaret Heffernan)

Social capital also transcends culture. The meaning of 'Ngunawal' is we, the people, or us. RoC works within Ngunawal, Ngambri, Wiradjuri and Pejar Aboriginal Land Council boundaries, and the depth of indigenous knowledge about the rivers we care about is essential to developing a holistic approach to restoring rivers. We endeavour to be inclusive and respectful of Aboriginal culture and knowledge in all that we do, as well as trying to weave traditional living knowledge into our RoC approach.

Keep it emotional

When it comes to the environment there is a lot of negativity and despair characterising public debate. Reflecting on this, it became clear that one of the reasons climate change is such a divisive issue and 'turn off' for people, is because of poor communication and scaremongering. With this in mind, the RoC team make a conscious effort not to use words like 'struggle', 'hard' and 'overwhelming' to describe river management. Instead, we offer people hope that they can make a difference, expertise that gives them confidence to act, and ongoing support.

The key word we use to describe what RoC is about is 'empower'—we empower people to act in response to climate change by restoring their streams to boost biodiversity, sequester carbon and promote wellbeing. Feeling empowered is wonderful, and it is the 'why' of our RoC work. The way we usually communicate is to talk about 'what we do' and 'how we do it', and this tends to be the facts, figures, techniques and practices. If you think about the many forms and reports you complete, it is these 'whats' and 'hows' that make up the bulk of our metrics about the work that we do. The thing about facts and figures, however, is that they are not what make people act—it is our emotions that govern our decisions, and emotion is what underpins our 'why'. Simon Sinek uses the Golden Circle to describe this approach and it permeates all that we do.

So what is the 'why' for RoC? The quote below describes the feelings that underpin our team, and this is how we introduce ourselves to the communities that we come to work with:

> **"Choosing to save a river is more often an act of passion than of careful calculation. You make the choice because the river has touched your life in an intimate and irreversible way, because you are unwilling to accept its loss." (David Bolling)**

Sharing these ideas

I am sharing these ideas with you because they come from my years working in river management, learning from others, reading, observing and giving things a go. Please take or leave the bits that relate to you, and which you feel you might be able to use in your work. I know for myself and my team that we believe our greatest achievement is when we inspire and support people to care for their rivers, and encourage them to pass their learnings on to others. We give people the hope that in the face of climate change they can do something to adapt to an uncertain future. If we manage our small streams well, then the big rivers they flow into are also healthier, more productive and wonderful places to be. Healthy rivers mean healthy communities, and for us, that is what Rivers of Carbon is all about.

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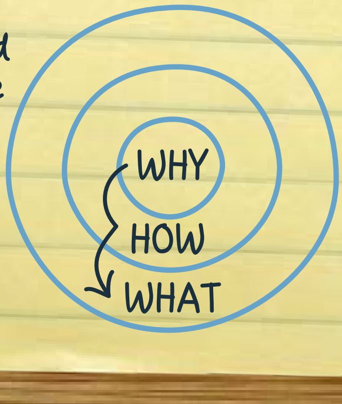
Act, think and communicate from the inside out!



Why—Your purpose.
Your motivation? What do you believe

How—Your process.
Specific actions to realise your 'why'

What—Your result.
What do you do? The result of 'why'. Proof

Waterbirds on the wing

HEATHER McGINNESS, **KATE BRANDIS**, **VERONICA DOERR**, **RICHARD KINGSFORD**, **RALPH MAC NALLY** AND **JOHN MARTIN** PROVIDE THE LOW DOWN ON TRACKING THE MOVEMENTS OF WATERBIRDS AND THEIR CHOICE OF HABITATS.

It's a subject that has mystified many Australians and resulted in heated debates—how is it that large numbers of waterbirds are able to turn up in the most remote and unexpected places after years of absence, thousands of kilometres from where they are usually seen? How do they get there, where are they coming from and what are they responding to from so far away? Where do they go to feed and shelter in the time between their irregular breeding events? Why do they select some places and not others?

Answers to these questions are critical for land and water managers, as well as the curious public. With waterbird populations in decline across the Murray–Darling Basin (MDB) and limited quantities of environmental water available to help address this decline, our efforts to improve and maintain waterbird habitats need to be guided by better knowledge of what waterbirds need, where and when. How can we be strategic with our limited resources to promote successful breeding, juvenile survival and healthy populations in both the short term and the long term?

Figuring this out in Australia can be tricky because many of our species are highly nomadic, and others are decidedly 'cryptic', meaning they are hard to find and study. These characteristics mean that even basic life history or demographic data for common waterbird species can be hard to measure (e.g. population sizes and extents, juvenile survival rates, adult survival rates and longevity).

However, technology is catching up to some Australian birds. Through work done by the Waterbird Theme of the MDB Environmental Water Knowledge and Research (MDB EWKR) project, we are starting to fill some of the knowledge gaps by tracking the movements of one waterbird species, the Straw-necked Ibis, by using satellite GPS transmitters.

The transmitters record hourly GPS location fixes between 7.00 am and 7.00 pm, as well as taking a midnight 'fix' to record roosting/nesting locations. The trackers have an accuracy of about 10 metres, are solar charged and expected to transmit for at least two years.

During spring and summer 2016–17, there were 20 ibises fitted with transmitters. Five adults and 10 juveniles were tracked from Barmah-Millewa forest in the southern MDB, and another five adults tracked from the Macquarie Marshes in the northern MDB. Another 20 or more ibises will be tracked from spring and summer in 2017–18.

Flying high

After just six months, the satellite tracking has already advanced our knowledge of previously poorly understood ibis movement and population patterns and trends.

Long-distance movements

Individual ibis have travelled long distances quickly. One adult female ('Gracy') was caught in the Macquarie Marshes in October 2016, and soon after travelled over 400 kilometres south to the Murrumbidgee River. In mid-November, she returned to the Macquarie River area before leaving in mid-January 2017 to travel north, reaching Townsville in early May, over 1200 kilometres from the Marshes.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

Far left: A Straw-necked Ibis. Spread: The satellite-tracking team in the Macquarie Marshes, October 2016. Below: An adult bird is released after having a satellite transmitter fitted. Photos throughout Heather McGinness.

Northern and southern ibises are mixing and using some of the same sites and routes, consequently Straw-necked Ibises in the MDB may be one interacting population. However, behaviour in the 2016–17 year may be unusual because of the extent and duration of flooding. This will need to be investigated with tracking in later years and with more birds.

Common 'flyways' or movement corridors for separate birds/groups

Six of the 10 adults and three of the juveniles travelled along a particular north-east to south-west route within the MDB, in different directions. This route corresponds to zones or boundary lines in maps of average climatic conditions, rainfall, topography, etc. For examples of climate zones, see the Bureau of Meteorology—http://www.bom.gov.au/climate/averages/maps.shtml

Foraging and stopover points and regions

The Lachlan River floodplain near Condobolin was an important area for foraging by many of the tracked ibises in the 2016–17 summer. Tracking identified the re-use of other sites by different birds at different times in both Victoria and New South Wales. Identifying these areas could be important for future bird management. We found that birds are foraging in a range of land uses, including agricultural and native habitats.

'Coupled' habitats for roosting and foraging—adults

Foraging habitats have remnant vegetation with large trees for roosting nearby. If these areas are preferred by the ibises, then the coupled habitats might be targeted for management.

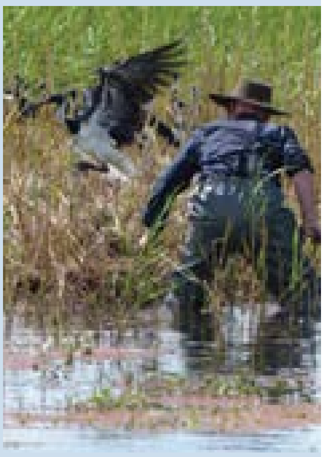
The Straw-necked Ibis (*Threskiornis spinicollis*) is a colonially breeding waterbird species, which means that it builds nests with other birds of the same or similar species in tight-knit groups. These colonies can number in the tens to hundreds of thousands of nests in wet years with widespread flooding. Colonially nesting waterbirds are the primary focus for study in the MDB EWKR project because:

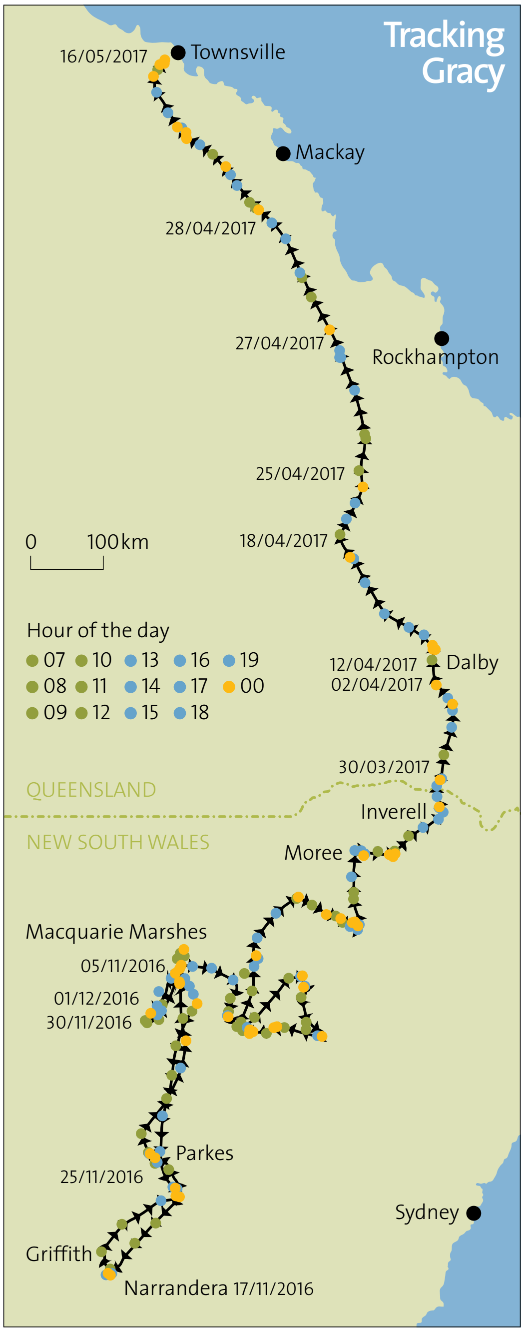
- They are one of the main waterbird indicators for environmental flows management and policy. There is good evidence this group of waterbirds provides a sound model for understanding relationships between environmental flows and waterbird recruitment.
- Response variables are more easily measured for these than for other species of waterbirds because their breeding events and nests are relatively easy to locate and survey. The sites of major colonies are known, as are some of the breeding thresholds related to flows and inundation.
- The effects of predation and other threats on these species are likely to be more easily measured because their nests, eggs and fledglings are fairly obvious.

The Straw-necked Ibis was chosen for satellite tracking because they are good representatives of the points noted above and are known to nest in large numbers in nearly all major MDB wetlands managed with environmental flows.

Straw-necked Ibises have spectacular rainbow-hued iridescent dark feathers on their wings and back, and distinctive straw-like feathers on their necks.

They are also known as the 'farmer's friend' because when on dry land they eat large quantities of pest insects such as locusts. When in wetlands, they eat frogs, aquatic insects, spiders, fish, molluscs and small reptiles. They are generally thought to be less adaptable and opportunistic than the Australian White Ibis and don't scavenge as much and tend to avoid saltwater areas. They are highly mobile and nomadic, and appear to have closer ties with inland floodplains and wetlands.





Above: Movements of 'Gracy', a female Straw-necked Ibis, from 17 November 2016 to 17 May 2017. Above left: Adult Straw-necked Ibis in the Macquarie Marshes breeding colony. Detailed maps of all tracked birds are on the project's website and Facebook page—https://www.facebook.com/ColonialWaterbirdScience/

'Coupled' night versus day habitats—juveniles at nesting sites

Juveniles roost in one part of the nesting colony but spend the day 'creching' together in another part of the colony up to 100 metres away.

Variation in propensity to travel or remain as residents

Some birds have remained in one general area or catchment for months, while others have travelled nearly continuously, with some moving more than 1000 kilometres. However, most birds 'settled down' for the winter, making only local movements during the colder months.

Movement associations with weather

Similarities in departure times and departure dates for long trips are probably associated with thermal upwellings, which is suggested by distances travelled per hour and by time of day. Weather changes may trigger long-distance movements, such as a drop in temperature with rainfall or a shift in wind direction.

High mortality rates—particularly for juveniles

There are multiple possible causes of death in colonially nesting waterbirds and their young, including predation (e.g. raptors, foxes, cats and dogs), disease (e.g. botulism, which was widespread in 2016–17), parasites, poisoning, starvation, entanglement in nesting material and heat exhaustion. Tracked ibises have died due to botulism (a soil-borne bacterium), predation and vehicle impacts. The initial cause of mortality often cannot be definitively ascertained, with scavenging of carcasses (and transmitters!) very common by birds and feral mammals. The extremely high temperatures recorded in the 2016–17 are likely to have had a negative impact on some birds. Juveniles are more susceptible than adults to these pressures, and so some losses from breeding events are not unexpected.

FOR FURTHER INFORMATION

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Data analyses to be conducted as part of the broader MDB EWKR project will explore these patterns and trends in more detail. Recommendations for land and water managers will be developed from the results, particularly focusing on the spatial and temporal locations, characteristics and requirements of foraging habitats and birds that may influence environmental watering, vegetation management or pest management decisions.

Feathering their nests

HEATHER McGINNESS, **KATE BRANDIS**, **VERONICA DOERR**, **RICHARD KINGSFORD**, **RALPH MAC NALLY** AND **JOHN MARTIN** ARE COLLECTING DATA TO PROVIDE MORE INFORMATION ON HOW THE SUCCESS OF WATERBIRDS BREEDING CAN BE IMPROVED IN THE MURRAY–DARLING BASIN.

Environmental watering events in the Murray–Darling Basin (MDB) target a range of environmental outcomes, including supporting the habitat and breeding of waterbirds. Through previous research and observation, we know where the key waterbird breeding locations are in the Basin, and the flows required to trigger and complete nesting events. However, there is limited information about the rates of 'nest success'—which is the number of eggs that hatch into chicks, and the number of chicks that survive to leave the nesting site and join the rest of the population.

As part of the MDB Environmental Water Knowledge and Research (MDB EWKR) project, we are investigating both rates and determinants of 'nest success', by examining the relative influence of flow, habitat and other pressures, as well as threats like predation, habitat changes and weather extremes arising from climate change. This knowledge will enable managers to focus limited resources on maximising nest success and the recruitment of young birds into the population.

Getting 'event ready'

We know from our discussions with water managers that they want to improve water provision, vegetation and feral animal management to ensure 'event readiness' at waterbird breeding sites. Maximising the recruitment of young birds into the adult population depends on having the largest possible number of chicks fledging from each site. Understanding and maintaining appropriate nesting site characteristics is crucial, so the questions our research is answering are:

1. How do nesting-habitat preferences differ among species, sites and events?
2. How do nesting-habitat characteristics influence the numbers of fledglings produced?
   - How much does predator access (nest position, water level) affect fledging rates?
   - How much does nesting habitat influence the exposure of chicks to extremes in temperature or weather?
3. Where do the first arrivals at a colony site decide to start nesting? Are there relationships between site vegetation and water characteristics and these choices? For example, how much does the ratio or distribution of water and vegetation affect the initial locations of nesting birds?
4. How can environmental flows be managed to support better nesting habitats?

Above: Cameras monitor the progress of Australian White Ibis nests.
Photos throughout courtesy of the authors.

Photos in film strip from left: [frame 2] Royal Spoonbills display and gift, [3] Royal Spoonbills display to one another, [4] Royal Spoonbill parents with eggs, [5] Australian White Ibis with egg, [6] Royal Spoonbills with chicks, [7] In a good year Royal Spoonbills can raise four chicks successfully, [11] Royal Spoonbill shades its chicks on a hot day. Photos from CSIRO monitoring cameras. Note: Film strip is for graphic purposes. Photos in egg shapes: Straw-necked Ibis chick and eggs (left), slightly older chick (right).

To answer these questions, we are working on:

- Measuring egg and chick development and survival rates using analysis of images from remote motion-sensing and time-lapse cameras.
- Monitoring predation (predator species, impacts, timing, and location) and waterbird behaviour using analysis of images from remote motion-sensing and time-lapse cameras focused on nests.
- Colony mapping, nest counts, and fortnightly monitoring of eggs and chicks at a subset of tagged nests.
- Surveys of nesting habitat characteristics (e.g. species, nest position, nest materials, water depth, vegetation type and distribution or density, nest density, location within colony, exposure).
- Analysis and modelling of relationships between flows (water-related variables), nesting habitat characteristics (particularly vegetation type and structure), predation, temperature and weather variables and nest success variables.

Straw-necked Ibis with chicks in the Macquarie Marshes.

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MDB EWKR Story Space — www.ewkr.com.au

Our discoveries

A pilot study was conducted in 2015–16 and analyses are underway for data collected in 2016–17, with a final year of data collection planned for 2017–18. The nests of three species are being monitored: Australian White Ibis (*Threskiornis molucca*), Straw-necked Ibis (*Threskiornis spinicollis*), and Royal Spoonbill (*Platalea regia*). So far we have found that:

- Australian White Ibises start new nests throughout the breeding season (spring–summer). Straw-necked Ibises start nesting later than white ibises and tend to be more concentrated spatially and temporally. Royal Spoonbills spend time courting, establishing territory and trampling rushes for several weeks before starting to lay. Consequently spoonbills may appear to be nesting when observed from the air, but may not in fact have nests, eggs or chicks. Young spoonbills are generally present in nests much later than ibis chicks. It is easy to confuse Royal Spoonbills with Australian White Ibis when viewed from the air because both are white.
- Clutch sizes differ among waterbird species and among years, with Royal Spoonbills in 2016–17 generally laying more eggs (two to four; mean 3.7) than Australian White Ibises (one to four; mean 2.9) and Straw-necked Ibises (two to three; mean 2.4). Abnormally large clutches of five or six eggs are sometimes seen.

- Hatching rates are quite low (30–60 per cent). Royal Spoonbill eggs are more likely to survive to hatching than Straw-necked Ibis eggs, while Australian White Ibis eggs are the least likely to survive to hatching.
- Most egg mortality is from predation, with some from parental rejection or abandonment of nests.
- Most predation events in Barmah-Millewa forest are in daylight by native bird species, including Purple Swamp Hens (*Porphyrio porphyrio*), Swamp Harriers (*Circus approximans*), Australian Ravens (*Corvus coronoides*) and White-bellied Sea-Eagles (*Haliaeetus leucogaster*). Anecdotally, predation by feral animals such as pigs, foxes and cats is more of a problem in other breeding sites like the Macquarie Marshes. Most predation events occur in limited areas of the colony, while other areas are not affected much. Entire clumps of nests are typically affected within short periods (minutes to days).
- Once hatched, chick survival (fledging) rates are generally high and similar among the three species (88–92 per cent).
- Nest-attendance patterns differ significantly between species and years. Royal Spoonbills are the most attentive to their nests, which may explain the relatively low mortality rates for their eggs and chicks. Australian White Ibises are the least attentive, and the most erratic in their nest-attendance patterns. Differences in attendance between years may reflect food availability.
- Nesting-habitat choices differ within and among sites. In Barmah-Millewa forest and parts of the Macquarie Marshes, both ibis species appear to prefer tall common reed (*Phragmites australis*) with 'water views' in the centre of regularly-inundated wetlands. Straw-necked Ibises in Barmah-Millewa forest also nest in large numbers in giant rush (*Juncus ingens*) surrounded by water. Royal Spoonbills appear to prefer giant rush surrounded by water at Barmah-Millewa, but nest in trees in other sites. Lignum is important in other systems such as Narran Lakes, the lower Murrumbidgee and lower Lachlan rivers. Although Royal Spoonbills congregate, they do not nest in as close proximity to one another like the ibises do, maintaining at least a couple of metres between nests.

Data analyses to be conducted as part of the broader MDB EWKR project will explore these results in more detail with recommendations for land and water managers during the next stage of this project.

Straw-necked Ibis attending to a nest in the Macquarie Marshes.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

Science meets management

JOHN KOEHN, **STEPHEN BALCOMBE** AND **BRENTON ZAMPATTI** OUTLINE THE BENEFITS OF USING A COLLABORATIVE APPROACH TO PRIORITISING RESEARCH.

PHOTO THIS PAGE: FISHING ON THE MURRAY, BEN GAWNE. OPPOSITE PAGE: MURRAY COD, JAROD LYON.

Using the 'best available science' for natural resource management is a phrase that easily rolls off the tongue and is readily supported, however, it does not always occur, and there can be a disconnect between the information user (the manager) and new knowledge from ecological research.

So, how do we address this? Well, how about asking managers what information they need in order to feel confident about making environmental flow decisions?

That is exactly what we did as part of our Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project to identify research that will be relevant to water managers. We used a questionnaire to find out manager's information needs, and convened a collaborative workshop involving 30 MDB water and fish managers together with ecologists to discuss what was needed. The outcomes from the workshop were then combined with a synthesis of contemporary ecological knowledge to identify gaps in understanding. This resulted in a set of flow-related fish ecology research priorities for the MDB.

Did the managers know what information they needed to enhance fish outcomes? YES—definitely!

The objective for managers can be defined simply as 'improvements to native fish populations', which means more adult fish. In particular, the managers we surveyed were interested in large-bodied fishes, especially angling species like Murray Cod, as well as species of conservation concern, like the Southern Purple-spotted Gudgeon. They wanted information to guide and support their environmental watering actions, and to share this applied knowledge with stakeholders (e.g. anglers, irrigators, environmental groups) to build an understanding of the benefits of environmental water.

A change in focus

There was also a desire by managers for the time frames and spatial scales of research to change. Originally, environmental water management in the MDB was largely local focused on short-term goals at small spatial scales, but we have now progressed to larger spatial and temporal scales that may include fish population connectivity across multiple catchments. We are now considering fish population dynamics, rather than specific life history stages (e.g. eggs and, larvae) in isolation; with the aim to promote recruitment to adult stages and grow fish populations.

The transferability of knowledge to other catchments, especially from the southern to northern Basin, where there has been less research focus, was also highlighted as being extremely important for managers wishing to learn from the environmental watering experiences of others.

PRIORITIES

PRIORITIES FOR MANAGERS AND ECOLOGISTS ARISING FROM THE KNOWLEDGE REVIEW AND WORKSHOP

Manager's priority knowledge needs

1. Population dynamics of all life stages
2. Successful recruitment from larvae to adults
3. Movement, dispersal and connectivity and their relevance to population processes
4. Mechanisms/causal links and thresholds (scale of variability; what are the drivers for survival and recruitment)

Manager's priority species

- Large-bodied native fishes (priority order): Murray Cod, Golden Perch, Trout Cod, Silver Perch, Macquarie Perch, Freshwater Catfish
- Small-bodied natives (priority order): Southern Pygmy Perch, Southern Purple-spotted Gudgeon, Olive Perchlet, Murray Hardyhead, Yarra Pygmy Perch
- Carp (understanding how to limit their spread)

Priority ecological knowledge gaps

- Population dynamics (of all life stages)
- Spatial and temporal scales and population processes
- Rates of survival and growth
- Drivers of successful recruitment

State of knowledge

In addition to the priorities identified by the managers, we undertook a synthesis of the current state of knowledge of the flow-related ecology of fishes in the MDB from the literature. While our knowledge has grown rapidly over the past decade, there are still many gaps. Most of our knowledge is for larger-bodied species, in relation to both life stages and recruitment, especially Black Bream, Golden Perch and Murray Cod. More needs to be known about Freshwater Catfish and Silver Perch, and we have much to learn about small-bodied species, particularly those of conservation concern like Southern Pygmy Perch. There remains limited knowledge of relative rates of survival and growth between life stages and how these are influenced by flow. For example, understanding the survival and development of the flow-responsive species Golden and Silver Perch from larvae to adults are key priorities for research.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

Research built on relationships

While we found there was general agreement between ecologists and managers on what research is needed, we learnt that managers also have clear views on the types of relationships they want with researchers. Managers want collaborative relationships with their scientific counterparts that allow them to learn about the latest results and to discuss knowledge needs and likely outcomes of their actions. They wanted researchers to be adventurous and learn from the many flow 'experiments' that the managers conduct.

Closer relationships build trust and allow both sides to develop a common understanding and language. Presentations at the end of a research project may not be enough. Such conversations need to be on-going and include discussions around other issues such as trade-offs, or ecosystem constraints to achieving objectives. Such two-way learning will greatly support flow management outcomes for fish across the MDB.

> We found working with managers and scientists on this project to be both insightful and rewarding, and are now keen to act on the recommendations outlined in this article.

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Conversations that count

BEN GAWNE DISCUSSES THE VALUE OF RELATIONSHIPS FOR THE SUCCESSFUL ADOPTION OF SCIENCE INTO PRACTICE.

Scientist and communicator Peter Cullen, described the boundary between research and management as 'turbulent'. This turbulence arises from differences in cultures and expectations between managers and researchers that create both positive and negative tensions. There are also challenges in synchronising research outputs with manager's needs, as the two realms move at different speeds, with managers having to deal with situations that arise over days and weeks, while developing new knowledge may take years. There are also challenges in applying new knowledge across different locations because of natural variability, and the uncertainty associated with applying knowledge to different systems.

These challenges present fertile ground for the Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project as it strives to ensure the research it undertakes is relevant to managers. To understand how best to do this, the MDB EWKR team asked managers how they access information to support their decisions, and where they feel effort needs to be made to improve the science to practice link.

What became clear as a result of these discussions, is that while similar environmental water planning decision-making processes are used across all jurisdictions, information is accessed from multiple technical, corporate, and local sources, with no single source to which all managers turn to for advice. Personal contacts and networks are extremely important and, unsurprisingly, favoured over Decision Support Tools (for example, flow response models) that are rarely used due to the complexity of issues being addressed, and the uncertainty associated with applying the same model to different situations.

For MDB EWKR, these findings have resulted in the project using a variety of techniques to maintain engagement and collaboration over the longer term. Within the context of an ever-evolving Basin Plan, MDB EWKR is now using a series of filters developed with managers that, when applied to new knowledge, ensures it can be used.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

The filters are:

1. **Accessibility**: If managers can't access the information it can't be used.
2. **Relevant**: The information must be relevant to the decision the environmental water manager needs to make.
3. **Applicable**: In many instances, the information will need to be adapted to the specific situation or integrated with other information in order to inform a decision.
4. **Feasible**: Applying the information must yield a feasible solution, that is, one that can be achieved without unacceptable risks.
5. **Credible**: The information needs to be trusted and conform with the managers' existing understanding of the system.

The filters enable the MDB EWKR team to interrogate the relevance of their research before recommending it be applied. They also provide excellent 'jumping off' points for conversations with managers and their networks.

Valuing conversations

Many managers said that one of the main ways they access information is through conversations with trusted experts. The relationships between managers and experts are more likely to develop with experts who make themselves available (Filter 1) and if the information they provide leads to success, then trust develops (Filter 5). The other major advantage is that the conversation gives the manager an opportunity to ensure the information is relevant (Filter 2), and provides a process whereby it can be applied (Filter 3) in a way that leads to a feasible solution (Filter 4). This approach is much more likely to yield positive outcomes than the manager sourcing answers from the internet or scientific literature that has little connection to 'real-life' environmental water challenges.

Understanding the opportunities and challenges presented by on-ground environmental water delivery and how new knowledge can assist in this process, is the subject of conversations across the MDB. Building relationships of trust within which these conversations can occur, and creating new scientist and manager networks is a priority for MDB EWKR, along with sharing new knowledge in multiple ways.

Over the next few months a new online MDB EWKR Story Space, social media, workshops, and this edition of *RipRap*, will enable anyone with an interest in environmental water to access our work. While these communication outputs are important, our main focus will remain on building trusted relationships and networks between scientists and managers, as it is these relationships that underpin the successful management and delivery of environmental water.

NANKEEN NIGHT-HERON, PHOTO ED DUNENS.

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Grow with the flow

CHERIE CAMPBELL ASKS WHAT OUTCOMES ARE WE SEEKING FOR WETLAND VEGETATION AND WHY?

Wetland and floodplain plants are critical components of both aquatic and terrestrial ecosystems, supplying energy to support food webs, providing habitat and dispersal corridors for animals and birds, and contributing to other ecosystem services such as nutrient and carbon cycling, water and sediment oxygenation. They are also beautiful parts of our river landscapes with aesthetic, cultural and recreational values, as well as intrinsic biodiversity value.

What, however, do you picture when you think of a wetland or floodplain plant? Is it a majestic 600 year old tree, a pond full of swamp lilies, tall reeds and grasses in which waterbirds build their nests, or is it a mass of green herbs that covers the floodplain after waters recedes?

The diversity of plants in Murray–Darling Basin wetlands and floodplains is tremendous, with more than 800 species. These take a myriad of structural forms, from floating ferns, to ancient trees, and provide a range of functions. Vegetation outcomes from environmental flow management may seek to achieve multiple objectives relating to composition, structure, and/or ecological processes that support other biota. These objectives are also scale dependent; with wider landscape objectives providing context for smaller site-scale objectives that will vary from location to location. For example, to improve adult tree condition in some areas, to recruit juvenile trees, or to control seedling recruitment in other parts of the floodplain. Clarifying multiple objectives allows managers to better define water requirements, monitor outcomes and communicate decisions and outcomes to stakeholders.

The Vegetation Theme of the Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project aims to provide a framework to assist in clarifying objectives, by considering the functions and services provided by different vegetation responses and the influence of flow across temporal scales. In addition, we want this framework to consider the context in which environmental watering decisions are made, in terms of water availability, delivery constraints and the influence of complementary management. The framework we are using has three main components.

A carpet of Red Water-milfoil (*Myriophyllum verrucosum*) as Lake Boich draws down, Hattah Lakes, 2015. Photo Fiona Freestone.
Below: A diverse aquatic wetland community following environmental watering, Scottie's Billabong, Lindsay Island, 2009. Photo Cherie Campbell.

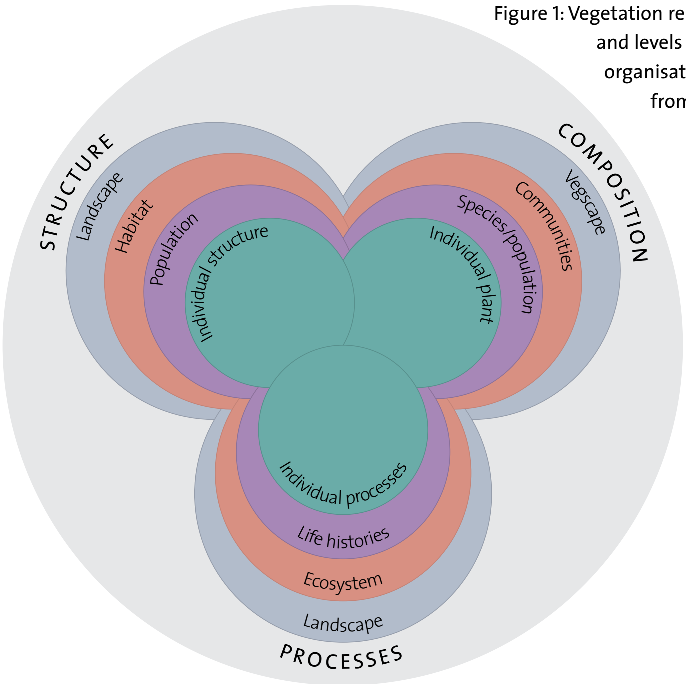


Figure 1: Vegetation response traits and levels of ecological organisation (adapted from Noss 1990).

Component 1: Response traits and levels of ecological organisation

There are three broad categories of vegetation response that may be included in managers' objectives; these are composition, structure and process. These responses may occur at different levels of ecological organisation, ranging from landscape to individual plant responses (Figure 1). For example, objectives may be focused on:

- promoting high species diversity (composition and communities)
- maintaining large, hollow-bearing River Red Gum trees (structure and population)
- increasing the abundance of Moira Grass (composition and species)
- stimulating germination of Black Box trees (processes and life histories) to improve age-class structure at a site (structure and population)
- maintaining a spatial array of reed beds, open water, and woodland communities (composition and vegscape)
- increasing the abundance and complexity of structural wetland plants (e.g. submerged, floating leaves, emergent sedges) (structure and habitat).

Habitat	Regulating	Production	Information
Refuge	Climate regulation	Food	Aesthetic
Nursery	Disturbance protection	Raw materials	Recreational
Corridor	Water regulation	Genetic resources	Cultural
Structural	Nutrient regulation	Ornamental	Educational

Figure 2 (above). Structural grouping of potential functions and services provided by vegetation (adapted from de Groot et al. 2002 and Capon et al. 2013).
Figure 3 (right). Nested flow regimes influencing vegetation responses.

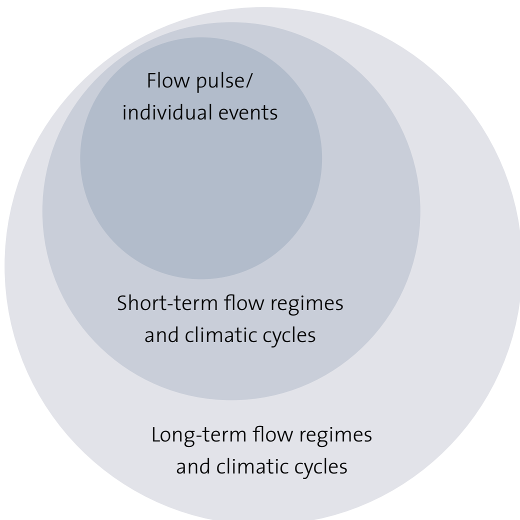
Component 2: Functions and services

Functions and services provided by vegetation can be grouped into four different types; habitat, regulating, production and information (Figure 2). For example, vegetation can provide nursery habitat for fish, corridor habitat for the movement of birds, or structural habitat for frogs. This model provides us with the scope to incorporate both ecological functions and services, as well as economic and social functions and services, such as food sources (e.g. honey production from River Red Gums), recreational values (e.g. improving submerged habitat at important fishing locations) and cultural values (e.g. health of scar trees or maintenance of totem species).

Component 3: Nested flow regimes

Vegetation responses to flows also occur at a variety of temporal scales that can be summarised into three broad flow regimes (Figure 3).

1. **Long-term** (decadal) cycles of wet and dry periods. At this scale, flow influences landscape patterns of vegetation such as the types, distributions and relative abundance of different vegetation communities. The key flow characteristics at this scale are:
   - average inundation frequency and patterns of frequency
   - average and maximum period without inundation
   - wet sequence duration (number of sequential years in which inundation occurs)
   - average and maximum inundation depth and duration
   - magnitude and connectivity of inundation
   - patterns of inundation seasonality.



River Red Gum (*Eucalyptus camaldulensis*) trees at Hattah Lakes following flooding in 2010/11. Photo Caitlin Johns.

ALLELOPATHY is a biological phenomenon by which an organism produces one or more biochemicals that influence the germination, growth, survival and reproduction of other organisms.

2. **Short-term** (1–10 years) flow regimes. At this scale, flow influences the composition of ecosystems and condition of populations within those systems. The important flow characteristics at this scale are similar to those for long-term flow regimes, however, the vegetation responses are smaller scale in recognition of the longer time frames over which landscape vegetation patterns change. The key flow characteristics at this scale are:
   - inundation frequency and patterns of frequency
   - maximum period without inundation
   - time-since-last inundation
   - wet sequence duration (number of sequential years in which inundation occurs)
   - average and maximum inundation depth and duration
   - magnitude and connectivity of inundation
   - patterns of inundation seasonality.

   Both long-term and short-term flow regime characteristics interact with land form and climate variables including average, maximum and minimum rainfall and temperatures to determine vegetation composition, structure and processes.

   There is also an important interaction between these two flow regimes in that the establishment of long-lived vegetation will have an influence on the understory that develops at the site. This is likely to be due to a variety of factors including the changes in the micro-climate under the canopy (e.g. light, temperature), changes in soil properties, competition for nutrients, water and allelopathic interactions.
3. **Flow pulses/individual events**. At this scale key flow characteristics influence individual plant responses which may include growth, reproduction, germination, dispersal, quiescence or death. The important flow characteristics include:
   - depth
   - duration
   - rate of recession
   - seasonal timing
   - magnitude and connectivity of inundation
   - velocity
   - turbidity/euphotic depth.

This framework will help land and water managers to develop specific objectives for different types of vegetation responses across a range of spatial and temporal scales, and for a variety of functional outcomes. The framework and related information will be published on the MDB EWKR website over the coming year.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

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Giving woody seedlings a fighting start

CHERIE CAMPBELL BEGINS WITH ROOTS AND ALL ADVICE ON GETTING THE BEST OUT OF THESE YOUNGSTERS.

Just like all of us, long-lived woody plant species need a healthy start to life to give them the best chance of growing big and strong. Providing woody seedlings with optimal conditions for growth and survival helps to ensure their success later in life.

The Vegetation Theme of the Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project are seeking to determine which watering regimes give woody seedlings a fighting start. This research will focus on four long-lived woody plant species common to the Murray–Darling Basin: River Red Gum (*Eucalyptus camaldulensis*), Coolabah (*Eucalyptus coolabah*), Black Box (*Eucalyptus largiflorens*) and Tangled Lignum (*Duma florulenta*). All of these plant species are structurally dominant on various parts of the floodplain throughout the Basin. They play an important role in providing refuge, habitat and food sources for a wide range of species, and contribute to ecosystem services such as carbon and nutrient cycling. The importance of these species is recognised by their inclusion in the Murray–Darling Basin Authority's Basin-Wide Environmental Watering Strategy.

Seedlings represent the next generation for woody trees and shrubs, so their periodic germination and survival into adulthood is essential to ensuring the long-term survival of these populations and ecosystems. Seedling germination and survival has been observed to be highly variable across the Basin, with seedlings being scarce in some areas and abundant in others. Land and water managers are keen to foster the growth and survival of woody seedlings which will grow up to form the next generation of forests and woodlands.

A cross section of the PVC pipes showing seedling growth. Inset: Measuring and recording root and growth development. Both photos Ben Gawne.

Getting the best start

In order to give woody seedlings the best start in life we are investigating the watering regimes that provide the best conditions for growth of roots, stems and leaves. Roots provide woody seedlings with access to water and nutrients, as well as anchoring the plant to the soil. Leaves are the energy powerhouse, providing the plant with access to food. Opportunities that result in greater root growth—longer and bigger roots—are likely to provide the plant with greater access to water and nutrients, increasing their capacity to survive dry periods. Similarly, healthy seedlings are likely to be taller and bigger with lots of leaf area, giving them the opportunity to produce more energy.

In order to determine optimal watering regimes for seedlings, we set up experiments at Wonga Wetlands in Albury, New South Wales. Seedlings from River Red Gum, Black Box, Coolabah and Tangled Lignum were germinated in pots, then transferred to PVC tubes and placed in tanks with different watering treatments applied. The treatments included five contrasting flow regimes:

1. constant dry
2. constant flood
3. flood then dry
4. dry then flood
5. alternating flood and dry periods.

These flow regimes focus on the effect of permanent inundation or drying, inundation during both early and later seedling life stages, and multiple wetting and drying periods during seedling establishment.

Measuring and analysis

In total, approximately 350 seedlings were assessed as part of this experiment. Measurements of mortality, seedling height, number, and area of leaves and root length were collected from harvests undertaken at the start of the experiment, in the middle and at the end. We also calculated above and below ground biomass. Comparing the results between harvest times will enable growth rates and the effect of water regimes to be determined over time.

Analysis of data collected during this experiment will show the relationship between flow parameters such as duration, frequency and interflow dry period and woody seedling growth and establishment. We will then work with water managers to ensure the information on seedling water requirements will help them to make decisions that provide woody seedlings with the best possible start to life.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

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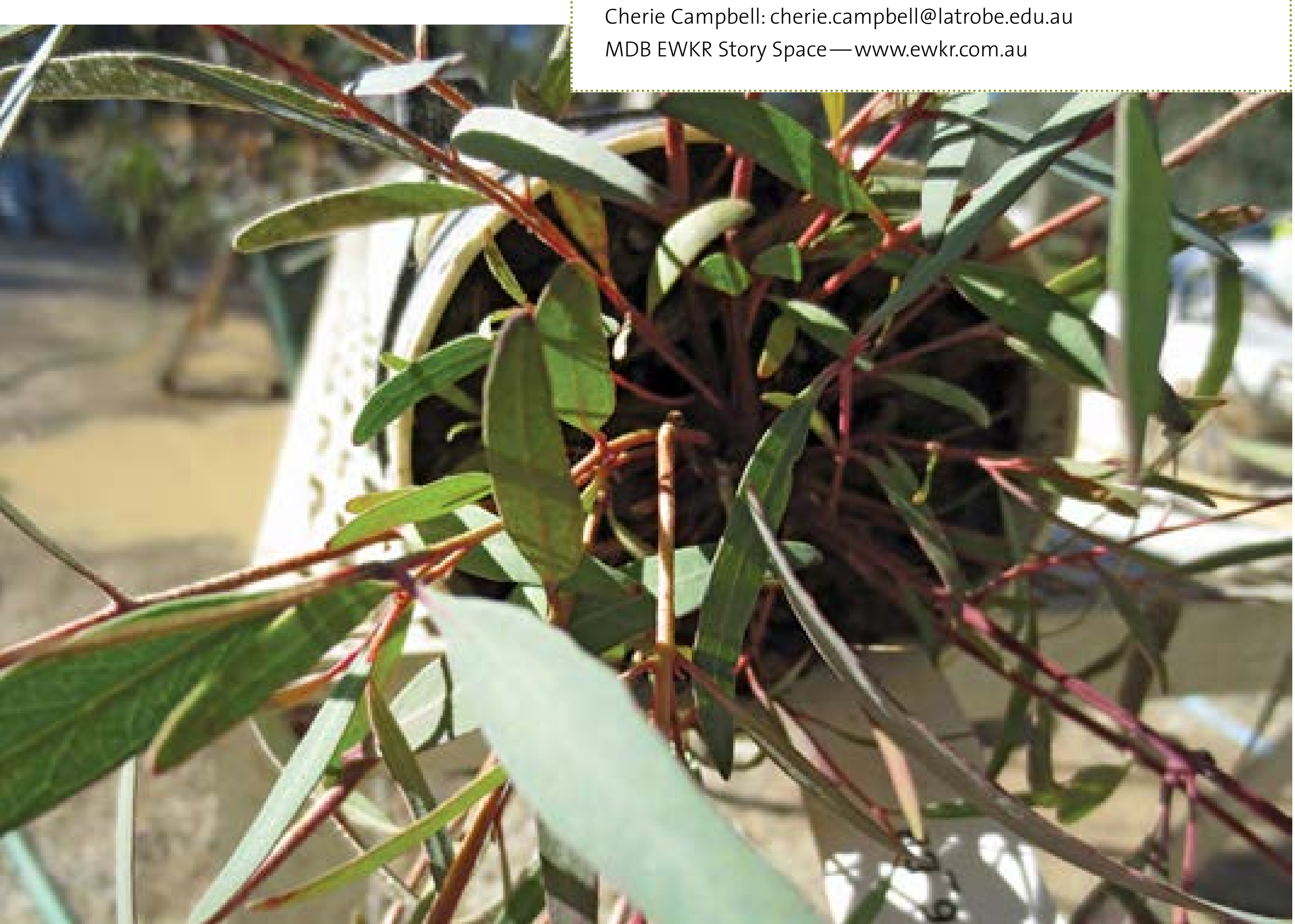
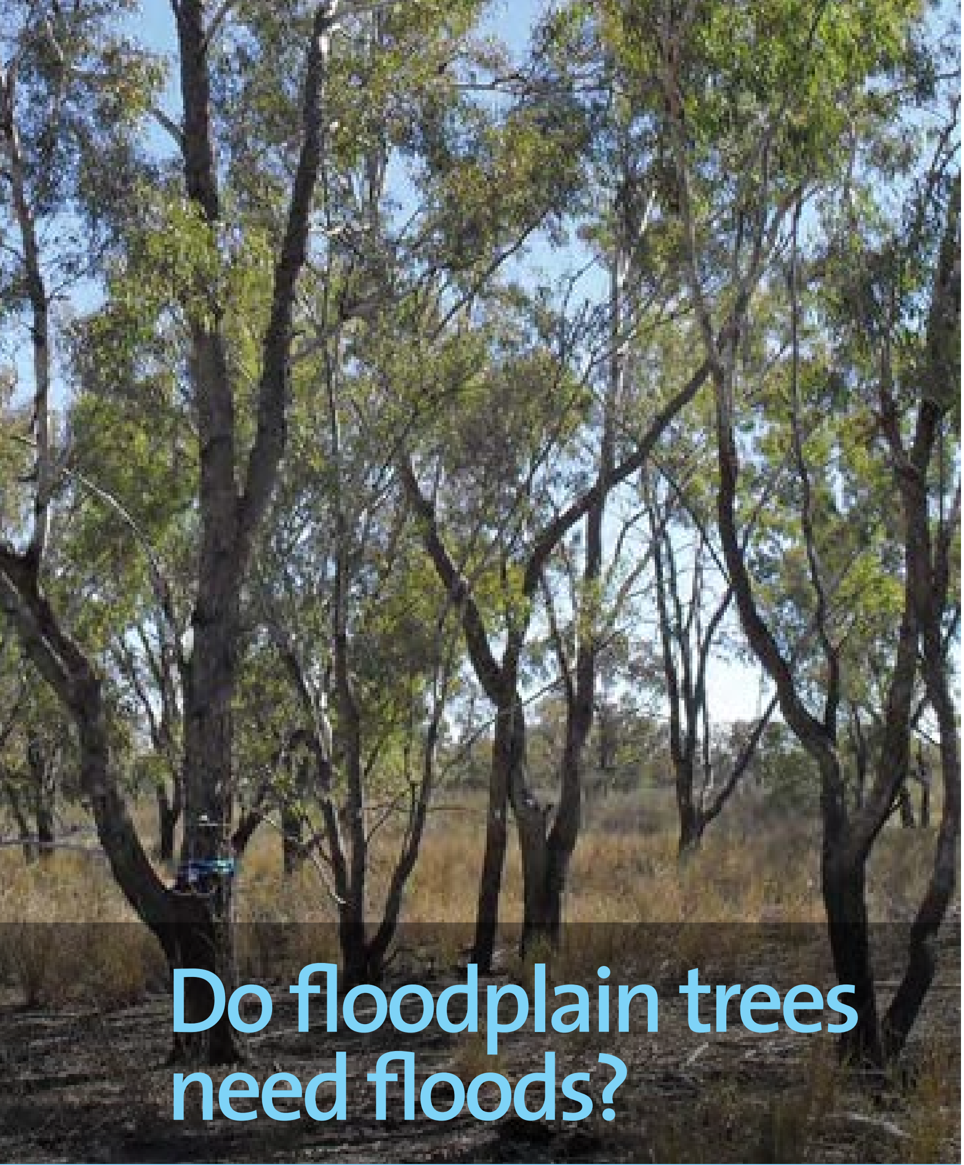
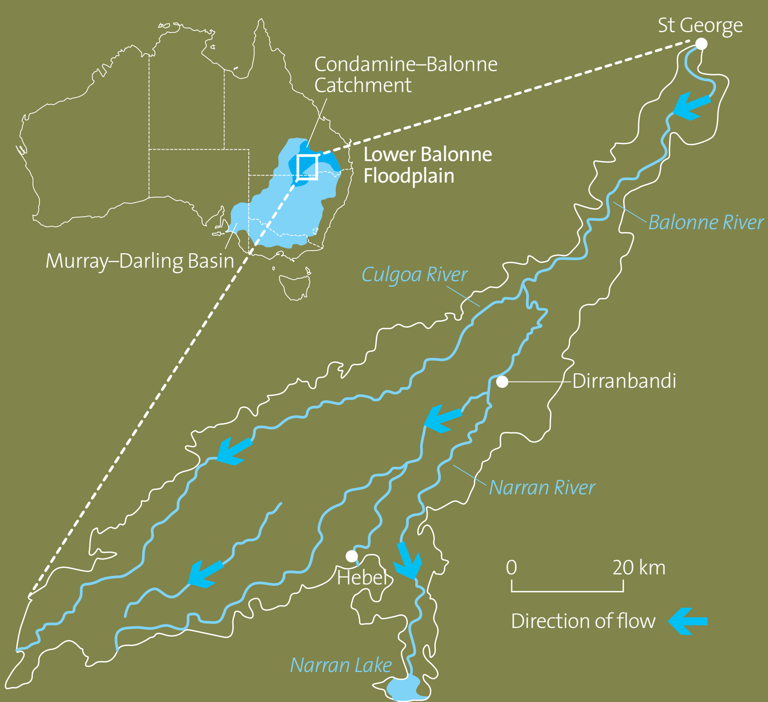
Below: Extensive coppicing of a Black Box seedling. Photo Cherie Campbell.





Do floodplain trees need floods?

BILL SENIOR EXPLAINS HOW TREES ON FLOODPLAINS ARE ALSO GETTING THE WATER THEY NEED TO SURVIVE FROM SOURCES OTHER THAN FLOODS AND THEY'RE NOT FUSSY ABOUT IT.



Every day, water managers throughout the Murray–Darling Basin (MDB) are faced with the difficult task of balancing precious water resources between the competing interests of agriculture, towns, and the environment. The 'environment' is a hard thing to pin down. It contains a myriad of components, of which extensive floodplain habitats, and the iconic tree species they support, are a significant and valued part.

Generally speaking, we try to preserve the things we value, and to do this we need to know how much water trees need to sustain themselves. Trees **need** water—it's a truism, but exactly where do they get it from? They use their roots to get it from the soil, I hear you say, but where exactly does the water in soil come from? The further you dig (literally!), the more complex and difficult the questions can become.

In the past, for broad-scale water planning purposes, there has been an assumption that watering requirements of floodplain trees were mainly met by inundation from flood events (e.g. species *X* must be inundated at least once every *Y* years for at least *Z* days/weeks). Such practical assumptions have been important in modelling studies. More local real-time decisions about water management can take account of local conditions including the age of trees, water quality, and water movement in the region.

Previous work by my colleagues who specialise in environmental risk assessments, particularly for water resource planning, have suggested that some of the floodplain trees in the Queensland portion of the northern MDB had experienced periods without flooding much longer than their published tolerance thresholds, and yet they still survive. Here was good evidence to suggest trees may be using other water sources. Shallow groundwater, in particular, was thought to be supporting the good condition of some trees in this region, but again, to what extent?

PHOTO COURTESY OF THE AUTHOR.

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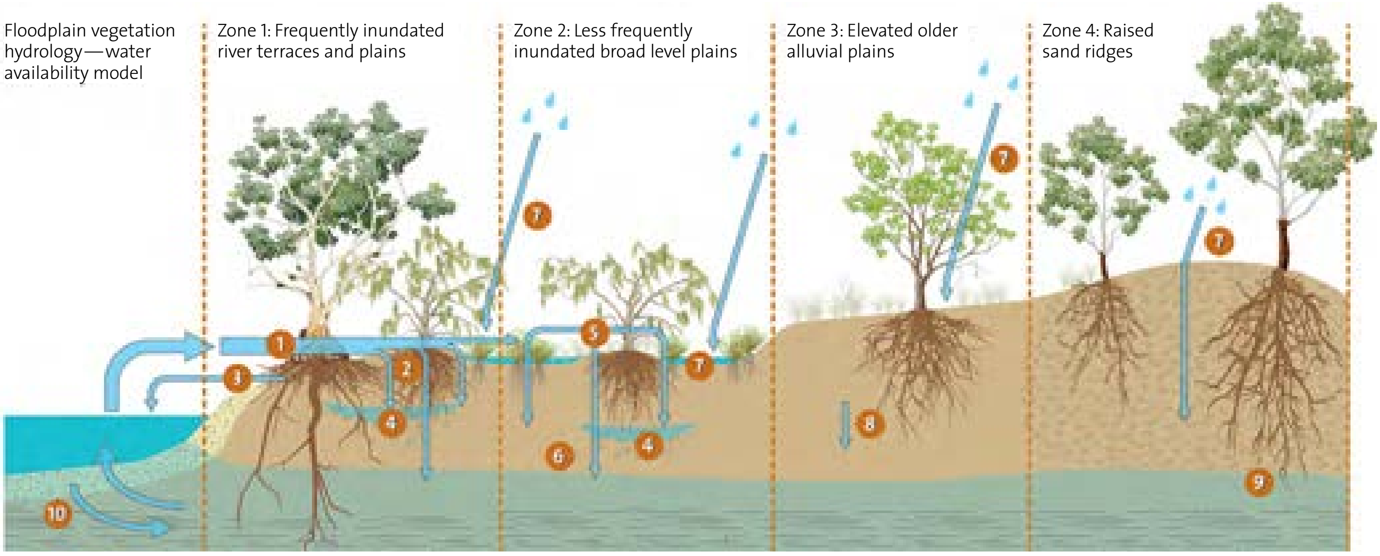


The numbered pathways on the diagram have focused the project's research questions to assess the different water pathways. With the knowledge gained so far, we have refined and updated the model throughout the project.

Answering those questions

All these questions (and more!) have formed the basis for this MDB Environmental Water Knowledge and Research study. For the last two and half years, a team of multi-disciplinary scientists from the Queensland Government have been investigating four key vegetation species, Coolabah, River Red Gum, Black Box and Lignum, in an attempt to understand the different water sources they use and amount of water they require to maintain their condition. We have been studying floodplain tree water use in the Lower Balonne floodplain, an area spanning the Queensland/New South Wales border within the northern part of the MDB. Our primary focus has been on Coolabah (*Eucalyptus coolabah*), as this tree species is the least researched, yet the most common large eucalypt species across the study area.

We have been investigating vegetation water use at two distinct spatial scales:

1. tree/site-based
2. vegetation patch/landscape-based.

At the small scale, we have collected a large amount of biological and physical data on specific water use by trees and undertaken a detailed characterisation of the underlying soils and hydrogeology.

At the larger scale, we have used a remote-sensing approach to assess vegetation condition across the region using a time-series of LANDSAT satellite imagery from 1988 to 2016. This information has been used to develop a conceptual model to help communicate our understanding, and piece together the story of what water is available to vegetation and how it's all connected.

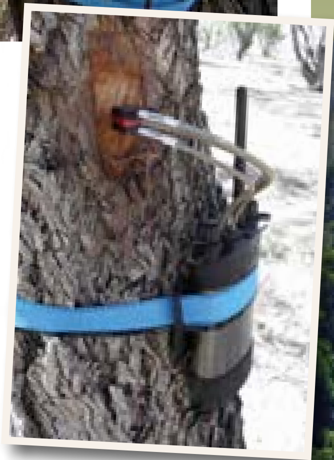
What have we found?

We are still bringing together all the results for this study, but some interesting findings are emerging that potentially challenge some of our conventional thinking.

The concept that a single inundation threshold can define the water requirement for a floodplain tree species has been confirmed to be simplistic. Continuing to gather data on floodplain tree species, and their health under different conditions, will continue to improve water management through thorough research such as this. We have good evidence from direct observation at the site scale and from remote sensing analysis that trees are using groundwater in certain locations. When we analyse the greenest trees during dry periods (those that are maintaining good condition despite a lack of rain or floods), it appears that there are many locations where trees look likely to be accessing groundwater. This can be seen by looking at the distribution of the greenest areas compared to mapped vegetation patches which are dominated by the individual species we are studying.

In other parts of the floodplain, where accessible groundwater may not exist, our results suggest the variation in condition of Coolabah trees is actually better explained by climate (rainfall and evaporation metrics) than it is by the occurrence of floods, at least over the last 30 years (the period for which we have satellite imagery).

The evidence is beginning to stack up. Some of these trees may not be as flood dependent as we thought.



Dr Andrew Biggs installing sap flow meter (see inset) into a Coolabah tree. Both photos Bill Senior.

Implications for managers

One thing we are sure of is that the story is complicated. As was said at the beginning of this article; trees **need** water—but ultimately they are not fussy where they get it from. The water sources trees use are dependent on many things such as their position in the landscape, whether it floods (or not), the soil they are sitting in, whether they are above accessible groundwater, whether that groundwater itself may be recharged by floods, and how often it rains on them (or not). Which means that in many (if not most) cases the sources of water that floodplain trees use will be specific to a particular location. While this makes it difficult to generalise, is it is hoped that findings from this project will have practical implications for water managers by highlighting the potential contribution of other water sources (particularly shallow groundwater) in maintaining the condition of trees on parts of the floodplain.

Our study started with many questions and it is almost certain that other, albeit potentially different questions, will remain at the end. It will contribute to the overall body of knowledge on vegetation water use, particularly in the northern MBD, where region-specific knowledge on floodplain vegetation has traditionally been thin on the ground. Ultimately it will hopefully lead to increased confidence in managing water resources for the benefit of all users in the region.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

Exploring links in the food chain

BEN GAWNE UNLOCKS SOME KEY INFORMATION ON THE EFFECTS OF FLOW ON NATIVE FISH AND WATERBIRDS.

The Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project is investigating how environmental flows may be used to ensure there is enough food to support the recruitment of native fish and waterbirds. Recruitment, which is the survival of offspring to adulthood, is believed to be sensitive to changes in flow, and declining populations of native fish and waterbirds have been linked to the effects of human flow modification.

The influence of flow on food resources is just one of a number of direct and indirect pathways by which flow may influence recruitment. There is, however, little known about how flow influences the amount, type and quality of food available to support recruitment. One of the reasons for this is that flow can influence food availability in a variety of ways, each of which has implications for environmental water managers.

Flow modification may influences both the transport of matter downstream and the import of material from riparian vegetation. Photo Haydn Burgess.

Influence 1: Overall productivity

For our food web research, 'overall productivity' is considered to be the amount of organic material generated by an ecosystem which is then converted into food for fish and waterbirds. There is now strong evidence that flow has a major influence on a river's overall productivity. Flow timing is important because changing temperatures and day lengths across the seasons influence the productivity of plants including algae and macrophytes. For example, a summer flow will be associated with a more rapid and greater response than flows in autumn or winter.

Influence 2: Nutritional value of basal resources

Nutritional value refers to the composition of organic matter, with variations in protein, amino and fatty acid composition contributing to nutrient content and affecting animals consuming the material. Flow is known to influence the types of primary production that occur (i.e. species of trees, macrophytes or algae), and this in turn, has an influence on the nutritional value of the organic matter produced. The nutritional value of the organic matter can significantly affect the growth rates and condition of consumers and their predators. One example is the effect of low flows in the Murray River and Murrumbidgee River which are associated with blooms of blue-green algae. Blue-green algae lack essential fatty acids and are a poor quality food resource. This nutritional deficiency then moves up the food chain affecting the health of fish, other aquatic organisms and predatory birds.

Influence 3: Critical connections that support transport of basal resources or food

Flow regulation has affected patterns of connectivity in freshwater systems through changes in flow regimes (e.g. reduced flooding, reduced short-term variation) and the installation of infrastructure like dams and levees. Protecting and restoring connectivity can influence waterbirds and fish by modifying food webs and facilitating the exchange of material between different parts of the river system like wetlands and floodplains.

One example is lateral connectivity (flows going overbank out onto floodplains) created during floods that promote the exchange of material between the river and the floodplain. This movement of organic matter make up a significant proportion of the total organic matter available to the system over the course of a year. Flows that restore lateral connectivity have the capacity to improve the amount and type of organic matter available to river channels in regulated systems.

Influence 4: Availability of critical foraging habitats

In addition to the amount and type of organic matter produced by an ecosystem, flow may also affect the availability of food. Colonial nesting waterbirds rely on floodplain inundation to support recruitment and provide food. Within the inundated area it is likely that some habitats are of greater value as a waterbird food resource than others in both productivity and availability. Changes to flooding characteristics may affect the area and availability of critical foraging habitats with potential consequences for waterbird breeding. See articles starting on page 6 about our work with waterbirds.

Influence 5: Food chain length

The length of a food chain is described by the number of times organic matter from the base of the food web is consumed before it reaches the top predators. Systems in good condition have longer food chains than systems in degraded condition. The shortening is often caused by the loss of higher predators such as large predatory fish and waterbirds. Shortening may also occur because there is less energy available to higher levels in the food web. This may occur in a number of ways.

1. There is less energy in the system (see Influence 1: Overall productivity).
2. The amount of energy that moves through the microbial loop increases. Some of the organic matter in aquatic ecosystems is consumed by microbiota such as bacteria and fungi. The material may be used several times by microbial communities, and each time it cycles through there is less material available for other consumers in the food chain.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

EASTERN GREAT EGRET, PHOTO JJ HARRISON

3. As flow affects the food web, the number of links in the food chain also change. If less food is consumed, only a small proportion is then available to the next link in the chain. As a consequence, adding another link would significantly reduce the amount of food available at the top of the food chain. Flow regulation in the Murray River has led to a change in macroinvertebrates from large long-lived specialist species such as crayfish and mayflies, to smaller short-lived generalist or opportunistic species such as chironomids and worms. Such changes to community composition add *trophic* links, because smaller invertebrates need to be consumed by something larger before their energy is available to larger fish. This change may mean a significant reduction in the energy available to predatory fish.

The potential for these types of food web changes to affect the outcomes of environmental flows reinforces the need to take an ecosystem perspective when managing our rivers and wetlands. Taking an ecosystem perspective means understanding the processes that sustain fish and waterbirds, and in some instances, delivering flows that support food webs and the condition of the ecosystem, rather than targeting direct benefits for particular species.

The trophic level of an organism is the position it occupies in a food chain. The word trophic derives from the Greek τροφή (trophē) referring to food or nourishment. A food chain represents a succession of organisms that eat another organism and are, in turn, eaten themselves.

Influence 6: Food web structure

The amount and type of food available to species may be affected by changes to the species present within the system. Two extreme examples are the introduction of an invasive species or the loss of a key species.

1. **Invasive species**
   a. Willows: In lowland systems where flows are highly variable, the spread of willows has been promoted by flow modification. In addition to the effects they have on native vegetation, recent work has revealed that willow leaves entering streams leach carbon more rapidly than native litter, subsequently fuelling a different component of the food web. They are a poor base for algae to attach to, with cascading effects on the macroinvertebrate communities dependent on that algae.
   b. Carp: A well-known invader whose spread and success has been linked to flow. Recent modelling of the effects of carp on food webs suggests that carp sequester a large proportion of the food available to fish. If this is the case, then carp probably interact with other food web changes to increase the stress on the fish community.
2. **Species loss**
   a. Frogs: One group affected by reduced flooding is frogs. Frogs and tadpoles represent a major food resource for waterbirds such as herons and bitterns. The loss of frogs may have contributed to declines in these bird populations.

Conclusion

Flow influences food webs in a variety of ways, all of which have the potential to affect fish and waterbirds. As a consequence, water managers need to look at using flows to support and enrich ecosystem food webs, so that organic matter can be transformed into high quality food resources.

The Food Web Theme is now collaborating with the MDB EWKR Fish and Waterbird Themes in undertaking field sampling that will generate data on the food webs upon which native fish and waterbird recruitment depend.

Flow modification has the potential to profoundly influence food webs in lowland rivers. Photo Richard Snashall.

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POWER SUPPLY

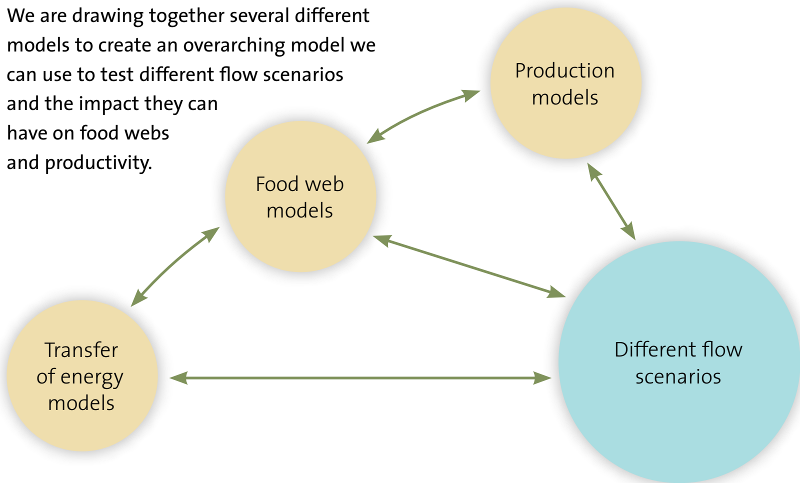
NICK BOND AND **REBECCA LESTER** ASK HOW MUCH ENERGY DOES A FISH POPULATION NEED?

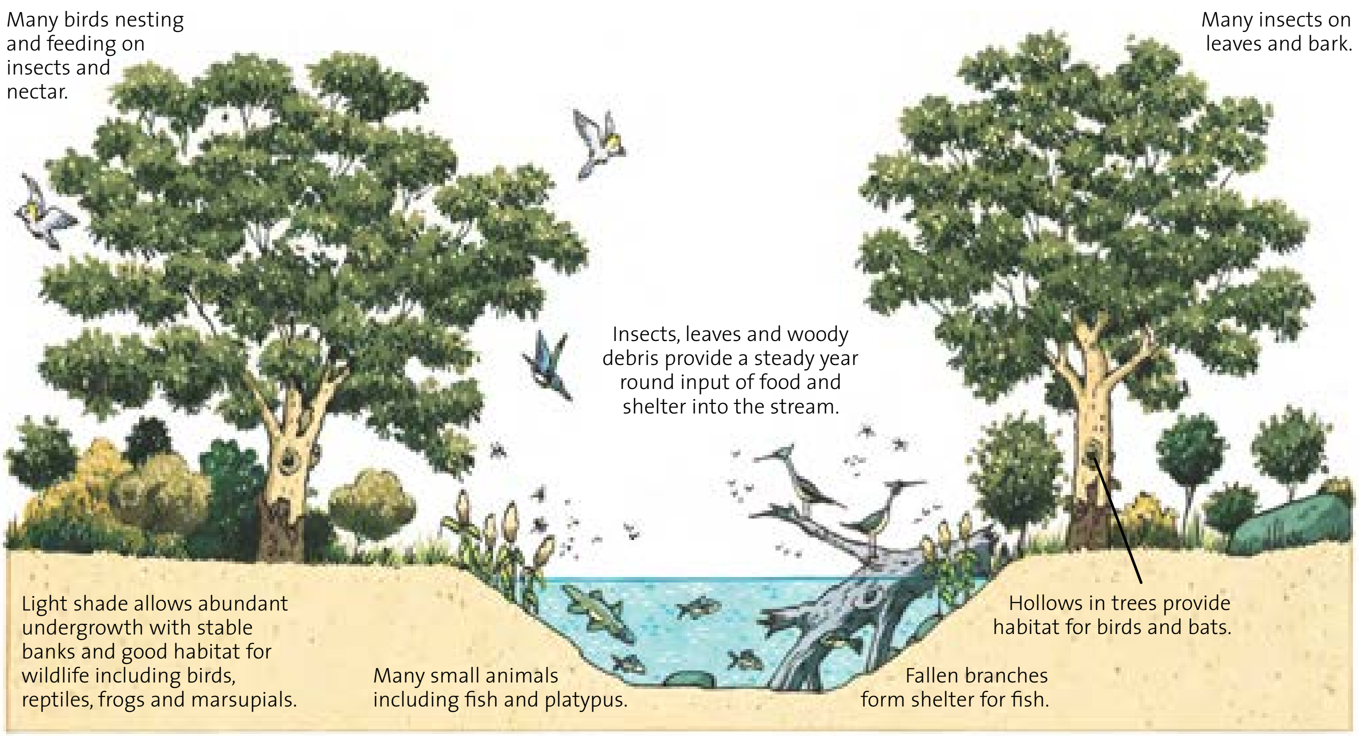
We often think about increasing the abundance of native fish and birds by promoting additional opportunities for breeding and recruitment. Another important question to ask, however, is whether there is sufficient food (or space or other resources) available to support larger populations? This carrying capacity—literally the capacity to 'carry' more individuals in a population, can be an important factor regulating animal abundances.

Finding these limits by measuring them empirically can be extremely difficult. Instead, scientists often try to estimate them by modelling, using information about the ecosystem that can be more easily measured. Such approaches are commonly used in marine ecosystems and are currently being explored within the Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Food Web Theme.

These coupled 'production/food web' models, incorporate estimates of rates of primary production by plants and algae, in the river and on the floodplain during floods, with representations of the food-web describing the transfer of energy between different food web 'compartments' (e.g. algae to zooplankton to fish), and the efficiency of those transfers from one compartment to the next. The outputs are approximations of the biomass of consumers (e.g. fish or water birds) that can be supported within an ecosystem. Comparing different scenarios can provide insights into the ways in which altered river flows and changes in food web structure might affect the size of populations that can be sustained.

We are drawing together several different models to create an overarching model we can use to test different flow scenarios and the impact they can have on food webs and productivity.





A healthy food chain has high carrying capacity. Illustration Paul Lennon

Reviewing and refining

Rather than starting from scratch, the MDB EWKR team are adopting an existing model developed from an earlier research project funded through the Australian Centre for Ecological Analysis and Synthesis (ACEAS) within the Terrestrial Ecological Research Network. A key first step is to publish the findings and modelling framework from that earlier project, so that its outputs and conclusions have been peer reviewed. Several members of the original team are currently working on behalf of the ACEAS team members to finalise a manuscript that will, in due course, provide confidence in the model validity and suitability for the current project.

Once completed, the model will provide a valuable tool helping the research team to understand the effects of carrying capacity on population dynamics, and to identify areas where energetic or food-web influences may limit the ability of populations to grow in response to increased breeding or recruitment opportunities. This will help scientists and managers identify situations where additional river flows or other complementary activities may be required to increase the capacity of the ecosystem to support larger population sizes of native fish. These background activities will be completed towards the end of 2017.

As well as applying the model to adult fish populations, the Food Web team will also be working with the MDB EWKR Fish Theme to explore similar questions regarding the role of flow in influencing food availability and larval fish survival. This work is being done at finer spatial and temporal scales and will continue into 2018. Updates will be shared through the MDB EWKR Story Space website as work progresses.

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.

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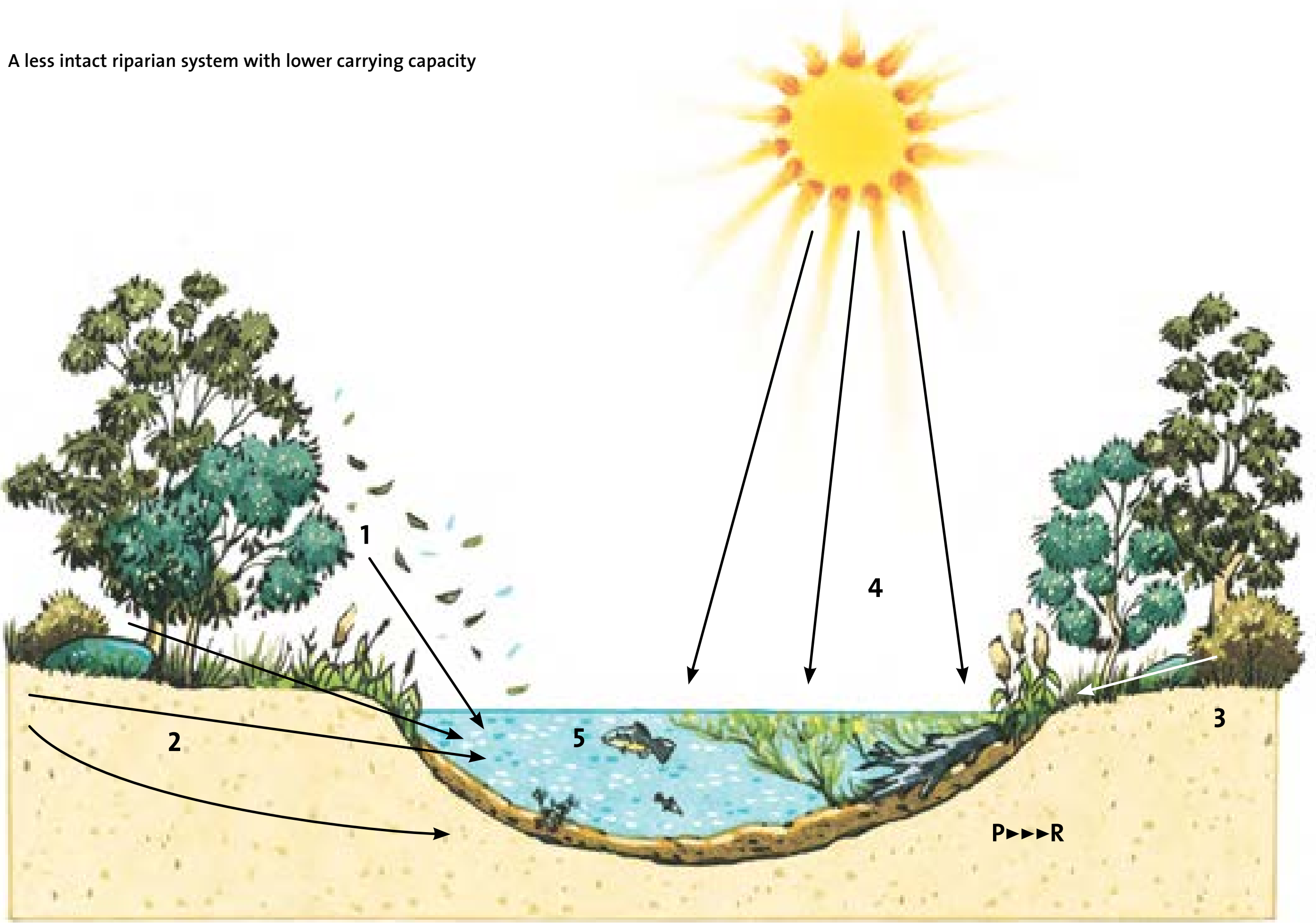
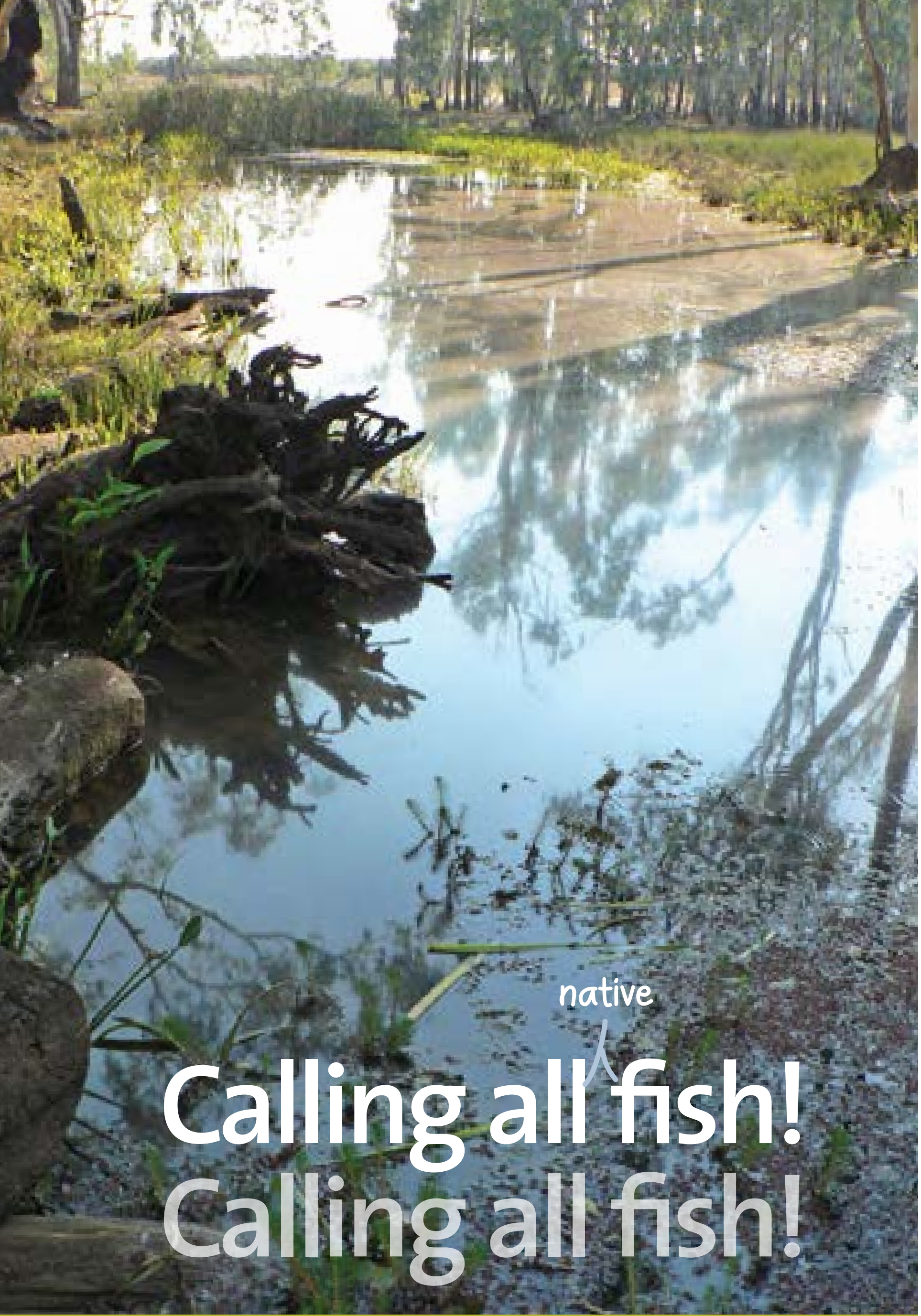
A less intact riparian system with lower carrying capacity



1. Reduced inputs of leaf litter and terrestrial invertebrates.
2. Changes in the quantity and quality of organic matter from surrounding catchment.
3. Reduced inputs of logs and branches.
4. Prolific growth of filamentous algae and aquatic macrophytes stimulated by high sunlight and nutrient run-off. These sources are not readily consumed by aquatic invertebrates and cause major changes in habitat.
5. High respiration from plant growth and decomposing organic matter leads to reduced oxygen and lowered water quality. This together with loss of habitat results in loss of biodiversity and major impacts to ecosystem function.

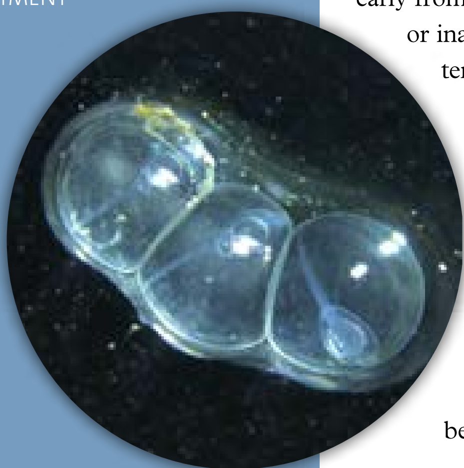
Source: S. Bunn (1998). Illustration Paul Lennon.



Calling all native fish!

Calling all fish!

PAUL HUMPHRIES, **ALISON KING**, **NICOLE McCASKER**, **R. KELLER KOPF**, **RICK STOFFELS**, **BRENTON ZAMPATTI** AND **AMINA PRICE** ROLL OUT THE SCIENCE THAT IS SUPPORTING FISH RECRUITMENT IN THE MURRAY–DARLING BASIN.



Main: Ovens River billabong, photo Paul Humphries.
Inset: Murray Cod eggs, photo Rohan Rehwinkel.

Although knowledge of when, where and why native Australian freshwater fish breed has come on in leaps and bounds in the past few decades, the processes that influence how many young fish survive, and how many die, has largely eluded scientists. It is this gap in our knowledge —and especially the influence of flow—that has motivated the development of a conceptual synthesis for fish recruitment in riverine ecosystems as part of the Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Fish Theme.

Fish recruitment

Most fish produce far more eggs, and the larvae that hatch from them, than can possibly survive. Fish are the most fecund of all vertebrates; with thousands, and sometimes millions of young generated in the hope (in an evolutionary sense) that a few will survive the 'slings and arrows of outrageous fortune' (thank you Shakespeare) that the environment delivers. It has long been the holy grail of fisheries scientists to uncover the reasons for why and how some of these super-abundant young fish survive and others do not. Furthermore, to be able to predict the strength of future year classes can be particularly important for commercial or recreational fisheries, and to ensure the survival of a species threatened with extinction.

Intriguingly, future population sizes are often able to be predicted from the number of young that survive the first few months of life. This is because most eggs and young fish die early from things like lack of food, being eaten, or inappropriate water quality, especially temperature. Temperature is an all-important environmental factor, because, being cold-blooded, a fish's physiology and metabolism, and hence growth rate, are mostly governed by it. Temperature also drives food production for young fish. Encountering the right temperature range during early life can mean the difference between life and death.

Ovens River floodplain (main) and slackwater in the Broken River. Both photos Paul Humphries.

Aside from water quality, most fish recruitment hypotheses consider food and predation as the most important biological factors that limit survival of young fish. There is general agreement that the faster a young fish grows, the less time it will spend being susceptible to predators. So, having lots of food while **not** encountering predators, is probably the key to good recruitment. We wanted to find out how and where these conditions exist, and how young fish, which tend to be poor swimmers, find them.

Building on liquid foundations

Rivers comprise a network of channels, connected by (mostly) downstream flow, which periodically connects to a much larger floodplain during overbank flooding. Flow plays a central role in rivers influencing: geomorphology; chemistry; the sources, storage, transformation and transport of energy and nutrients; the transport of sediment; the movement and reproduction of animals and plants; and patterns and processes associated with food webs.

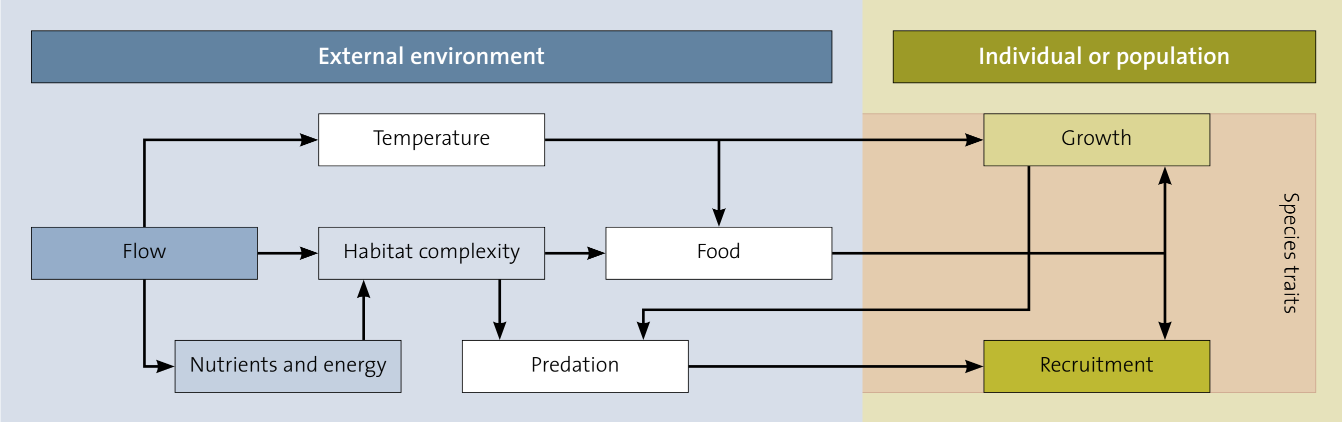
The river ecosystem concepts that have emerged in the last few decades to explain how rivers work (for example, river continuum concept, flood pulse concept and riverine productivity model), attempt to integrate many of the patterns noted earlier and processes in order to explain what we see in natural and modified rivers, but none specifically considers fish recruitment. This is not surprising: that was not their aim, but it leaves us somewhat *floundering* … if you'll excuse the pun.

It does, however, provide us with the foundations on which to build more specific recruitment-related concepts for rivers. What would be ideal is a synthesis that relates how the early stages of a fish's life interact with the physical, chemical and biological features of rivers, and especially with flow, to create the next generation of fish—for *all* fish in *all* types of rivers.

Putting it all together

As a rule, river fish breed at about the same time each year. On the other hand, the abundance of the main type of food for young fish, zooplankton, fluctuates with flow and temperature at shorter time intervals. As a result, fish may breed at a time and location where there is lots of food, if the cues for both are in 'sync', or, if the cues are out of 'sync', fish may breed at a time and location when food is scarce. If a young fish finds lots of food quickly, not only will it survive during the critical first-feeding phase, but it will grow fast. The faster a fish grows, the shorter the time it will be vulnerable to predators. So, successful life history strategies for parents are those that get young to places that are food-rich and predator-poor. We wanted to know where and when are these places and what makes them special?

The MDB EWKR project is funded by the Australian Government's Commonwealth Environmental Water Office.



The key components of the external riverine environment that are affected by flow and that interact with individuals and populations through fish species traits to create conditions conducive for recruitment.

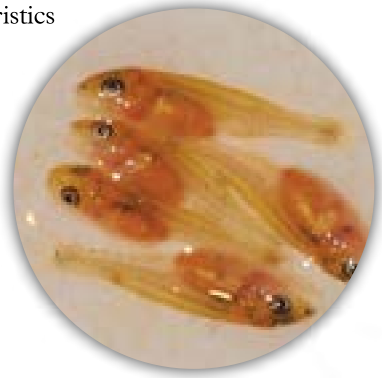
Rivers are characterised by a wide range of habitats that perform different functions from one location and time to the next, as water levels changes. Many of these habitats are unsuitable as nursery habitats for young fish, because they either contain little of the right types of food, have too many predators, or are of poor water quality. Some habitats—typically the slow-flowing, more structurally complex ones—are not only good for producing food, but also for concentrating this food so that it is able to be used by poorly swimming larvae, while also providing sheltered refuges from larger predators. In-channel summer slackwaters (the slow or still margins or backwaters of channels) are one such habitat, and seem to act as important nursery grounds for many Murray–Darling Basin fishes. Inundated floodplains, if they occur at the right time of the year, may also be another.

The synthesis

Unlike other fish recruitment concepts, models and hypotheses developed for river fishes in Australia, our synthesis brings together the key environmental components that are known to drive fish recruitment: flow, fundamental resources supplying energy and nutrients, food, predation and temperature (see figure). The synthesis allows generalisation to all fish species in all types of rivers. It was built on the foundations of previous work done on freshwater fish in Australia and overseas.

We argue that flow drives the production of the food of larval fish through its effects on energy and nutrients and its interactions with the complexity of riverine habitat and temperature. Habitat complexity is critical for the retention and concentration of the food, while also providing refuge for young fish from predation. Abundant food also means fast growth rates, which are also a form of predator protection. The final combination of all of these pathways and relationships will result in the number of surviving young. Importantly, the nature of these relationships will be greatly influenced by the species traits, such as life history, physiology and behaviour, of the fish that is the target of study.

The MDB EWKR project is now testing the predictions of our flow-recruitment synthesis in an attempt to improve our understanding of the critical hydraulic habitats and their key characteristics (food, temperature, structure) through field sampling in the Ovens River in northern Victoria. This knowledge will be shared with water managers, to assist them in boosting fish recruitment across the Murray–Darling Basin's rivers.



Murray Cod larvae, photo Tim Kaminskas.

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MANAGING THE SOUTHERN CONNECTIONS

NATASHA CHILDS EXPLAINS THE SYSTEM-WIDE APPROACH BEING TAKEN IN LOOKING AFTER THIS NETWORK OF RIVERS.

The Southern Connected Basin is a network of rivers that feed into the Murray River between the Hume Dam and the sea. The network includes Victoria's Goulburn, Campaspe and Loddon rivers, along with the Murrumbidgee, Edward-Wakool, Darling Rivers and, occasionally, the Lachlan River, of New South Wales. As a connected system, managed flows in one area can have a significant positive influence on environmental outcomes in another.

Environmental water managers, river operators, researchers and community representatives are currently collaborating to design fish flows for each major river system within the Southern Connected Basin. New South Wales Office of Environment and Heritage Senior Team Leader Paula D'Santos said this system-wide approach means water managers can achieve more with a limited amount of water.

"

Improved coordination enables cross-border agencies to achieve better results by using available water more efficiently and effectively. This system-wide approach ensures that outcomes achieved at individual sites fit into the overall basin strategy for the benefit of a healthier and more productive Southern Connected Basin. It allows water managers to work toward the key environmental goals for the region including, healthier and more resilient fish populations, Paula said.

"When it comes to native fish, watering events can be strategically delivered throughout the system to ensure a steady transfer of carbon from the floodplain floor into local rivers and wetlands. This carbon is the basic building block of the food web. When released regularly, it supports a robust food web and, at the same time, reduces the risk of low oxygen blackwater events. The aim is to ensure suitable habitat can be managed more effectively to ensure sufficient food for the lifetime of the fish and provide breeding and dispersal cues.

"These strategies will help to build source populations of native fish throughout the system. This will, in turn, help native fish populations to strengthen and recover from hypoxic blackwater events," Paula said.

The entire lifecycle of native fish (from birth to maturity) can take several years for some larger bodied species, and parts of the lifecycle may occur in different river systems. Strategic releases of environmental water can improve the health and condition of native fish populations, and provide opportunities for them to disperse throughout the river system.

By working with partner agencies, environmental water managers can target key locations and/or native fish populations to provide winter flows or summer refuges. The technique also paves the way for trialling different flows at different times of the year, ensuring fish can move throughout the system, even when irrigation demand is low and dams and weirs are traditionally shut down.

A system-wide approach to managing the Southern Connected Basin enables water managers to target the environmental objectives of the Basin Plan more effectively to achieve outcomes for:

1. River flows, carbon, nutrients and connectivity
2. Native vegetation and habitat
3. Waterbirds
4. Native fish.

"Another benefit of managing environmental water across the whole Southern Connected Basin is the ability to make greater use of any water that is being delivered for maximum environmental outcomes. This involves enhancing the effects of existing system flows by adding environmental water rather than creating an event that consists entirely of environmental water," Paula said.

Agencies have started trialling multi-site watering events as part of this system-wide approach. The events are being monitored to assess the outcomes for the broader landscape. Work is underway to establish mechanisms that make the most efficient use of environmental water and other existing system flows to ensure the maximum benefit from all available flows throughout the year.

OPPOSITE PAGE MAIN PHOTO: RIBBONWEED AND RIVER RED GUM IN THE MURRUMBIDGEE VALLEY, J. MAGUIRE OEH. SMALL PHOTOS (CLOCKWISE FROM TOP LEFT): 1 AND 2 UPPER CATCHMENT, J. MAGUIRE OEH; EDWARD RIVER NEAR LAWSON'S SYPHON, N. CHILDS OEH; THE DARLING RIVER MEETS THE MURRAY, ANTONOV14; WETLAND IN THE LOWBIDGEE, J. MAGUIRE OEH. THIS PAGE: RIVER RED GUM AT SUNSET, P. CHILDS OEH.

FOR FURTHER INFORMATION

www.environment.nsw.gov.au/environmentalwater/what-is-it.htm

Good advice from anglers

NATASHA CHILDS LETS US IN ON THE STORIES OF SOME RECREATIONAL FISHERS WHO ARE SHARING THEIR LOCAL KNOWLEDGE TO BOOST INLAND FISH NUMBERS.

Local knowledge is a valuable tool in the management of inland rivers. Recreational fishers are on the water regularly, they see the rise and fall of waterways, changes in the health of nearby bushland and variation in their catches. Water managers are now combining the passion and experience of local anglers with the best available science and expertise to ensure a sustainable future for fish and fishing in local rivers.

In southern New South Wales, this important partnership is yielding promising results for water managers and fishing enthusiasts alike. Wayne and Debbie Lennon, owners of Oar-Gee Lures, recently took part in a field trip with staff from the Office of Environment and Heritage (OEH), Department of Primary Industry and Fisheries (DPI), DPI Water and the Commonwealth Environmental Water Office to collaborate and share their local knowledge about fish in the region.

For Wayne Lennon, the field trip provided direct access to information about the work being done to re-instate flows that native fish need to breed, feed and thrive.

“We’ve built our business on understanding the needs of native fish— creating lures to target yellow belly [Golden Perch] and cod [Murray Cod], as well as other species. Since the field trip, we have an even better understanding about what native fish require in terms of habitat and flows in a regulated river.

“In the days before river regulation, you could walk across the Murrumbidgee River in summer, but in winter you didn’t have a chance. These days, it’s the opposite. Back in the day, spring storms would put a pulse through the river, prompting fish to spawn. The next season, you could be guaranteed there would be plenty of fish, but it’s different now. Dams capture the rain, and when water is released it’s often at the wrong time of year to benefit native fish.

“I’ve been fishing for 60 years but until recently I didn’t understand the importance of blackwater for feeding native fish. I used to think that blackwater killed ‘my fish’. Like most people, I was ready to blame anybody without knowing what actually caused it. I now know there’s good blackwater and bad blackwater.

“Regular flushing flows—at the right time of year—help to feed the rivers and the native fish. Natural flows and environmental water have an important role to play in the process.

“Bad blackwater—the type that takes the oxygen out of the water and kills fish—can be exacerbated by no flows or badly-timed flows, allowing carbon to build up on the floodplain. We need to start putting the rivers first. By all working together we can make good things happen,” Wayne said.

FOR FURTHER INFORMATION

www.environment.nsw.gov.au/environmentalwater/what-is-it.htm

BOTH PHOTOS: RECREATIONAL FISHING IN THE GULPA CREEK, D. FINNEGAN OEH.

Troy Bright has been fishing the Deniliquin area for more than 30 years. He is a strong advocate for combining the efforts of local communities and government agencies to achieve positive outcomes for all river users.

"There is a lot of great work being done locally to support native fish populations and provide benefits for communities up and down the river. Managing water to support the lifecycle needs of native fish is one of the most important strategies.

"When I was growing up, native fish were hard to come by. I was out on the river regularly, but it wasn't until I was 18 or 19 that I angled my first Murray Cod. I've noticed a big difference since the introduction of environmental flows. Native fish numbers are increasing.

"There's a lot of other work being done as well. Re-snagging has seen a massive increase in the number of native fish in some sections of the river, and landholders have been fencing riparian zones to rehabilitate stream banks and protect these important sources of shelter and food for native fish. Water managers have worked with irrigation companies to use irrigation escapes to create fresh water refuge pools for native fish during hypoxic blackwater events.

"In Deniliquin, we've also been working to establish a fish park at Brown's Lagoon. It's a place where people from all walks of life can come to experience fishing and learn about the great native fish that live in our rivers. The fish park is in the heart of town so it's easy to access for tourists, recreational fishers, students and the community.

"All of these projects mean money for our towns. Good fishing brings tourists to town. Upgrading water infrastructure means work for tradies. Environmental water also means additional income for irrigation companies when their infrastructure is used for delivery.

"Best of all, our rivers are healthier and native fish can make a comeback," Troy said.

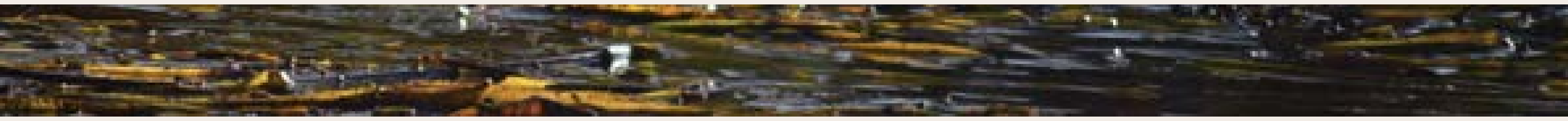
OEH senior environment water manager Paul Childs joined the field trip to give local fishers a fresh perspective on work being done.

"The knowledge and enthusiasm of recreational fishers is a fantastic resource for local communities. By working with local people, we can achieve practical outcomes with multiple benefits — not just healthy rivers and improved fish populations but economic benefits for towns as well.

"As water managers, we want to share our knowledge and learn from the skills and experience of people who are out on the rivers every week. We all have a passion for local rivers for lots of different reasons. Finding the common ground and building on it will mean terrific outcomes for fish, for anglers and communities.

"It's an exciting field to be working in and seeing the passion and enthusiasm of local people who want to look after their rivers is fantastic. We are looking forward to continuing our work with local anglers and fishing clubs on some great outcomes for everyone," Paul said.

In 2012, Deloitte Economic valued recreational fishing in the Murray valley at just over $200 million per annum. Across New South Wales, recreational fishing provides an estimated economic boost of close to $1 billion. Bringing together local fishing knowledge, and with the scientific and practical understanding of water managers, is a match that will result in even better outcomes for fish and the habitats they need to survive and thrive.



Fish friendly flows

IN THE CENTRAL MURRAY

NATASHA CHILDS RUNS THROUGH WHAT IS BEING DONE TO KEEP FISH HAPPY IN CENTRAL MURRAY RIVERS.

Rivers in the central Murray valley once teemed with native fish like Golden perch and Murray cod, both primary sources of food for Aboriginal people. These large-bodied fish were also abundant during the early days of European settlement, and anglers were assured of a catch.

During high seasonal flows, creeks provided extra territory for the fish to feed or breed. Wetlands were a favourite nursery habitat for young fish seeking food and safe haven and every part of the floodplain, from ephemeral creek to wetland depression and river channel, played a vital role in providing food and habitat, as well as transporting both fish and essential nutrients throughout the system.

As human demands grew, however, dams and weirs were constructed to ensure a steady supply of water for towns and farms. These structures have permanently changed the way rivers function and today, native fish can no longer access all parts of the river and floodplain, even during high flows. Natural breeding cues have been interrupted, and opportunities to re-populate sections of the river system are obstructed by dams, weirs and changed river regimes.

The life-giving flows that used to flush food from the floodplain into the rivers now occur much less frequently with the result for native fish being less food, fewer breeding cues, reduced habitat, impeded passage and populations that have declined substantially since river regulation. Water managers, fish ecologists and anglers alike are now working to arrest this decline and improve the health of local rivers for the benefit of native fish and local communities alike.

PHOTOS (THIS PAGE): N. CHILDS OEH. OPPOSITE PAGE: GULPA CREEK AT SUNSET, N. CHILDS OEH; TROUT COD, G. SCHMIDA.

What is being done?

Researchers and NSW Office of Environment and Heritage (OEH) water managers are working together to deliver flows and monitor fish responses to different flow interventions. The work is being done in selected waterways within the central Murray valley, along the Edward River and Gulpa Creek. The population structure of large-bodied native fish is being assessed, with 40 Murray Cod and Trout Cod tagged so their movement can be detected by acoustic loggers installed throughout the system.

Fish ecologist Dr Clayton Sharpe said if appropriate flow regimes were provided, the creeks and anabranches of the central Murray floodplain offered ideal habitat for large-bodied native fish.

"There is real potential to restore and expand Murray Cod and Trout Cod populations throughout hundreds of kilometres of creek habitat in the central Murray region by applying flow regimes that match the lifecycle requirements of those species," Clayton said.

"During periods of high flow in the Murray, when anabranch creeks begin to flow, research shows that Murray Cod and other native fish species move into regulated and unregulated floodplain creeks. When water begins to recede and flows in unregulated creeks cease, fish move back into the river seeking flows that support their habitat requirements. We also know fish in regulated creeks become stranded behind weirs and other structures upon their retreat back to the river, and are unable to reconnect with the main river channel.

"So, while creeks can provide excellent habitat, inappropriate flow regimes, weirs and other water management structures limit their usefulness for native fish populations to be able to expand and ultimately repopulate the river system," he said.

To restore Murray Cod populations, four conditions are needed:

- flowing water which varies in speed and volume
- perennial flow without a winter shutdown
- stable spring flows to complete spawning
- physical habitat (snags).

"These components are present across hundreds of kilometres of central Murray anabranches—with the exception of perennial flows," Clayton said.

"At present, our river systems are more-or-less shut down during winter when demand for irrigation water subsides. This is effectively the bottleneck that dictates the carrying capacity for large-bodied fish populations. By restoring these crucial elements of flow regime we are confident that the floodplain creeks and anabranches of the central Murray can once again become the engine rooms for Murray cod and other native fish recovery. That gives the central Murray an opportunity to expand permanent, self-sustaining Murray Cod and other large-bodied native fish populations," he said.

The knowledge gained through this research will be used as part of an adaptive management project being managed by OEH and co-funded with The Living Murray Program. Water for the project has been sourced from the Commonwealth Environmental Water Office, The Living Murray and River Murray Increased Flows.

Senior Environmental Water Manager Paul Childs said the trial had great potential to demonstrate the role of fish-friendly flows in restoring the capacity of floodplain creeks to breed native fish and repopulate the system from a local source.

"We are using water to provide flows for the environment at a range of levels in the target river and creek systems. The challenge is to deliver flows over the traditional April to July 'shut-down' period that are low enough to avoid riverbank slumping and allow the forests to dry, but high enough to provide a much greater area of habitat for large-bodied native fish such as Murray Cod, Trout Cod and Golden Perch. Flow measurements, coupled with data on fish movement will give us an indication of the most suitable flow pattern to achieve best fish outcomes using floodplain creeks.

"The potential to restore nursery habitat for native fish in the central Murray could have significant flow-on effects for local communities. Recreational fishing is a billion dollar industry in New South Wales. If we can boost fish numbers by making better use of existing natural resources then communities, local businesses and recreational fishers will also benefit.

"At present, research tells us that most Golden Perch in the central Murray have actually originated from the lower Murray and Barwon-Darling rivers. This project is a terrific opportunity to establish best practice principles that restore flows and open up the rivers, creeks and anabranches for use as nursery habitat and native fish breeding grounds," he said.

The research project will assess improvements in fish populations, redistribution and dispersal of fish and population structure over time.

FOR FURTHER INFORMATION
www.environment.nsw.gov.au/environmentalwater/what-is-it.htm

Fine dining from waterways

NATASHA CHILDS SERVES UP A FEAST OF INFORMATION ON WETLAND FOOD WEBS.

MAIN PHOTO: PELICANS ON THE WATER, D. HERASIMSTCHUK. **SMALL PHOTOS** (FROM LEFT): ALGAE, TOGETHER WITH BIOFILM ARE A SOURCE OF FOOD FOR TINY RIVER AND WETLAND CREATURES, Y. KOBAYASHI OEH; CLADOCERANS FEED ON THEM AND BECOME FOOD FOR SMALL FISH, Y. KOBAYASHI OEH; COPEPODS CONSUME ALGAE, BIOFILMS AND OTHER TINY ANIMALS AND ALSO BECOME FOOD FOR SMALL FISH, Y. KOBAYASHI OEH; BIOFILM FORMS ON SUBMERGED BRANCHES, J. OCOCK OEH; BONY BREAM, G. SCHMIDA.

Rivers and wetlands are a haven for native wildlife. Where there's water, there's food… and a long list of wetland animals waiting to dine out on a menu of plants, insects, fish, frogs and more.

The aquatic food web begins at a microscopic level. Water triggers the release of vital nutrients and carbon from wetland soils and leaf litter. These essential elements are taken up by plants and tiny animals. They in turn become food for other wetland creatures, and so the food web grows. Water also plays an important role in transporting nutrients and carbon from floodplain to river channel and back again, providing food for water dependent plants and animals throughout the river system.

The NSW Office of Environment and Heritage (OEH) is working with communities to deliver water strategically in order to allow flows to flush floodplain areas and return vital nutrients and carbon back to the river system to support aquatic food webs.

Environmental Water Management Officer James Dyer said river regulation had significantly affected the frequency, length and volume of events that supply food to rivers.

"This has affected food supplies for native fish as well as many other native plants and animals throughout the river systems of New South Wales. The frequency and duration of high flows that reach out onto the floodplain have also been reduced. Less food, less often, has had a significant effect on native fish populations and invasive species like European carp have now moved in to compete for the limited resources available," James said.

Water has several important roles in rivers and wetlands:

- Water in rivers **carries** sediments and other nutrients that help to feed water dependent plants and animals and enrich floodplain soils.
- Water also **triggers** the release of nutrients within the wetland, making essential elements available to plants and animals.
- Water **connects** the landscape, carrying these vital nutrients from one part of the river system to another.
- Water is also a form of animal **transport**, carrying juvenile fish into the relatively calm waters of wetlands where they eat and grow before returning to the river to repopulate other areas of the system.

Rivers of carbon

Rivers and wetlands rely on the movement of water to transfer carbon throughout the system and sustain the aquatic food web. Carbon is the basic building block of all living things. It is found in DNA, fats, proteins, starches and sugars that are critical for the growth and functioning of living creatures. Carbon incorporated into these types of molecules is referred to as 'organic carbon'.

River regulation has altered the amount and pattern of carbon transfer within local river systems. This has affected food supplies for native fish and other wetland dependent animals.

How does carbon enter the wetland food web?

Dr Julia Howitt, a senior lecturer in chemistry at Charles Sturt University, said much of the organic carbon present in wetlands was formed by plants during photosynthesis, using carbon dioxide from the atmosphere.

"Water triggers the release of organic carbon from leaves, sticks, bark and grasses that have accumulated on the wetland floor. Some carbon will also be released from the soil. This carbon dissolves into the water where it is taken up by plants and animals," Julia said.

"Fungi (such as mould) and bacteria in the water, begin to feed on the dissolved carbon and other nutrients released from the plant litter. A thin film of mould and bacteria begins to form on the leaf litter. This slimy substance is known as biofilm and may also include algae. As the biofilm continues to feed, it forms clumps which become a source of food for slightly larger organisms, and so the wetland food web begins to grow. Not all carbon is equally digestible. The presence of other nutrients and the temperature of the water will affect the speed at which the biofilm develops," she said.

In wetlands, carbon may also be present as particles attached to fragments of soil, pieces of leaf, seeds or other fragments of plants or algae. These particles may be eaten directly by small wetland animals.

Rivers provide transport for carbon moving in and out of wetlands. Strategic flows and natural high-river events also allow juvenile fish to access these sites and move between the river and wetlands during the course of their lifecycle. These fish then become a source of food for birds, frogs and other fish.

It is a dynamic system that requires a 'big-picture' approach to ensure key populations of native wildlife, and the habitat they require, are connected and in peak condition to ensure a sustainable future.

MAIN PHOTO: AQUATIC VEGETATION FORMS PART OF THE WETLAND FOOD WEB, N. CHILDS OEH. **SMALL PHOTOS** (FROM LEFT): MURRAY COD ARE A TOP-ORDER PREDATOR IN THE FOOD WEB, N. CHILDS OEH, EGRET HUNTS FOR ITS DINNER, D. HERASIMTSCHUK.

FOR FURTHER INFORMATION
www.environment.nsw.gov.au/environmentalwater/what-is-it.htm

Flows through our land

NATASHA CHILDS LINKS US WITH THE NETWORK OF WATERWAYS CONNECTING PEOPLE AND ANIMALS IN OUR LANDSCAPES.

Not too far from where we are, a patchwork of forests, farms and towns stretches out across the landscape. Bush tracks connect country kids with school bus routes. Rail lines carry world-class food and fibre to market. Freeways bring this wide brown land a little closer to our doors.

There's another layer to this dynamic system. Water—the lifeblood of countless inland communities—is flowing through a network of rivers and creeks, feeding crops, watering stock and nourishing whole communities.

It's not just people relying on this vital resource. Hidden under a canopy of River Red Gum and Black Box, these rivers and creeks give life to a host of unique native plants and animals that call this country 'home'. They too have their own networks and pathways that allow them to survive and thrive.

There's the Southern Bell Frog that spends its days hunkered down by a river or swamp, waiting for nightfall to serenade the wetland.

The Superb Parrot that nests in a hollow tree by the river, alighting at dusk and dawn to forage on the ground or find fruity treats in the understorey.

There's the Antechinus, a mouse-sized marsupial that sleeps all day in a fallen log before scampering out onto the forest floor, bulldozing its way through the leaf litter in search of spiders and insects.

Overhead, a Barking Owl emerges at dusk and watches silently over the forest floor awaiting its next meal, perhaps an unsuspecting Antechinus, a frog or a snake.

Each has its own territory, its own paths and corridors all intrinsically linked to the floodplain and the river of life running through it. In that river are the fish, yabbies, water rats, platypus, insects, tadpoles and microscopic animals that help make up the wetland food web.

It's an interlinked and dynamic system that has evolved over millennia. Rivers have carved their way through the terrain, sometimes moving quickly, sometimes slowly. They have spread out onto the floodplain, pooled and reconnected.

Native plants have adapted to the numerous and varied ecosystems along the river's course. And animals have too. Some retreating into dormancy until conditions are just right, others travelling thousands of kilometres to enjoy times of plenty, and more still just making do until conditions improve.

Today, rivers are a shared resource. Large dams ensure a steady supply of water for towns, agriculture and industry, but the needs of people don't always align with those of the environment. The timing and extent of natural flows through rivers and wetlands has been permanently altered with significant impacts on native wildlife. While some plants and animals seem to survive on the promise of rain, others have more particular requirements.

That's where the work of the NSW Office of Environment and Heritage (OEH) comes in, with OEH managing a share of the water held in dams to direct that water to rivers and wetlands at times when they need it most. This water is the trigger for plants to regenerate, reproduce and set seed. Water gives the tiniest of wetland insects the cue to multiply. They become food for other animals and the food chain boom begins. Waterbirds hone in on these freshly-watered sites and arrive in their thousands to feed, build their nests and raise the next generation of young.

Behind the scenes, OEH and partners are employing the best science and natural resource management to ensure these plant and animal lifecycles reach completion, and the floodplain ecosystem remains healthy and productive, while posing the least disruption to other river users. Water from wetlands returns to the rivers richer in carbon and nutrients, and ready to fulfil the needs of plants, animals and people downstream.

Australia's longest river, the iconic Murray, is managed by a team of water resource champions, all devoted to maintaining the balance between human demands and the needs of the environment.

Senior Environmental Water Manager Paul Childs grew up in southern New South Wales, just a stone's throw from the Murray River. His childhood was filled with stories of ancient River Red Gums, monster Murray Cod and the shifting landscape that changed the course of the Murray 10,000 years ago.

"

It's a great privilege to return to the region where I grew up and work alongside farming families and communities to ensure a healthy river environment.

"The river is such a focus for the people who live alongside it. Everyone you meet has memories of swimming there, throwing a line in the water, camping under a gum tree and taking a boat upriver.

"I now work with landholders and communities to find the balance between human needs and protecting these beautiful wetlands.

"Along the Murray and its tributaries there are hundreds of wetland sites where threatened and endangered plants are known to live or visit to breed. The requirements of each site can vary significantly. Plants like the River Red Gum require a regular cycle of flooding and drying to remain healthy.

"In the wetlands of the Millewa National Park, we find the Moira Grass plains. It's a threatened ecological community that needs regular inundation of a particular depth and duration in order to grow, form grassy mats, set seed and slowly die down, ready for the next watering event.

"Water is used to support habitat for particular species like the endangered Southern Pygmy Perch. This small fish has very particular requirements and our work is helping to restore the habitat that it requires to breed and survive.

"Every effort we make has a flow-on effect for plants and animals in and around wetlands. It's an amazing field to work in and one that allows you to see the positive outcomes of your work on a daily basis," Paul said.

Photos. Opposite: Wetlands in the Lower Murray, D. Wood. This page background: Tracks in the soil, T. Cooke. Circular images from left: Southern Bell Frog, J. Ocock; Yellow-footed Antechinus, R. Webster; Murray Cod, N. Childs; Egret chick, V. Bucello; Turtle J. Maguire.

Emma Wilson grew up on a rice farm near Coleambally and now works as an Assistant Environmental Water Manager with OEH.

> “Farmers know the value of a healthy landscape. They are the custodians of 80 per cent of wetlands in New South Wales. In my job I work with these landholders to identify wetlands on private property that can benefit from environmental water.
>
> “In the past 15 years, water has been delivered to more than 200 wetlands and 280 kilometres of creeks in the Murray valley. We’re seeing threatened Southern Bell Frogs expand their territory and respond to targeted watering throughout the valley. Monitoring is revealing new nesting sites for endangered birds like the Australasian Bittern.
>
> “All manner of native plants are responding, creating healthier ecosystems, stronger food webs and more robust wildlife networks that can support a diverse range of native animals like the endangered Southern Bell Frog, the fishing bat and the Great Egret,” Emma said.

Limits on water availability from season to season influence the management of the water flowing through this network of rivers, creeks and wetlands. During dry times, environmental water managers prioritise the sites that will receive water according to a range of criteria including ecological significance, species survival, river health, water quality and international agreements on the protection of rare or important environments and the plants and animals that rely on them.

Every day the work of water managers is making a difference to the health and long-term sustainability of New South Wales floodplains from the Macquarie and Gwydir catchments in the north, to the Lachlan, Murrumbidgee and Murray in the south. It’s a complex and ever-evolving system that enables Australia’s unique native plants and animals to survive and thrive alongside the people who also enjoy the myriad riches of the floodplain environment.

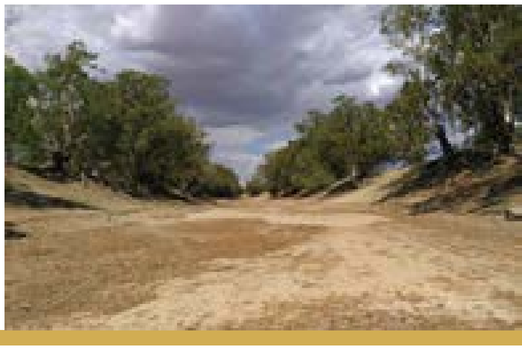
The national parks of inland New South Wales provide the perfect vantage point to see the rivers, wetlands and floodplains that support our native plants and animals. At many locations across the state you will find walking trails, lookouts, bird hides and camping spots that enable visitors to experience nature close up. Take a moment. Look, listen and be a part of your amazing environment.

FOR FURTHER INFORMATION
www.environment.nsw.gov.au/environmentalwater/what-is-it.htm

Main photo: Booligal Wetlands, OEH. Circular images from left: Moira Grass, V. Bucello; Frog spawn in wetland vegetation, J. Ocock OEH; Egret chick, J. Spencer OEH.

CONSERVING CRUCIAL CORRIDORS

PAULA D'SANTOS, **CLAYTON SHARPE**, **IAIN ELLIS**, **IRENE WEGENER** AND **ADAM SLUGGETT** FILL IN THE DETAILS OF FLOWS BEING PROVIDED FOR NATIVE FISH IN THE L OWER DARLING.



LDR reduced to isolated pools (above) due to cease-to-flow conditions (below) from 2013 to August 2016. Photos provided by the authors.

Native fish populations across the Murray–Darling Basin have been adversely effected by river regulation, water extraction and associated habitat loss. Environmental water is increasingly being used to supplement and create crucial flow corridors that native fish need to support their lifecycles.

Environmental water managers in New South Wales are using newly developed 'flow requirement' frameworks to help guide their management decisions. The frameworks combine changes in river hydrographs (i.e. the rise and fall of a river flow) with knowledge about how flow supports different aspects of native fish lifecycles (e.g. habitat, spawning, dispersal, and recruitment). This is then applied to day-to-day river operations, using environmental water to achieve the flows required for positive native fish outcomes.

The recent 2016–17 Lower Darling River Native Fish Flow provides an excellent example of putting this approach into practice, with environmental flows developed specifically for Murray Cod and Golden Perch.

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Flows for Murray Cod

The Darling River is one of the world's most hydrologically variable rivers. The lower 700 kilometres (referred to as the Lower Darling River or LDR) includes the Menindee Lakes, and extends south to the confluence with the Murray River at Wentworth. The LDR is considered a 'hot spot' for native fish, supporting strong populations of Golden Perch, Murray Cod and a suite of small-bodied native fish species. Threatened Silver Perch and Freshwater Catfish also persist in the LDR. Flows to the LDR have been highly regulated since the 1960s due to the modification of the Menindee Lakes system for water storage.

Upstream river regulation, storage and extraction in the northern tributaries of the Barwon-Darling system have substantially altered the duration, magnitude and frequency of flows that reach the Menindee Lakes and the LDR. From 2013 to August 2016, the Menindee Lakes system experienced record low inflows. Consequently, cease-to-flow conditions in the LDR prevailed, and the river contracted to a series of isolated pools (see photos above). A lack of replenishing flows and deteriorating water quality threatened the health of the LDR's native fish stocks, and created unfavourable conditions for spawning and recruitment of the river's robust Murray Cod population for three consecutive years 2013, 2014 and 2015. *(Note, recruitment in this context refers to survival of fish from tiny larval stages through to adult stages that can potentially breed themselves.)*

When flooding upstream in August 2016 finally led to a recommencement of flows into the Menindee Lakes, environmental water was prioritised to support the LDR Murray Cod population. A project team, lead by the Office of Environment and Heritage and consisting of fish biologists and environmental water managers, developed a flow delivery hydrograph based on the known flow requirements for successful Murray Cod spawning and recruitment (see diagram on following page).

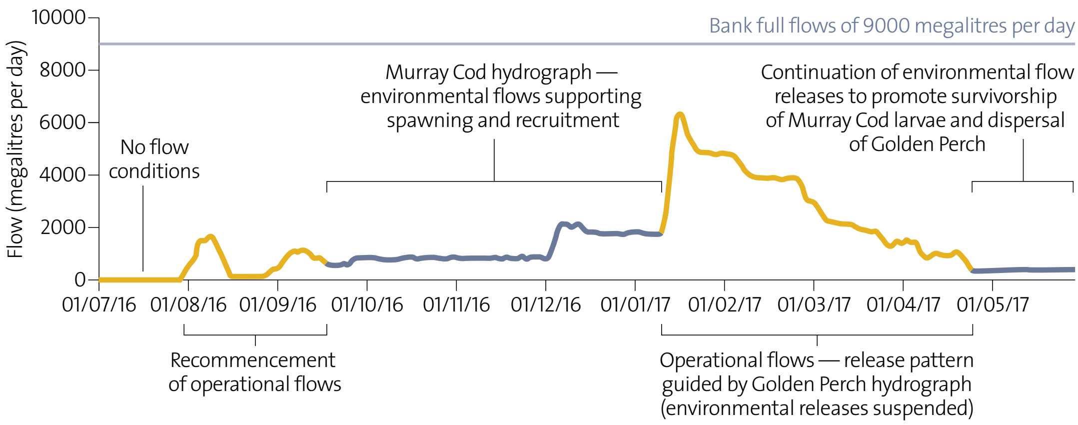
Fine meshed nets (left) set from snags in the river channel were used in the monitoring program to catch drifting Murray Cod larvae (right). Hundreds of larvae were collected at sampling sites throughout the monitoring period, supporting the commitment of environmental water and Murray Cod recruitment. Photos Clayton Sharpe.

This 'Murray Cod hydrograph' was implemented using environmental water sourced from The Living Murray program and the Commonwealth Environmental Water Holder. A monitoring program, funded by the Commonwealth Environmental Water Office, was implemented to evaluate the hydrograph. Specifically, the monitoring assessed if Murray Cod in the LDR spawned in association with the environmental flow, and evaluated the intensity of spawning and the distribution of spawning effort from Menindee to Wentworth. The monitoring information was used to refine and optimise ongoing environmental flow delivery in 2016 and 2017.

The Murray Cod hydrograph helped reinstate flow connectivity and hydrodynamic diversity (i.e. 'fast' as well as 'slower' flowing areas) to the LDR channel. It also increased the availability of submerged habitat for nesting sites (like snags), and primed the river for a boost in productivity, generating food for the predicted Murray Cod larvae.

Monitoring indicated that the intensity of Murray Cod spawning in spring 2016 was extremely high, with hundreds of larvae collected at sampling sites (compared to a handful of larvae sampled in previous years), and the distribution of spawning effort was over hundreds of kilometres downstream of Menindee. In response, the environmental flow was increased to inundate dry low-lying benches in the channel to further increase food availability and nursery habitat for these larvae (see photos above). Environmental flows were continued throughout the 2017 autumn and winter period, with the aim of maintaining habitat and feeding opportunities for the 2016 Murray Cod cohort. Continued monitoring will document the strength of recruitment (survival and growth) of these young, and further evaluate the success of the 2016–17 Murray Cod hydrograph in the LDR.

Murray Cod and Golden Perch conceptual hydrograph. Lower Darling River (Weir 32) environmental flow releases 2016/17.



Large numbers of Golden Perch juveniles collected in the Menindee Lakes in December 2016, provided the basis for commitment of environmental water, and created an opportunity for these young fish to disperse from the lakes and recruit to the Lower Darling, the Darling Anabranch and Murray River populations. Photos Clayton Sharpe.

Flows for Golden Perch

A conceptual model for Golden Perch breeding in the Darling River developed by ecologist Clayton Sharpe was used as the basis from which environmental flows could be delivered to support recruitment opportunities in the LDR and dispersal in to the Murray River and connected streams. The model predicted three key aspects:

1. Golden Perch spawning would occur in response to the winter 2016 flood event in the Barwon-Darling river system from the Border Rivers to Menindee.
2. Strong recruitment was likely to occur in the productive ephemeral nursery habitats of the Menindee Lakes.
3. Flows from the Menindee Lakes into the LDR, and the Darling Anabranch, would act as dispersal 'corridors' for juvenile perch (~four months age) to move into the River Murray system, and thereby support recruitment of Golden Perch populations to the Murray River and connected streams.

Monitoring of the Menindee Lakes in December 2016 confirmed the model's first two predictions of the presence of juvenile Golden Perch, in high numbers, and provided evidence to support the delivery of environmental water to the LDR (see photos above).

Environmental water releases following on from the Murray Cod flows discussed earlier were continued through autumn 2017 to support the dispersal of juvenile Golden Perch from the Menindee Lakes nursery habitat, throughout the LDR, from Menindee to Wentworth. Simultaneously, environmental flow releases in the Darling Anabranch provided another crucial 'corridor' to connect the Menindee Lakes with the Murray River system.

Protecting and maintaining crucial corridors

Recent research examining natal origins (akin to birth places) of native fish has indicated that Darling River derived Golden Perch are an important contributor to populations in the Southern Connected Murray–Darling Basin. Populations sampled in 2014 in the lower and mid-Murray, as well as in the Edward-Wakool River systems, were dominated by a cohort of Golden Perch that originated from the Darling River during the 2009 flood flows.

The 2016/17 Lower Darling River Native Fish Flow has highlighted the important role that the Darling River plays in the ecology of Golden Perch and Murray Cod—both important recreational angling species. From a management perspective it emphasises the need for protecting particular flows in the Barwon-Darling River system that support spawning and downstream transport of larvae, the function of the Menindee Lakes as key nursery areas for Golden Perch recruitment and the importance of providing opportunities to connect with other Southern Basin populations. The project also highlights the critical role carefully planned environmental flows can play in supporting Murray Cod spawning and dispersal throughout the Lower Darling River—a particularly important outcome in light of the devastating fish kills which occurred in the summer months of 2016 throughout the Murray River system.

Crossing the threshold

CHRIS BICE AND **BRENTON ZAMPATTI** DRAW OUR ATTENTION TO DIADROMOUS FISH.

The fish of the Murray-Darling Basin (MDB) exhibit a variety of life histories that require specific consideration in regard to flow restoration. Diadromous fish move between marine and freshwater environments to complete their lifecycles, and are reliant on flow and connectivity to stimulate and enable migrations. In the MDB, diadromous fish have declined as a result of barriers to movement (e.g. flow regulating structures) and altered flow regimes, but in recent years, research in the River Murray and Coorong Estuary has highlighted how environmental water can be used to support migrations and rehabilitate populations.

Congolli

Congolli is a medium-bodied (maximum length 350 millimetres) benthic (bottom-dwelling) species with a unique life history, including sex-based differences in size and habitat use. Mature males (length 100–150 millimetres) live in the Coorong Estuary, while the larger females (longer than 150 millimetres) are most abundant in the freshwater Lower Lakes and River Murray. Females migrate downstream in winter, and must pass through the Murray Barrages and Murray Mouth before meeting males in the Southern Ocean for spawning. Juveniles migrate upstream through spring–summer and must also pass through the Murray Barrages to reach freshwater habitats. Downstream passage is enabled when the barrage 'gates' are open, while upstream migrations are now facilitated by a series of 10 fishways.

The diadromous fish of the MDB can be grouped by the form of 'diadromy' they represent and the spatial scale of their life histories. *Catadromous* fishes, like Congolli, live in fresh water as adults and undertake downstream migrations to spawn in marine waters, with juveniles migrating upstream. In contrast, *anadromous* fishes, like the Pouched and Short-headed Lamprey, live in marine habitats as adults, followed by upstream migration, freshwater spawning and corresponding downstream juvenile migrations. Catadromous species are most common in the lower 200 kilometres of the Basin, while anadromous lampreys may migrate vast distances (hundreds to thousands of kilometres) upstream in the River Murray en route to spawning habitats. Both fish species migrate during specific seasons, with flow (including environmental water) and connectivity influencing migration and population dynamics.

Top: Adult Pouched Lamprey and inset, an adult female Congolli. Opposite: Tauwitchere Barrage, with small vertical-slot fishway in foreground, one of five major structures that constitute the 7.6 kilometre Murray Barrage network. Photos courtesy of the authors.

FOR FURTHER INFORMATION

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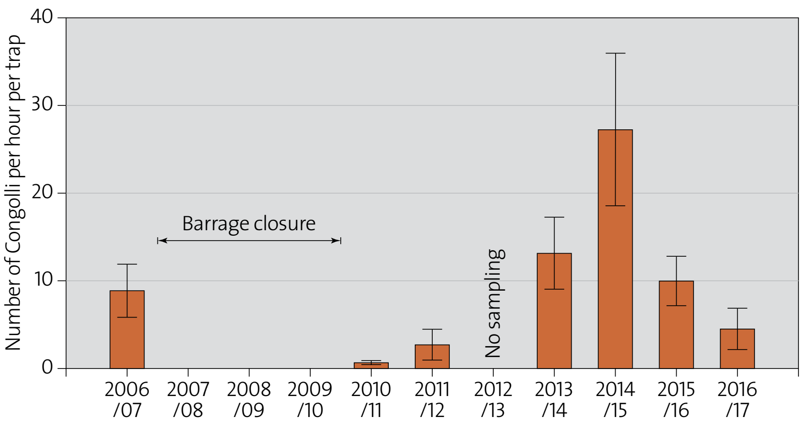
Closure of the Murray Barrages between 2007–10 during the Millennium Drought obstructed downstream spawning migrations and caused large (more than 95 per cent) declines in juvenile abundance (see figure below). During 2010–17, however, freshwater discharge through the barrages in winter has maintained connectivity, allowing downstream female migrations, and corresponding increases in the numbers of juveniles migrating upstream in spring–summer. This has happened because winter discharge and year-round fishway operation have been supported by environmental water allocations.

Pouched Lamprey

Pouched Lamprey are primitive, jawless, eel-like fish (maximum length 650 millimetres), and adults are parasitic feeders on marine fish. Upstream spawning migrations at the Murray Barrages start during winter and historical records show they moved far upstream—up to 2000 kilometres from the Murray Mouth in the River Murray, and into tributaries like the Goulburn River. Pouched Lamprey are now only found at the Murray Barrages in years of considerable freshwater flow. Lamprey have a highly developed sense of smell, and the presence of cues from the river, for example, pheromones from juveniles and low salinity water, are vital for stimulating upstream migrations.

Our research suggests that the maintenance of flow from upstream juvenile rearing habitats to the ocean may be important in guiding migrations. In winter 2015, there were 55 Pouched Lamprey caught at the barrages which were implanted with passive integrated transponder tags, with 25 individuals subsequently detected using fishways on main channel weirs of the River Murray, and one individual reaching Lock 11 (Mildura, Victoria), 878 kilometres upstream. Long distance upstream migrations in 2015 coincided with environmental water from the Goulburn River that flowed uninterrupted down the River Murray and out the Murray Mouth.



Relative abundance (± standard error) of upstream migrant Congolli sampled at the Tauwitchere Barrage vertical-slot fishway during spring/summer from 2006/07 to 2016/17.

Environmental flows to support diadromous fishes

The migration traits of diadromous fish are aligned with specific components of the flow regime, and in the modern MDB, environmental water is crucial to stimulating migration and providing river connectivity (e.g. via fishways), and enabling these species to complete their lifecycles. One component that is seldom considered in the highly regulated MDB is winter flow pulses, which are critical for migrations of both Congolli and lamprey.

Throughout the River Murray there is now a reversal of the natural flow regime, with reduced flows in winter and increased flows in the summer irrigation season. At the end of the River Murray, it has not been unusual for zero or very low flows to be passed through the barrages in autumn and winter. Given the management of 'consumptive' water over this period is typically focused on capture and storage, diadromous species are often dependent upon environmental water. Importantly, a growing focus on providing environmental water in winter for ecological objectives in upstream catchments (particularly the Goulburn) offers the opportunity for multi-site watering that will maintain the longitudinal integrity of flow (intact flow over long stretches of river to estuary), and will benefit both freshwater and diadromous fish.

Ensuring that both upstream and downstream (bi-directional) migration can occur is critical to support populations of diadromous fish. For Congolli, in addition to winter flow, this includes flow to enable the upstream spring–summer migration of juveniles. This is achieved at the Murray Barrages by ensuring water is available to operate fishways and provide 'attraction flow' adjacent to fishways to guide migration and maximise fishway performance.

Our knowledge of bi-directional movement for lamprey in the MDB, is incomplete, particularly regarding the timing of downstream juvenile migrations, and the locations of specific spawning and rearing habitats.

Understanding the life histories and ecology of diadromous fish like Congolli and lamprey will better inform environmental water delivery that focuses on maintaining flow integrity between adult and juvenile habitats, potentially over thousands of kilometres of river and ultimately benefiting both freshwater and diadromous fish in the MDB.

Watering in 2017–18

CARL BINNING LISTS THE PRIORITIES FOR ENVIRONMENTAL WATER IN 2017–18.

To make the best use of water available for the environment, each year the Murray–Darling Basin Authority (MDBA) identifies which rivers, wetlands and floodplains are the priority for watering across the Basin. We work with environmental water holders and managers to develop these priorities.

High flows in 2016 were good news for many parts of the Basin, but many sites and species need follow-up watering to build on these benefits, and boost their resilience for the dry periods ahead.

Along with our partners we have identified priorities for native fish, waterbirds, native vegetation and river flows in 2017–18.

Flows for fish

We have already seen some great results from last year, which we are now building on. For example, in spring and summer 2016, environmental water delivered to the Lower Darling helped maintain habitat and food for Murray Cod, and led to a large breeding event in the Lower Darling.

Meanwhile, in the north, good rainfall resulted in flows ideal for Golden Perch spawning leading to eggs and juveniles being washed into the Menindee Lakes. Food in the lakes helped these fish to thrive. Environmental flows were then used to release the Golden Perch from the lakes into the Lower Darling and the Darling Anabranch.

This year, the environmental watering priorities aim to encourage these one-year-old Golden Perch to spread even further through the system. The right flows will cue young fish to move upstream, downstream, and into tributaries of the Murray, where they will increase the number of fish found in rivers like the Goulburn, Campaspe and Edward Wakool.

Fish also did well in the mid-Murray River. Silver Perch are a threatened species, they breed regularly in the mid-Murray River (Torrumbarry to Euston), but their survival is much higher following years when flooding has occurred. As a result of flooding in 2016, there are currently good numbers of one- to two-year-old Silver Perch in the mid-Murray River. These young fish are highly mobile, and need to move to habitat that is better suited for growing into adults. Without regular recruitment of young fish to adulthood, this species continues to be under serious risk.

Above main: The Darling River past the Main Weir at Menindee Lakes, photo Jeremy Buckingham (Wikimedia Commons). Inset: Golden Perch, photo provided by MDBA. Opposite page: Pelicans breeding at Kietta Lake in Nimmie Caira, Murrumbidgee catchment, photo Erin Lenon. Circular image: *Ruppia tuberosa*, photo provided by MDBA.

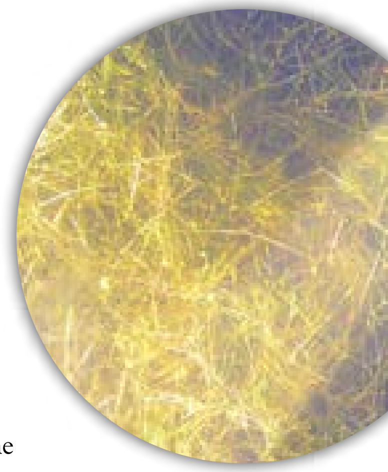
One of this year's priorities aims to provide flows that trigger these young Silver Perch to migrate upstream and into tributaries like the Goulburn, Loddon and Campaspe Rivers. Flows need to be coordinated and timed correctly so the fish receive the right signals to migrate and find the right habitat. These signals have been lost under traditional river operations so we are now reinstating them using environmental water. Silver Perch that colonise the tributaries until they reach breeding age, can then contribute to future breeding events in the Murray, and provide a more resilient population.

Ruppia results

We have also seen some good results in places like the Coorong at the mouth of the Murray River. In 2016, we had continuous flows through the barrages and low salinity levels in the South Lagoon of the Coorong. Environmental water that had been used for other watering actions upstream contributed to these flows and the reduction in salinity.

Ruppia tuberosa is a plant that grows in the South Lagoon of the Coorong and provides food resources for waterbirds and habitat for native fish and macroinvertebrates. It is a key indicator of the health of the Coorong and the flows supported a germination event of *Ruppia tuberosa*. Unfortunately, even though we had good conditions for Ruppia to grow and set seed, algae started growing over the plants and their flower-heads, which destroyed them before they could produce seeds. So while we had good conditions and Ruppia flowered, it wasn't able to produce a viable seed set to build its resilience for next year.

The Ruppia experience is an example of why it is going to take some time to improve the health of the Basin's environment. Sometimes things happen that we don't anticipate as we are still building our knowledge of these complex ecosystems and it is going to take the right climate conditions, water planning, coordination and delivery over multiple years to make a difference.



Another priority for this year is to work on our long-term goal of improving the connectivity between freshwater, estuarine and marine environments in the Coorong, Lower Lakes and Murray Mouth to boost habitat condition and support the ecosystems that depend upon flows for their survival.

The 2017–18 annual watering priorities are available on the MDBA's website.

FOR FURTHER INFORMATION
www.mdba.gov.au/managing-water/environmental-water/priorities

OARSOME

DOMINIQUE HARALDSON GIVES A SHOUT OUT TO THE MASSIVE MURRAY PADDLE AND HOW IT CONNECTS PEOPLE, RIVERS AND COUNTRY.

In late November 2016, an energised team of Murray–Darling Basin Authority (MDBA) staff joined almost 350 paddlers on the Murray River to kayak from Yarrawonga to Swan Hill over five days. It was a great opportunity to be on the river and talk with people equally passionate about water and healthy rivers.

The Massive Murray Paddle totals some 404 kilometres. The first paddlers to make this epic journey were a group of nine people in 1969 raising money for the Red Cross. Since then, the event has raised an estimated $3–4 million for the Red Cross and the YMCA. The MDBA chose to fund raise for the Cerebral Palsy Alliance, and were delighted to raise $7300 for this worthy cause. Overall the event raised $100,000 for local community programs.

The paddle is not for the faint-hearted. The week included sweltering hot weather, rain and wind storms, multiple blisters and sore muscles, but all that is forgotten when you get to see everyone having a go, explore parts of the river you haven't seen before and connect with local communities.

The Massive Murray Paddle brings together all sorts of competitors. From those who have competed for more than 30 years, to fresh-faced newbies who really didn't know what they were in for—in our case most of the MDBA team! There were also many different paddling crafts—event goers can paddle on kayaks, canoes, outriggers and other home-made boats.

As the race was on the back of natural flooding, it was really amazing to see how the river changes in years of flood. Many reaches had freshly-deposited sand bars, ideal for landing a boat, and in many places the river remained high enough to allow paddlers to see over the banks into the flourishing floodplains beyond. It was also great to see the river channels first-hand, and to get a better understanding of how and why the river changes throughout this reach.

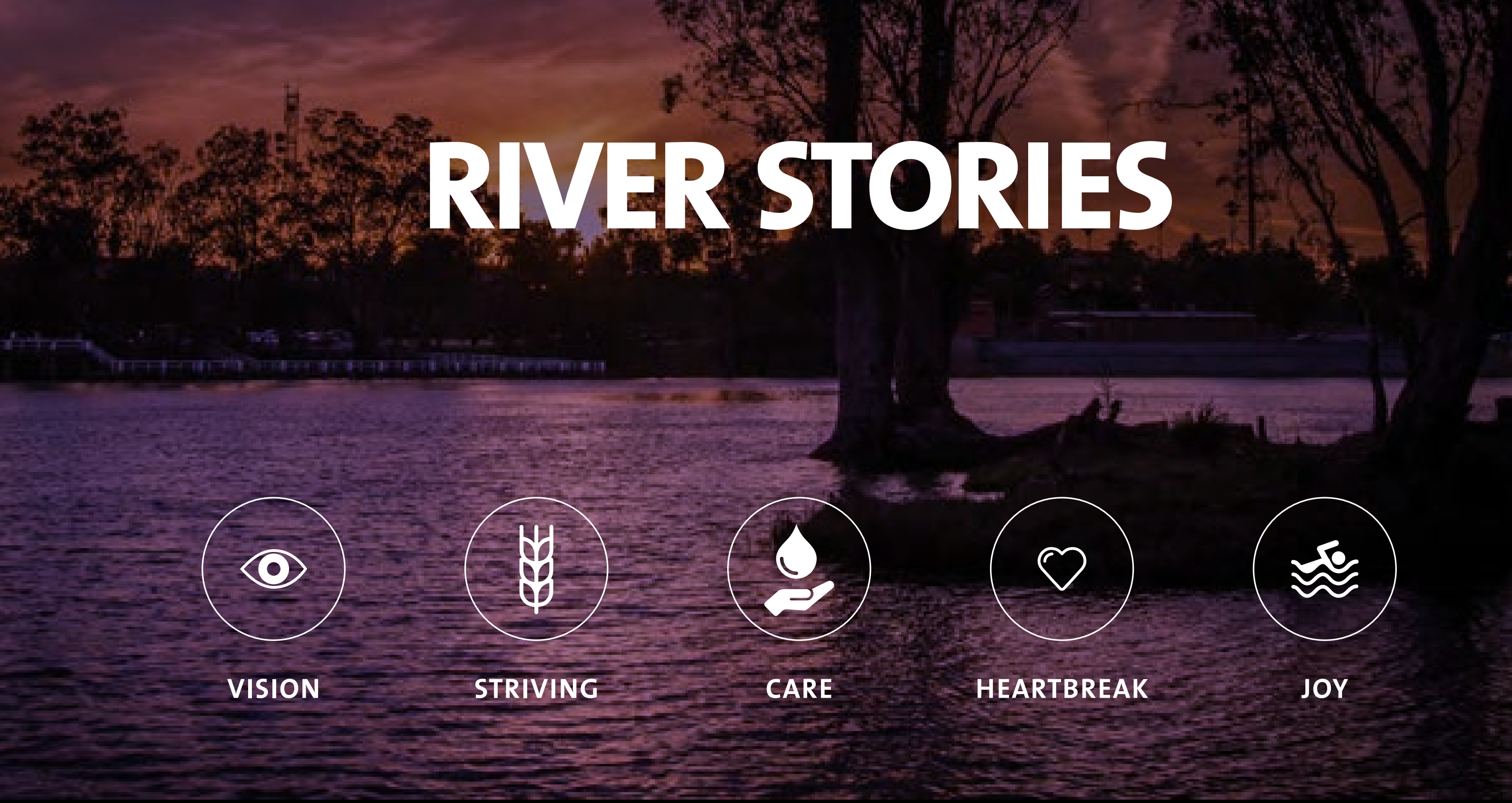
Conversations we had while on the river included comparing notes on the best paddle technique, the best snacks, and how we all came to be in the race. Once we started talking about the MDBA's work, many paddlers agreed something had to be done to help the river—but not everyone agreed on how this should be done, highlighting how complex the issue of water management is.

The Massive Murray Paddle was a fantastic experience, which a team from the MDBA hope to take part in again in 2017.

Above: Early morning mists were a feature of the Massive Murray Paddle. Photo courtesy MDBA.

FOR FURTHER INFORMATION

https://www.massivemurraypaddle.org.au/



SCROLL THROUGH THE RICH STORIES OF AUSTRALIA'S MOST ICONIC RIVERS

The Murray and the Darling Rivers form one of the world's most significant river systems. The Murray–Darling Basin is home to Australia's largest river system and extends across 14 per cent of Australia's landmass.

The Basin is also home to a diversity of life. From the more than 2 million people that live there, and the more than 3 million people that rely on its water, to the 46 species of native fish and 98 species of waterbird that call it home.

The diversity of landscapes and life that can be found in the Basin have now been captured in a new website.

River stories features people, their lives and their links with the rivers of the Murray–Darling Basin. It provides local 'lived' history, alongside the key events and changing perspectives on water and the environment that have shaped the Basin over the last 100 years.

From Traditional Owners, to new migrants, environmental managers, engineers, farmers and irrigators — many have poured their hearts into the Basin. People like Valerie May, Australia's first full-time freshwater phycologist, who pioneered research on toxic blue green algae.

If you have ever wondered how communities and governments are working together to protect our Ramsar-listed wetlands, or about the significant place that the River Murray holds in Aboriginal dreaming stories, these are just some of the topics you can explore.

It is also a story that continues to evolve and the Murray–Darling Basin Authority is keen to hear your stories about life on the river, and the care being taken to maintain a healthy, productive river system.

You can check out the website at riverstories.mdba.gov.au and follow the MDBA on Facebook for all our latest news: @MDBasinAuth. Message us on Facebook if you have your own river story to share.

riverstories.mdba.gov.au

PHOTO JACQUI BARKER.

Third time lucky?

NICK WHITEROD AND **SCOTTE WEDDERBURN** WEIGH UP THE ODDS OF WHETHER THE YARRA PYGMY PERCH HAS A FUTURE IN THE MURRAY–DARLING BASIN?

Are we facing the first extinction of one of the 46 freshwater fish species in the Murray–Darling Basin (MDB)? The answer is probably, unfortunately, 'yes', and if you were placing a bet, the odds-on favourite to go is the nationally vulnerable Yarra Pygmy Perch (*Nannoperca obscura*).

This unassuming species is tiny (maximum length of 8 centimetres) and short-lived (only a couple of years). Although it has been in the river system for thousands of years, it was only formally recognised in the MDB in 2002. Yarra Pygmy Perch has very particular habitat and life history requirements associated with wetlands that were once common in the lower Murray before river regulation. The species is now only found at the very end of the Basin in the South Australian wetlands fringing Lake Alexandrina, and the lower reaches of a few streams in the Eastern Mount Lofty Ranges.

Things became dire for this species during the 'millennium drought'. By 2009, its few remaining habitats were lost when critical water shortages reduced river flows, and led to a rapid drop in water levels in Lake Alexandrina to 1 metre below sea level. Thanks to the dedication and persistence of a small group of people, the species received a reprieve, with a few hundred Yarra Pygmy Perch rescued just as habitats were disappearing.

PHOTOS THROUGHOUT PROVIDED BY THE AUTHORS.

The rescued fish were temporarily held in ponds. To better safeguard the species, captive breeding facilities (mostly located at Flinders University in South Australia) and surrogate refuges were set up. Surrogate refuges are temporary homes for the fish, and are usually farm dams or constructed wetlands with suitable water quality and habitat. Such refuges are important, because they can produce larger numbers of fish that are more attuned to natural conditions compared to captive-bred individuals. Surrogate refuges have been used to conserve other small-bodied freshwater fishes across the region, such as the Southern Purple-spotted Gudgeon and Murray Hardyhead.

These captive and surrogate populations became the only source of fish for future reintroduction back into the wild following the drought. One of the surrogate Yarra Pygmy Perch refuges soon boomed to contain thousands of fish, ready to go back into the wild as soon as the drought broke. In late 2010, as drought-breaking rains and flooding occurred across much of the Basin, return flows to the Murray River and tributary streams helped to restore water levels in Lake Alexandrina.

Attention then turned to assessing suitable locations for more reintroductions. Fish needed to go into locations with the right water quality and habitat. Critically for the Yarra Pygmy Perch, these sites could not have high numbers of alien fishes, particularly the predatory Redfin Perch and competitive Eastern Gambusia.

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Attempt one

Almost 6000 Yarra Pygmy Perch were reintroduced into five former locations from spring 2011 to autumn 2014. Initial responses were positive, with monitoring suggesting there was short-term (6–18 months) survival and wild recruitment. Yet the species did not establish a self-sustaining population, and the fish soon disappeared. The reasons behind this failure are largely unknown. Possibly, habitats had not quite returned to former conditions, or the sudden increase in numbers of predatory Redfin Perch soon after the fish were reintroduced placed additional burden on the them. What was clear, however, was that an expanded and sustained effort would be required to re-establish Yarra Pygmy Perch in the Basin.

At this critical stage, when more fish were needed for reintroductions, the water level in the main surrogate refuge rapidly dropped and the population collapsed. Similar issues also started affecting other surrogate refuges.

Attempt two

In spring 2015, coinciding with managed high water levels in Lake Alexandrina, more fish were reintroduced into three former habitats (one that had previously received reintroduced fish and two new locations). More extensive post-release monitoring was undertaken, exploring survival in the days, weeks and months after the release, as well as the availability of prey and diet of Yarra Pygmy Perch. This monitoring found that released fish were soon consumed by wild prey and persisted for at least a month after the reintroductions. These Yarra Pygmy Perch recaptured during monitoring in December 2015 were the last record of the species in the wild.

The need for attempt three

As it stands now, Yarra Pygmy Perch appear lost to the wild in the Basin (for the third time) as they have not been observed for more than 18 months, despite considerable monitoring efforts. In further bad news, a second surrogate refuge has collapsed, meaning that only limited numbers of backup fish remain. But there is still hope!

There is still time to secure the future of the Yarra Pygmy Perch, but it will take the expanded and sustained effort of scientists, managers, landowners and local communities to conserve the species. Without this effort, the first freshwater fish extinction from the MDB will occur.

FUNDING/ ORGANISATION DISCLOSURE

The initial emergency actions and reintroductions were funded by the Australian and South Australian Government (Drought Action Plan and Critical Fish Habitat projects) and conducted by Aquasave–Nature Glenelg Trust and SARDI. The reintroductions were enhanced by genetically-informed captive breeding done by the Molecular Ecology Lab at Flinders University as part of an ARC Linkage project with several partners. Since mid-2014, the management of surrogate populations and reintroductions (and targeted monitoring) has been funded by the SA MDB Natural Resources Management Board (South Australian Government). Over this time, complementary monitoring has been conducted by Aquasave–Nature Glenelg Trust as part of annual condition assessment of EMLR streams (funded and managed by SA MDB NRM Board) and The University of Adelaide (managed by South Australian Government; funded through The Living Murray, a joint government initiative coordinated by the Murray–Darling Basin Authority).

Regent Parrot reigns again

VIC HUGHES EXPLAINS HOW ENVIRONMENTAL WATER AT HATTAH LAKES IS HELPING A THREATENED SPECIES, THE REGENT PARROT.

In November 2016, the ABC reported that 1600 Regent Parrots had been sighted in just two hours in north-west Victoria. This was extraordinary, as the beautiful Regent Parrot is a threatened species in eastern Australia and before this sighting, it was thought there were only about 500 left. The birds are generally found in the Mallee region of north-west Victoria, nesting in the River Red Gums that line the banks of the River Murray.

The ABC news story suggested that the increase in numbers was due to the floods along the Murray during late 2016, but there is more to this story than a single flood…

The birds were seen near the Hattah-Kulkyne National Park, which includes the Hattah Lakes, a site that has been receiving environmental water since 2005. Bird surveys conducted by Richard Loyn and Guy Dutson at Hattah Lakes in 2014, 2015 and 2016, recorded increasing numbers of Regent Parrots, with environmental watering clearly benefiting the species.

In 2014, surveys found that Regent Parrots were among the most common birds sighted, especially in areas that had received environmental water in the past. They were seen in flocks of more than 100, feeding on seeds in sites that had been watered in earlier years.

The 2015 surveys had similar findings, with Regent Parrots among the most common birds sighted. Along with other seed-eaters they had increased in numbers, taking advantage of the environmental watering in 2014.

The 2016 survey reported the same findings, with honeyeaters also thriving from environmental watering enabling Black Box trees to flower and attract insects and other pollinators. The flow-on effect was that insect-eating birds were also more abundant due to the increased ecosystem productivity.

Above left: Regent Parrot at a nesting hollow, Hattah Lakes, photo Vic Hughes, MDBA. Left: A juvenile, photo JJ Harrison.

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The 2016 survey concluded:

> "The increase in birds on sites that were flooded in 2014, and the stability or decrease on sites that were not flooded in 2014, shows clearly that the environmental flows have had a beneficial effect on bird abundance, and that the short-term effects observed in 2015 have continued into 2016 when all water had gone. Many species appeared to have benefited, including one species classed as threatened (Regent Parrot), which continued to make extensive use of Black Box woodlands for feeding." (Loyn and Dutson)

It is clear from these 2014–16 bird survey results that providing environmental water to the Hattah Lakes icon site has been a blessing for Regent Parrots. The food resources it has generated have helped them not just to survive, but to thrive, with a large increase in numbers sighted in November 2016.

These results provide evidence that woodland and insect-eating birds prosper from environmental watering, and that the cumulative effect of regular watering builds population size and, hopefully, resilience.

HATTAH LAKES

Hattah Lakes are wetlands of international significance under the Ramsar Convention. Located in the north-west of Victoria, the lakes begin to fill naturally when high flows occur in the River Murray. River regulation has reduced the frequency and duration of high flows, isolating the lakes from the river. The last natural large-scale filling of the lakes was in 1993. In response to declining ecological condition, between 2005 and 2010 relatively small quantities of environmental water were delivered to target specific sites.

In 2013, environmental water management structures were completed, allowing much larger-scale watering. In 2013, the lakes were filled, and in 2014 they were surcharged, delivering water to the Black Box woodlands on the floodplain (some of which had not been flooded since 1993). There was a strong ecological response to the waterings; native fish and waterbirds bred, and there was good growth of non-woody vegetation in the wetlands and on the floodplain.

Environmental watering at Hattah Lakes is coordinated by the Mallee Catchment Management Authority, in cooperation with Parks Victoria, Goulburn-Murray Water, the Commonwealth Environmental Water Holder, Victorian Environmental Water Holder and the Murray-Darling Basin Authority (MDBA).

Environmental water inundating Black Box woodland at Hattah Lakes in 2014, photo Vic Hughes, MDBA.

COMMUNITY SPIRIT

DEBORAH NIAS AND **ADRIAN WELLS** SHARE THEIR STORY OF WORKING WITH INSPIRING COMMUNITIES OVER THE PAST 25 YEARS TO RESTORE WETLANDS ALONG THE MURRAY AND DARLING RIVERS.

Photos throughout courtesy of the authors.

To many people in the Murray–Darling Basin, terms such as 'environmental flows', 'restoring wetting and drying cycles to wetlands', and 'cultural flows' are very much part of community discussions about implementing the Basin Plan. They are also regarded as relatively new terms. Yet, 30 years ago, community groups began to trial these concepts, many of which have now been replicated by governments and have strong relevance in delivering environmental flows today. These efforts also developed workable and effective frameworks for how environmental watering can best occur.

Much of this knowledge and experience has been implemented by the Murray Darling Wetlands Working Group, which celebrates its 25th anniversary this year. Founded in 1993, it has an enviable record of research, community engagement and on-ground delivery that has attracted regional, national and even international recognition.

In 1992, the New South Wales Murray Wetlands Working Group was formed with the aim of rehabilitating wetlands along the Murray River, and within the first 12 months, had successfully flooded Lake Gol Gol, and was undertaking a preliminary investigation of Thegoa Lagoon at Wentworth. Funds for a regulator at the Moira Lake had also been sourced, and piezometers were installed in the Poon Boon Lakes to study groundwater movement. A management plan for Gulpa Creek was being drawn up, and wetland management guidelines for councils had been published.

The Moira Lake 'springboard'

It was the Moira Lake project that brought the group wide recognition and became the springboard for some of its innovative work. By 1992, Moira Lake in the Barmah-Millewa Forest had been permanently flooded for at least 50 years due to high summer flows in the Murray River. There had been a major decline in environmental values, impacting in particular on waterbird and fish breeding. Despite some reservations by the then Murray–Darling Basin Commission, the Wetlands Working Group secured the required funds to complete a series of regulators around the lake. With the lake completely regulated, it began to dry out for the first time in 50 years, with an almost immediate environmental impact. The project was the first to also engage with Aboriginal people through the Yorta Yorta Nation Aboriginal Council.

An unanticipated outcome of the Moira Lake project was the realisation by the Wetlands Working Group that by regulating the water entering and leaving the lake, significant water had been 'saved'. In 1993, the Wetlands Working Group prepared a proposal for the NSW Department of Water Resources, suggesting that an allocation of the saved water be given to them to rehabilitate more wetlands. In 2001, they become the custodians of 32,000 megalitres of government high and low security water for the next eight years. The Wetlands Working Group could also trade a portion of unused water, with the funds to be used to improve environmental flow conditions.

Over eight years, just over 74,000 megalitres of environmental water was delivered to 215 wetlands, covering more than 67,000 hectares. As well as the 150 landowners involved, the project collaborated with Aboriginal groups, irrigation companies, government agencies, and catchment management authorities.

Watering wetlands on private property

The idea of rehabilitating wetlands on private property was first raised with the Wetlands Working Group in September 1995. Many of the wetlands in the Murray catchment are on irrigation farms. Even though they are scattered, collectively they add enormously to the diversity of the landscape. By 2000, many had been dry for up to 30 years, cut off from flow paths of high rivers because of irrigation infrastructure. Following discussions with Murray Irrigation Ltd, the Wetlands Working Group decided it could probably get water into these private wetlands by using the company's irrigation infrastructure.

The project clearly demonstrated that it was possible to deliver environmental water using irrigation infrastructure and pumps. While responses to the waterings varied, some wetlands that had been isolated from their natural water sources for up to 30 years responded with positive ecological outcomes. Consecutive watering events in wetlands greatly improved tree condition, helping to establish a diverse and abundant understorey community. The project also identified growing awareness amongst irrigators about the significance of wetlands, and how their ecological processes could contribute to commercial farming operations. Some irrigators started to put their own precious water into wetlands on their properties, others donated water for wetlands on public land.

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The role of civil society

Today, water for the environment is largely managed and controlled by Commonwealth and state agencies. There is, however, increasing interest and demand from sectors of 'civil society' to be more directly engaged with watering for environmental and/or cultural outcomes.

In 2016, the Wetlands Working Group (now Murray Darling Wetlands Working Group Ltd) joined with The Nature Conservancy Australia to manage and own Australia's first Environmental Water Trust. The Trust is dedicated to improving social and ecological outcomes for the wetlands and rivers of the Basin, and is supported by the Murray–Darling Basin Balanced Water Fund, which brings social impact investment into conservation using market-based initiatives.

This unique model is enabling partnerships between community and government to achieve ecological and social outcomes at a local and landscape scale. It is also demonstrating that cooperation across many stakeholders and jurisdictions is not only possible, but desirable. For example, through the Trust the Wetlands Working Group are working with Aboriginal communities and the Commonwealth Environmental Water Office to integrate cultural and environmental outcomes in New South Wales, as well as implementing projects with private landholders and irrigation companies to deliver water for conservation. This new market-based approach to water management for environmental and social outcomes in the Murray–Darling Basin is a significant and historic moment in Australia's water reform process.

Wetland champions

AS THE MURRAY WETLAND CARBON STORAGE PROJECT APPROACHES THE END OF ITS FINAL YEAR, **SARAH NING** AND **SUSANNE WATKINS** EXPLAIN HOW THE SUCCESS OF THE PROJECT HAS RELIED ON BUILDING STRONG RELATIONSHIPS WITH LANDHOLDERS.

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Landholders and communities have played a large part in the rehabilitation of more than 3000 hectares of wetlands in inland New South Wales, thanks to a partnership between Murray Local Land Services and the Murray Darling Wetlands Working Group Ltd to increase the capacity of wetlands to store carbon.

The Murray Wetland Carbon Storage Project is a six-year initiative funded by the Australian Government, which works with landholders, both public and private, to rehabilitate wetlands. Through the development of strong partnerships, the project has far exceeded the original target of 2000 hectares. Additional outcomes of the project have been the increased capacity of landholders to undertake restoration works and monitor their wetlands, with some landholders becoming local 'wetland champions'.

Wetland degradation and carbon storage

Wetlands are the largest terrestrial carbon store—they are capable of storing 30 to 40 times more carbon than forests. Inland wetlands contain 33 per cent of global soil carbon, despite only occupying 8 per cent of the land surface area. Inland wetlands are also the largest source of the greenhouse gas methane; however, these emissions become negligible over the long-time frames relevant to climate modification. Wetland degradation associated with land use changes, however, may impact their ability to sequester carbon.

Rain-filled wetlands in inland New South Wales

In inland New South Wales, rain-filled wetlands are common in agricultural areas. Here they are threatened by livestock grazing, vegetation clearing, cropping, pests and weeds which impact on their ability to sequester and store carbon. In other wetland systems such as floodplain wetlands, manipulating hydrology, a critical driver of carbon capture and storage, is a common way to improve carbon sequestration and storage. Rain-filled wetlands, however, offer a challenge for the management of carbon sequestration and storage because the hydrology of these systems is almost entirely driven by rainfall.

Landholder partnerships offer hope for degraded wetlands

The Murray Wetland Carbon Storage Project is working with landholders who were directly targeted and driven by economic priorities, presenting a key challenge for increasing their capacity to appreciate, understand and manage their wetlands. To meet this challenge, the project successfully implemented a program which invested staff time to build relationships with landholders, rather than management payments, used contractors to deliver on-ground works to free up landholder's time, and allowed for the development of management actions that integrated their farming activities with biodiversity and carbon storage interests.

The success of the project to date is largely due to the many landholders who have enthusiastically embraced the project.

A 'fit for purpose' funding model has been providing landholders with on-ground works tailored to each individual site with the aim of improving carbon storage and biodiversity.

These works have included:

- revegetation of endemic wetland, riparian and woodland vegetation
- changed grazing regimes, including fencing to exclude stock and alternative watering points
- pest animal and weed control
- educational and community engagement resources and facilities, including signage, bird hides and community events.

Three investment rounds have been completed, with a fourth and final round currently underway. To date 26 landholders have taken part in rehabilitating over 3000 hectares of wetlands in the Murray Local Land Services district.

Wetland monitoring

Through the project's monitoring program, Deakin University's Blue Carbon Lab have found that rehabilitation of freshwater inland wetlands, through on-ground works such as fencing and revegetation, significantly improves soil carbon stocks, increasing further, the longer the wetlands have been restored. Furthermore, rehabilitation of degraded wetlands greatly improves carbon stocks, regardless of the degree of degradation, with sequestration capacity returning in as little as five years.

Websites—www.murray.lls.nsw.gov.au or www.bluecarbonlab.org or www.murraydarlingwetlands.com.au

SALVAGING A SAVERNAKE SWAMP

Farmers Bill and Cecile Nixon participated in the project to store wetland carbon and attract birds back to their Savernake property. Cecile explains that she "wanted to better manage the area to encourage native vegetation growth and to bring woodland and wetland birds back to the site". The Nixons are thrilled to be part of the project and can't wait to see changes to the vegetation and wildlife at their 8 hectare wetland area which is dominated by sedges, rushes, grasses and Grey Box. Cattle used to access the area, though now with the fencing in place the site is protected from trampling stock, particularly during the wet times, allowing for a greater diversity of wetland plants to establish.

BIRDS GET A NEW HOME AT BALLDALE

Through the project the McDonalds fenced an 82 hectare wetland (Emu Swamp) to manage stock grazing, and installed a bird hide and nest boxes. Ross and his wife Lea wanted to encourage birds and animals to the wetland and establish a few more trees around the wetland edge. The McDonalds consider the wetland to be a really attractive part of the farm. They have installed a bird hide for bird watching so they can learn to identify different bird species. Ross said there were several farmers in the area working on wetland and native vegetation conservation on their properties and together they are building a network of wildlife habitat links. "By each of us doing a little bit we can make a real difference to the local environment". The wetland has responded well to the altered grazing regime with an improved cover of wetland plants emerging at the site, providing a home for many waterbirds, which the McDonald family enthusiastically view from their bird hide.

Photos. Opposite: Intermediate Egret, Bernard Clark; Little Black Cormorant, Chris Tzaros. Above: The Nixons and the McDonalds, Murray Local Land Services.

Touch wood

BRITT GREGORY DESCRIBES THE HANDS-ON WORK BEING DONE BY THE LOCAL COMMUNITY TO PROTECT, LINK AND ENHANCE REMNANTS OF KYNETON'S GRASSY WOODLANDS.

Granite outcrops emerge from the vast, windswept rolling hills. Scattered majestic gums tower overhead, and at times are twisted and gnarled, shaped by the years. Wattles, shrubs and saplings grow among a lush carpet of delicate wildflowers, native grasses, mosses and lichens. Pipers Creek meanders through the striking landscape with its permanent waterholes and fringing vegetation, providing critical habitat linkage for a range of species in this landscape of fragmented habitat opportunities.

It may come as a surprise to see a woodland project featured in a river management magazine, but healthy waterways are essential components of all landscapes, and one small creek to the north-east of Kyneton, in Victoria's Macedon Ranges, has become the centrepiece for the Kyneton Woodlands project.

Grassy woodlands, once widespread, are now considered highly threatened with only 20 per cent remaining, mostly as small and isolated patches. Rich in biodiversity, over 240 species of indigenous plants have been recorded in the 24,000 hectare Kyneton Woodlands project area, including populations of the nationally threatened Clover Glycine (*Glycine latrobeana*) and Matted Flax-lily (*Dianella amoena*). Some of the woodland patches are also classified as 'White Box-Yellow Box-Blakely's Red Gum Grassy Woodland'; a nationally threatened ecological community.

With funding from the Australian Government, the North Central Catchment Management Authority has been working closely with almost 60 landholders in this iconic landscape for the past five years to protect, link and enhance these remnant woodlands.

Some of this valuable remnant vegetation remains largely untouched because of the inaccessibility of the rocky terrain. This has resulted in some rare areas of relatively intact grassy woodlands.

These patches of grassy woodlands are at great risk from threats such as invasive weeds, and natural events such as fire or periods of drought. To assist their long-term survival, the Kyneton Woodlands project worked with the local community to link, buffer and expand these patches with consideration of existing terrestrial vegetation and waterway linkage opportunities.

Wildflowers such as the Golden Cowslips shown above can thrive after grazing livestock are removed. Photo above and opposite North Central Catchment Management Authority.

Pipers Creek is an important feature of the project area. A 24 kilometre intermittent waterway, the creek flows through granite, basalt and sedimentary hills, before entering the mid reaches of the Campaspe River at the geologically significant Barfold Gorge.

Pipers Creek provided the opportunity to achieve the significant landscape-scale objectives of the project. Fortunately, the adjoining landholders also shared in this vision resulting in a continuous, protected corridor along 10 kilometres of Pipers Creek—that's almost half of the entire length of the waterway! The areas protected under the project extended beyond the riparian zone and up to 200 metres wide in some areas, as the Australian Government investment objectives were about enhancement of biodiversity. This often extended away from the waterway and up to nearby remnants along hilltops and also connected vegetated roadsides and areas of public bushland, resulting in a network of corridors across the landscape through which native fauna can move.

While the Kyneton Woodlands project concluded on 30 June 2017, it provided a ground swell of community interest. Excitingly, in one small creek in the project area we have re-discovered the Southern Pygmy Perch, a species listed as vulnerable on the Advisory List of Threatened Vertebrate Fauna in Victoria (the Murray–Darling lineage of the species). Using environmental DNA technology, we are planning to undertake further sampling for this and other fish species in spring 2017. We're hopeful additional recordings may well provide the justification for a future riparian project for the remaining length of Pipers Creek and adjoining Jews Harp Creek.

In partnership with many groups and organisations, since 2012 the Kyneton Woodlands project has:

- protected and enhanced 1280 hectares of remnant grassy woodland vegetation
- planted more than 64,000 native seedlings
- direct seeded 126 kilograms of native seed
- increased the extent of grassy woodlands by 290 hectares
- installed 87 kilometres of fencing to protect vegetation from livestock
- protected and revegetated a continuous 10 kilometre stretch of Pipers Creek
- treated invasive weed species over an area of 120 hectares
- engaged almost 1000 people in biodiversity awareness raising events.

Grassy woodlands that were once widespread are now considered threatened with only 20 per cent of this vegetation type remaining in the project area.

Inset: Aerial view of Pipers Creek showing direct seeding lines. Photo Australian UAV.

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Interactive Story Map—http://bit.ly/kynetonwoodlands

Fishin' the creeks

KATHRYN STANISLAWSKI AND **PHILIP SLESSAR** DELIVER INFORMATION ON HOW IRRIGATION CREEKS CAN ALSO SUPPORT FISH.

Main: Pyramid Creek. Inset: Murray Cod in Gunbower Creek. Opposite: Gunbower Creek. All photos Kathryn Stanislawski.

When you think of the conduits for delivering irrigation water, you might conjure up an image of straight cut, steep sided, bare, sometimes plastic-lined channels, adjacent to irrigated farmlands. In contrast to this image is northern Victoria, where two major creek systems, the Gunbower Creek and Pyramid Creek, form a major part of the Torrumbarry Irrigation Area delivery system.

These creeks became part of the irrigation system in 1923, with the construction of the Torrumbarry Weir, and since then have been operated just like a channel for the supply of water for irrigation and towns. Under the typical annual irrigation flow regime, water is delivered when there is irrigation demand, and the creeks cease to flow during winter when the irrigation system is shut down. Despite this intensive impact on creek flows, 13 out of the 22 native fish species known to have existed in these creeks are still present today, albeit in very low numbers.

In Victoria, a state-wide method (referred to as the FLOWS method) is used to establish ecological objectives and determine the environmental water flow regime using the natural flow paradigm. Using this approach, environmental water is used to recreate the natural range and variability of flows. In Gunbower Creek and Pyramid Creek there are few natural flows. Even in the most recent large floods of 2010 and 2016, there were no unregulated (not ordered) flows through Gunbower Creek, and Pyramid Creek was mostly protected from flooding by upstream storage in Kow Swamp.

Gunbower Creek

The challenge, in such highly-regulated systems, is to deliver environmental flows without impacting on irrigation supply. To achieve this, in Gunbower Creek the delivery of environmental water has used a conceptual model of the Murray Cod life history to develop a full-year hydrograph to drive environmental flow delivery, without compromising irrigation flows. We have targeted Murray Cod, because our monitoring revealed a marked decline in fish numbers, and little evidence of recruitment in the population since the Millennium Drought.

The conceptual model identified the following flow components as being vitally important for Murray Cod—*winter flows*, *spring rise*, *stable flows*, *engaging the littoral zone* and *ramp down*.

Of these, the winter flow component was the easiest to achieve as we are the only player in the system during the off-irrigation season, so can achieve this target without impacting on other water users. Irrigation demand and supply generally achieves the spring rise, littoral zone and ramp down flow components.

The stable flow component is the most challenging and to achieve it we used environmental water to raise the water level, filling the gap between irrigation demand and our target flow rate. This enables us to meet our target hydrograph, and to smooth out the overt variation.

Review of past hydrographs from weirs in Gunbower Creek provided examples where, within a few hours, flow rates changed by more than 300 megalitres per day. This situation occurs because of automation in the irrigation system enabling a short turn around time for irrigators to call on water. While good for irrigators, it has come at the cost, with much fluctuation in flow over some regulators. We were concerned that these fluctuations may discourage male Murray Cod from tending their nest around the critical November breeding period.

To combat this overt flow variation, we set our target environmental flow rate quite high, well above the usual irrigation demand, so our flow operators had the flexibility needed to be able to achieve the stable flows. This enabled us to smooth the hydrograph and reduce sub-daily variation.

Pyramid Creek

In Pyramid Creek a similar approach was used to provide flows to stimulate fish movement, particularly Golden and Silver Perch, through the lower Loddon River and the Pyramid Creek system.

Pyramid Creek was dredged in the 1960s to create a greater channel capacity, destroying all geomorphic variability and turning the creek into a canal. Flows in Pyramid Creek meet the Loddon River at Kerang Weir, where consumptive water is diverted to irrigators via the Kerang Wetlands and conduits flow to the west of the Loddon River. We recognise now that Pyramid Creek is an important conduit between the Loddon River system and the Gunbower Creek system, with the high-value wetland habitat Kow Swamp, an important environmental asset connecting these two systems.

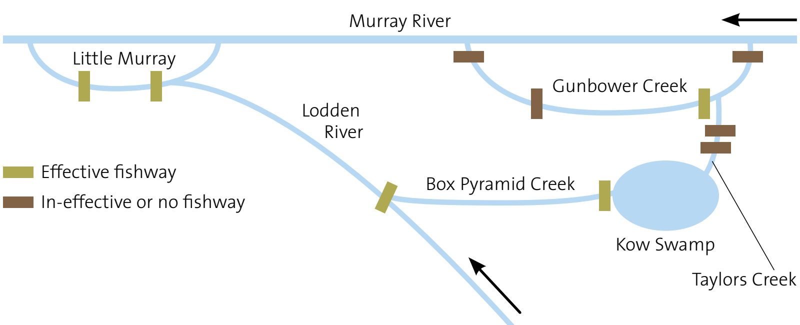
We decided to target our flow at two critical components to enable fish to move between the two systems. As with Gunbower Creek, we reintroduced the winter low flow, with the Pyramid Creek FLOWS study also prescribing high flow events to stimulate upstream fish movement from the Murray River.

In April 2017, following the completion of a fish passage structure at Kow Swamp, we delivered an environmental flow through Pyramid Creek and over Kerang Weir during peak irrigation season.

To achieve the flow required to stimulate fish movement, while not compromising consumptive needs, environmental water was delivered with consumptive water to Kerang Weir. To supplement the water that was diverted for irrigation requirements, water was also delivered to meet the flow at Kerang Weir, from the Loddon River. Combining these flows provided the balance between consumptive water in Pyramid Creek, and the flow required downstream of Kerang Weir to encourage fish movement.

The resulting flow rate at Kerang Weir stimulated the movement of large- and small-bodied native fish species through the fishway at the weir—some moved upstream into the Loddon River, and others through Pyramid Creek, using a new fish lock accessing Kow Swamp.

Our work on Gunbower and Pyramid creeks will be linked as part of the Native Fish Recovery Plan being implemented in northern Victoria. The delivery of environmental flows is only one component of a large breadth of work, identified in the long-term vision of this Plan as being required to improve overall river health and improve conditions for native fish. Other complementary actions are also being implemented, including the installation of fishways to open up historic pathways, reinstating instream woody habitat, and undertaking fencing and revegetation works.



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DECISIONS, DECISIONS, DECISIONS

PAUL MAISEY EXPLAINS THE THREE OPTIONS FOR COMMONWEALTH ENVIRONMENTAL WATER HOLDINGS.

Nearly 10 years ago, on 3 September 2007, the Commonwealth *Water Act 2007* obtained Royal Assent. The Water Act established Commonwealth environmental water holdings and the position of the Commonwealth Environmental Water Holder (CEWH) to manage the holdings. In August 2008, Ian Robinson was appointed as the first CEWH. By 30 June 2009 there were 65 gigalitres of water entitlements in the Commonwealth environmental water account.

From this starting point, the holdings steadily increased and at 30 June 2017, the third CEWH, David Papps, was responsible for the management of 2562 gigalitres of entitlements. These entitlements will be held by the Commonwealth in perpetuity for the purpose of protecting and restoring floodplains, wetlands and river systems across the Murray–Darling Basin (see diagram opposite).

The Commonwealth portfolio comprises more than 100 different types of water entitlements across 22 catchments in the Basin. Water entitlements, whether they are owned by the CEWH, a farmer or any other entity, provide an annual share of the available water resource within a particular catchment or river system.

Every year, the relevant state government allocates a volume of water to each entitlement. How much is available to allocate, depends largely on the climate—how much rain has fallen and how full the dams are.

The different types of water entitlements held by the Commonwealth have characteristics that define where and how the water can be used: whether the water is in a surface or groundwater (aquifer) system, where the water can be accessed, whether it is linked to a regulated water source such as a dam or reservoir, and the reliability of the water source—that is, whether you would expect to receive an allocation in most years or only intermittently. The characteristics, rights and rules of each entitlement are set by the state governments and apply to all entitlement holders.

When the CEWH's position was established in 2008–09, the Murray–Darling Basin was in the midst of the Millennium Drought, a period of historically low rainfall across the entire Basin. Due to the dry conditions, the CEWH's initial 65 gigalitres of entitlements were only allocated 14 gigalitres of water. That's about 6000 Olympic swimming pools. Of this, 13 gigalitres were used during the water year, with the remaining gigalitre carried over for use in 2009–10. The first place to receive Commonwealth environmental water was the Chowilla Floodplain in South Australia, where 338 megalitres were pumped into a few creeks and billabongs in March 2009.

Administering the annual allocation of Commonwealth water is a complex task and involves the management of more than 200 separate water accounts. This is done in exactly the same way as an irrigator would manage their water account, including the payment of annual fees and charges to the relevant state water authority. The CEWH also has the same management choices as other entitlement holders—to use, to carryover or to trade the allocation.

ABOVE: LOWER LACHLAN PHOTO ERIN LENON. RIGHT NORTH REDBANK (WYNBURN), PHOTO CEWO.

Little Hattah before and after environmental water. Photos throughout provided by the CEWO.

The decision to use water

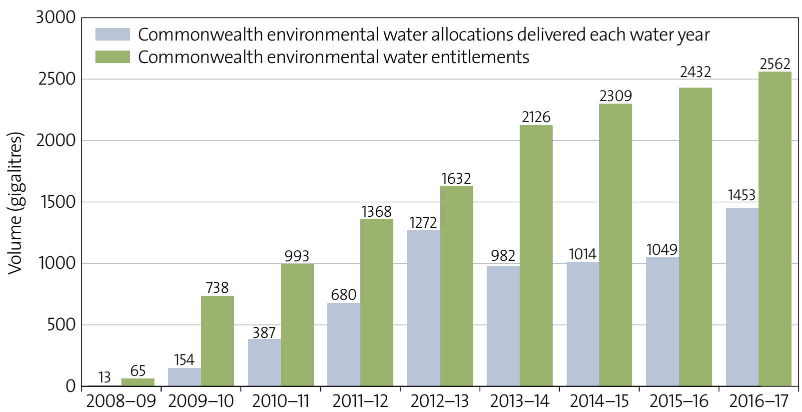
The water allocated each year to the Commonwealth's entitlements is used to protect and restore the environment of the Murray–Darling Basin. Over the past nine years a total of 7003 gigalitres of water allocated to the Commonwealth's holdings has been delivered for this purpose across 16 catchments, equivalent to the volume of 14 Sydney Harbours (see histogram).

Examples of how water has been used by the Commonwealth with state delivery partners are described elsewhere in this edition of *RipRap* on the following pages.

The decision to carryover water

A large number of water accounts held by the Commonwealth have water allocation 'carryover' rules, which allow allocated water remaining in accounts at the end of the year to be carried over to the following year. Carryover rules are set by the state governments and vary for different entitlements across the Basin.

Like any other entitlement holder, the Commonwealth uses the carryover rules to provide flexibility in the timing of water use from one year to another. This flexibility can be important when meeting environmental requirements in late winter and early spring, typically to maintain or enhance natural hydrological cycles, before new season allocations have been announced.



FOR FURTHER INFORMATION
https://www.environment.gov.au/water/cewo/about/water-holdings

Carryover also enables water to be held in storages within catchments that typically experience extreme cycles of wet and dry conditions. In this situation, carryover allows the CEWH to reserve water allocated in wet years for use in subsequent dry years, for the purpose of protecting and maintaining important environmental assets.

Carryover of environmental water is often misunderstood or misrepresented, but thanks to the way carryover rules are applied, no water entitlement holder can fill up dams to the exclusion of other water users. Whether a year is wet or dry determines whether a dam spills or not, rather than the water management choices of any individual entitlement holder.

The decision to trade

To date, the CEWH has not purchased water entitlements or allocations. All purchasing of water for the Commonwealth portfolio is done at arm's length by the Department of Agriculture and Water Resources. However, since 2014, the CEWH has sold approximately 33 gigalitres of environmental water allocations — that is, 'temporary water' in three separate tenders, raising $9.7 million in revenue. These funds are primarily being held in reserve to purchase water at a future time.

The sale of 33 gigalitres represents less than half of one per cent of Commonwealth environmental water delivered to date, and has not had a material impact on the achievement of environmental watering objectives.

The CEWH has established a water-trading framework in consultation with water market participants. The framework ensures that the Commonwealth sells water in a responsible, fair, and equitable manner. It includes measures to minimise impacts on the water market and steps to address any potential access to market sensitive information.

Nearly 10 years after the creation of Commonwealth environmental water holdings, the portfolio continues to grow towards the recovery targets determined by the Basin Plan. For more information on the water holdings please refer to the website.

CLEVER WAYS WITH WATER

Location of the Long-Term Intervention Monitoring (LTIM) project's 'selected areas'.

In seven regions across the Murray–Darling Basin there is a lot of monitoring, measuring, analysing and testing going on. Why? To learn how environmental water impacts native plants, animals and ecosystems in different riverine environments. The focus of this work is to collect data across seven 'selected areas' (see map at left) in a consistent manner, to better understand the contribution of environmental water to protecting environmental assets, as well as enabling quantitative Basin-scale evaluations. These evaluations, undertaken over five years and at a cost of $30 million, will provide managers, planners and local communities with the ability to reflect, refine and adapt their environmental water management to gain the best on-ground results.

What does this mean in practice? It means that the long-term intervention monitoring can be used to improve outcomes from environmental water. Adaptive management of environmental flows is occurring in all 'selected areas' over short-time scales, with evaluation results being used in real-time communications to inform environmental watering decisions, as well as underpinning annual watering plans and on-ground management decisions.

Longer term, the project is providing a wealth of targeted empirical data to help us better understand ecological responses to flow restoration in Australia's most flow-impacted river systems.

Lake Tarwong in May 2017. Photo Fiona Dyer, University of Canberra.

Scientist George Giatas (SARDI) counting Bony Herring in the Lower Murray in April 2016. Photo Alana Wilkes, CEWO.

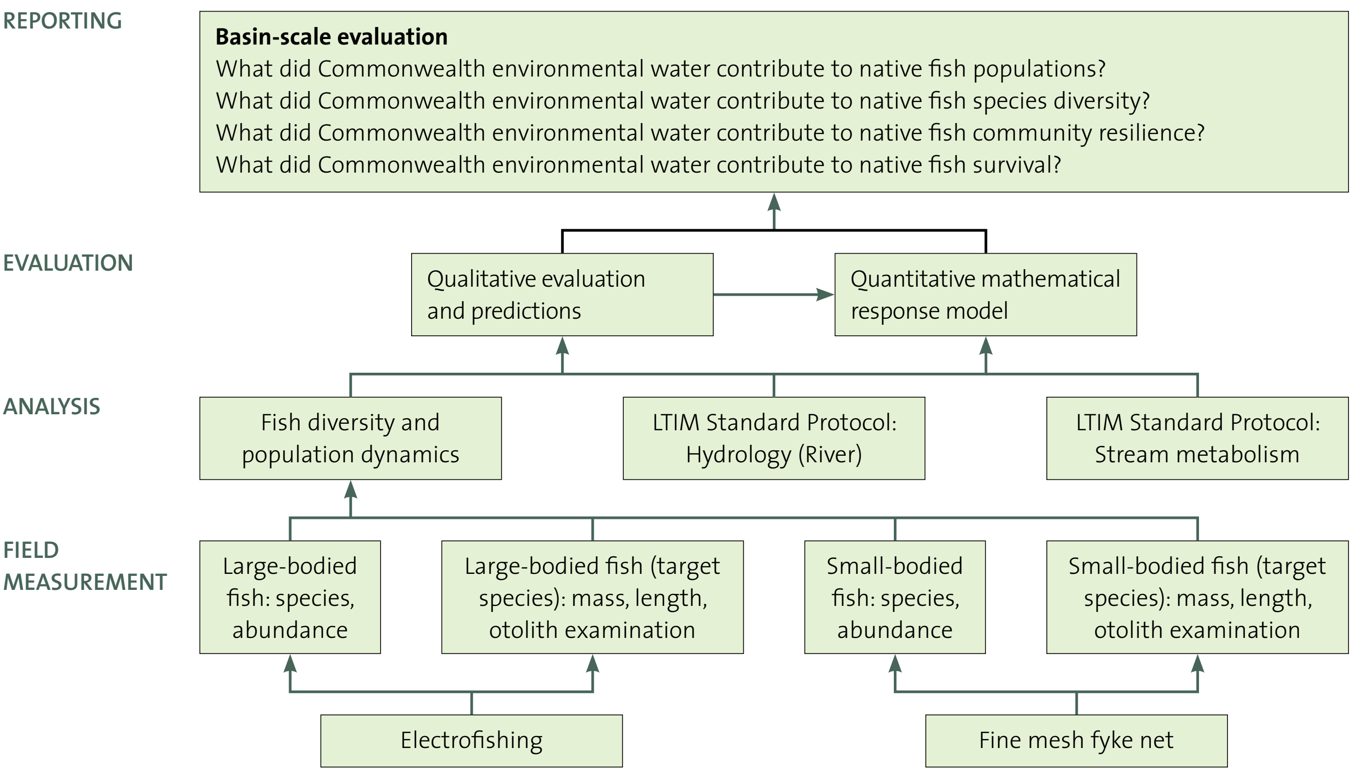
Adaptive management in practice: Goulburn River case study

Environmental water delivered to the Goulburn River during the 2014–15 water year is a good example of environmental water holders working in close cooperation with local water delivery partners, community groups and scientific monitoring teams, to design watering events that lead to good ecological outcomes, while meeting community needs.

Based on scientific results from previous years, environmental water deliveries to the Lower Goulburn River focused on increasing base flows throughout the year to increase food and shelter for native fish and water bugs. Additional 'freshes' (pulses of higher river flow) were then delivered in spring and autumn to provide cues for native fish breeding and passage, maintain water quality and support plant growth on riverbanks.

These deliveries for the environment were timed in consideration of community needs and feedback from meetings between the Commonwealth Environmental Water Holder and community representatives, including local members of parliament. What came out of these meetings was a two-week window of low flows being provided in between November water 'pulses' to give irrigators access to pumps. All pulses were timed for completion by 1 December to avoid potential disruption to local angling activities.

Below: LTIM project hierarchy of objectives, using 'fish (river)' as an example.

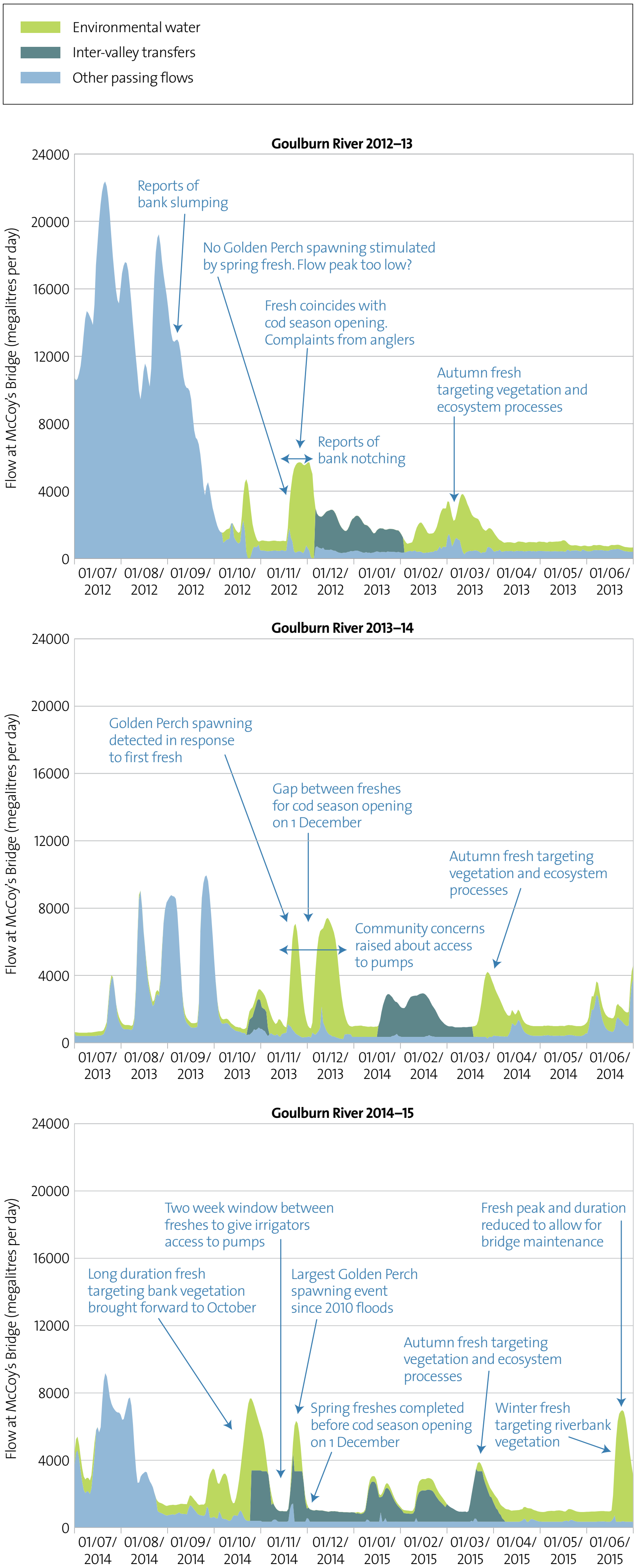


Long-term intervention monitoring undertaken on behalf of the Commonwealth Environmental Water Office, and led by the University of Melbourne in partnership with local water managers and multiple research institutions, confirmed that the environmental water delivered during spring played an important role in triggering the largest ever recorded Golden Perch spawning event for a managed flow in the Goulburn River.

Monitoring also found after the spring freshes, increases in the number and types of water bugs and the re-establishment of flood-tolerant plants on the riverbank. These increase in bugs and plants are important for providing food and habitat for native fish, as well as for stabilising riverbanks.

Long-term intervention monitoring and evaluation is ongoing in the Goulburn River, with water holders and local water managers working closely with scientific and community partners to ensure that the health of this important system continues to improve, and that native fish not only spawn, but grow to adulthood.

The three figures to the right demonstrate how environmental water has been used in the Goulburn River and the many different factors contributing to management decisions.



Plumed Whistling Ducks at Gwydir Wetlands.
Photo Peter Knock Ecological Australia.

Southern Bell Frog at Yarradda Lagoon, July 2017. Photo Jarrod McPherson, Charles Sturt University.

Mid-Murrumbidgee wetlands: Yarradda Lagoon

Yarradda Lagoon in the mid-Murrumbdigee wetlands is another positive example of how monitoring and evaluation can shape the way environmental water is delivered to achieve improved ecological outcomes.

Historically, Yarradda Lagoon was frequently connected to the main river channel and very rarely dried. Like many wetlands in the mid-Murrumbidgee, however, the reduced frequency of minor and moderate river flows caused the wetland to dry out for several years between 2001 and 2010.

Recovery of plant and animal communities at Yarradda Lagoon was guided by a combination of longer-term data collected from the wetland between 1998 and 2014, and the more intensive monitoring and evaluation activities undertaken as part of the Commonwealth Environmental Water Office's Long Term Intervention Monitoring project.

In 2014, monitoring of Commonwealth environmental water led by Charles Sturt University, identified very small patches of Spiny Mudgrass, Tall Spike Rush and Fringe Lily. These are relatively long-lived wetland plant species and require annual inundation, as they can only tolerate short (preferably less than one year) drying periods. Follow up environmental watering was scheduled to allow the cover and extent of these species to increase. As vegetation communities started to recover, wetland dependent animals also arrived, with the vulnerable Southern Bell Frog successfully breeding at Yarradda Lagoon in 2015–16.

Re-establishing these once abundant species was driven by feedback to the Commonwealth Environmental Water Holder from the monitoring team. Scientific input demonstrated that wetlands like Yarradda that have been dry for extended periods, can be slow to recover and have low abundance of water-dependent species. With repeat environmental watering, however, the abundance of native species increased which is a great outcome for the environment and community alike.

The Commonwealth Environmental Water Office has been working closely with New South Wales state water managers and the monitoring team since 2014 to design watering events of this nature. Repeat environmental watering of Yarradda Lagoon over the past three years has not only supported the re-establishment of native species, but also led to a steady increase in species diversity and percentage cover after long periods of decline.

The CEWO would like to thank the hard work and dedication of the scientists involved in the collection and evaluation of intervention monitoring data under this project.

FOR FURTHER INFORMATION

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IBIS Hey, heavenly Booligal!

ERIN LENON, BRUCE CAMPBELL, EBONY MULLIN AND LIZ SYMES

LOOK TO THE SKY AND THE LAND AT BOOLIGAL.

During winter to spring of 2016, rivers in the southern and central regions of the Murray–Darling Basin experienced well above average rainfall, which led to widespread flooding. In the Lachlan River system, major riverine flooding culminated in one of the largest flood events recorded, and attracted hundreds of thousands of waterbirds to the Booligal Wetlands.

ABOUT BOOLIGAL

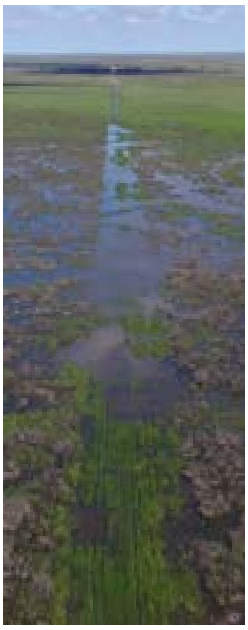
The Booligal Wetlands are typical of lowland arid river systems of the Basin being very flat, with braided channel systems. The creeks and wetland areas have widespread Lignum shrublands which during wet times flood extensively. Vast numbers of waterbirds, especially Straw-necked Ibis, breed in the wetlands in sustained wet conditions.

Boom times at Booligal

Following reports from neighbouring landowners of large numbers of ibis gathering and trampling Lignum to nest, scientists from University of Canberra, University of NSW, NSW Office of Environment and Heritage (NSW OEH), and the Commonwealth Environmental Water Office (CEWO) geared up to survey and monitor the site. It was soon realised that a large colony of birds had established at a site where no breeding had previously been recorded.

During the flood the colony was dynamic, and breeding pairs kept flocking to the wetland as the flood progressed. The flood at Booligal lasted from early September to mid-December. Over this time 110,000 nests were estimated—a very large colony!

Towards the end of the flood a second smaller colony established at a previously recorded breeding site nearby, with 8000 nests of predominantly Straw-necked Ibis (more than 80 per cent) and smaller numbers of Australian White Ibis, Glossy Ibis, Royal Spoonbill and Nankeen Night-Heron. The first breeding event came to an end approximately 90 days after it began, and by March 2017, the juvenile birds fledged at the second colony site.



Bucking the trend

The results at Booligal are exciting because waterbirds are in serious decline across the Murray–Darling Basin, with long-term research showing a reduction in abundance, diversity and numbers. These reductions, according to well-known bird researcher Richard Kingsford and his team, are associated with changes to long-term flow volumes. In light of this, the Booligal Wetland event is even more important to the sustainability of Basin bird populations.

Straw-necked Ibis, a colonial waterbird species, require a sizable flood event to breed. They live an estimated 10–16 years, and are sexually mature around 3–4 years. The birds need to breed successfully twice in their lifetime to maintain population size. With the changes to flow regulation in the Basin, there are longer periods between floods events: while intermittent large flood events still take place, the small to medium floods are compromised, and are often smaller and shorter duration. It is these smaller flows which are needed to maintain the vegetation and food resources in good condition. For waterbirds, the impacts of less habitat and shorter, less frequent floods results in less breeding (or failed breeding attempts) which have a cascading negative impact on population numbers.

A 'new' breeding site?

Over 110,000 nests were surveyed bordering/adjacent to Booligal Station. There is no previous record of breeding at this site.

- Largest breeding colony in Booligal Wetlands since the 1980s
- Mainly Straw-necked Ibis (more than 90 per cent), with Australian White Ibis, Glossy Ibis and Royal Spoonbills around the edges
- Other species included Magpie Geese and Australian Bitterns
- Multiple eggs per clutch, multiple clutches per nest were observed
- High breeding success (fledging)
- Estimates of more than 500,000 birds.

What role did Commonwealth and New South Wales environmental water play in the 2016–17 event?

The question for environmental water managers is to what extent did the wetter conditions in combination with environmental watering since 2012 contribute to a larger bird breeding response?

In order to ensure a successful bird breeding colony on the back of a natural flood many factors need to be right. Water levels need to be maintained without sudden drops throughout the event. Lignum or other nesting vegetation needs to be in good starting condition to support nests with sometimes up to 15 nests being built on one plant. Foraging grounds with plentiful food need to be available for both the adult birds as they feed young and for new juvenile birds after they fledge.

Since 2011 the Commonwealth Environmental Water Holder and NSW OEH have directed environmental water to the Booligal Wetlands to restore and maintain wetland and floodplain health. These flows have ranged from small flows in dry years to large whole of system flows that were designed to follow up post drought breaking floods in 2011–12, consolidating a recovery of wetland vegetation including the Lignum vital for large bird nesting colonies. These deliberate contributions have augmented flows from other sources including high local rainfall totals and translucent flow releases in 2015. All of these sources of water have contributed to improving vegetation condition.

This year environmental water was delivered to the Booligal Wetlands to maintain the second breeding event. As flood levels were dropping away environmental water was used to slow the flood recession to maintain water levels to avoid birds abandoning their nests, helping to ensure the large majority of chicks fledged.

The role of entitlements held for the environment is to allow booms to finish and to ensure that busts are not unnaturally long—or the next boom won't occur.

FOR FURTHER INFORMATION
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Getting the outcomes

The CEWO and NSW OEH work together and invest in the delivery, oversight and monitoring of environmental water in the Lachlan catchment. A team of managers, landholders and scientists meet regularly to discuss monitoring results, and to plan for any problems or water needs.

A novel monitoring approach was used in 2016–17 to count nests and measure the colony extent using unmanned aerial vehicles (UAVs), or drones. This is believed to be the first UAV survey of a major bird breeding colony in Australia outside of Kakadu.

In addition to the UAV work is Heather McGinness's ibis satellite tracking project that is also following bird movements. The results from both projects will provide us with important information about how we can best supporting waterbirds and the ecosystems that support them with environmental water delivery. You can read about Heather's work starting on page 6.

What is intriguing about the Booligal response is that the ibis tracking study so far, shows little interaction between the eastern wetland sites such as the Macquarie Marshes and Barmah-Millewa wetlands, with western sites such as Booligal. It is too early to draw firm conclusions, however future results will be viewed with interest to see whether these preliminary observations are repeated.

Watch this space

With a new watering season upon us, we will use the results of these projects to inform our environmental water management decisions. Flood events are undoubtedly essential for productive and thriving rivers, floodplains, wetlands, and the species that depend upon them. Along with our partners, we will continue to deliver environmental water to maintain these special places to offset the effects of river regulation.

IMAGES PROVIDED BY THE CENTRE FOR ECOSYSTEM SCIENCE, UNIVERSITY OF NEW SOUTH WALES, JUST McGANN.

Southern syndicates

MICHELLE CAMPBELL UNLOCKS THE MYSTERY AND EXPLAINS THE MUTUAL BENEFITS OF COMMONWEALTH ENVIRONMENTAL WATER IN SOUTH AUSTRALIA.

Environmental water can be a difficult concept to grasp, as most Australians are not directly involved in planning, delivering or monitoring what environmental water can do for our native plants and animals.

The Commonwealth Environmental Water Holder has made a clear decision to engage with local communities to get them involved in achieving local watering outcomes that contribute to Basin-wide environmental targets. To do this, partnerships to deliver environmental water have been established between the Commonwealth Environmental Water Holder and local community organisations, the first of which commenced in 2012 with the Nature Foundation SA of South Australia (NFSA).

Main: The Coorong is culturally significant to the Ngarrindjeri, and environmental water plays an important role in protecting and restoring this unique place. Insets. Top left: David Papps (Commonwealth Environmental Water Holder) with Peter Duggin (Chair of Renmark Irrigation Trust) and Humphrey Howie (Chair of Renmark Irrigation Trust Environmental flows committee). Bottom left: David Papps with members of the Ngarrindjeri Regional Authority. Right column: South Australian delivery partners.

FOR FURTHER INFORMATION
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http://www.environment.gov.au/water/cewo/delivery-partners
http://www.environment.gov.au/water/cewo/local-engagement

Over the past five years, the NFSA has delivered nearly 5 gigalitres of Commonwealth environmental water to more than 40 sites in the South Australian Murray–Darling Basin, involving more than 200 volunteers. These volunteers are local landholders or land managers who use their own pumps or equipment, move sprinklers, count bird numbers or frog species, and take before and after photos of their local sites.

Following on from the success of the NFSA collaboration, in 2015 a three-year partnership was established with the South Australian Murray–Darling Basin Natural Resources Management Board. The board works closely with land managers, private landholders, community groups, local councils, non-government organisations, national parks, Ngarrindjeri Regional Authority and the First Peoples of the River Murray. One success story of this partnership is the conservation work helping to restore populations of the nationally endangered Murray Hardyhead at Berri Basin and Dishers Creek, both salty irrigation drainage basins in which Murray Hardyhead thrive. Commonwealth environmental water is delivered to these sites to keep the water salinity at levels optimal for Murray Hardyhead recruitment and breeding (see full story at www.finterest.com.au).

The Accolade Wines/Banrock Station group also entered into a partnership with the Commonwealth Environmental Water Holder in 2015 to deliver water to their internationally-listed Ramsar site, where the nationally endangered Regent Parrot is found. Environmental water is being used to maintain the condition of River Red Gum trees, which are preferred nesting habitat of the Regent Parrot. Water also supports the understorey vegetation, some of which is likely to be an important food source of the Regent Parrot, which helps supports the survival of chicks and juvenile birds.

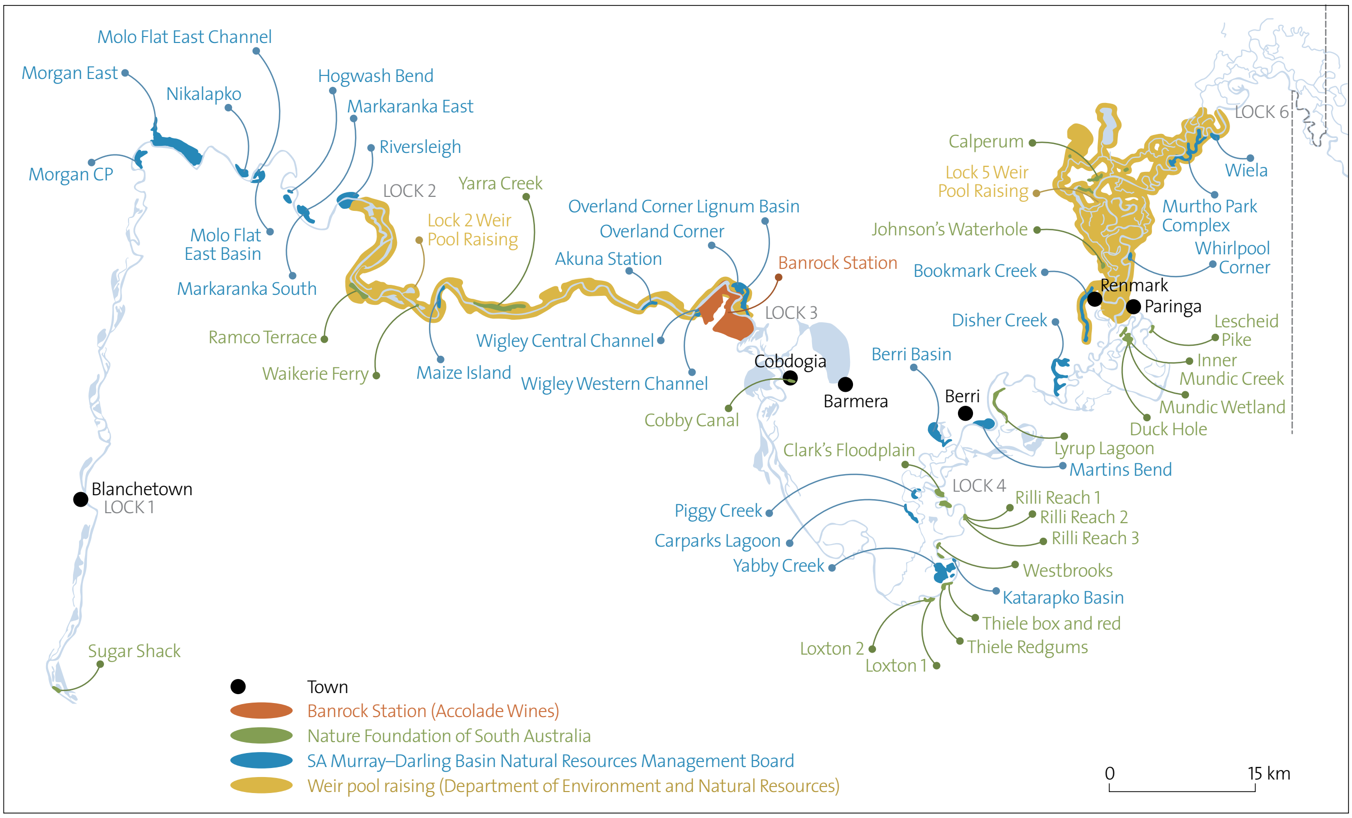
In 2016, the Commonwealth Environmental Water Office signed two new partnerships with the Ngarrindjeri Regional Authority and the Renmark Irrigation Trust.

The partnership with the Ngarrindjeri Regional Authority will provide environmental and cultural benefits for wetlands in the lower River Murray and surrounding Coorong and Lower Lakes in South Australia. Working on ground with the Ngarrindjeri means that local knowledge and cultural values can be incorporated into the delivery of environmental water, leading to both cultural and ecological outcomes. There are many opportunities where environmental and cultural water needs intersect; for example, supporting growth of the native reeds used in basket weaving. Species such as pelicans, turtles and River Red Gum that are of cultural significance to the Ngarrindjeri, and will also benefit from the delivery of environmental water.

This partnership forms part of a concerted effort by the Commonwealth Environmental Water Holder to work with Indigenous people to plan, deliver and monitor the use of environmental water across the Basin.

The five-year partnership with the Renmark Irrigation Trust will enable the delivery of Commonwealth environmental water to wetland and floodplain sites in the local region, using the Trust's extensive irrigation infrastructure during the irrigation off-season. This offers economic and environmental benefits, while also potentially increasing tourism by restoring a degraded floodplain, and boosting the health of Black Box and River Red Gums near a major regional town.

Partnerships like these remove the mystery of environmental water by getting locals involved in all aspects of its management and delivery. The Commonwealth Environmental Water Holder is grateful for the expertise, advice, feedback and support provided by its delivery partners across the Basin and appreciates their help in achieving Basin-wide ecological objectives.



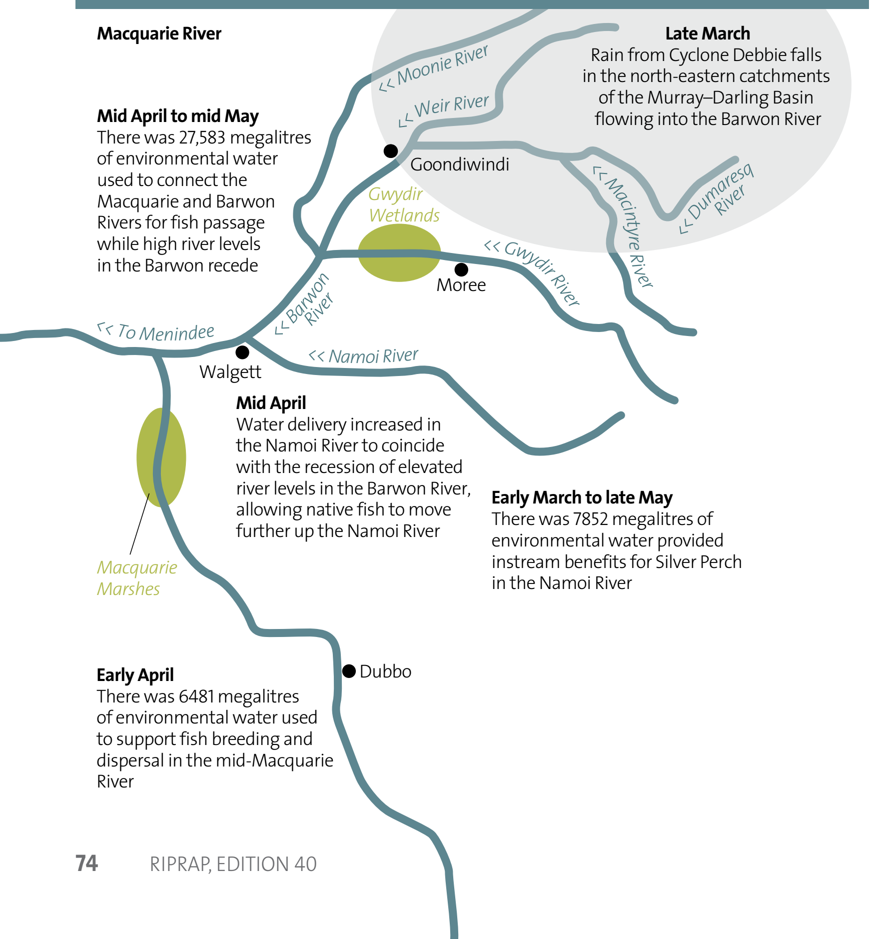
Sites where Commonwealth environmental water was distributed in the Riverland by delivery partners including NFSA, Banrock Station, SA Murray–Darling Basin Natural Resources Management Board and the Department of Environment and Natural Resources during 2015/16.

Northern passage

ADRIAN CLEMENTS EXPLAINS HOW ENVIRONMENTAL WATER AFFECTS FISH IN THE NORTH OF THE BASIN.

In March and April 2017, swollen inland rivers, as a result of remnant rainfall from Cyclone Debbie, presented an opportunity to deliver environmental water for native freshwater fish. Monitoring had shown that a large native fish spawning event had occurred in the Barwon River in spring 2016. For the first time, environmental water was delivered in the Namoi and Macquarie catchments to deliberately connect with flows in the Barwon to enhance connectivity and enable greater fish dispersal between these systems.

> In dry to average years, when flows are low, environmental water can be used to help connect in-channel waterholes, allowing fish to move up and down rivers in dry times. Medium-level flows are used to wet river benches, returning valuable carbon and nutrients to the river for primary production, and increasing the amount of food available for fish and other aquatic fauna. When flows are naturally high, such as in the Barwon River in April 2017, environmental water can be used to enhance connectivity between rivers allowing for greater dispersal of fish throughout the river system.



In the Namoi River, which joins the Barwon near the township of Walgett, environmental water was already being delivered as the peak of the Barwon flows reached the Namoi. This delivery was designed to maintain base flows in the river channel to support 50,000 Silver Perch fingerlings released by the New South Wales Department of Primary Industries as part of a conservation stocking program. With the advent of flows from Cyclone Debbie, water delivery was increased to connect the Namoi and Barwon Rivers during the recession of the elevated river levels in the Barwon, thereby allowing fish to move further up the Namoi. An estimated 7852 megalitres of environmental water was used between the beginning of March and the end of May 2017 with the aim of boosting native fish numbers, particularly Silver Perch.

At the same time, the Macquarie River, which joins the Barwon River approximately 80 kilometres downstream of the Namoi, was also experiencing wetter conditions following heavy rain in March. With the rains bringing flows from tributary streams, combined with warm weather, an ideal opportunity was created for environmental water to be delivered to help generate a short and sharp flow to encourage native fish movement downstream of Burrendong Dam and through to the Macquarie Marshes.

Over a period of eight days in April 2017, an estimated 6481 megalitres of environmental water from the New South Wales Office of Environment and Heritage and the Commonwealth Environmental Water Holder was used to promote Golden, Silver and Spangled Perch, as well as Murray Cod dispersion after natural flow peaks triggered breeding. These flows continued through to the Macquarie Marshes, providing benefits to the

Main: Junction of the Namoi and Barwon Rivers showing environmental water flowing from the Namoi River. Photo A. Clements, CEWO.

A yabby caught in the Macquarie River in 2017. Photo Rod Price, NSW DPI.

Large Golden Perch caught in the Macquarie River during connection flow. Photo Rod Price, NSW DPI.

wetland ecosystems along the way, as well as reinvigorating the entire length of the Macquarie River channel during its five-week journey from Burrendong Dam to the Barwon River.

Environmental water deliveries and tributary inflows in the Macquarie, combined with flow pulses in the Barwon River, provided a rare opportunity to deliberately connect both rivers. An estimated additional 27,583 megalitres of Commonwealth environmental water was then used to connect the mid-Macquarie River to the Barwon via the Macquarie Marshes and lower Macquarie River. The flows were designed to connect the two river systems for at least 10 days and enable native fish movement between river systems in both directions. These flows connected a diversity of aquatic environments for feeding, breeding, dispersal, migration and re-colonisation, all of which are essential for the survival of native fish populations and other aquatic fauna.

Getting enough water through the length of the Macquarie for the benefit of fish and the environment was a whole community effort, and followed careful planning among local landholders, community members and government water managers. In particular, advice from the Macquarie-Cudgegong Environmental Flows Reference Group was pivotal to the success of this environmental watering, as were irrigators on the lower Macquarie River, who reduced their draw of water for a brief time in order for the river to retain the critical flow volumes to allow fish to move.

Preliminary monitoring data has found both small- and large-bodied native fish such as Golden Perch, Bony Herring and Carp Gudgeon, moved between the Barwon and Macquarie river systems during these flows. Additionally, monitoring shows young fish that hatched in October 2016, were able to use this flow to migrate into the Macquarie system, helping to replenish numbers and maintain genetic diversity.

Delivering environmental water with episodic rainfall and natural flow events is a practical rehabilitation measure to support native fish populations, by helping to preserve flow pulses and providing access to food and habitat. This is particularly important for juvenile fish such as Golden, Silver and Spangled Perch, and Murray Cod, which may have been spawned in spring 2016. Providing connection between river systems in the north encourages fish to move between these systems, which will help increase the survival, genetic diversity and long-term viability of native fish populations in the northern basin. The findings from the monitoring will inform the adaptive management and continue to improve the delivery of any future connection flows.

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A drink for our darling

IRENE WEGENER AND **PAULA D'SANTOS** FILL US IN ON THE ENVIRONMENTAL WATER TOPPING UP THE GREAT DARLING ANABRANCH.

The Great Darling Anabranch, along with the Lower Darling River, form an important meeting point between the northern and southern basins of the Murray–Darling Basin. This connection is of critical importance for maintaining healthy, diverse native fish populations across the Basin due to the significant large-bodied native fish spawning and dispersal that occurs in this region.

The Lower Darling River and Great Darling Anabranch are located in the semi-arid plains of south-west New South Wales, between the Menindee Lakes and the River Murray. Little local runoff flows through these watercourses, with nearly all the water fed from the upstream Barwon-Darling river system. As such, the Anabranch's natural hydrology is marked by a highly variable pattern of wetting and drying cycles.

The Great Darling Anabranch was once the primary path of the Darling River. Around 11,000 years ago, the Darling River changed its course just south of Menindee Lakes, leaving the Anabranch channel to dry, only flowing into the River Murray during flood events. The region boasts numerous sites of cultural significance to the local traditional owners of the land, the Barkindj, who have a long history of occupation that is apparent through artefacts such as stone tools, middens, burial sites and scar trees scattered across the landscape.

When the Menindee Lakes Scheme was constructed in the 1960s, the flow regime of the Great Darling Anabranch became largely permanent due to the delivery of an annual replenishment flow to landholders for stock and domestic water supply. As a consequence, high salinity and blue-green algae affected native aquatic biota and supported conditions for the proliferation of non-native species such as European Carp.

In 2007, a pipeline was constructed along the length of the Anabranch to supply adjacent landholders, removing the need for ongoing flows in the channel. This returned the Anabranch to an ephemeral system. Up until 2017, there had been two environmental watering events in the Anabranch of 25 gigalitres and 55 gigalitres in 2010 and 2013 respectively.

From 2013 to 2016, the Menindee Lakes received their worst inflow on record. This meant there were no opportunities to support environmental flows in the Anabranch. Following significant rains across the northern Basin in winter–spring 2016, the Menindee Lakes filled, providing environmental water managers with an opportunity to supply the Anabranch with a welcome drink. The planned action was designed to support dispersal of native fish, maintain native vegetation and to connect the Anabranch with the River Murray.

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Above: Environmental water flows down the Anabranch. Opposite below: Windmill Bend, before (March) and during (May) the delivery of environmental water to the Anabranch, photos CEWO. Opposite above: Golden Perch 10 months old, photo Clayton Sharpe.

Anabranch gets a drink

The 2017 environmental watering action was the largest undertaken in the Anabranch to date, with a total 100 gigalitres provided by the Commonwealth Environmental Water Holder and New South Wales Office of Environment and Heritage. The event complemented environmental flows released in the adjacent Lower Darling River (see article, page 43 in this edition of *RipRap*). Drawing on best available science, a model of how Golden Perch respond to flows was developed to'... guide environmental water management decisions for the Anabranch, as well as the Lower Darling. Working with Water New South Wales, flows down the Anabranch commenced in mid-February.

Monitoring in the Menindee Lakes and Lower Darling was critical to the success of this event. Real-time monitoring was integrated into decision making on the timing, duration and release rates of environmental water. Once monitoring detected large numbers of juvenile Golden Perch in the Lakes, and following the Golden Perch model, environmental water was delivered to the Anabranch which enabled these fish, and other native fish species, to leave the Lakes and make their way to the River Murray.

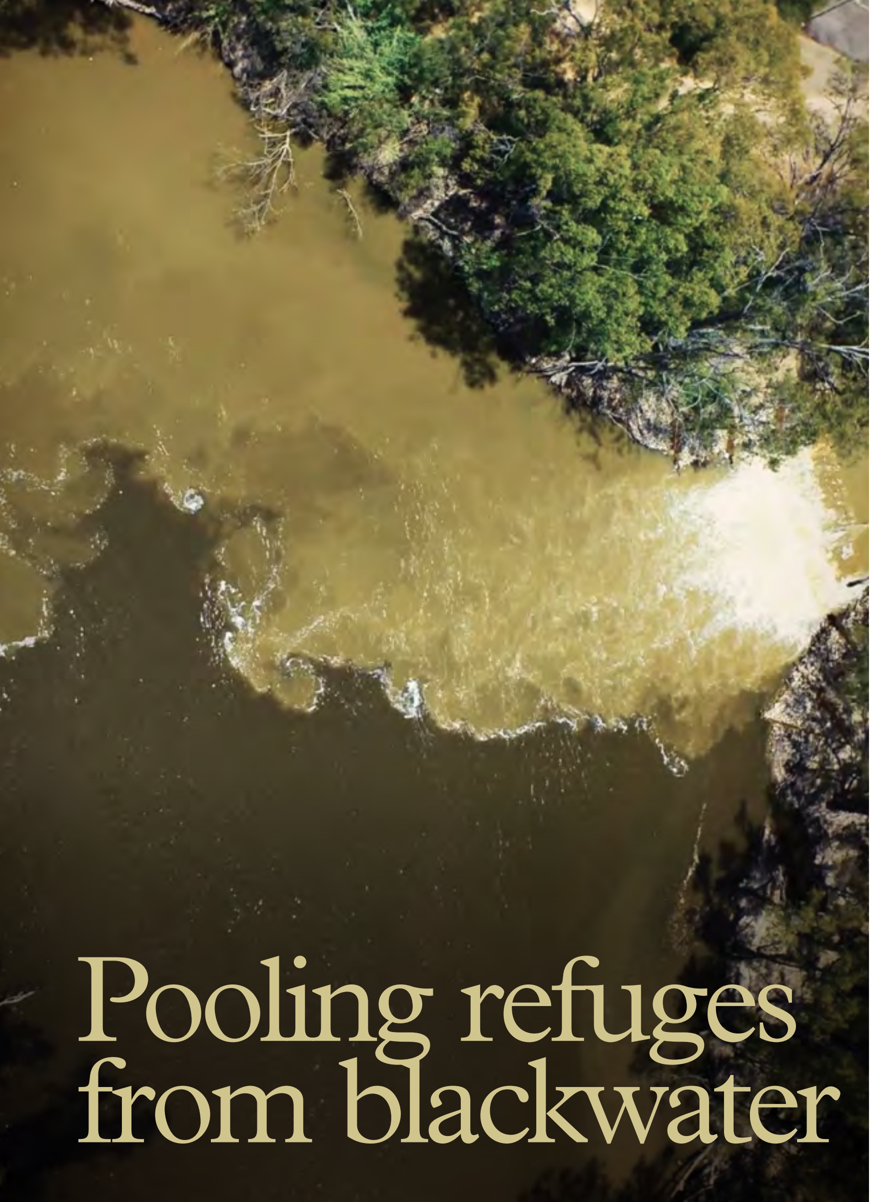
There was strong support from the local community. Many Anabranch landholders became actively involved in monitoring the release by providing real-time information about the flow's downstream progression, recording water level heights and noting any incidental observations such as fish, bird or vegetation responses. The flow took approximately two and a half months to reach the River Murray.

What happened?

Initial results have shown high abundances of Golden Perch, and other species including Bony Bream and Spangled Perch, dispersing from the Lakes and making their way downstream to the River Murray. Without the release of environmental water from Lake Cawndilla (the source lake for flows into the Anabranch), it is likely these fish would have become stranded. A number of Golden Perch have been tagged with transponders, enabling their movements to be tracked across the southern-connected basin in years to come. The environmental water release has also had a myriad of other ecological benefits, such as supporting large numbers of waterbirds, growth in riparian vegetation, and mobilising and exporting salt and nutrients.

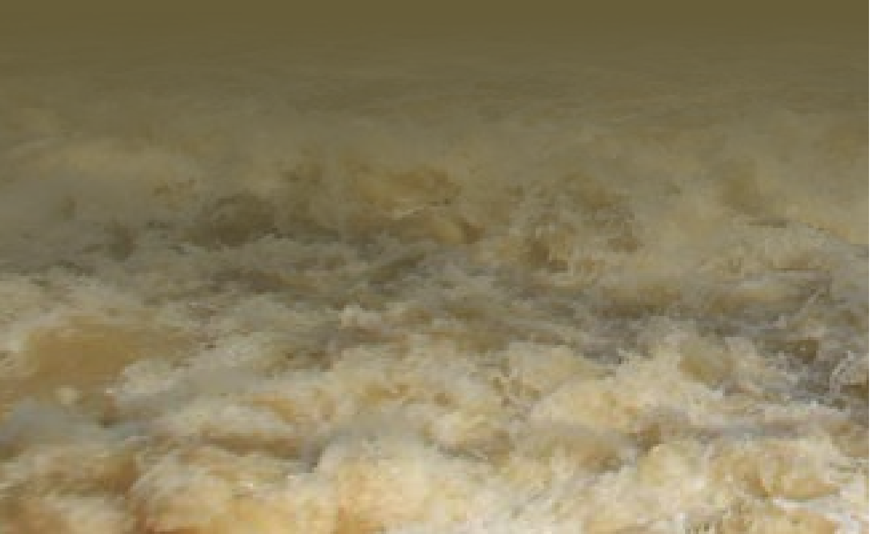
Monitoring of this and past events has shown the Menindee Lakes to be an important nursery habitat for juvenile Golden Perch. The project has shown how environmental water can be delivered to provide connectivity between the northern and southern areas of the Basin and support the dispersal and movement of native fish. The results from the project, and others like it, are important for informing decisions on how the Lakes are managed, including environmental water use, operational releases and any potential infrastructure changes in the future.

The success of this event has been underpinned by the collaboration of state and federal government agencies including environmental water holders, regional land and water managers, local ecologists and the community of the Great Darling Anabranch. Partners in this event were the Commonwealth Environmental Water Office, NSW Office of Environment and Heritage, DPI Fisheries, CPS Enviro Pty Ltd, WaterNSW and the Murray-Darling Freshwater Research Centre.



Pooling refuges from blackwater

ELIZABETH SYMES, **THOMAS HART** AND **BRUCE CAMPBELL** FLUSH OUT THE FACTS ON BLACKWATER AND HOW ENVIRONMENTAL WATER AND COMMUNITY EFFORTS IMPROVED CONDITIONS FOR NATIVE FISH AFTER FLOODING.



In 2016, New South Wales recorded its wettest year since 2011, with rainfall well above average across the inland regions of the state. Between May to September, the heavy rain during winter and early spring caused widespread flooding in lowland river systems, particularly the Edward/Wakool, Lachlan and Murrumbidgee. Above average rainfall in the Goulburn River in late December also occurred, producing some of the highest localised rainfall rates ever recorded in Victoria.

These significant rain events led to widespread flooding, and the inundation and mobilisation of organic material from vegetation, litter and debris deposited on the floodplain. When excessive loads of organic material are inundated and washed into waterways as dissolved organic carbon, bacteria consume the carbon and the available oxygen in the water. In early October 2016, oxygen concentrations dropped below critical threshold levels, threatening the survival of native fish that were unable to relocate to a more suitable oxygenated habitat.

Environmental water and low dissolved oxygen

When many sites across the southern and central Murray–Darling Basin were found to have low dissolved oxygen (DO) concentrations, environmental water holders worked with partners and stakeholders to devise watering actions that would generate fish refuges. A combination of strategies were used with interventions undertaken when the flood had receded, thereby avoiding additional flooding.

Images throughout this article show Commonwealth environmental water refuge flows, including at the Edward River Escape, by Damian McRae.

This is consistent with the Commonwealth Environmental Water Holder's good neighbour policy of 'no third party impacts'. Strategies included ordering environmental water allocations to irrigation channel outfalls or 'escapes' to supply high DO water, and using dam releases where the reach below the dam had fallen below flood levels to provide refuge from hypoxic blackwater entering from tributary catchments downstream.

Oversight of environmental water during the 2016 flood events was a considerable undertaking, particularly in the Edward/Wakool system, where there are opportunities for intervention using environmental water delivered through Murray Irrigation Limited's canal system 'escapes'. With the rapid decline in water quality, prompt action was needed, and the Edward-Wakool Environmental Water Reference Group was instrumental in developing and delivering environmental water into the local river systems following the natural floods.

The decisions to discharge environmental water to moderate hypoxic conditions were based on real-time DO data, informed judgements and, where possible, a blackwater intervention computer model previously developed by the Murray-Darling Freshwater Research Centre. The model uses available data from gauging stations and other water quality parameters to forecast various flow scenarios and develop watering actions to help a return to acceptable conditions as soon as possible. Discharge volumes required adjustment on a frequent basis, often daily during the blackwater event, as waters receded.

BUSTING THE MYTHS

Is all blackwater bad?

No! 'Blackwater' is created by high loads of dissolved organic carbon. Hypoxic conditions can be lethal for fish and other aquatic fauna. Carbon is, however, essential to productivity and the long-term health of rivers, floodplains and wetland ecosystems. The bacteria responsible for oxygen depletion are at the bottom of the food web, and their growth represents an opportunity for the whole food chain, ultimately benefiting native fish, waterbirds and other water dependent taxa. Even during hypoxic blackwater events, downstream ecosystems benefit from the organic carbon inputs once the water has re-aerated.

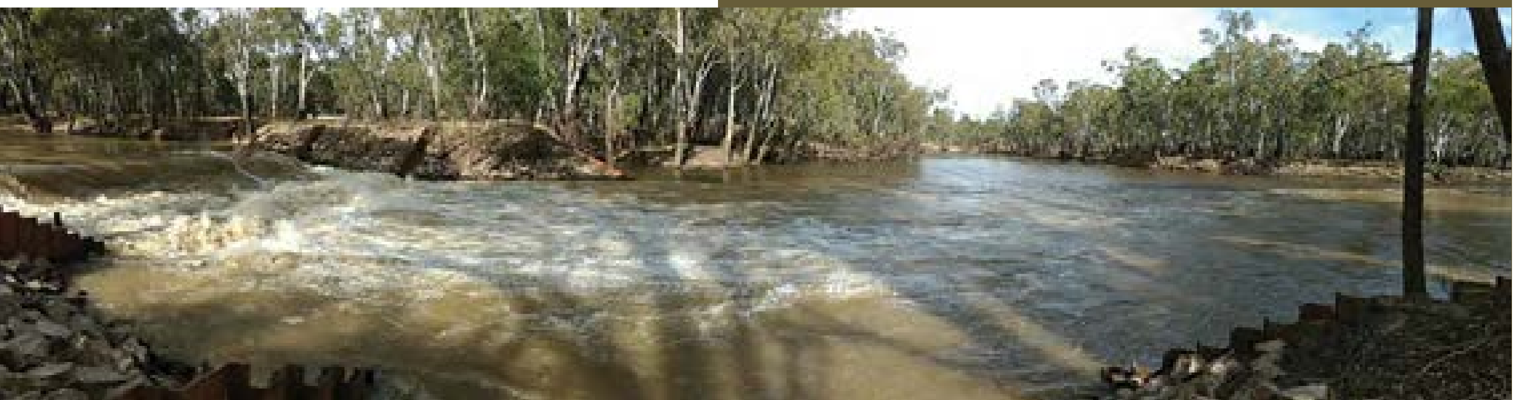
Should we stop flooding red gum forests?

No—and we can't anyway. Floods like the 2016 event are associated with sustained, large amounts of rainfall. Even large dams such as Hume and Dartmouth in the Murray system fill and spill in these conditions leading to significant downstream flooding.

In the Goulburn River system in 2016–17, hypoxic blackwater was caused by intense local rainfall on largely cleared catchment areas. The sources of organic carbon that caused hypoxic blackwater in 2016 were not restricted to River Red Gum forests, in the Lachlan system, flooding of the un-forested Bland Creek floodplain generated high carbon loads leading to hypoxic conditions. To the extent that leaf litter from floodplain forests contributes very large sources of dissolved organic carbon, there is an argument for more regular, smaller flooding of the forest to better manage carbon loads, both as 'preventative maintenance' and to stimulate productivity in downstream ecosystems, improving their capacity to withstand shocks such as hypoxic blackwater.

Hypoxic blackwater events have never occurred before—are they a new threat to native fish?

Local media reports of fish kills in the mid-Murray region can be traced back as far as the mid to late 1800s, and their demise was possibly associated with large flood recessions and low oxygen conditions. In more recent times, a 20 year old, large-bodied (say 800 millimetre) Murray Cod, has been able to either avoid or survive hypoxic blackwater events that occurred in the mid-Murray in 2000, 2004 and 2010. Most of our native fish have evolved mechanisms that enable them to thrive despite variable water quantity and quality conditions. Why mature large-bodied native fish survive some hypoxic blackwater events only to be killed in a subsequent event remains a mystery worthy of better scientific understanding.



Getting innovative

Innovative solutions were essential to managing environmental water during the floods. Murray Irrigation Limited's Escapes at Edward River, Wakool River, Thule Creek and several others were used to divert water around the flooded forests via the Mulwala Canal. As these flows do not immediately mix with surrounding blackwater, a 'plume' of oxygenated water, lasting for a considerable distance (up to several kilometres) provided fish refuges downstream.

The input and feedback from the community on the ground, was instrumental in understanding the effect of these staged water releases. Community members also took direct action, with many landholders on properties adjacent to rivers installing aerators to generate local fish refuge. The machinery to drive the aerators often operated for 24 hours per day, and to offset costs, the local land services and community network provided support. This effort shows the strong 'care' ethic of those who live and work along our rivers.

How effective?

Local anglers observed Murray Cod around the Edward River Escape almost immediately on release of the environmental water, providing the first evidence of positive effects from the watering actions. Preliminary results from the Commonwealth Environmental Water Holder's Long Term Intervention Monitoring project show that while there has been a significant loss of native fish, the numbers surveyed appear to be an improvement on results following the previous hypoxic blackwater event in 2010. The Commonwealth Environmental Water Office will continue to review watering actions and learn from experience to refine and optimise environmental watering outcomes for local communities and the environment.

The authors acknowledge the work of Damian McRae, Linda Duffy and members of the Edward-Wakool Environmental Water Reference Group.

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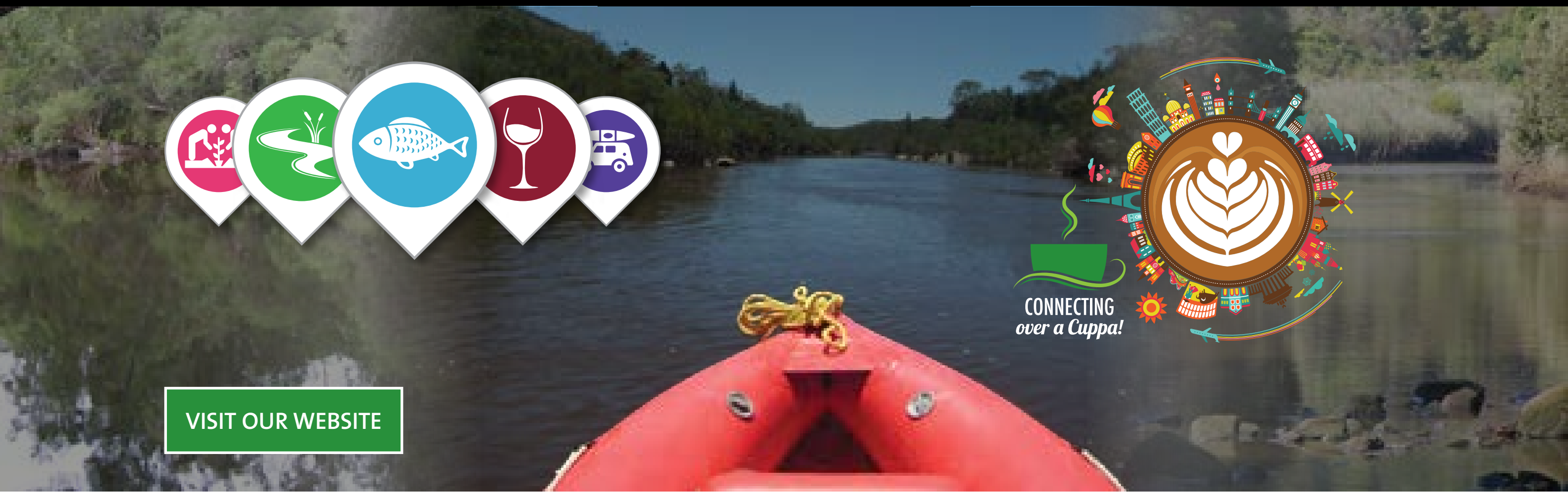
ARRC

The Australian River Restoration Centre (ARRC) is a not-for-profit organisation established to share knowledge, restore and protect rivers for all to enjoy, and value people and the work they do.



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Managing rivers

We value our rivers for the multiple benefits they provide — life-giving water, plants, animals, transport, economic wealth, recreation, and the spiritual connection so many of us feel when we sit or walk along a riverbank. For many years we have been doing research into how rivers function ...

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True Tales of the Trout Cod — Stories about the bountiful fish life that once existed throughout the Murray–Darling Basin.

RipRap — RipRap celebrates our riverine environments by featuring science and stories about different topics.

FINTEREST — A knowledge sharing website featuring the latest Native Fish Strategy research and practice.

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ARRC Australian River Restoration Centre

At the Australian River Restoration Centre we believe in sharing knowledge, restoring and protecting our rivers for all to enjoy and valuing people and the work they do. We do this by:

- Inspiring and supporting people passionate about rivers
- Creating and distributing *RipRap* magazine
- Sharing knowledge in multiple ways
- Collaborating and networking with a range of organisations
- Managing on-ground and science communication projects

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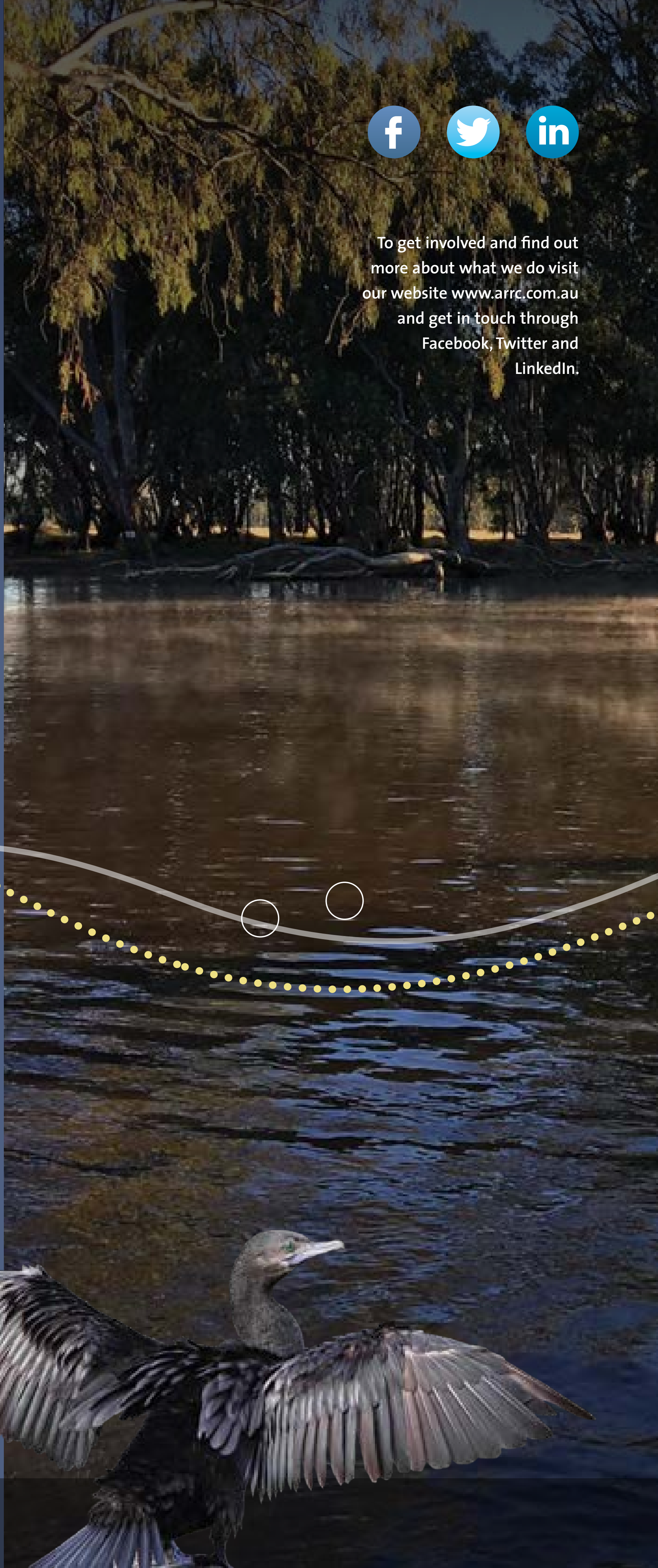

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