# Victorian Environmental Flows Monitoring and Assessment Program

## Stage 6 Synthesis Report 2016–2020

Z. Tonkin, C. Jones, P. Clunie, L. Vivian, F. Amtstaetter, M. Jones, W. Koster, B. Mole, J. O’Connor, J. Brooks, L. Caffrey and J. Lyon

August 2020

Arthur Rylah Institute for Environmental Research
**Technical Report Series No. 316**

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

**Acknowledgment**

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

**Citation**: Tonkin, Z., Jones, C., Clunie, P., Vivian, L., Amtstaetter, F., Jones, M., Koster, W., Mole, B., O'Connor, J., Brooks, J., Caffrey, L., and Lyon, J. (2020). Victorian Environmental Flows Monitoring and Assessment Program. Stage 6 Synthesis Report 2016-2020. Technical Report Series No. 316, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

**Front cover photo**: Campaspe River (Felicity Nicholls); Murray-Darling Rainbowfish (Annique Harris); *Persicaria hydropiper* on the Campaspe River (Chris Jones)



ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))

ISBN 978-1-76105-273-6 (Print)
ISBN 978-1-76105-274-3 (pdf/online/MS word)



## Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au or contact us via the National Relay Service on 133 677 or www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au

# Victorian Environmental Flows Monitoring and Assessment Program

## Stage 6 Synthesis Report 2016–2020

Zeb Tonkin[1], Chris Jones[1], Pam Clunie[1], Lyndsey Vivian[1], Frank Amtstaetter[1], Matthew Jones[1], Wayne Koster[1], Bryan Mole[1], Justin O'Connor[1], Jacqui Brooks[2], Laura Caffrey[2] and Jarod Lyon[1]

[1]Arthur Rylah Institute for Environmental Research
123 Brown Street, Heidelberg, Victoria 3084

[2]Water and Catchments Division, Department of Environment, Land, Water and Planning
8 Nicholson Street, East Melbourne, Victoria 3000

Arthur Rylah Institute for Environmental Research
**Technical Report Series No. 316**

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
Heidelberg, Victoria

# Acknowledgements

VEFMAP Stage was funded by the Catchments, Waterways, Cities and Towns Division of the Department of Environment, Land, Water and Planning (DELWP). For contributions to the program, including design, fieldwork, data compilation, biometric support and reporting, we thank Zac Atkins, Renae Ayres, Ana Backstrom, Bill Coates, Gabriel Cornell, Dave Dawson, Peter Fairbrother, Ben Fanson, Graeme Hackett, Annique Harris, Lauren Johnson, Karl Just, Adrian Kitchingman, Freya Thomas, Rustem Upton, Scott McKendrick, Ivor Stuart, Jason Lieschke, Kim Loeun, Damien McMaster John Mahoney, Paul Moloney, Justin O'Mahony, Dylan Osler, Andrew Pickworth, Scott Raymond, Stephen Saddlier, Jo Sharley, Kasey Stamation, Charles Todd and Jian Yen. Thanks to Fern Hames for valuable insights to early planning and development of the Communication and Engagement Plan. Ashley Sparrow and John Koehn provided valuable guidance on earlier drafts of the report.

Many Catchment Management Authority (CMA) and Melbourne Water staff are thanked for their significant contribution to the design and implementation of the program, including developing key evaluation questions, monitoring methods and locations, planning fieldwork, and providing invaluable information regarding flow management on their respective river systems. They include Darren White and Phil Slessar (NCCMA), Greg Fletcher (WCMA), Minna Tom, Stephanie Suter and Jemima Milkins (WGCMA), Cheryl Edwards (MW), Stephen Ryan and Bryce Morden (GHCMA), Daniel Lovell, Meegan Judd and Simon Casanelia (GBCMA), Jayden Woolley and Robert Bone (CCMA) and Ian Wright and Alan Williams (GMW).

Many staff from Victorian universities were involved in collaborations within VEFMAP Stage 6, including:

- University of Melbourne
  - Joe Greet, Justin Costelloe and Angus Webb for their supervision of student research projects.
  - Masters degree students Vanja Kitanovic, Alanna Main and Marjorie Pereira.
  - Rowan Berry, Sascha Andrusiak, Rob Dobal and Brett Hough (Burnley) for assistance with the nursery experiments setup. Elliot Gould and William Morris for data analysis contributions.
  - Jian Yen was supported by a McKenzie Fellowship.
  - Jon Woodhead for provision of otolith microchemistry services.
- La Trobe University — Katherine Harrison (Post-doctoral Research position) and James O'Dwyer (PhD student) on genomic projects.
- Deakin University — Tim Fernando for data collection and his Honours project on diadromous fish.

We also acknowledge the Independent Review Panel: Sam Capon (Griffith University), Brenton Zampatti (formerly SARDI, now CSIRO), Peter Vesk (University of Melbourne) and Nick Bond (La Trobe University).

And the Project Steering Committee: Stephen Ryan (GHCMA), Minna Tom and Stephanie Suter (WGCMA), Meegan Judd and Simon Casanelia (GBCMA), Mark Toomey (VEWH), Paul Reich and Terry Chan (DELWP).

Thanks to the Goulburn Long Term Intervention Monitoring Project (funded by the Commonwealth Environmental Water Office), Victorian Fisheries Authority, Catchments, Waterways, Cities and Towns Division (DELWP) and Melbourne Water for the provision of monitoring data for the lower Goulburn, Ovens and Bunyip rivers.

Other State and Commonwealth agencies collaborated with VEFMAP Stage 6 by sharing knowledge, data and results. These included SARDI (South Australian Research and Development Institute), NSW Department of Primary Industries, Murray-Darling Basin Authority, CEWO, Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The following consultancies are also thanked for their input:

- Jacobs — Nicolaas Unland and Greg Hoxley for their work on the soil moisture study.
- Streamology — Jess Littlejohn and Steve Clarke for hydrology data processing.
- Austral Ecology (Dion Iervasi) and Fishology Consulting (Kris Pitman) for fish fieldwork contributions.
- Fish Ageing Services (Kyne Krusic-Golub) for advice and services in otolith preparation.

Thanks to the following landowners, who provided access to their properties: Janette Mitchell, Mike Reilly, Ron and Denise Reynolds, John and Natalie White, Scott Farquharson, David Spencer, Steve Smithyman (Geelong City Council), Batesford Quarry, Tarrawarra Abbey, Keith Oberin, Justin Weaver and Les Rowe.

This study was completed under Victorian Flora and Fauna Guarantee Permit 10007273, Fisheries Victoria Research Permit RP-827 and animal ethics permits 15/05, 14/04 and 19/008 (DELWP Animal Ethics Committee).

# Contents

# Summary


## Context

This synthesis report summarises fish and vegetation monitoring and research conducted for Stage 6 of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP), as well as communication and engagement efforts. A range of supplementary materials accompany the report, including journal articles, client reports, factsheets and summary brochures (see ARI website).

## Objectives of VEFMAP Stage 6 (2016-20)

Through extensive planning and consultation, three overarching objectives were developed for Stage 6:

1. Enable the Department of Environment, Land, Water and Planning (DELWP) and its water delivery partners to clearly demonstrate the ecological value of environmental water management to the community and water industry stakeholders.
2. Fill knowledge gaps to improve planning, delivery and evaluation of environmental water management in rivers across Victoria.
3. Identify ecosystem outcomes from environmental water to help meet Victoria's obligations under the Murray-Darling Basin Plan (Schedule 12, Matter 8).

## Approach

To achieve the broad objectives, ongoing performance monitoring and refinements were made across all aspects of the Program, including governance, data management, communication and engagement, and monitoring and research. Specific approaches to each of the core aspects of the Stage 6 Program were:

*Governance and delivery*

Delivery of the program was facilitated by comprehensive planning, review processes and documentation requirements. An Independent Review Panel (IRP) of relevant scientists and a Project Steering Committee (including catchment management authority (CMA), Victorian Environmental Water Holder (VEWH) and DELWP staff) contributed to ongoing planning and review to ensure strong science and effective program delivery.

*Data and information management*

A Microsoft SQL Server relational database was created with in-built quality assurance (QA) measures for data entry. A user-friendly database interface was developed for CMA staff to view and extract data summaries relevant to their area.

*Monitoring and research*

Key Evaluation Questions (KEQs) relating the response of fish and vegetation to environmental water delivery formed the basis of the research program. These were developed in collaboration with CMAs and the VEWH. A flow-event based ('intervention-style') monitoring approach was adopted for Stage 6, to complement the existing long-term annual condition monitoring, which began in 2007.

A wide range of monitoring methods were used to thoroughly investigate the KEQs, including standard practice surveillance approaches as well as genetics studies, population modelling, research experiments and analysis of in-situ soil moisture content.

*Communication and engagement*

Communication and engagement were an important focus during Stage 6, to provide information in a timely manner to inform effective adaptive management of water resources, along with demonstrating the value of environmental water to stakeholders. There was a strong emphasis on working closely with environmental water managers to inform and support environmental water management. The broad suite of activities and tools used included direct contact, presentations, workshops, written material, online and social media content. An angler citizen science pilot project in northern Victoria aimed to gather supplementary scientific samples and build stronger connections with anglers.

## Results

*Monitoring and research*

For the Fish theme, a combination of event-based intervention monitoring, annual condition monitoring and stochastic population modelling was used to assess four KEQs relating to the role of environmental flows in governing the processes and dynamics that lead to changes in native fish populations. Understanding how river discharge correlates with these processes (which in turn lead to changes in population size) is critical to allowing water managers to deliver flows in a way that can influence populations. Key results generated for KEQs are as follows:

*KEQ 1: Can environmental flows promote immigration by diadromous fishes in Victorian coastal rivers?*

We found a positive association between spring river discharge and catches of juvenile diadromous fishes, which to our knowledge is the first to demonstrate such links. Indeed, increasing discharge had a linear correlation with increasing immigration of juvenile fishes. Our results indicate that the greatest benefit of environmental water for enhancing the immigration of diadromous fishes into rivers would be to target systems and years when spring discharge rates have been low. When there are large spring discharge volumes driven by extensive rainfall events, very large numbers of fish are attracted into coastal rivers; during these times environmental flows will provide little additional benefit in promoting immigration. Instead, we suggest this water is best used to enhance the dispersal and survival of recruits during the following summer.

*KEQ 2: Do environmental flows enhance dispersal, distribution and recruitment of diadromous fishes in Victorian coastal rivers?*

Upstream dispersal of juvenile diadromous fish increased significantly in response to environmental flow releases during summer and early autumn across multiple systems. For example, in the Glenelg River there were almost six times as many juvenile Common Galaxias (*Galaxias maculatus*) and Short-finned Eels (*Anguilla australis*) and almost 40% more juvenile Tupong (*Pseudaphritis urvillii*) moving upstream during environmental freshes compared to baseflow conditions. Importantly, fish population surveys in the Glenelg River have shown that since 2017, when environmental water has been used to deliver these freshes, the abundance of Tupong and Common Galaxias have increased by 16.0 and 5.8 times respectively.

Fresh releases should be used in the lower reaches of rivers where there are no restrictions to fish passage and where sufficient flows exist to maintain suitable water quality and habitat for survival and maturation through summer. Fresh releases provide the greatest population level benefits in years when the abundance of new recruits is relatively high.

*KEQ 3: Do environmental flows support immigration of native fish into, and dispersal throughout, northern Victorian rivers?*

We found that environmental flows play an important role in enhancing both immigration and dispersal in flow stressed regulated rivers. For example, Silver Perch (*Bidyanus bidyanus*) movement within and among habitats throughout the mid-Murray and lower reaches of the Goulburn and Campaspe rivers was influenced by river discharge and time-of-year, with environmental flow releases contributing to these movements. In the lower Loddon system, acoustic telemetry and fishway trapping showed upstream movement of both large- and small-bodied species increased substantially during environmental flow releases in comparison to low baseflow conditions.

*KEQ 4: Does environmental flow management used for large-bodied species enhance: (i) survival and recruitment, (ii) abundance and (iii) distribution throughout northern Victorian rivers?*

Our analyses of long-term monitoring data generated through VEFMAP and other research programs is the first to quantify links between attributes of river flows and Murray Cod (*Maccullochella peelii*) recruitment and population dynamics. Trend analysis also found links between river flows and abundance and biomass of Golden Perch (*Macquaria ambigua*), Silver Perch and Trout Cod (*M. macquariensis*). The contribution of environmental water appears to be river, species and process specific. For example, based on our monitoring data and subsequent model estimates, environmental flows have enhanced recruitment and survival, and increased the abundance of Murray Cod in the Campaspe River. Under the current flow recommendations in the Campaspe River, the adult population of Murray Cod is predicted to improve in comparison with all other management flows in most years, increasing by an average of at least 7% from 2009 to 2019. These same environmental flows do not appear to have enhanced recruitment of Golden Perch in the Campaspe River, but rather, the survival and distribution of stocked fish.

For the Vegetation theme, a combination of event-based intervention monitoring, snapshot and multi-year monitoring and experimental studies were used to assess five KEQs relating to the role of environmental flows in governing the processes and dynamics of native vegetation populations and communities. Key results generated for the KEQs are as follows:

*KEQ1: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of aquatic and semi-aquatic vegetation at a sub-reach scale?*

Vegetation mapping data from 44 sites across Victoria showed many regulated waterways lack the hydraulic habitat conditions suitable for many aquatic species, with very high or low flow volumes acting as a barrier to colonisation and growth. Environmental flows are, however, able to have significant benefits for aquatic plants where they can provide essential baseflows and freshes in drier systems. We found that alterations of flow patterns to expose soils in higher flow systems can improve aquatic vegetation recruitment. We also quantified the effects of factors such as high turbidity, livestock grazing, canopy cover, channel form, and other flow variables that alter the relative abundance, extent and diversity of aquatic vegetation, which proved critical for evaluating the effects of environmental flows and represents a significant knowledge gap for environmental flow research. Findings from this work can be used to directly inform management of aquatic vegetation through the delivery of environmental flows, the manipulation of flows, the additional management actions required to address other confounding factors, and the specification of realistic objectives for management of aquatic and semi-aquatic vegetation in Victoria.

*KEQ 2: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of emergent vegetation at a sub-reach scale?*

Our analyses showed emergent species do not require permanent water resources to survive along waterways; however, the provision of environmental flows or natural high flow events increases the growth and recruitment of these species. Specifically, individual spring freshes result in increased cover, spatial distribution up the bank and germination of emergent species, and baseflows are important for increasing emergent plant growth and abundance. Environmental flows (in the form of freshes and baseflows) also help to inhibit terrestrial species, which reduces competition with emergent species. Responses shown by emergent species vary between sites and within and between reaches based on flow regimes, species present, rainfall, livestock grazing and other factors, including presence of exotic riparian species. Indeed, our results showed environmental flows are unable to benefit native emergent species where livestock grazing pressure is moderate to high or exotic riparian species dominate.

*KEQ 3: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of fringing herbaceous vegetation at a sub-reach scale?*

Data collected through VEFMAP Stage 6 provides some of the most conclusive evidence for vegetation responses to environmental flows in Victorian waterways, particularly for fringing riparian species (e.g. grasses and herbs). These species are provided a competitive growth advantage by individual spring fresh deliveries, relative to terrestrial species. Our data showed this effect is cumulative, meaning that successive years of deliveries can reinforce and consolidate benefits from previous years. Spring freshes broaden the distributions of fringing species to higher bank elevations and help sustain healthy high-bank fringing populations by increasing fringing plant propagule dispersal and germination, and by providing temporary water resources to young or shallow-rooted species. This means the riparian vegetation extent is much broader than it would be without environmental flows, which increases habitat resources, stabilises banks and increases overall plant community resilience to large flood events.

Our analyses showed the provision of appropriate baseflows is also vital for fringing plant growth and abundance. Additionally, our experimental studies highlighted the critical role freshes have in mitigating the encroachment of terrestrial plant species to lower bank elevations. Importantly, our data have quantified these effects and shown that most plants are highly tolerant of cool-season inundation, but much less tolerant as the season progresses and temperatures increase, such that only highly tolerant species can survive extended summer inundation. As with the emergent species, environmental flows have little benefit for native fringing vegetation if livestock grazing pressure is high or the bank is dominated by inundation-tolerant exotic species. However, our grazing exclosure field experiments showed many sites recover quickly after grazer removal, a process aided by environmental flows.

*KEQ 4: How does environmental flow discharge influence the recruitment and establishment of emergent, fringing herbaceous, and woody vegetation at a sub-reach scale?*

Our field and nursery studies showed that environmental flows, particularly spring freshes, have a significant role in increasing riparian vegetation seed abundance and germination. While rainfall plays a large role in vegetation recruitment, spring freshes are important for triggering germination and for dispersal of riparian species propagules to higher bank elevations. Germination patterns vary among and within species groups, but environmental flows that replicate natural flow patterns change the distribution and composition of plant communities to favour riparian species (over terrestrial species). Our studies also highlight the importance of low flows in late summer, which play an important role in promoting germination of aquatic, emergent and low-bank fringing species. Riparian shrubs benefit from elevated environmental flows for germination and establishment, although those requiring overbank flows typically require natural floods. While the dominant canopy species in most Victorian regulated waterways (River Red Gum) does not require environmental flows to germinate, seedling survival and establishment may be increased by environmental flows.

*KEQ 5: How are vegetation responses to environmental flow discharge influenced by additional factors such as grazing, rainfall, soil properties, and season?*

Our findings showed that livestock grazing was correlated with reduced native vegetation cover in all systems. Native riparian vegetation communities will only benefit from environmental flows if heavy grazing is dramatically reduced and exotic riparian species are controlled where they occur in high abundance, which is more common in higher rainfall parts of Victoria.

Results from our soil moisture monitoring found that the provision of soil moisture through managed environmental flows is critical in drier streams. In more permanent waterways, freshes are important for providing soil moisture to shallow-rooted or young plants on the stream bank in drier years or seasons, particularly where soil properties reduce groundwater connections.

Given the lower abundance of exotic riparian species, the reduced flow availability and reduced soil moisture in lower rainfall areas, environmental flows generally provide a proportionally larger benefit to vegetation communities in lower rainfall areas. Since much of the state is predicted to have reduced rainfall under climate change, riparian vegetation will become more reliant on environmental water in the future.

*Communication and engagement*

Strong, effective partnerships between the project team, CMAs and other water managers were developed during Stage 6. Regular interactions regarding planning, progress and results established genuine collaborations, which directly influenced management of environmental water. Participation in CMA Environmental Water Advisory Groups provided a valuable approach to directly engage with members of the public. Evaluation of the communications of the program over time, including via questionnaires of core stakeholders and direct liaison, indicated distinct improvements on views of VEFMAP. The angler scientist pilot study provided valuable supplementary ear bone samples and age data, established strong connections between anglers and scientists and provided an avenue to increase water literacy.

*Collaboration with other monitoring and research programs and researchers*

Stage 6 has built close collaborations with a range of scientists, research institutes, consultancies and government agencies. This has been achieved through joint projects with Melbourne Water, the Commonwealth Environmental Water Office's (CEWO) Flow-MER program and La Trobe University's fish genetics program, and through involvement in the Murray-Darling Basin system scale acoustic telemetry arrays and Fish Gen project. Work with researchers from The University of Melbourne, Burnley Campus, included three research projects led by Masters students, and collaboration with Jacobs and The University of Melbourne enabled the examination of soil moisture responses to flows.

*Informing management*

Regular communication between the VEFMAP project team and CMAs, the VEWH, CEWO, MDBA and other relevant stakeholders has allowed direct input of information and learnings into decision-making processes for environmental flow delivery, within a seasonal, annual and longer-term context. Observations and results from VEFMAP monitoring have been used to support existing flow regimes, inform changes to the timing and magnitude of flow events and enable delivery of desired hydrographs to enhance key population processes. Results have also been used to guide flow recommendations for waterways through FLOWS studies, to inform regulatory decisions around the delivery of inter-valley transfers and assist with the development of annual CMA seasonal watering proposals (and subsequent Seasonal Watering Plans).

## Conclusions and implications

VEFMAP Stage 6 has provided a substantial contribution to the science of environmental flows and significantly improved our understanding of flow-ecology relationships across Victoria and the southern Murray-Darling Basin. Results from the program provide evidence for significant benefits from environment watering for native fish and vegetation, and targeted knowledge gaps relating to the magnitude and mechanisms for ecosystem responses have successfully been filled. Data and information gained through VEFMAP Stage 6, together with the close connections established with waterway managers and stakeholders, mean that environmental flows throughout Victoria are being delivered more efficiently and effectively to provide better outcomes for the environment, and to ensure better value for money from this vital resource.

# 1 Context

## 1.1 VEFMAP Stages 1 – 5

The acquisition and delivery of water for the environment by the Victorian and Commonwealth Governments represents a significant investment in aquatic ecosystem health and rehabilitation. Water is a scarce resource, so maximising the efficiency and effectiveness of its use is vital.

Across Victoria, many agencies work together to develop and implement environmental water management programs, including the Department of Environment, Land, Water and Planning (DELWP), the Victorian Environmental Water Holder (VEWH), catchment management authorities (CMAs), land managers and water authorities, the Commonwealth Environmental Water Office (CEWO) and the Murray–Darling Basin Authority (MDBA).

Maximising the efficiency and effectiveness of environmental water use requires clear ecological objectives and an adaptive management framework that builds on evidence and key learnings from environmental watering outcomes. With this in mind, the Victorian Government established the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) to investigate ecosystem responses to environmental watering in priority rivers across Victoria.

Following the development phase of the program (Stages 1 and 2), monitoring commenced in eight regulated rivers in 2007 (Stage 3, 2007–2016). Stage 4 involved a detailed analysis of VEFMAP data through to 2012 (Miller et al. 2014), as well as a full program review (Cottingham et al. 2014), which recommended that future VEFMAP monitoring should focus on native fish and riparian vegetation. Stage 5 consolidated eight years of data, discussions and expert recommendations to refocus the approach for VEFMAP, in preparation for the most recent phase, Stage 6 (Figure 1.1.1).

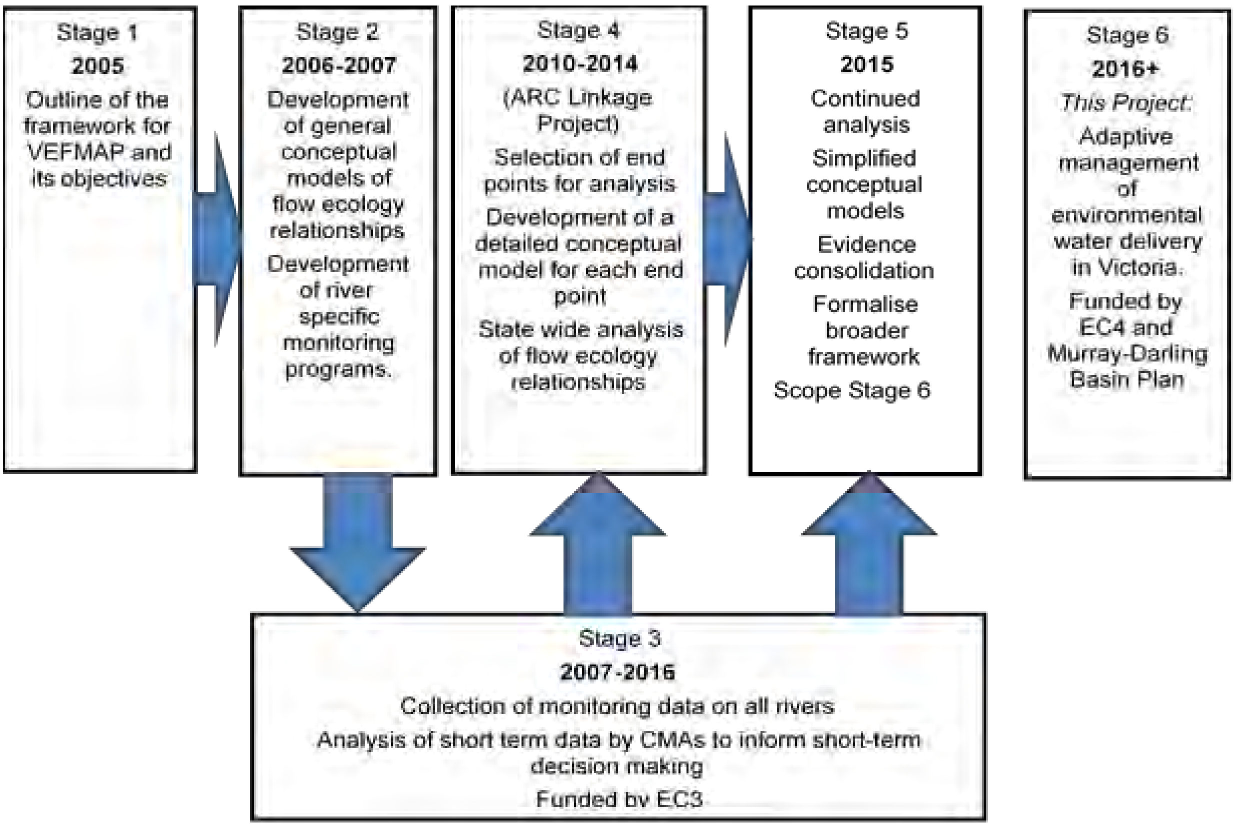



**Figure 1.1.1** VEFMAP Stages 1–6.

## 1.2 Stage 6 development and objectives

Planning for VEFMAP Stage 6 involved a strong collaboration between DELWP's Environmental Water and Waterway Health team, the Arthur Rylah Institute (ARI), Victorian CMAs, VEWH, The University of Melbourne (UoM) and other key stakeholders.

After extensive planning and consultation, three overarching objectives were developed:

1. Enable DELWP and its water delivery partners to clearly demonstrate the ecological value of environmental water management to the community and water industry stakeholders.
2. Fill knowledge gaps to improve planning, delivery and evaluation of environmental water management in rivers across Victoria.
3. Identify ecosystem outcomes from environmental water to help meet Victoria's obligations under the Murray–Darling Basin Plan (Schedule 12, Matter 8).

To address these objectives, work during Stage 5 included additional data analysis, the refinement of conceptual models and the development of flow-ecology hypotheses for native fish and riparian vegetation. Monitoring fish spawning events during 2015–16 used an intervention-style approach, sampling before, during and after environmental water deliveries. Data from this work provided evidence for a response by fish to environmental flows (e.g. Amtstaetter et al. 2016). This presented a strong rationale for the inclusion of flow-event based monitoring in VEFMAP Stage 6, in addition to the continued collection of annual condition data. This combination enabled an assessment of environmental flow responses at a process level (short-term means objective of environmental flow delivery) while tracking long-term population trajectories (long-term fundamental objective).

Preparations for Stage 6 also included the development of key evaluation questions (KEQs) for investigation. Objectives identified in CMA Environmental Water Management Plans (EWMPs), MDBP Long-term Watering Plans (LTWPs) and the VEWH's Seasonal Watering Plans (SWPs) provided a preliminary set of potential KEQs.

A thorough consultative process involving CMAs, the VEWH, UoM and DELWP identified key knowledge gaps for environmental water management and highlighted the needs and interests of CMAs regarding future monitoring and research.

Based on this consultation process, and in conjunction with the latest scientific understanding of ecological responses to changes in flow regimes, a shortlist of KEQs was developed for native fish and vegetation. These questions were further refined through workshops, individual meetings with CMAs, and independent expert advice, to compile a final set of KEQs that were:

- directly relevant to key knowledge gaps for environmental water management
- regionally relevant to CMAs
- realistically answerable and able to demonstrate the value of environmental water for engaging local, regional and state-wide stakeholders
- based on the latest conceptual understanding of ecological responses to flow
- weighted toward flow-driven population processes (e.g. dispersal, spawning, recruitment, vegetation cover)
- able to complement rather than duplicate data collections underway for other monitoring programs.

The scope of VEFMAP Stage 6 has included three years of monitoring and evaluation from 2016–17 to 2019–20, followed by a full analysis and program evaluation in 2020. A detailed breakdown of the program context, rationale, key evaluation questions, study design and sampling methods for fish and vegetation can be found in:

- *VEFMAP Stage 6 Part A: Program context and rationale* (DELWP 2017a)
- *VEFMAP Stage 6 Part B: Program design and monitoring methods* (DELWP 2017b).

During Stage 6, any modifications and refinements made to the study design were included in annual monitoring plans and reviewed by an Internal Review Panel (see Section 1.3.1). VEFMAP Stage 6 has been an exciting way forward for Victoria's state-wide monitoring of environmental water, operating on a strong foundation of communication and collaboration with CMAs, scientists and other key stakeholders.

## 1.3 Approach to Stage 6

VEFMAP Stage 6 is consistent with the adaptive management framework identified in the Victorian Waterway Management Strategy (DEPI 2013, Figure 1.3.1). Stage 6 was designed on the condition that aspects of the Program, including survey design, may change depending on progress, advice, recommendations and the outcomes of sampling. Continuous reflection and performance monitoring of all aspects of the program, including governance, communication and engagement, and monitoring and research, ensured a flexible and responsive approach, which enabled continuous improvement throughout the four years of Stage 6.


**Figure 1.3.1** The adaptive management cycle underpinning the Victorian Waterway Management Strategy (DEPI 2013).

### 1.3.1 Program planning, review and evaluation

Ongoing reflection and evaluation of progress towards achieving program objectives and meeting milestones has been an integral component of VEFMAP Stage 6. This has been facilitated through the program's comprehensive planning and review processes and requirements for documentation, including:

- monthly project team meetings
- review of results and monitoring outcomes
- annual proposals for monitoring and research
- independent scientific advisory input to planning
- communication and engagement
- quarterly update reports
- annual reports.

A crucial element of this approach has been the involvement of the VEFMAP Stage 6 Independent Review Panel (IRP), the Project Steering Committee (including CMA and DELWP staff), and CMA environmental water reserve officers and waterway managers, who participated in various ways to inform ongoing planning and review. The IRP was closely involved with the refinement of the program design, providing ongoing input and critical evaluation to inform program objectives, key evaluation questions and monitoring methods.

### 1.3.2 Informing management

Regular communication between the VEFMAP project team and CMAs, the VEWH and other relevant stakeholders has allowed information and learnings to be fed directly into decision-making processes for environmental flow deliveries. Results from VEFMAP monitoring have informed changes to the timing and magnitude of flow events and enabled the delivery of desired hydrographs, to trigger fish spawning and movement and to support aquatic, fringing and riparian vegetation in Victorian river systems. Information gained through VEFMAP has also informed the development of annual seasonal watering proposals (and subsequent SWPs) (Figures 1.3.2, 1.3.3).

Stage 6 monitoring for VEFMAP has filled important knowledge gaps and improved the effectiveness of environmental water interventions. Figure 1.3.2 highlights the role of VEFMAP in informing the management of Victoria’s environmental water reserve.

### 1.3.3 Data and information management

Earlier stages of VEFMAP highlighted the importance of robust and defensible data collection and management practices. VEFMAP Stage 6 used a refined data management system, including quality assurance (QA) and quality control (QC) checks to ensure that the data were accurate and up-to-date. Quality assurance procedures put in place to produce monitoring data that are fit-for-purpose included:

- training for contractors
- data standards and accepted methods for data capture
- chain of custody and traceability of data
- auditing to ensure data providers adhered to the designated protocols
- calibration of equipment
- review of the monitoring data to check for consistency, accuracy and completeness, and to identify errors or highlight data anomalies (e.g. outliers) that require further investigation or correction.

All Stage 6 QA and QC procedures were designed to ensure that VEFMAP data were of the highest quality and could be used to evaluate KEQs with high levels of confidence.

VEFMAP data (old and new) are stored in a Microsoft SQL Server relational database. The database has in-built QA measures to ensure consistency in the data entered. A user-friendly database interface allows CMA staff to view and extract data summaries relevant to their area; external users are not able to input or change data. Data can be extracted by the curator, in consultation with data users. The curator works closely with the research team to develop data queries that meet ongoing reporting needs. Anomalies in the data that are identified during the reporting phase can be investigated and rectified.

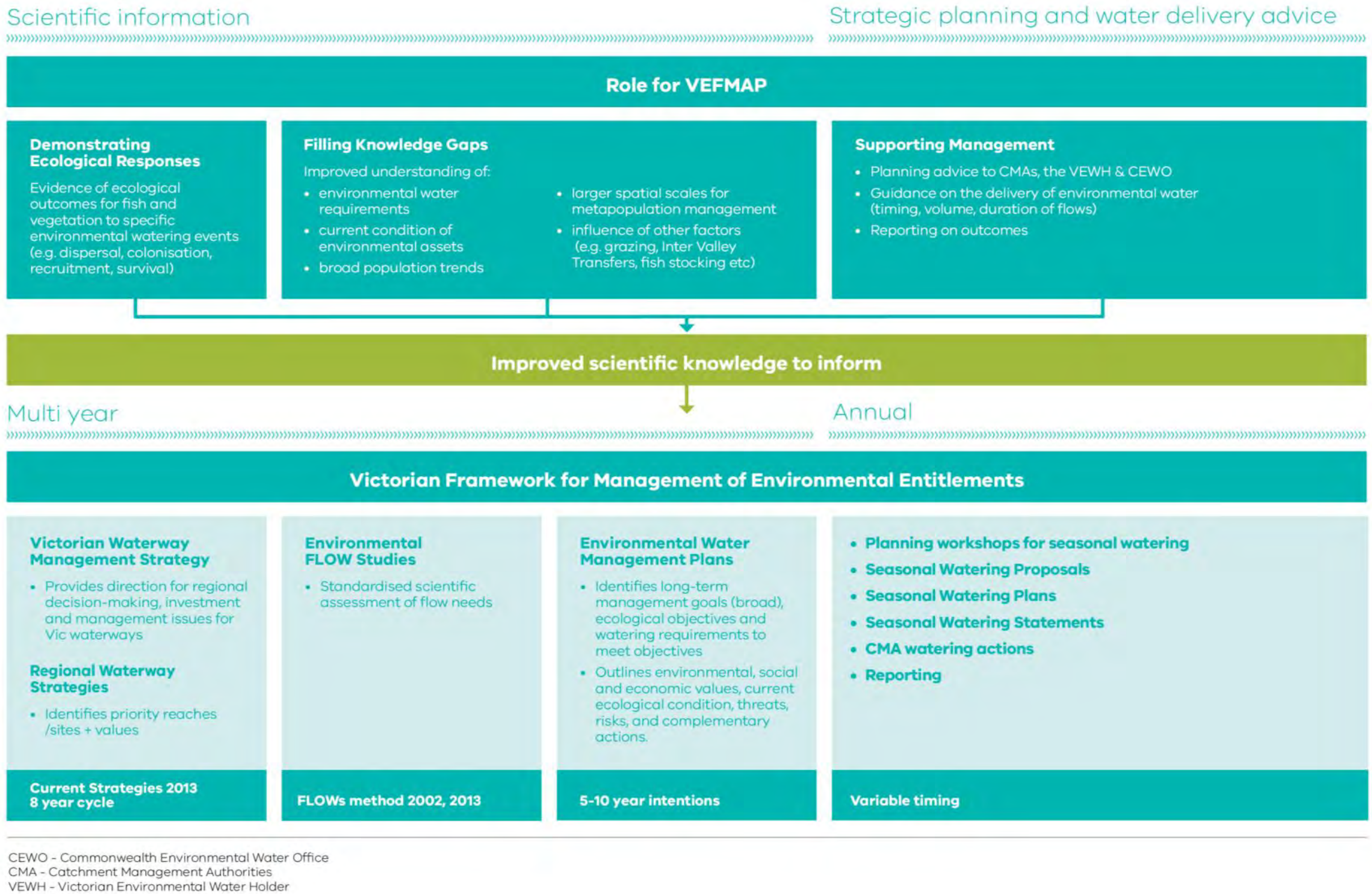



**Figure 1.3.2 The role of VEFMAP in supporting the Victorian framework for management of environmental entitlements.**

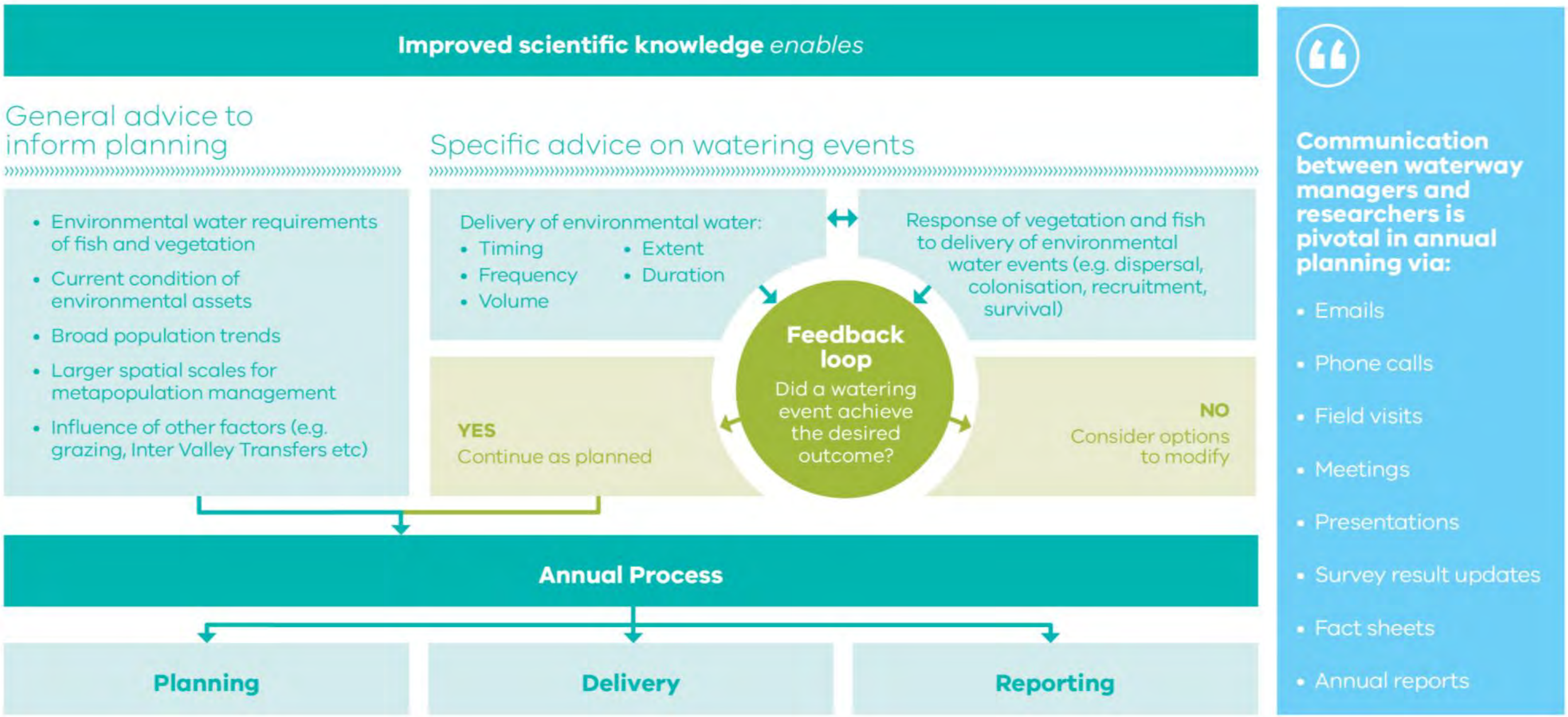



Figure 1.3.3 The role of VEFMAP in supporting annual planning for the management of environmental water.

### 1.3.4 Communication and engagement

Communication and engagement have been a key focus for VEFMAP Stage 6. Providing information to inform effective adaptive management of water resources was the primary focus, along with demonstrating the value of environmental water to other water industry stakeholders.

Communication and engagement approaches have included a mix of annual monitoring reports, fact sheets, workshops, presentations, online content, social media presence, newspaper articles, a poster and videos. Participation in CMA Environmental Water Advisory Groups proved to be a successful way to communicate and engage directly with members of the public, as has an Angler Citizen Science Project conducted in northern Victoria.

Multiple modes of communication and engagement have fostered strong partnerships between DELWP, CMAs and research providers and have helped to ensure accountability and transparency, prompt delivery of information and advice, scientifically sound ecological data and assessments, and an improved understanding of ecological links to flow. Refer to Chapter 4 of this report for more information.

### 1.3.5 Collaboration with other monitoring and research programs

Results from VEFMAP Stage 6 have been significantly improved by close collaborations and sharing of knowledge, data and learnings with a broad range of scientists, research institutes and government agencies (Table 1.3.1).

VEFMAP is one of several long-term environmental water monitoring programs in south-eastern Australia – others include the Commonwealth Environmental Water Office's Monitoring, Evaluation and Research program (MER; previously LTIM and EWKR), The Living Murray Program (TLM), Melbourne Water's river and wetland monitoring programs and DELWP's Wetland Monitoring and Assessment Program for environmental water (WetMAP).

Partnerships with these and other programs and organisations have enabled:

- effective sharing of knowledge, data and results
- more efficient use of funds, by sharing effort, expertise and equipment
- the creation of multi-disciplinary teams to make use of diverse and targeted expertise
- shared mentoring and supervision of university students, increasing student development opportunities.

Significantly, working with other State and Commonwealth agencies has also contributed to system-scale management of species with broad distributions, such as Golden Perch (Section 2.4).

**Table 1.3.1 Research partners and collaborators for VEFMAP Stage 6.**

| | |
|---|---|
| **Victorian agencies**<br>Catchment Management Authorities<br>Melbourne Water<br>Victorian Environmental Water Holder<br>Victorian Fisheries Authority | **Other State and Commonwealth agencies**<br>South Australian Research and Development Institute<br>NSW Department of Primary Industries<br>Murray–Darling Basin Authority<br>Commonwealth Environmental Water Office<br>Commonwealth Scientific and Industrial Research Organisation |
| **Universities**<br>Deakin University<br>La Trobe University<br>The University of Melbourne | **Consulting companies**<br>Jacobs<br>Streamology<br>Austral Ecology |

## 1.4 The content of this synthesis report

This report provides a synthesis of the work undertaken during VEFMAP Stage 6. We first provide background information to articulate the planning, governance, collaboration and information management used during Stage 6. This is followed by a summary from the core themes of Fish (Chapter 2) and Vegetation (Chapter 3) monitoring, as well as the Communications and Engagement component of the program (Chapter 4).

The summaries of each monitoring theme are presented as a series of subchapters, which largely align with the initial key evaluation questions. Each section provides context, outlines aims and hypotheses, methods and results, as well as conclusions and the implications for flow management. Most of these subchapters are linked to supplementary materials (in the form of journal articles and scientific reports) containing details of the specific research. Several subchapters represent case studies, and therefore do not have supplementary material.

We then provide an outline of the approach taken for communication and engagement, including identified target audiences, the suite of activities and tools undertaken, and a discussion of evaluation. A pilot angler citizen scientist project is also provided. The report ends with a conclusion and recommendations for Stage 7.

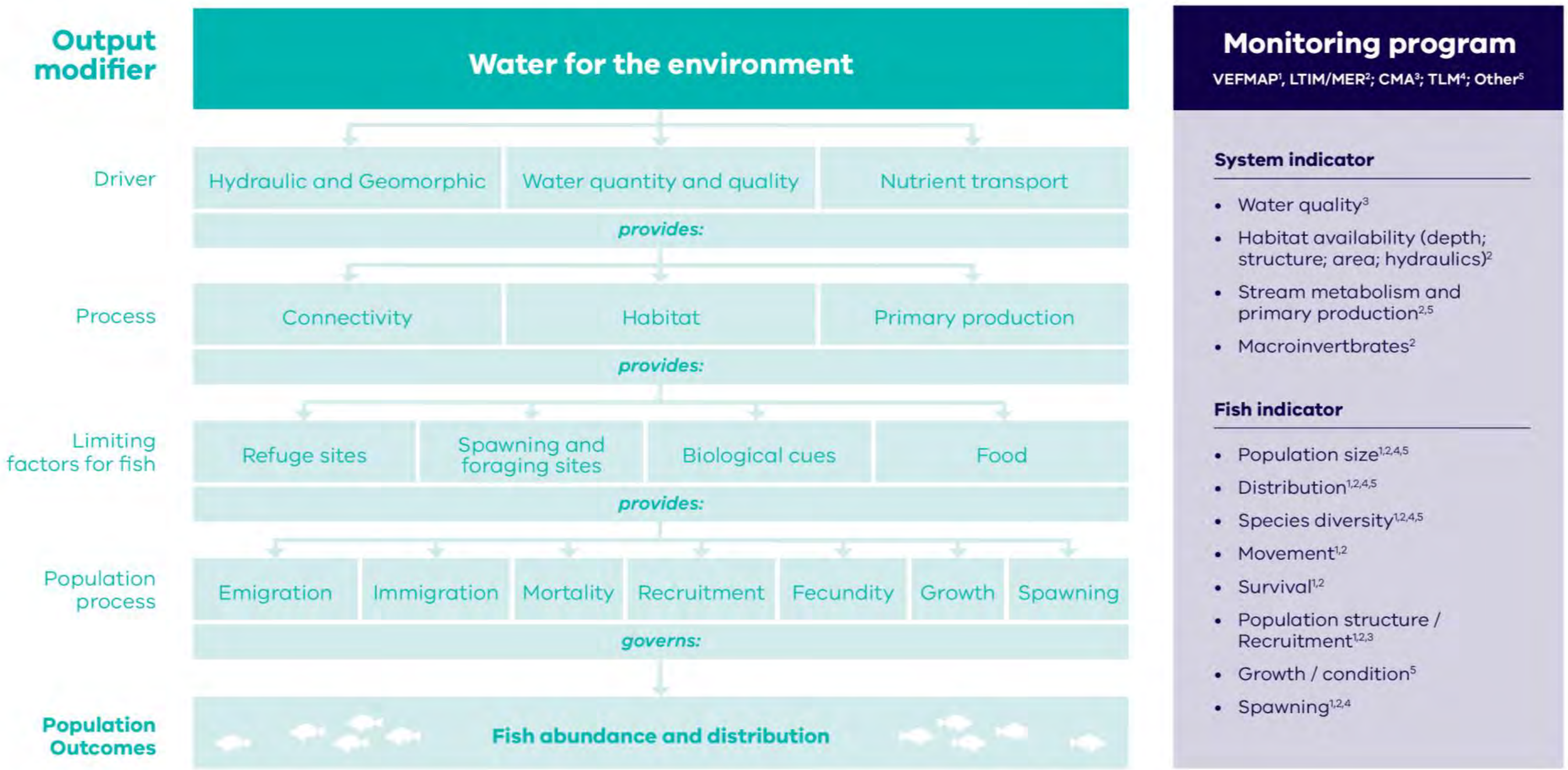
# 2 Fish theme: Monitoring responses to environmental water

## 2.1 Introduction

River regulation and subsequent changes to the natural flow regime have significantly altered or disrupted the critical life history processes of Australian native fish species, contributing to major declines in their distribution and abundance. Supporting native fish populations through informed adaptive management is a major objective of Victorian and Commonwealth biodiversity strategies (e.g. Victorian Waterway Management Strategy; Murray–Darling Basin Plan (MDBP)). Notably, the provision of environmental flows to support native fish populations is a key part of the management strategies for many Victorian rivers, as outlined in the State's Environmental Water Management Plans (EWMPs). Providing environmental water is a significant financial investment in river restoration, so it is critical to evaluate the effectiveness of environmental flows in achieving intended outcomes for native fish. Quantifying relationships between fish population outcomes and the delivery of environmental water help with the adaptive management of flows by providing evidence to support decisions about environmental water deliveries and justify expenditure. The cultural, recreational and economic value of native fish is an important point of engagement with the public (Figure 2.1.1), and research on native fish generates important opportunities for engagement with environmental water managers.

The magnitude and rate at which fish populations change are determined by the interplay between four key population processes: *recruitment, mortality, immigration* and *emigration* (Wootton 1998; Milner et al. 2003; Harris et al. 2013). Each of these population processes are themselves governed by several key sub-processes, such as growth and spawning, and a variety of intrinsic and extrinsic factors (Figure 2.1.2). Intrinsic factors are generally innate to a species and include its life-history strategy, which consists of attributes such as fecundity (e.g. Reznick 1983), behaviour (e.g. Jonsson 2006) and genetic makeup (e.g. Pavlova et al. 2017). Extrinsic factors are associated with a population's environment and may be biotic (such as competition and predation) or abiotic (such as river flows and connectivity). Optimising the benefits of environmental water delivery for fish is therefore contingent on restoring key aspects of the flow regime that are linked to the processes governing population dynamics. In Victoria, the planning and delivery of environmental water for native fish populations is generally targeted at enhancing these population processes.

**Figure 2.1.1** Healthy fish populations provide many recreational, economic and cultural values.




VEFMAP - Victorian Environmental Flows Monitoring and Assessment Program
LTIM - Long-Term Intervention Monitoring Program/
MER - Monitoring, Evaluation and Research Program
CMA - Catchment Management Authorities
TLM - The Living Murray Program

**Figure 2.1.2** The conceptual model that underpins the key pathways and processes linking water for the environment (management output) to fish population outcomes. Examples of indicators used to monitor these processes as well as existing monitoring programs underway across Victoria recording these indicators are also shown.

While environmental flows can play a role in mitigating the detrimental impacts of river regulation, quantitative links between the life history processes of native fish and flow are not always clear (Arthington 2012). The scrutiny to which environmental flow outcomes are subjected demands that there are clear links between watering, life history processes and, ultimately, improvements in fish populations. The Fish theme for VEFMAP Stage 6 included a strong emphasis on 'intervention' or 'flow-event' type monitoring to assess the effects of environmental water on the specific processes governing population dynamics. It also continued a large portion of the long-term condition monitoring from previous stages, which was tracking progress towards achieving the desired outcomes for native fish populations.

The overarching objective of the Fish theme was to examine the importance of environmental flows in promoting the growth and rehabilitation of native fish populations via immigration, dispersal, recruitment and survival in Victorian rivers. Four KEQs were selected to monitor and assess this objective:

KEQ 1: Can environmental flows promote immigration by diadromous fishes in Victorian coastal rivers?

KEQ 2: Do environmental flows enhance dispersal, distribution and recruitment of diadromous fishes in Victorian coastal rivers?

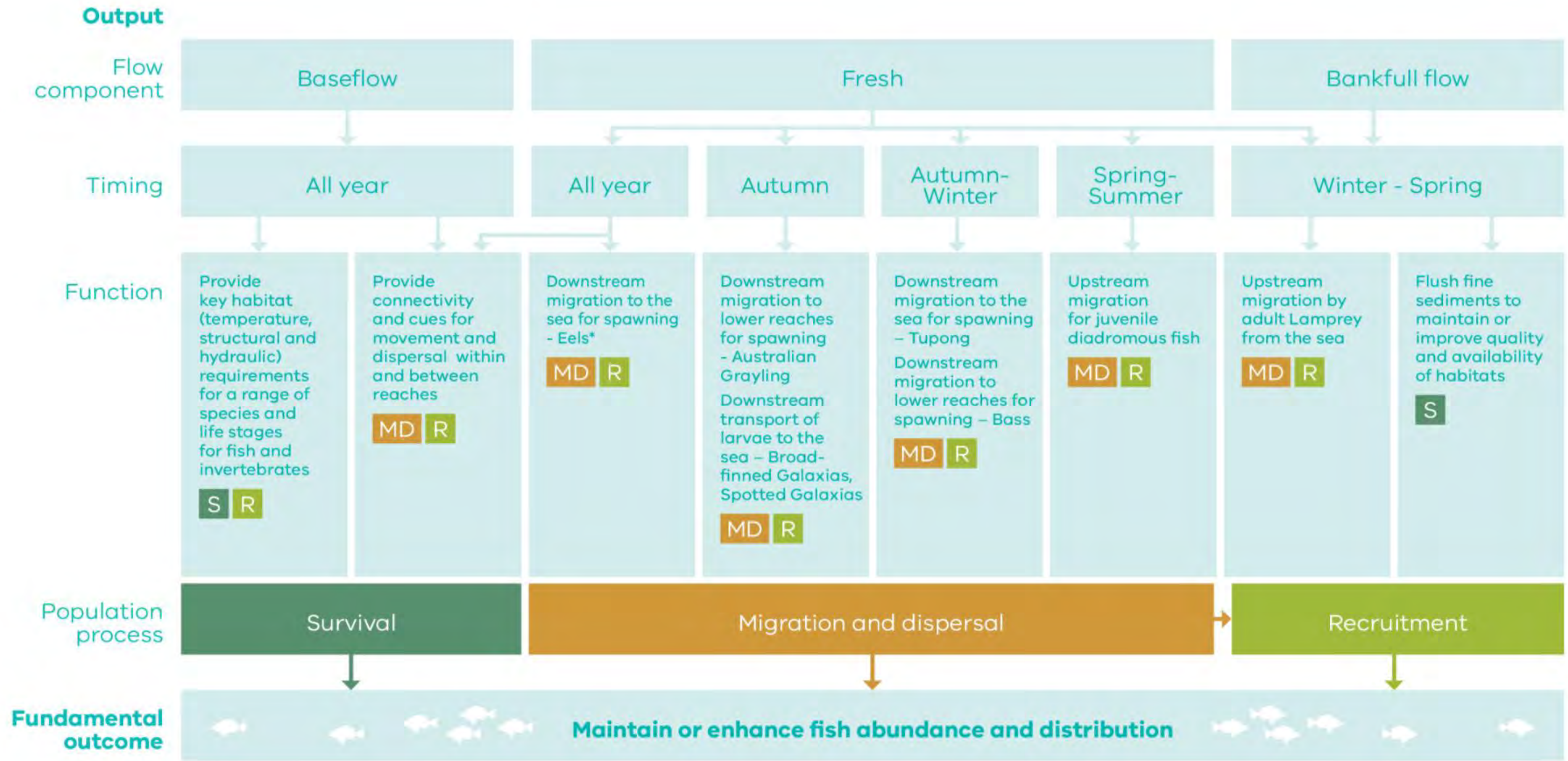
KEQ 3: Do environmental flows support immigration of native fish into, and dispersal throughout, northern Victorian rivers?

KEQ 4: Does environmental flow management used for large-bodied species enhance: (i) survival and recruitment, (ii) abundance and (iii) distribution throughout northern Victorian rivers?

These KEQs were developed in accordance with two broad conceptual models depicting how environmental water is currently managed to influence several key processes governing the population dynamics of native fish (Figure 2.1.3,Figure 2.1.4). These models utilise the previous conceptual understanding developed during the early stages of VEFMAP (Chee et al. 2006) and were refined using recent ecological knowledge collated from the published literature and expert workshops. Although both models are broadly similar, the first model is only for diadromous fish species in Victorian coastal rivers (Figure 2.1.3). Diadromous species are those that must undertake migrations between estuarine or marine and freshwater environments to complete their life cycle. They comprise almost 70% of native fish species in coastal catchments (Harris 1984). The second model is for non-diadromous fish, which spend their whole lives in fresh water (Figure 2.1.4). More detailed conceptual models specific to each KEQ are presented below.

The monitoring program for the Fish theme for VEFMAP Stage 6 considered the collaborative research and monitoring projects occurring throughout south-eastern Australia, and chose species, systems or processes that avoided duplication and were complementary to these programs. Several collaborations and data sharing arrangements have evolved in recent years as a result (see Section 1.3.5).

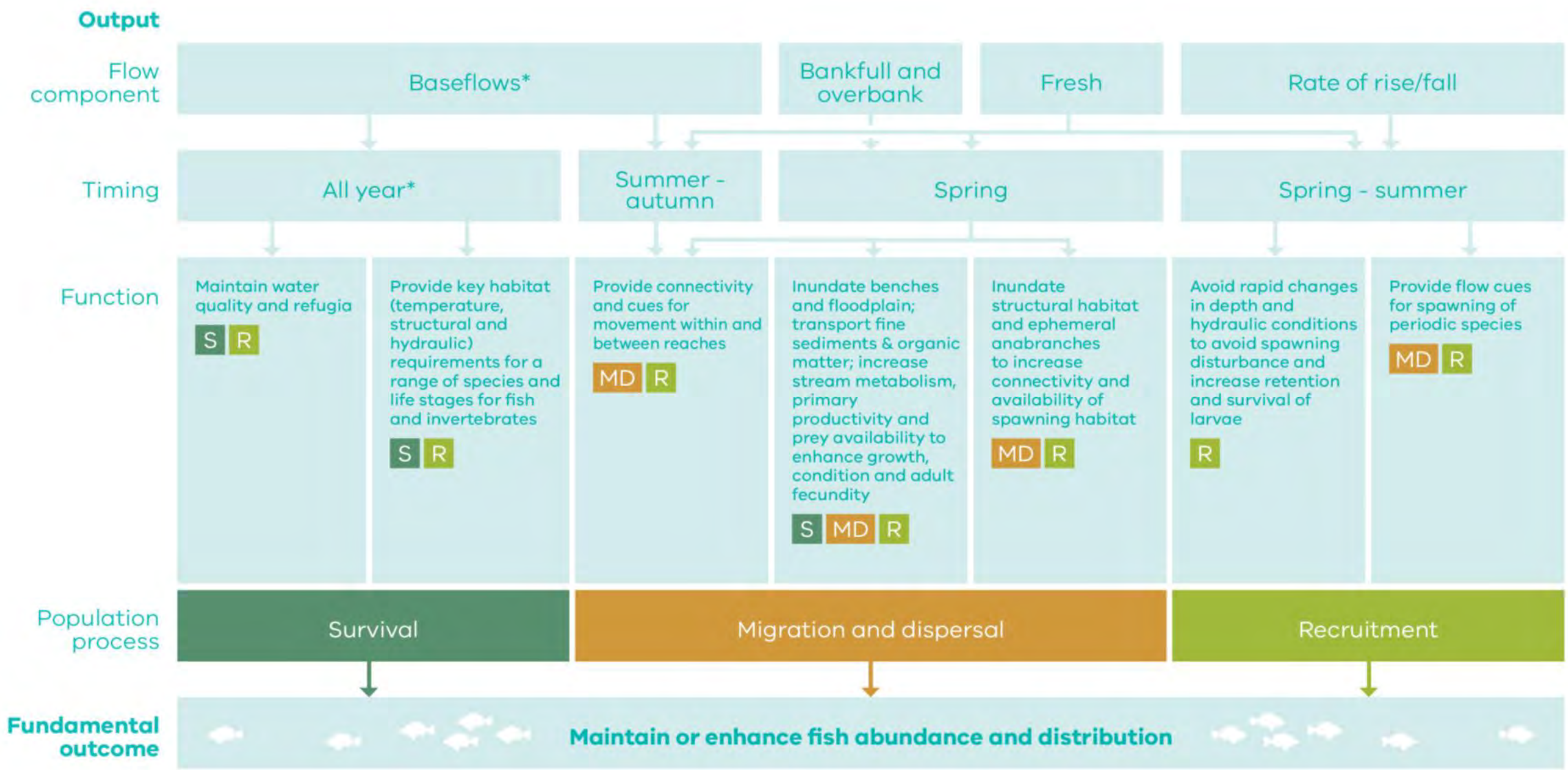
VEFMAP Stage 6 has encompassed almost four years of monitoring and evaluation (2016–2020). Much of the data collected for the Fish theme was used to assess how key population processes respond to individual flow events (i.e. KEQs 1–3). However, assessing how river flows influence processes such as survival, distribution and subsequent population dynamics (forming part of KEQ 4) required the collection and interpretation of long-term population demography data, which for VEFMAP has been underway since 2007. In this section, key research outcomes are presented for each Fish theme KEQ, along with a synthesis of several long-term data evaluations to inform progress towards the program's fundamental objective of enhancing native fish populations at reach, regional and state scales.




*Baseflow level variable according to time of year

S = spawning; R = recruitment; MD = migration and dispersal

**Figure 2.1.3** Conceptual model depicting how environmental water is currently managed to influence key processes governing the population dynamics of diadromous fish species in Victorian coastal rivers.




*Baseflow level variable according to time of year

S = spawning; R = recruitment; MD = migration and dispersal

**Figure 2.1.4** Conceptual model depicting how environmental water is currently managed to influence key processes governing population dynamics of non-diadromous fish species in Victorian rivers.

## 2.2 The role of river discharge in promoting the immigration of juvenile diadromous fishes into Victorian coastal rivers (KEQ 1)

This work is a summary of the research project presented in Supplementary Material 1.

**Supplementary Material 1**: Amtstaetter, F., Koster, W., Tonkin, Z., O'Connor, J., Stuart, I., Hale, R. and Yen, J.D.L. (2020). Elevated river discharge promotes the immigration of juvenile diadromous fishes into rivers. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 2.2.1 Context

Diadromous fish migrations are influenced by environmental conditions, particularly river flow. Quantifying the effects of river discharge on migrations at various life stages is critical for supporting the adaptive management of environmental water that enhances fish outcomes. For example, it has been demonstrated that environmental flow releases can trigger downstream spawning migrations and spawning by Australian Grayling *Prototroctes maraena*, a threatened, diadromous species that inhabits Victorian coastal rivers. However, the successful recruitment of diadromous species also relies on immigration of juvenile fish back into freshwater from their early life stage at sea. This is followed by their upstream dispersal and survival in upstream reaches, where they mature (Figure 2.2.1). Conceptually, increased volumes of water flowing into marine environments could attract more juvenile diadromous fishes into Victorian coastal rivers (e.g. larger volumes of fresh water create a signal over a larger area of the inshore ocean). In some systems environmental flows are being used to facilitate this process, however, the outcomes of these actions or general links between diadromous fish immigration and river discharge have not yet been thoroughly tested.

This KEQ focused on assessing whether the immigration of juvenile diadromous fishes into Victorian coastal rivers is affected by river discharge. We used netting data from five coastal systems over a three-year period to determine whether the abundance of four species of diadromous fish species (Climbing Galaxias *Galaxias brevipinnis*, Common Galaxias, Spotted Galaxias *G. truttaceous* and Australian Grayling) was affected by discharge when moving into the lower freshwater reaches of rivers. The results are used to make recommendations for future environmental flow management in Victorian coastal rivers.

### 2.2.2 Aims and hypotheses

We used two approaches to assess links between the number of diadromous fishes in the lower freshwater reaches of Victorian coastal rivers and river discharge. The first approach compared catch rates between rivers experiencing different discharge rates (the effect of general spring discharge). The second approach assessed within-river trends in catch rates in relation to several flow-related factors, as well as factors not related to flow (e.g. day-of-year, moon phase, tide) that may affect immigration into rivers or migration into freshwater reaches (the effect of event-based discharge). Specifically, our hypotheses related to river discharge were:

1. Catch rates will be highest in rivers during years of high spring discharge.
2. More fish will move into freshwater reaches following periods of high river discharge (lagged response to flow events).

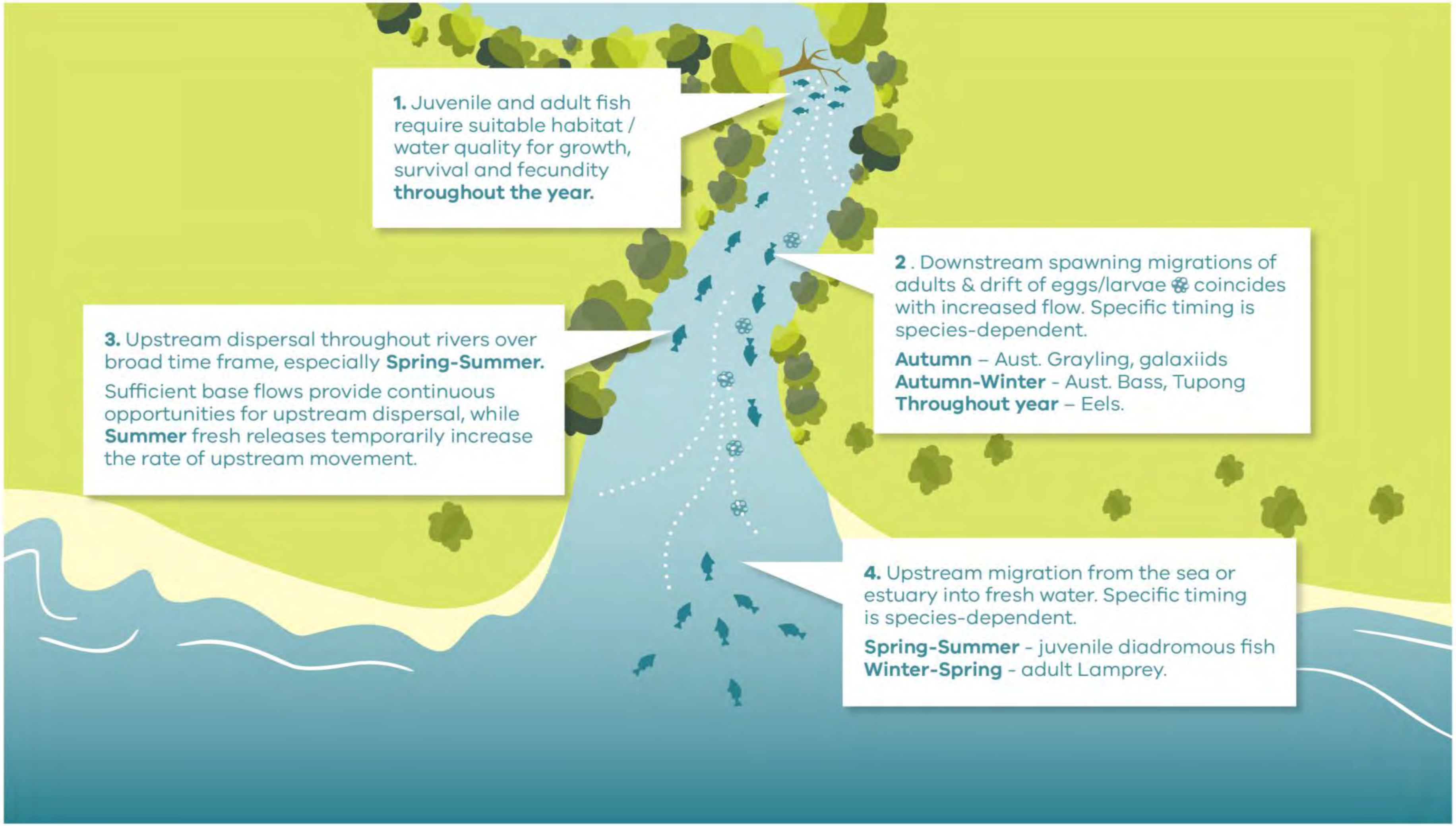



**Figure 2.2.1** Conceptual model showing broad life-history stages and links with river flows for diadromous fishes in Victorian coastal rivers. The key evaluation question presented in this section has focused on testing the role of river discharge influencing Stage 4 of this model.

### 2.2.3 Methods

We investigated the effects of variable spring/early summer discharge rates on the immigration of juvenile (specifically young-of-year (YOY)) diadromous fishes at a single location in each of five streams: Cardinia Creek and the Werribee, Bunyip, Barwon and Tarwin rivers. This suite of rivers was selected to provide data in response to environmental flow releases during spring, as well as to natural fluctuations in discharge at the same time. Study sites were located as close to the upstream extent of the estuary as water depth and access permitted. The streams are regulated, except the Tarwin, which is largely unregulated. Streams were sampled using fyke nets (Figure 2.2.3), except in the Barwon, where sampling was by trapping in the vertical-slot fishway.

We used an ordinal regression model to compare catch rates among rivers experiencing different discharge rates. Broad catch rates in fish abundance were determined from the distribution of catch data over three years in all five rivers. To do this, we used the largest breaks available in the catch data while attempting to keep the number of records within each category uniform (by targeting one third of the catch records for each catch level). The catch classifications of fish abundance were low (0 to 603), medium (722 to 2,632) and high (2,812 to 86,500). We included four spring discharge measures to represent key spring flow attributes (mean daily flow from September to October, mean daily flow in September, peak flow from September to October, and peak flow in September) in separate models.

To assess within river trends in catches, we used a Bayesian hierarchical model to identify associations between daily counts of each species and seven predictor variables (day of the year, moon illumination, maximum tide, mean daily discharge on day of sampling, mean discharge 8–14 days prior to sampling, mean discharge 15–21 days prior to sampling, and mean discharge 22–30 days prior to sampling). The use of a hierarchical model enabled us to include the four study species and five rivers in a single model, allowing separate associations in each species and river while still sharing information among all species and rivers.

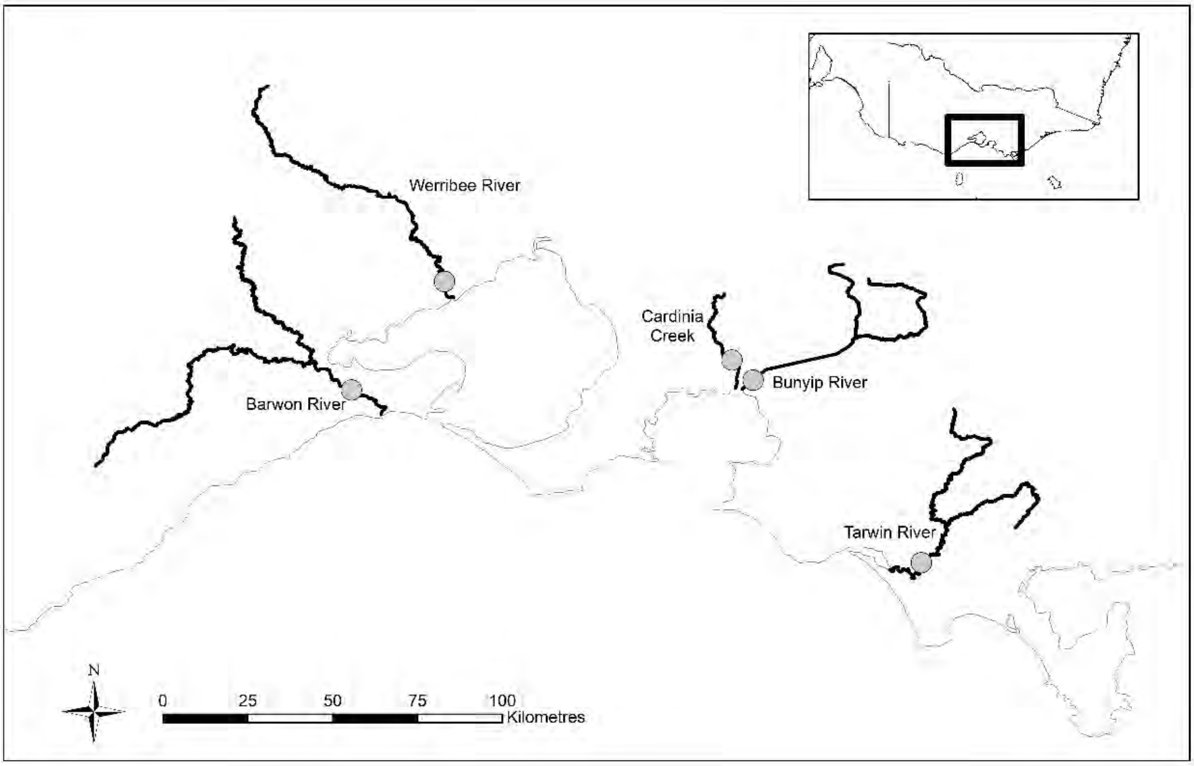



**Figure 2.2.2** Location of sampling sites used to determine the effect of river discharge on the immigration of diadromous fishes into Victorian coastal rivers.

**Figure 2.2.3** Double-wing fyke net set in the Tarwin River to monitor the movement of diadromous fishes into freshwater reaches of coastal Victorian rivers.

## 2.2.4 Results

- Over 600,000 YOY individuals of the four target species were captured during the study. Catches were dominated by Common Galaxias (*n* = 588,140), followed by Spotted Galaxis (*n* = 12,015), Climbing Galaxias (*n* = 8,538) and Australian Grayling (*n* = 1,958). Generally, the highest catch rates were in the Tarwin River and the lowest in Cardinia Creek. However, the highest catch rates for Australian Grayling and Spotted Galaxias were in the Bunyip and Barwon rivers, respectively.
- The catch rates of the target species varied between rivers and years, and all three rates (low, medium and high) were observed in eight of the 14 river/year combinations. Individual catches were more likely to be high in rivers and years with higher mean September discharges. The probability of a high catch rate at any time during the sampling period increased with mean September discharge, and the probability of a low catch rate at any time during the sampling period decreased with mean September discharge (Figure 2.2.4).
- For our event-based analysis, the predictor with the most support in determining catches of diadromous fishes was day-of-year. Strong associations with flow were detected for Climbing Galaxias (all rivers; peaking late September to late October), Spotted Galaxias (all but the Tarwin River, peaking mid-September to late October) and Australian Grayling (all but the Tarwin River; peaking late October). The timing of peak catches of Common Galaxias was much less certain and more protracted than the other species (see Supplementary Material 1).
- Of the flow effects, river discharge 22 to 30 days prior to sampling had the most support for predicting catches of diadromous fishes (compared to 8–14 days or 15–21 days prior to sampling). This relationship was strongest in the flow-stressed Werribee River (Figure 2.2.5).

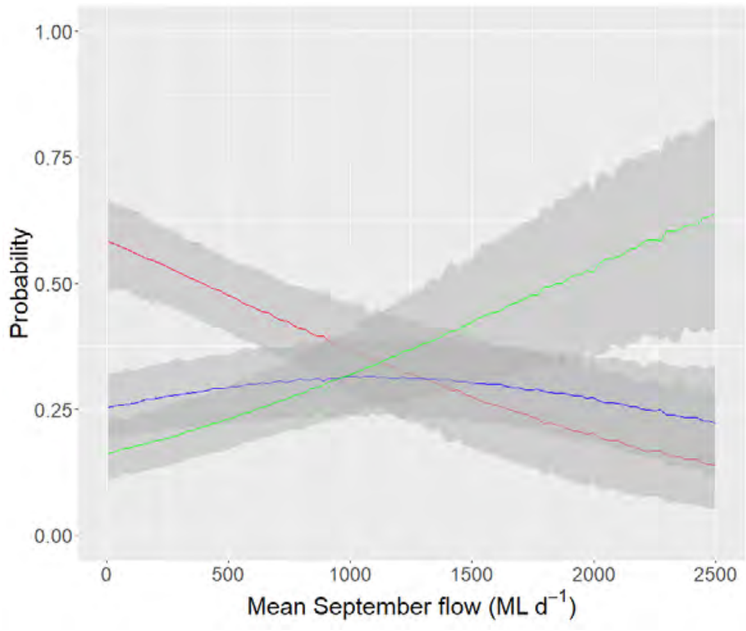



**Figure 2.2.4** Probability of low (red line), medium (blue line) and high (red line) catches of juvenile diadromous fishes entering the lower freshwater reaches of rivers during their spring and early summer migration period, in response to mean September discharge. The model is based on daily catches of Common, Spotted and Climbing Galaxias and Australian Grayling analysed with an ordinal regression model. Shaded areas indicate 95% confidence limits.

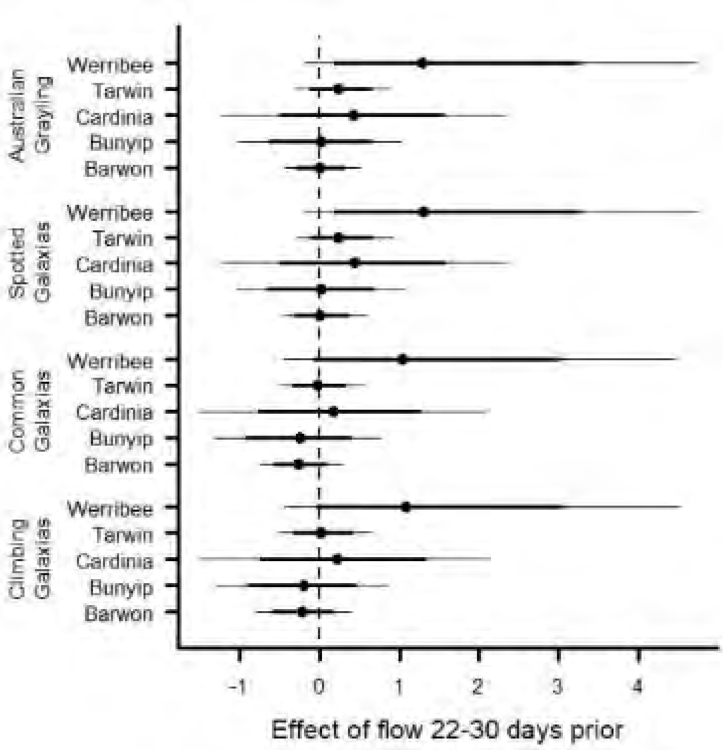



**Figure 2.2.5** Effect of discharge (as coefficient values) 22 to 30 days prior to sampling on daily counts of Common, Spotted and Climbing Galaxias and Australian Grayling in five rivers, estimated using a hierarchical Bayesian model. Points are median coefficient estimates, thick bars span 80% credible intervals, and thin bars span 95% credible intervals. Values to the right of the dashed line are positive effects, values to the left of the dashed line are negative effects.  Coefficient values are relative to predictor variables standardised to zero mean and unit variance.

### 2.2.5 Conclusions and implications for flow management

These results provide new information on the timing and role of flows on the immigration of juvenile diadromous fishes into coastal rivers. The time of year was clearly a key driver of the magnitude of our catches for three of the four species studied, although the peak migration period differed between species. Therefore, the timing of environmental flow releases, aimed at attracting these fishes into freshwater, must consider peak immigration periods on a species by species basis. For example, early-to-mid spring for Australian Grayling and Spotted and Climbing Galaxias, and spring for Common Galaxias.

Our results indicate that the greatest benefit of environmental water for enhancing the immigration of diadromous fishes into rivers would be in rivers and years when spring discharge rates have been low. For example, catches in the Werribee River typically increased three weeks after an environmental flow release that followed a relatively dry spring. Although this type of response was observed in a year which had very large natural pulses in river discharge, the result was very small relative to the response to the large natural pulse. Additional data are required to improve our confidence in whether river discharge over the preceding 22 to 30 days in the Werribee River (where the strongest relationship was observed) is impacting the number of fish moving into freshwater.

The results also indicate large volumes of water are required to promote the immigration of very high numbers of the four target species into freshwater reaches (>1,500 ML $d^{-1}$ for a month). These large discharge volumes are driven by extensive rainfall events, at which time, very high numbers of fish are attracted into coastal rivers (e.g. the Werribee River in 2016). During these times environmental flows will provide little additional benefit in promoting immigration. Instead, we suggest this water is best used to enhance the dispersal and survival of recruits during the following summer, as discussed in Section 2.3.

## 2.3 The use of environmental flow releases to stimulate the upstream movement of juvenile diadromous fishes (KEQ 2)

This work is a summary of the following research project presented in Supplementary Material 2.

**Supplementary Material 2**: Amtstaetter, F., Tonkin, Z., O'Connor, J., Stuart, I. and Koster, W. (2020). Environmental flows stimulate the upstream movement of juvenile diadromous fishes. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 2.3.1 Context

Diadromous fish populations rely on migrations to complete their life cycle, so quantifying the effects of river discharge on migrations at various life-stages is critical for the adaptive management of environmental water to enhance fish outcomes (Figure 2.1.3). KEQ 1 generated important information linking spring river flows with the timing and magnitude of response by juvenile diadromous fishes migrating into rivers from the marine environment to help inform flow management. This represents a critical stage in the recruitment of diadromous fishes, but these species also need to continue their dispersal back upstream in order to survive and mature (Figure 2.2.1). Because there is some evidence that increases in river flows increase the upstream movement of juvenile diadromous fishes, environmental flows are being used to enhance this process in regulated coastal streams. While conceptually sound, the outcomes from these environmental flow releases have rarely been tested.

This KEQ focused on assessing whether the process of upstream dispersal (the migration of juvenile diadromous fishes) can be enhanced using environmental flow releases. We used netting data from two coastal systems over a period of three years to determine how the upstream movement of three species (Common Galaxias, Tupong and Short-finned Eel) changed between periods of baseflows and summer/early autumn fresh releases (a short period of elevated river discharge). The results are used to make recommendations for future environmental flow management in coastal rivers.

### 2.3.2 Aims and hypotheses

We tested the hypothesis that the number of juveniles of three diadromous fish species that migrate upstream is higher during summer/early autumn flow pulses (termed 'freshes') than during baseflow periods. The results could be used to guide future water delivery actions aimed at enhancing diadromous fish populations.

### 2.3.3 Methods

We investigated whether summer and early autumn fresh releases increase the number of juvenile diadromous fish moving upstream using fyke netting at six sites in each of the Glenelg and Moorabool rivers (impact rivers), and at two to three sites in each of the Stokes and Barwon rivers (control rivers; Figure 2.3.1 and Figure 2.3.2). All sites in the Barwon River were below Buckley Falls, which is a natural barrier to fish movement in the river. The impact rivers received environmental flow fresh releases in summer and early autumn, with the objective of improving the upstream dispersal of diadromous fishes. The control rivers, which are in the same catchment and have similar climatic conditions, did not receive releases of environmental water. Sampling occurred before and during fresh releases (Figure 2.3.3). Sampling in the Glenelg and Stokes rivers occurred from 2017 to 2019, and in the Moorabool and Barwon rivers in 2018. Sampling was expanded to the Moorabool and Barwon rivers following the successful use of the method in the other rivers in 2017. However, it appears that a barrier downstream of the study sites in the Moorabool River impacted fish movements (and hence our ability to monitor the dispersal) for two of our three species, so sampling in that river system was discontinued after one year.

Negative binomial, generalised additive models were used to test for changes in the number of juvenile fish moving upstream prior to and during summer and early autumn fresh releases at environmental flow sites, relative to the control sites. The species used for the assessment were YOY Common Galaxias and Tupong in the Glenelg River and juvenile Short-finned Eel in the Moorabool River. Because of a lack of YOY Tupong at the control sites, the model was only used to assess catches of Tupong at environmental flow sites (before and after).

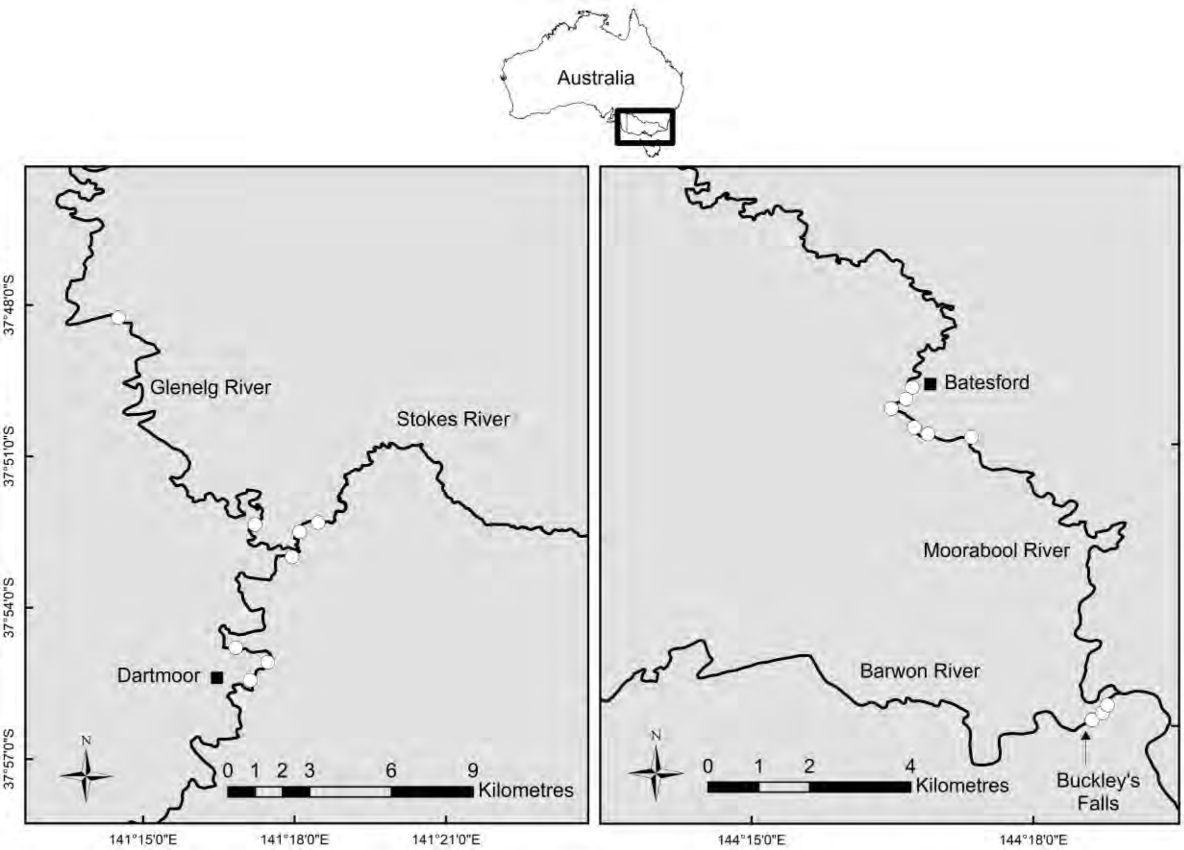



**Figure 2.3.1** Location of sampling sites used to determine the effectiveness of environmental flow releases on increasing the upstream dispersal of juvenile diadromous fishes.

**Figure 2.3.2** Double-wing fyke net set in the Moorabool River to monitor the upstream movement of diadromous fishes, summer 2017, before the flow pulse (fresh) release (top) and during release (bottom).

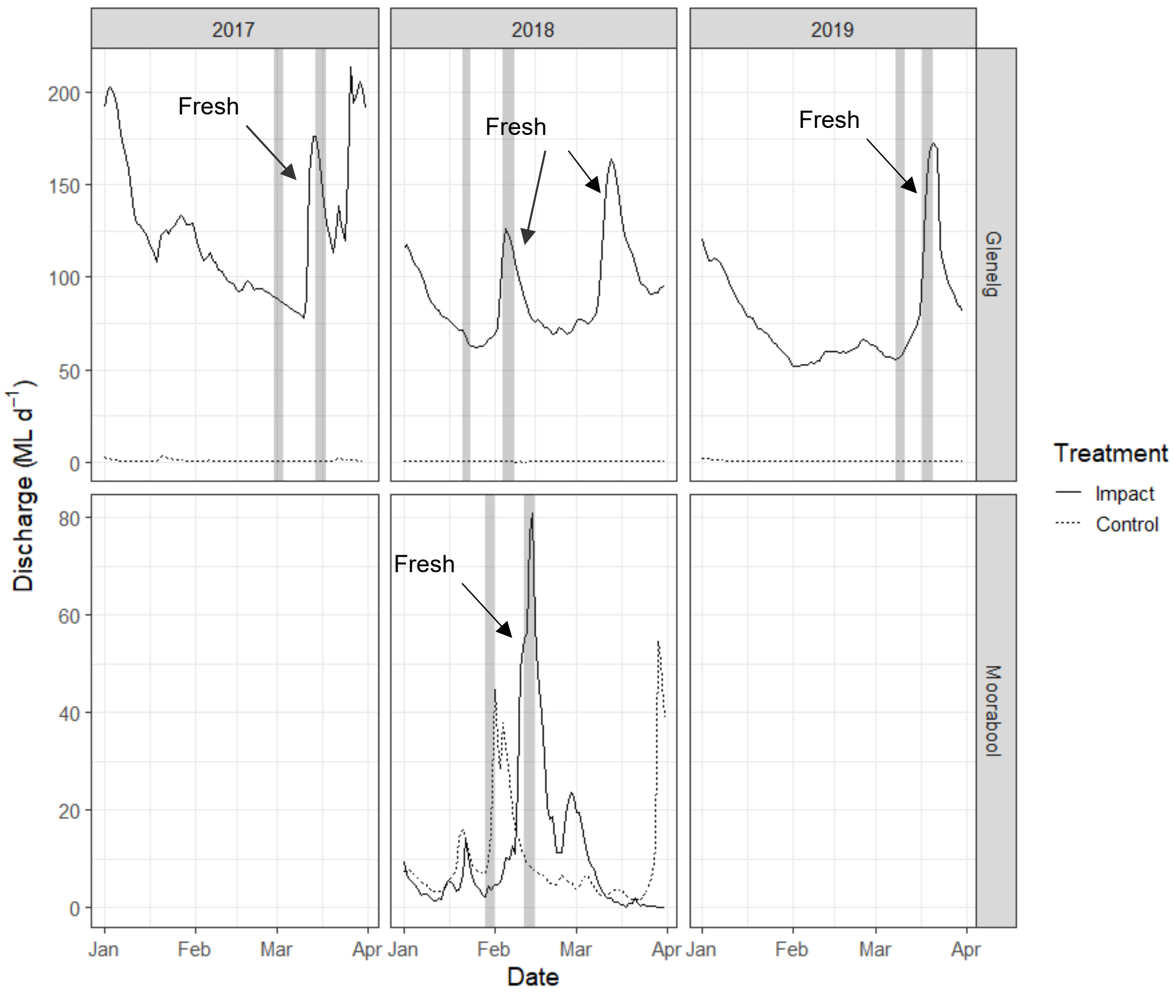



**Figure 2.3.3** Summer/early autumn river discharge in the Glenelg and Moorabool impacted rivers, and in the Barwon and Stokes control rivers, 2017 to 2019. Grey bars represent sampling periods. Environmental flow 'fresh' events also highlighted.

## 2.3.4 Results

*Glenelg and Stokes rivers*

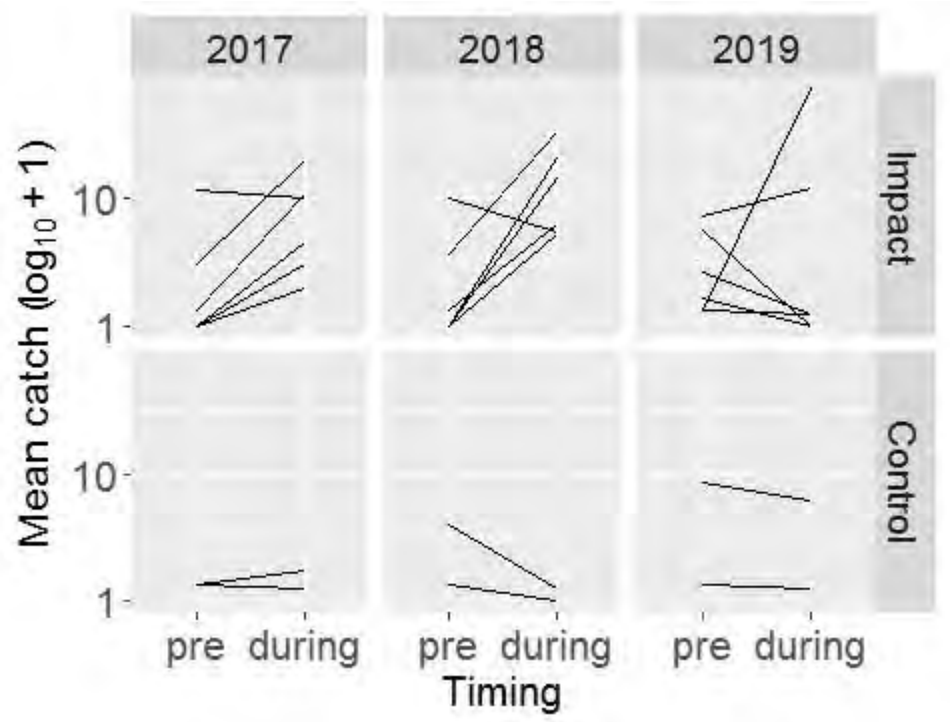
There was a statistically significant increase in the catch of YOY Common Galaxias during the fresh releases relative to the baseflow conditions ($p = 0.019$). In most cases, the catch in the Glenelg River was higher at sites during the fresh releases than during baseflows (Figure 2.3.4). Overall, the mean catch rate during the fresh releases was six times higher than during the baseflow periods. In contrast, the catch was similar or lower at sites in the Stokes River (control) during the Glenelg River fresh release compared with the baseflow period (Figure 2.3.4).

In 2017 and 2018, catches of YOY Tupong were higher during the fresh releases compared with the baseflow period at most sites in the Glenelg River (Figure 2.3.4). Overall, the mean catch rate during the fresh releases was 39% higher than during the baseflow period, although this difference was not statistically significant ($p = 0.11$). No YOY Tupong were captured at any of the control sites in the Stokes River over the three-year sampling period, nor in the Glenelg River in 2019.

*Barwon and Moorabool rivers*

There was a statistically significant increase in the catch of juvenile Short-finned Eel during the fresh releases relative to the baseflow conditions ($p < 0.001$). In most cases, the catch in the Moorabool River was higher at sites during the fresh release than during the baseflow period (Figure 2.3.5). Overall, the mean catch rate during the fresh release was two times higher than during the baseflow periods. In contrast, the catch was lower at most sites in the Barwon River during the Moorabool River fresh release compared with the baseflow period (Figure 2.3.5).

Common Galaxias




Tupong

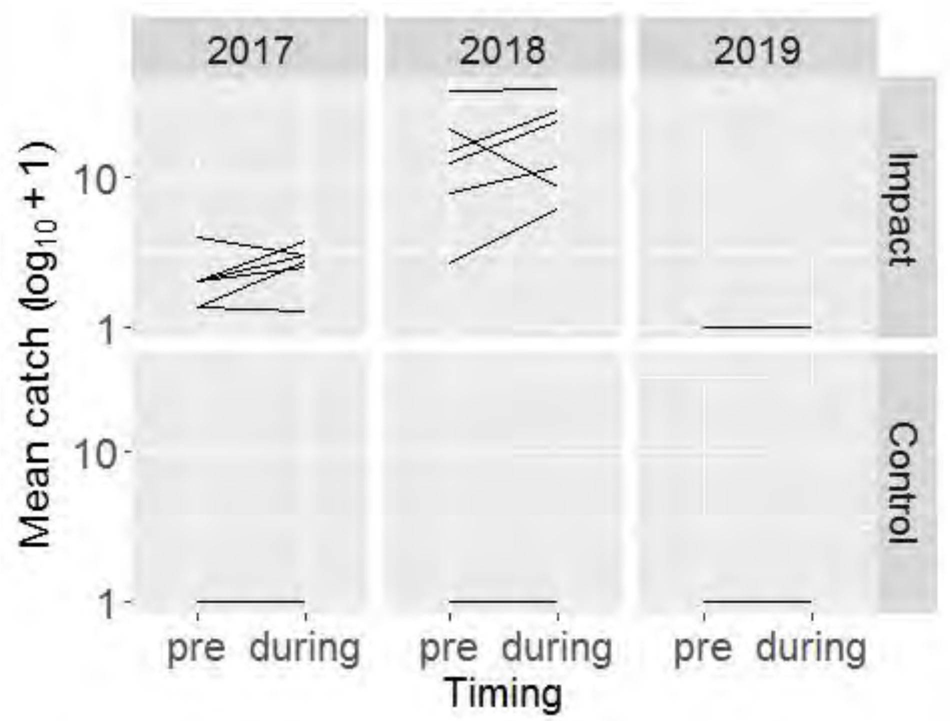



**Figure 2.3.4** Mean catches of YOY Common Galaxias (< 65 mm in fork length; top panel) and YOY Tupong (< 80 mm in total length; bottom panel) per 24-hour sampling at each site in the Glenelg (impact) and Stokes (control) rivers before and during summer or early autumn environmental flow releases in the Glenelg River (2017–2019).

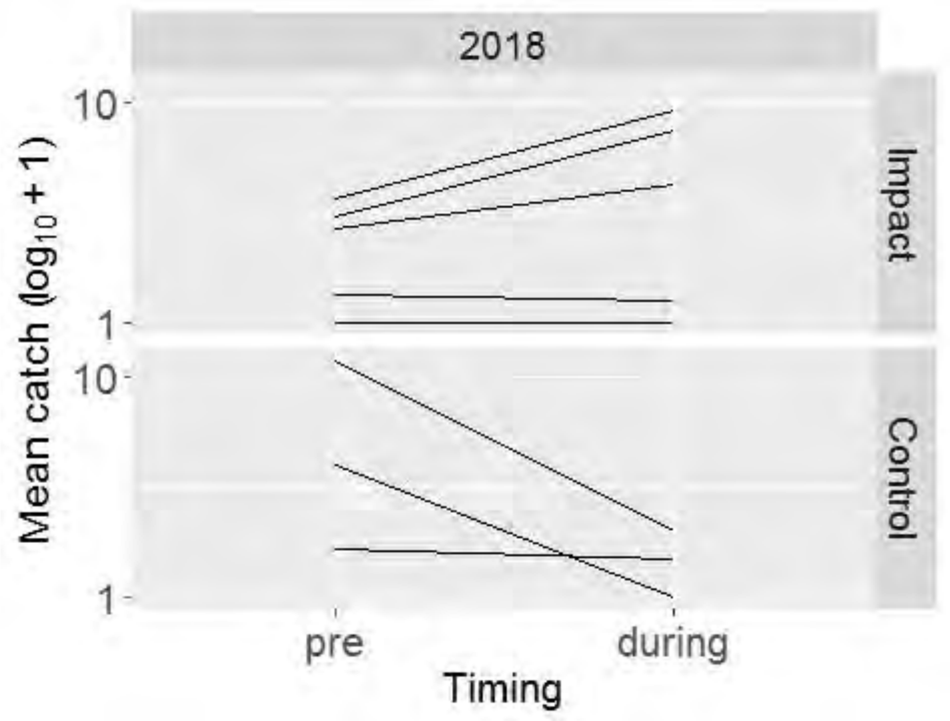



**Figure 2.3.5** Mean catches of juvenile Short-finned Eel (< 250 mm in total length) per 24-hour sampling at each site in the Moorabool (impact) and Barwon (control) rivers before and during a summer environmental flow release in the Moorabool River in 2018.

### 2.3.5 Conclusions and implications for flow management

These results provide an important scientific basis for the rationale and implementation of flow management aimed at improving the upstream dispersal of juvenile diadromous fishes. There was a significant response in upstream dispersal of juvenile Common Galaxias and Short-finned Eel to environmental flow releases during summer and early autumn, with an average sixfold increase in catches during freshes compared to baseflow conditions. Although a significant result was not detected for Tupong, a 39% increase in movement during these releases was observed. This is the first time the effectiveness of these types of environmental flow releases have been assessed for diadromous fishes and provides support for their continued use.

The ability for this study to test its existing hypothesis regarding upstream movement of juvenile fish in response to flows was dependent upon the presence of the target species and the relevant life-stages. In the Moorabool River, Common Galaxias and juvenile Tupong were absent during monitoring, which is likely the result of a man-made barrier downstream of the study site that blocked the passage of fish during the preceding low to moderate discharge. This situation highlights the importance of considering potentially interrelated factors when planning environmental water management.

We recommend that environmental flows be used for improving the upstream dispersal of fish, provided barriers in the lower reaches of rivers do not block fish passage (unless the flows allow movement past the barrier) and sufficient flows exist to maintain suitable water quality and habitat for survival and maturation. In streams with barriers, environmental flows may have little or no benefit for diadromous fishes until the barriers are removed or circumvented (e.g. using fishways).

The delivery of freshes may provide the greatest population-level benefits in years when the abundance of new recruits is relatively high and in years of low flow. Increased upstream dispersal decreases the densities of fish in the lower reaches and the consequential risk of density-dependent mortality.

Although the magnitudes of the environmental flows in this study have been effective for the study species, flows provided at different magnitudes or times may benefit other species. Continuing to monitor such flows at different times, magnitudes and in other river systems will help refine environmental flow delivery aimed at enhancing diadromous fish populations in Victorian coastal rivers.

## 2.4 Do environmental flows support immigration of native fish into, and dispersal throughout, northern Victorian river networks? (KEQ 3)

This work is a summary of the following three research projects presented in Supplementary Material 3-5.

**Supplementary Material 3**: Koster, W.M., Stuart, I.G., Tonkin, Z., Dawson, D., and Fanson, B. (2020). Environmental influences on migration patterns and pathways of a threatened Australian fish in a lowland river network. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

**Supplementary Material 4:** O'Connor, J., Jones, M. and Tonkin, Z (2020). Managing river flows to enhance upstream dispersal and retention of Golden Perch in a highly regulated lowland river system. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

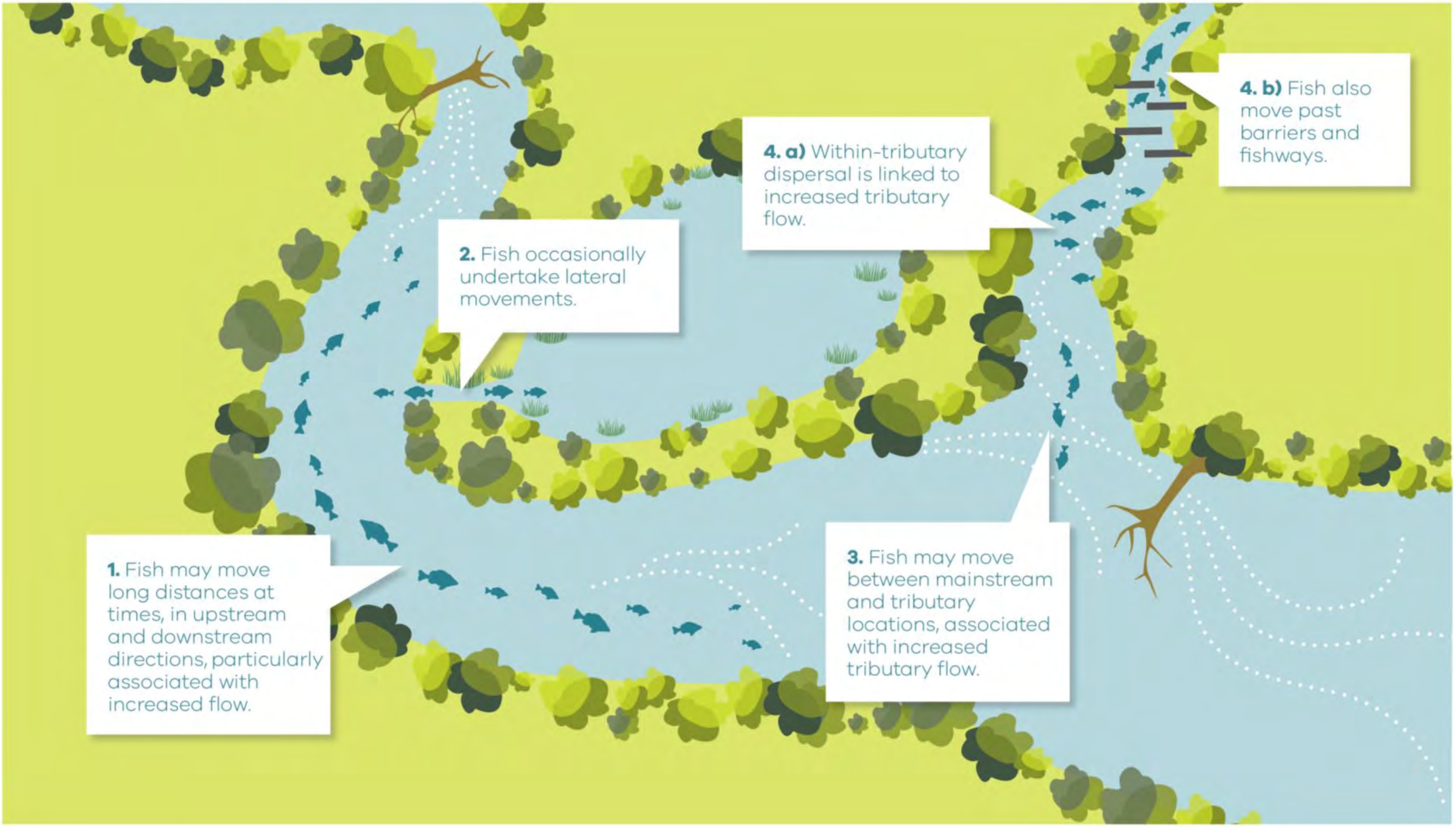
**Supplementary Material 5**: Jones, M.J., O'Connor, J., Clunie, P., Lyon, J., Stuart, I., Saddlier, S., Hackett, G., Pickworth, A., Mahoney, J. Fairbrother, P., Moloney, P. and Tonkin, Z. (2020). Environmental flows cue fish movement and improve fishway functionality: case studies from a semi-arid river-floodplain system. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 2.4.1 Context

Animal movement is an important process that affects the structure and dynamics of populations, communities and ecosystems. There is growing evidence that movement of biota among different parts of a river network can be fundamental to the functioning and sustainability of riverine populations. For example, the viability of some fish populations depends on large-scale movements at different times to access specific habitats for growth, reproduction and refugia. Quantifying these movements and identifying their drivers (such as stream flows) is important for understanding patterns in population dynamics and predicting population responses to environmental changes.

Many human activities (e.g. dam construction, altered flow regimes) impair riverine fish movements through reduced river connectivity and cues. This often has severe consequences for fish populations, such as isolation, failed recruitment and local extinction. For wide-ranging or migratory riverine fishes, the impacts of reduced connectivity have been particularly severe. To remedy these issues, conservation measures such as fishways to facilitate passage, and environmental flows to cue movements and restore hydrologic connectivity, are being developed and implemented in regulated rivers. In Australia's Murray–Darling Basin, research has found that some species such as Silver Perch and Golden Perch can move hundreds or even thousands of kilometres within and between river systems, and that immigration from the Murray River can be an important source of fish occupying tributaries (Koster et al. 2014; Zampatti et al. 2015; Thiem et al. 2017). Environmental flows are now being used to promote the immigration of native fish from the Murray River into, and dispersal throughout, Victorian tributaries (e.g. VEWH 2020). These flows are also used to enhance passage through fishways on irrigation infrastructure, facilitating further dispersal (Figure 2.4.1). Until now, very few studies have tested the effectiveness of such interventions.

This KEQ focussed on assessing links between immigration and dispersal and flows, including whether these movements could be enhanced using environmental water releases. We draw on the results of three separate studies. The first two studies examine the timing and extent of movement of Silver Perch and Golden Perch among different parts of a river network and identify potential environmental variables (including river discharge) that might help predict when these movements occur. The third study looks more specifically at the movements of a suite of native and exotic species through fishways, and how environmental flows enhance this process. The results from all these studies are used to help predict when movements occur, so that more targeted flow management actions can be developed to benefit native fish.




* Fish movement occurs mostly during the warmer months from spring through autumn (September – March).

**Figure 2.4.1.** Diagrammatic conceptual model showing the role of river flows in governing immigration and dispersal of native fish in northern Victorian rivers. The Key Evaluation Question presented in this section has focussed on testing the role of environmental water releases in influencing each of the stages in this model.

### 2.4.2 Aims and hypotheses

The three studies presented in this section, and their respective aims and hypotheses, are as follows:

*Study 1: Assessing the role of river flows on migration patterns and pathways of migratory fishes in a lowland river network (Supplementary Material 3)*

This study examined the timing and extent of movement of Silver Perch and Golden Perch between different parts of the Murray River, its tributaries and the floodplain. The aim was to identify potential environmental variables (including river discharge) that might help predict when movements occur, so that more targeted management actions could be developed to support the conservation management of these species.

*Study 2: Managing river flows to enhance upstream dispersal and retention of Golden Perch in a highly regulated lowland river system (Supplementary Material 4)*

The aims of this study were to examine the role of managed flows in governing upstream dispersal and retention of Golden Perch in a flow-stressed lowland river network. Specifically, we hypothesised that:

- upstream movement would be enhanced by increases in discharge in spring and autumn
- retention of Golden Perch in a reach would be dependent on baseflow conditions with downstream movement out of a reach occurring when discharge decreased

*Study 3: Environmental flows cue fish movement and improve fishway functionality: case studies from a semi-arid river-floodplain system (Supplementary Material 5)*

The aim of this study was to assess fish movement through fishways in response to environmental flows. We hypothesised that:

- the flows would cue fish to move, increasing the abundance and diversity of native fish moving through fishways
- higher discharges would result in greater abundances of fish moving
- rising tailwater levels during environmental flows would drown out fishway turbulence and low-level weir crests, thereby improving opportunities for fish movement across barriers.

### 2.4.3 Methods

*Study 1*

This study was undertaken in the middle reaches of the Murray River, three of its tributaries (Campaspe and Goulburn rivers and Broken Creek), one anabranch (Edward River), and their floodplain habitats (Figure 2.4.2). Silver Perch and Golden Perch were collected ascending the Torrumbarry fishway on the Murray River and tagged with acoustic transmitters during February 2017 and February–April 2019. Passive integrated transponder (PIT) tags were also implanted into fish to determine movements into Broken Creek, where a PIT tag reading system exists.

Acoustic listening stations were deployed in the Murray River from immediately downstream of Torrumbarry Weir to Yarrawonga Weir, including at junctions with the Campaspe, Goulburn and Edward rivers and Broken Creek (Figure 2.4.2). A listening station was also deployed within each of these systems 1 km from the Murray River, except in Broken Creek where an existing PIT tag reading system in the lower reaches at Rices Weir was used to determine movement into the system.

An additional eight listening stations were deployed in July 2018 to provide information on movement into floodplain habitats in the Barmah Forest region (Barmah Lake, Moira Creek, Bunnydigger Creek, Budgee Creek, Cutting Creek, Tongalong Creek (upper and lower), Gulf Creek) (Figure 2.4.2).

Generalised additive mixed models (GAMMs) were used to explore the influence of environmental variables (including river discharge) on the probabilities of tagged Silver Perch moving in the Murray River and entering a tributary, and the time spent in a tributary. The tributary analysis was restricted to the Campaspe and Goulburn rivers because there were few observations for the other systems. Samples sizes for Golden Perch were too low to perform a formal analysis.

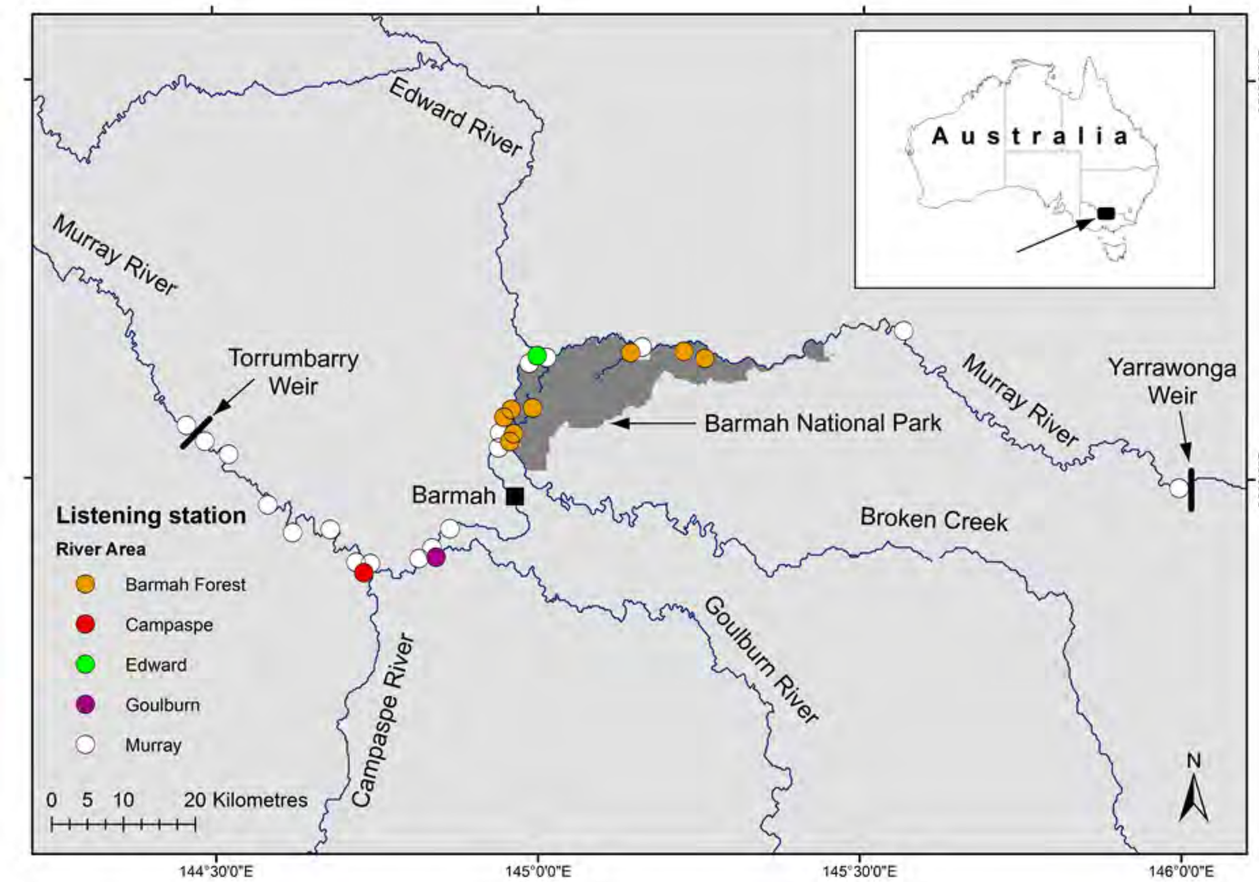



**Figure 2.4.2** The location of the study area for Study 1.

*Study 2*

The study was undertaken in the Loddon River catchment, in north-western Victoria (Figure 2.4.3), where we used acoustic telemetry to monitor Golden Perch movements between January 2017 and November 2019. Acoustic tags were implanted into 113 Golden Perch, ranging in size from 166 to 555 mm (TL length) at numerous locations in the lower Loddon River catchment (Figure 2.4.3A). Twenty-two 69 kHz AVR2W Coded Acoustic Receivers (VEMCO, Nova Scotia, Canada) were deployed throughout the study area between January 2017 and September 2018 (Figure 2.4.3B). Discharge data were obtained from various gauges in the lower Loddon River system (Figure 2.4.3C).

As most fish were released at the base of the lower Loddon River and the Pyramid Creek, we focused our analysis on these fish. Discharge metrics, along with day of year and fish length (also thought to potentially influenced movement behaviour) were used to explore the influence of environmental variables on fish movement using Generalised additive models (GAMs).

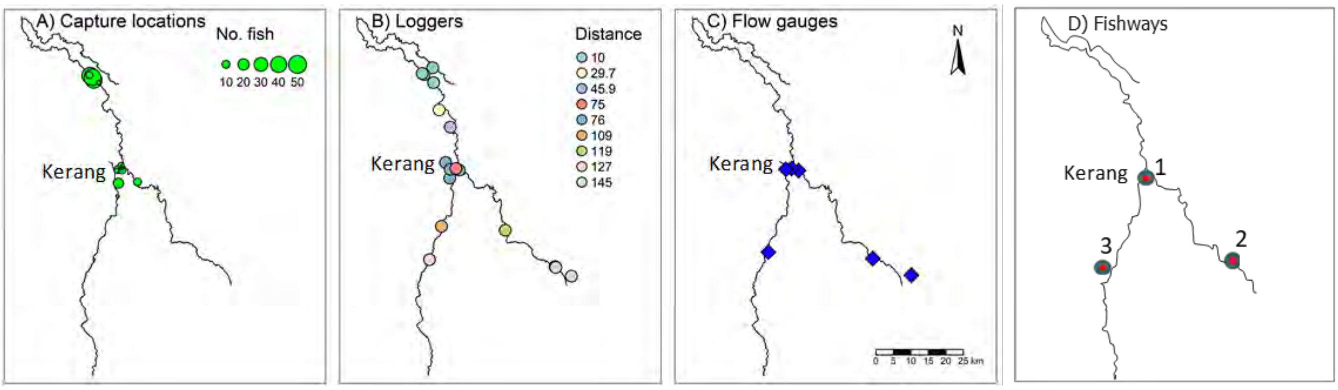



**Figure 2.4.3** The location of (A) capture sites, (B) loggers, (C) discharge gauges and (D) fishways (1=Kerang, 2=Kow and 3 =The Chute fishways) in the Loddon–Pyramid system. In (A), the size of the circle represents the number of fish tagged at that site. In (B), different colours indicate the locations of loggers; units are kilometres from junction.

*Study 3*

The study also focused on the lower Loddon River system. Five fishways facilitate fish movement in the study area, with three of these sampled to assess fish movements in response to environmental flows; Kerang Weir fishway (reach 5), The Chute fishway near Appin South (reach 4), and Box Creek fish lock (reach 5). A high flow fresh (750 ML $d^{-1}$) was delivered to reach 5 of the Loddon River in autumn 2017 and in spring 2017, 2018 and 2019. On each occasion the flow peak was held for 10 days, with a ramp up and ramp down; 450 ML $d^{-1}$ of the flow in reach 5 passed through reach 4 from the Loddon River weir. Environmental flow objectives for the Loddon River included maintaining the water quality and connectivity of pool habitats and protecting and increasing native fish populations by providing flows as cues for movement, spawning and recruitment.

Kerang Weir headwater and tailwater levels were measured over three consecutive 5-day periods in spring 2019. This enabled an assessment of changes in stream hydrology and to provide data for modelling fishway hydraulics (cell turbulence and velocity) at low, medium and high water levels/discharges to predict outcomes for fish passage. The modelling was undertaken using the Jacobs vertical slot fishway hydraulic and biological modelling tool (Jacobs 2020), and results were compared against the Victorian Fish Passage Guidelines (O'Connor et al. 2017).

Fish trapping was used to assess fish numbers moving through each fishway in response to environmental flow delivery. Fishway traps were custom-built for each fishway and for target fish size ranges; all fish greater than approximately 40 mm in length were trapped in Kerang Weir fishway and The Chute fishway, while only larger fish (>70 mm) were trapped at the Kow Swamp fish lock due to debris issues limiting use of finer mesh sizes. Each fishway was sampled for 24 hrs, four times in each 5-day period, and traps were checked once each day. Sampling was conducted prior to, and during environmental flow released during one or more fresh events in each reach in spring and autumn. Sampling occurred over a three-week period in autumn 2017 (March–April), a four-week period in spring 2017 (September–October), a two-week period in spring 2018 (September–October), and a three-week period in spring 2019 (October–November). All fish collected were identified, counted, and measured for length.

The data was analysed using Bayesian analysis (zero-inflated negative binomial), where discharge, water temperature and location were used as fixed variables, and each trip/location was included as a random effect. Initial exploration of the discharge data showed that discharges tended to be clumped at either a 'high' or 'low' level at each site, with 'high' levels occurring during periods of environmental water releases. It was therefore decided that the discrete levels of 'low' and 'high' discharge (for each location) were more appropriate to model and report.

### 2.4.4 Results

*Study 1*

*Fish movement in the Murray River*

- Silver Perch were detected undertaking upstream and downstream movements. Most Silver Perch were recorded moving upstream, as far as 100 km (Goulburn River confluence) from Torrumbarry Weir.
- The probability of upstream movement of an individual Silver Perch in the Murray River was greatest between September and February (spring and summer) and during moderate increases in discharge (Figure 2.4.4). Downstream movement of Silver Perch in the Murray River was more likely during large increases in discharge (Figure 2.4.4).
- Although few Golden Perch were collected for tagging, both upstream and downstream movements were detected. Upstream movement of Golden Perch in the Murray River decreased with time since tagging.

*Fish movement between Murray River and tributaries*

- Silver Perch were recorded moving from the Murray River into the Campaspe, Goulburn and Edward rivers. The time spent in tributaries ranged from one day to over 20 months. The last known location for almost one quarter of all fish tagged was in a tributary.
- A higher tributary discharge relative to the Murray River (i.e. a higher ratio of tributary to Murray discharge) was associated with an increased probability of Silver Perch moving into a tributary (Figure 2.4.5).

- Silver Perch were more likely to enter the Goulburn River between March and May (autumn) and November and December (late spring to early summer) and the Campaspe River between April and July (autumn to winter) (Figure 2.4.5).
- Silver Perch entering tributaries between December and May (summer to autumn) were more likely to stay longer than those entering between June and November (winter to late spring) (Figure 2.4.4).

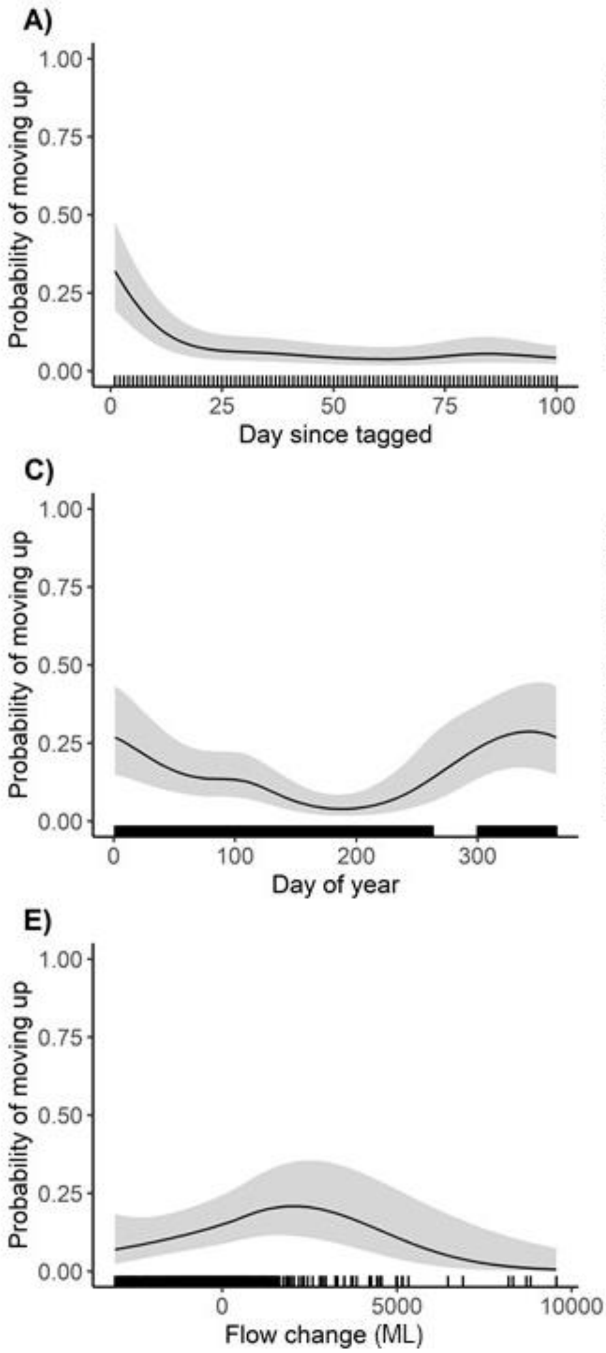



**Figure 2.4.4** Effect of days since tagged, day of year and flow change (ML $d^{-1}$) on the probability of Silver Perch moving upstream (A, C, E) or downstream (B, D) in the Murray River. Grey shading denotes 95% credible interval. Tick marks on the horizontal axis refer to individual observations.

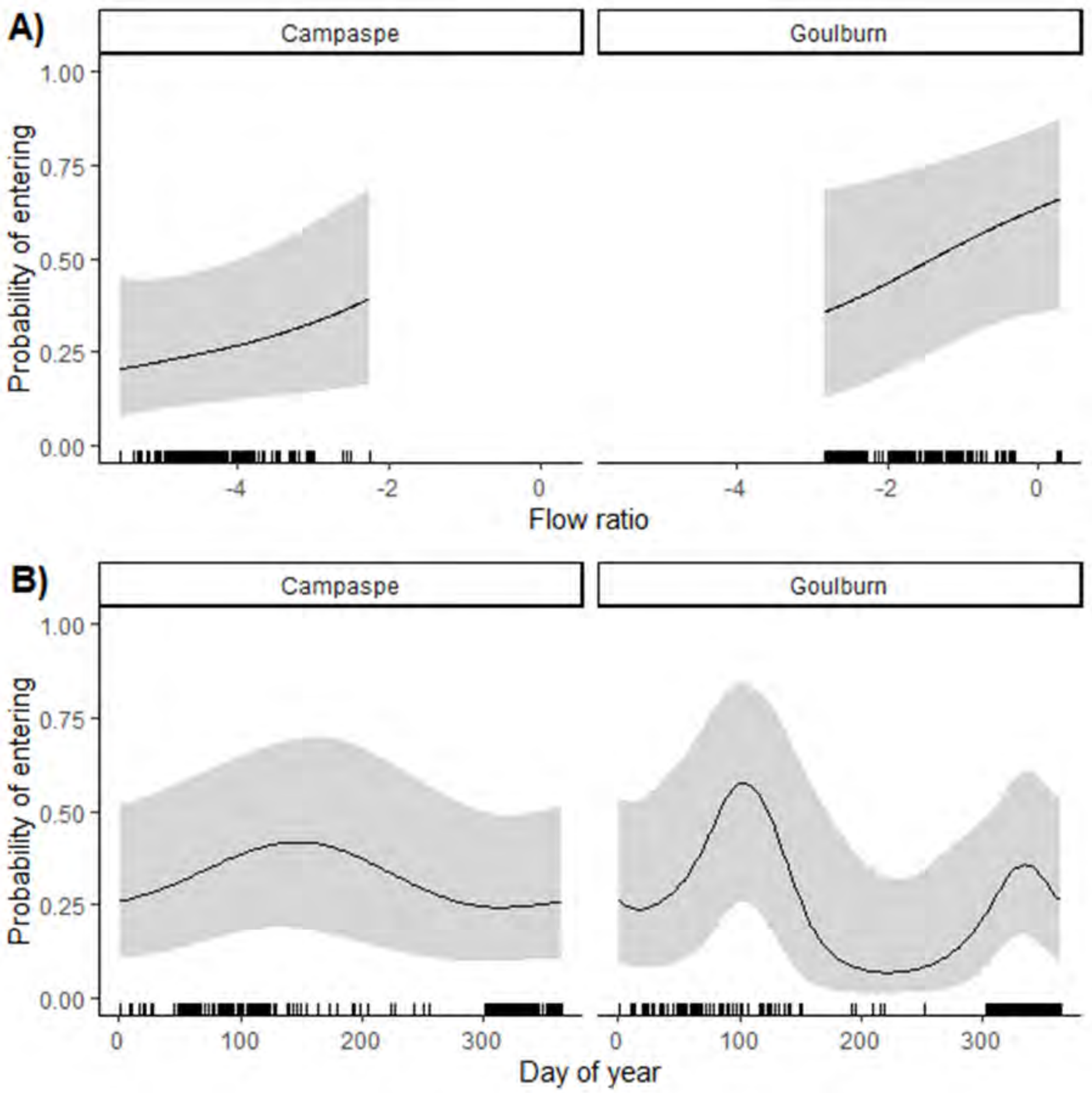



**Figure 2.4.5** Effect of flow ratio and day of year on probability of Silver Perch entering a tributary from the Murray River. Grey shading denotes 95% credible interval. Tick marks on the horizontal axis refer to individual observations.

*Fish movement into floodplain habitats*

- A total of 120 entries to floodplain habitats (Barmah Lake fish 59; Moira Creek 44; Budgee Creek 6; Cutting Creek 7; Tongalong Creek 4) by 20 individual fish were recorded, with some fish visiting multiple sites. The time spent in floodplain habitats ranged from one day to 63 days per entry. Approximately 70% of floodplain visits lasted less than 2 days.
- Fish were detected in floodplain habitats from September to April, with most (16 out of 20) fish detected between November and January, which coincided with a period when discharge in the Murray River at Barmah increased to around 8,000 to 10,000 ML $d^{-1}$.
- The last known location of two fish was in a floodplain habitat (one in Barmah Lake and one in Moira Creek).

*Study 2*

- More than 50% of fish in the lower Loddon River, and all fish in the lower Pyramid Creek, moved upstream (15 km to over 70 km), and these were typically associated with discharges above 700 ML $d^{-1}$ (associated with both natural and environmental flow events). The best model for the effect of discharge on upstream movement was an increase in the average daily discharge over the previous five days (Figure 2.4.6).
- Most fish eventually returned downstream, but in Pyramid Creek they tended to remain upstream for longer periods. Six fish in the Pyramid Creek spent between 336 and 602 days upstream before moving back downstream during or close to the winter drawdown period, when discharge in the Pyramid Creek had decreased to below 200 ML $d^{-1}$. The best model for the effect of discharge on downstream movement was the change in magnitude of discharge over the previous 10 days (Figure 2.4.6).

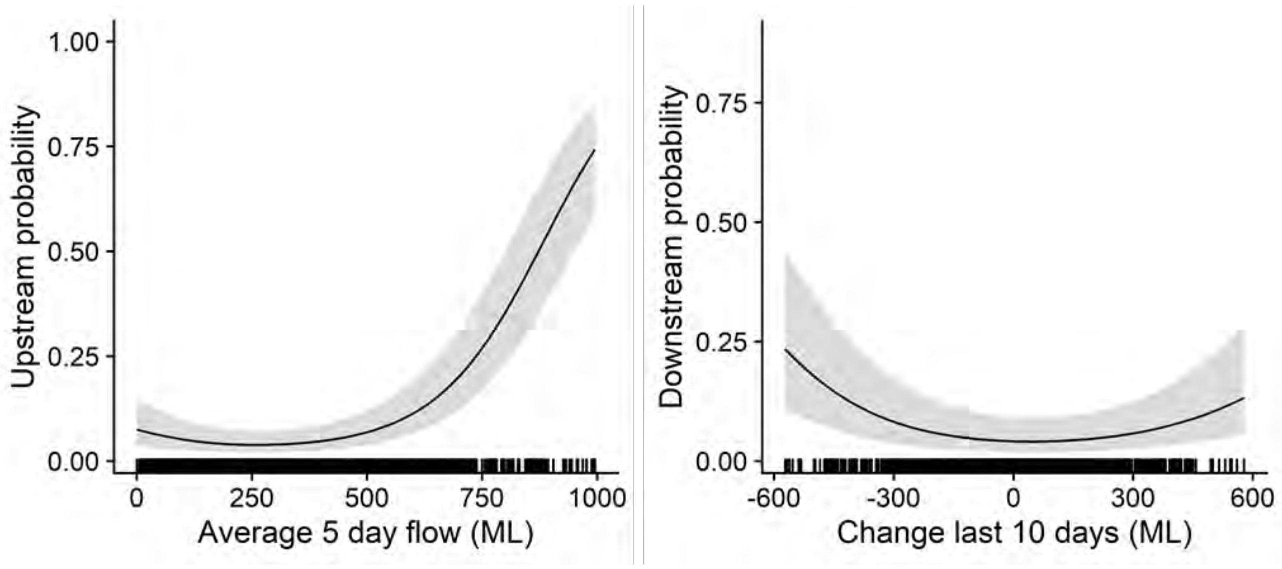



**Figure 2.4.6** Modelled relationships between the probability of moving upstream and the average daily discharge over the previous five days (left), and the probability of moving downstream and the change in average daily discharge the previous ten days (right). Black curves show the predicted relationship and shaded areas show the 95% credible interval. Tick marks on the horizontal axis refer to individual observations.

*Study 3*

*Fishway functionality*

- The Kerang Weir and fishway was partially drowned out during environmental flows (> 750 ML $d^{-1}$).
- Fishway pool turbulence and velocity increased with rising discharge, but then decreased as the environmental flow caused the Kerang Weir tailwater to drown out the fishway, improving fishway functionality (Table 2.4.1).
- Passage efficiency was highest for small-bodied native fish during environmental flows of 750–800 ML $d^{-1}$.

**Table 2.4.1 Modelled fishway hydraulic details for Kerang Weir under three different flow scenarios.**

| Scenario and river level AHD | Pool depth (m) | Velocity ($ms^{-1}$) | Maximum pool turbulence ($W\ m^{-3}$) | Fishway discharge ($ML\ d^{-1}$) | Biological functionality (sized fish) |
|---|---|---|---|---|---|
| 250 $ML\ d^{-1}$; level 75.38 m | 0.9 | 1.3 | <60 | 14 | Medium, Large |
| 500 $ML\ d^{-1}$; level 75.48 m | 1.0 | 1.4 | <70 | 17 | Medium, Large |
| 800 $ML\ d^{-1}$; level 75.60 m* | 1.3 | <1.1 | <32 | 18-19 | Small, Medium, Large |

* This scenario corresponds to the environmental water release.

*Fish movement response to stream discharge*

- A total of 7,289 fish were detected moving through fishways. The number detected during environmental flows was 3.6 times the number detected during low flows (5,715 versus 1,574). Nine native fish species were detected during environmental flows, and seven were detected during low flows.
- The number of Australian Smelt (*Retropinna semoni*) and Carp Gudgeon (*Hypseleotris* sp.) moving during environmental flows increased by a factor of 141 and 25, respectively (Figure 2.4.7).
- The number of Golden Perch moving through Kerang Weir and The Chute fishways increased during environmental flows by a factor of 11 and 25 respectively (Figure 2.4.7).
- The Silver Perch model showed moderate evidence that environmental flows increased the number of fish moving.
- Golden Perch were very abundant at the Kow Swamp fish lock in the first autumn and spring sample, but a link between abundance and stream discharge could not be established. This result is likely to have been influenced by the accumulation of fish in Pyramid Creek because of the opening of the newly constructed fish lock, as well as the relatively elevated nature of pre-release flows, which were all above 400 $ML\ d^{-1}$.
- Oriental Weatherloach (*Misgurnus anguillicaudatus*) movement increased in response to environmental flows by a factor or 27.6, and Goldfish (*Carassius auratus*) movement increased by a factor of 12.2 at The Chute and Kerang Weir but declined by 83% at Kow Swamp (Figure 2.4.7). There was insufficient evidence that Carp (*Cyprinus carpio*) movement is related to environmental flows.

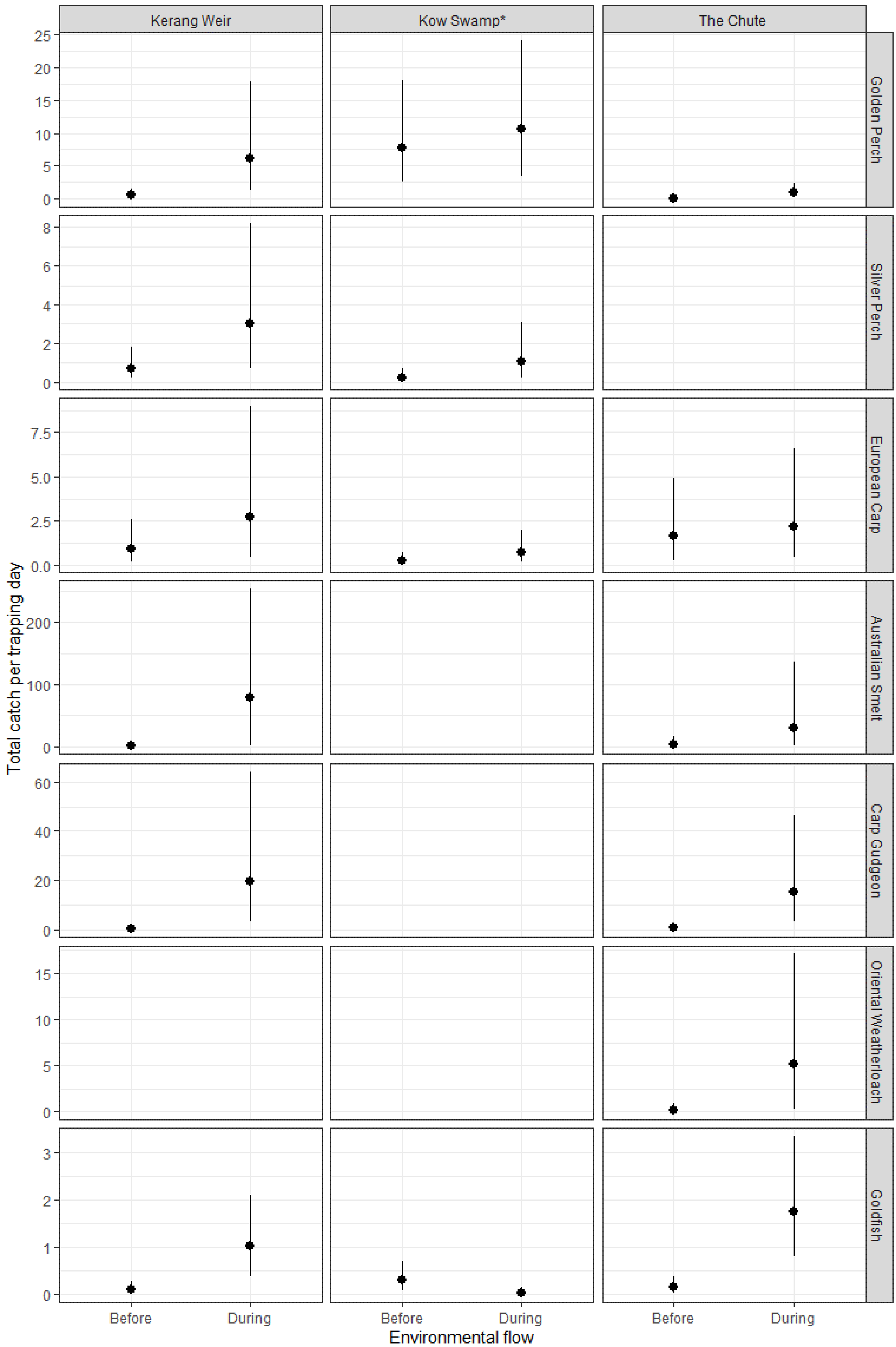



**Figure 2.4.7** Mean catch of each fish species moving through fishways before and during environmental flow releases. Bars show the 95% credible interval; * indicates that discharges at Kow Swamp were similar before and during monitoring in 2019.

### 2.4.5 Conclusions and implications for flow management

The results from the three studies clearly demonstrate the importance of flows as a key driver of fish movement throughout river networks, with environmental flows playing an important role in enhancing this process in flow-stressed regulated rivers.

The linkages between fish movement and discharge found in each of the studies also highlight how flow regulation may have contributed to the demise of native fish in the region. For instance:

- upstream movements are likely to have been reduced by the damping of natural fluctuations in streamflow, caused by the loss of small to moderate rises in river discharge as a result of regulation.
- reductions in streamflow may limit the exchange of fish between mainstem and tributary habitats, as well as movement through fishways.

Study 1 showed that discharge and time of year are important drivers of Silver Perch movement within and between habitats. The results also highlight the importance of managing Silver Perch populations in a riverscape context rather than at reach or river scales. Expanding the range of Silver Perch is a key management objective for river managers, because few self-sustaining Silver Perch populations remain. We suggest that the following actions will be important in recovering these populations:

- restoring suitable flow conditions for colonization, along with improving fish passage.
- incorporating small to moderate variations in flow, especially between September and February, to promote upstream movement along the Murray River.
- considering flow conditions interdependently across rivers, given our finding that higher tributary discharge relative to that of the Murray River influenced immigration rates.

In the Loddon system, acoustic telemetry and fishway trapping revealed that fish movement increased substantially during environmental flow releases. The response of small native fish represents some of the first records of a link between stream discharge and movement. Key results and management recommendations for the lower Loddon system include the following:

- Large upstream movements of Golden Perch corresponded with increases in the average daily discharge, typically for environmental flows above 700 ML $d^{-1}$, over the previous 5 days. Conversely, large decreases in daily discharge in a reach, particularly in the lower Loddon River, resulted in movement out of the reach.
- Baseflows may be important in retaining fish upstream as many of the fish that had remained upstream in the Pyramid Creek for extended periods moved back downstream during the winter drawdown when baseflows were typically below 200 ML $d^{-1}$. We suggest that a minimum baseflow be introduced, starting at 350 ML $d^{-1}$, to increase habitat availability and encourage fish residency.
- Environmental flows resulted in high tailwater levels at Kerang Weir, improving fishway functionality and passage efficiency, particularly for small species. Seasonal watering plans indicate that up to 900 ML $d^{-1}$ can be delivered for 10 days into reach 5 of the Loddon River. Although flows in our study were purposefully restricted to 750 ML $d^{-1}$ for trapping purposes, we suggest that the higher discharge should be adopted into the future. We also suggest that extending the duration of flow in reach 5 from 10 to 20 days would provide a stronger flow cue for those fish located lower in the reach and allow more time for small-bodied species to move past Kerang Weir.
- Fish movement increased at The Chute (reach 4) in response to the 450 ML $d^{-1}$ (10 days) environmental flow from the Loddon weir. We suggest further testing at higher discharges (up to 700 ML $d^{-1}$) to provide data on the relative value of the 450 ML $d^{-1}$ flow. We also suggest that a simpler seasonal watering plan be adopted to ensure the integrity of the flow cue for migratory and resident fish — 150 ML $d^{-1}$ year-round base/low flow and a minimum of 450–700 ML $d^{-1}$ fresh for spring and autumn throughout reach 4. The flows could also be extended to 20 days to encourage upstream immigration into reaches 4 and 5.

Climate predictions indicate that Australia will continue to become hotter and dryer, with reduced run-off in the southern Murray–Darling Basin, so there will be more reliance on intervention measures for maintaining river ecosystems. Our results emphasise a need for waterway mangers to consider the value of cooperative flow and barrier-related intervention programs for achieving restoration objectives by enhancing fish movement across the landscape.

## 2.5 Linking flow attributes to recruitment dynamics of Murray Cod to inform flow management in northern Victorian rivers (KEQ 4)

This work is a summary of the following journal article presented in Supplementary Material 6.

**Supplementary Material 6**: Tonkin, Z., Yen, J., Lyon, J., Kitchingman, A., Koehn, J., Koster, W., Lieschke, J., Raymond, S., Sharley, J., Stuart, I., and Todd, C. (2020). Linking flow attributes to recruitment to inform water management for an Australian freshwater fish with an equilibrium life-history strategy. *Science of The Total Environment*, doi.org/10.1016/j.scitotenv.2020.141863.

### 2.5.1 Context

Quantifying the processes by which fish populations respond to changes in river discharge is critical for supporting adaptive management of environmental water for fish-related outcomes. This can be relatively straightforward for species such as Golden Perch, which exhibit strong links to attributes of a river's natural flow regime such as seasonal high flows. However, this can be challenging for species that exhibit equilibrium life-history strategies, because of their long-lived nature and typically regular and stable patterns in recruitment. In the Murray–Darling Basin there is increasing evidence that flow and flood pulses can be used to enhance the spawning, movement and recruitment of Golden Perch. However, studies supporting similar recommendations for species such as Murray Cod (*Maccullochella peelii*) are rare, with many of the links between flows and recruitment dynamics still largely theoretical.

This study addressed some of the challenges associated with understanding how flow management can be used to enhance recruitment outcomes for Murray Cod. We collated over two decades of annual survey data from five rivers in the southern Murray-Darling Basin. Using a novel analytical approach, we tested several hypotheses linking key attributes of the flow regime to recruitment dynamics. This section summarises the approach and key outcomes of the study.

### 2.5.2 Aims and Hypotheses

The study's aim was to test the following hypotheses linking recruitment strength with a series of flow covariates thought to influence reproduction and subsequent survival of Murray Cod in their first year of life (Figure 2.5.1):

1. Extreme variation in river discharge during spawning and the early larval period (October – December) will negatively influence recruitment strength, by disturbing spawning behaviour and egg survival/retention of larvae within a reach.
2. Increased bank-full flows or flooding during spring will enhance recruitment by increasing availability of spawning habitat such as anabranches, or by providing additional food resources to larvae.
3. High flows and flooding in the year prior to spawning will enhance recruitment by improving growth, condition and reproductive fitness of adult fish.
4. That lower flows (below the annual average discharge) during summer and early autumn will enhance recruitment by increasing water temperature and concentrating food resources for juvenile fish.
5. Increased winter flows will increase habitat availability and reduce predation on juvenile fish.

These hypotheses are strongly linked to key attributes of the flow regime that have been modified by river regulation, and therefore are highly relevant to remedial water management actions, especially the use of environmental flows. Broadly, we expected the recruitment stability of Murray Cod populations to be greatest in larger, regulated river systems, and that each of the specific flow attributes (hypothesised to influence a key process or life history stage) would influence recruitment strength. We also expected the relationship between recruitment strength and each of these flow attributes to be idiosyncratic among rivers, because of system-specific interactions between river flow, geomorphology and key habitat attributes.

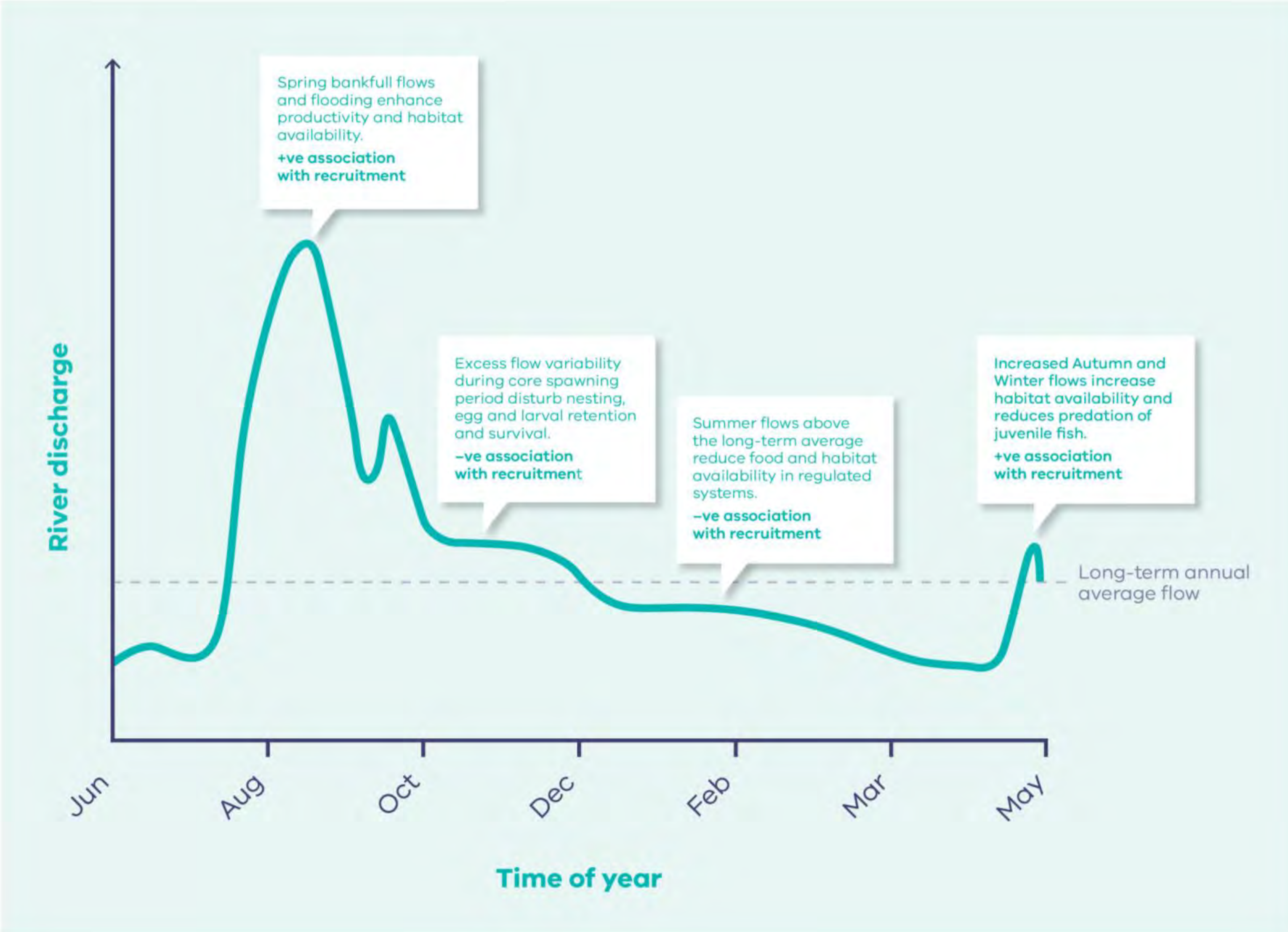



**Figure 2.5.1 Conceptual model showing key flow components influencing recruitment of Murray Cod in northern Victorian rivers.**

## 2.5.3 Methods

We investigated the recruitment dynamics of Murray Cod using capture (count) data of fish recorded during annual electrofishing surveys in the Murray, Goulburn, Broken, Ovens and King rivers, conducted between 1999 and 2019 (Figure 2.5.2). These rivers were chosen because they spanned a gradient of waterway size, habitat attributes and regulation status; have been the subject of long-term monitoring; and have populations that appear to be self-sustaining. Furthermore, in the past two decades each population has not been influenced heavily by hypoxic blackwater events, stocking for recreational fishing (see Supplementary material 10: Harris et al., 2020), or major habitat degradation, maximising our ability to tease apart flow effects from other drivers of recruitment.

To estimate recruitment strength, we used a novel modelling approach that draws on length-age relationships from fish and otolith samples collected from the study sites, to estimate ages of fish where individual lengths were recorded but ages were unknown. We then compared counts of each year class for fish aged 0–5 as our measure of recruitment in each river, accounting for survey effort. Each of the flow variables, which were standardised to a proportion of the long-term annual mean of each river, was then included in the model to test our hypotheses.

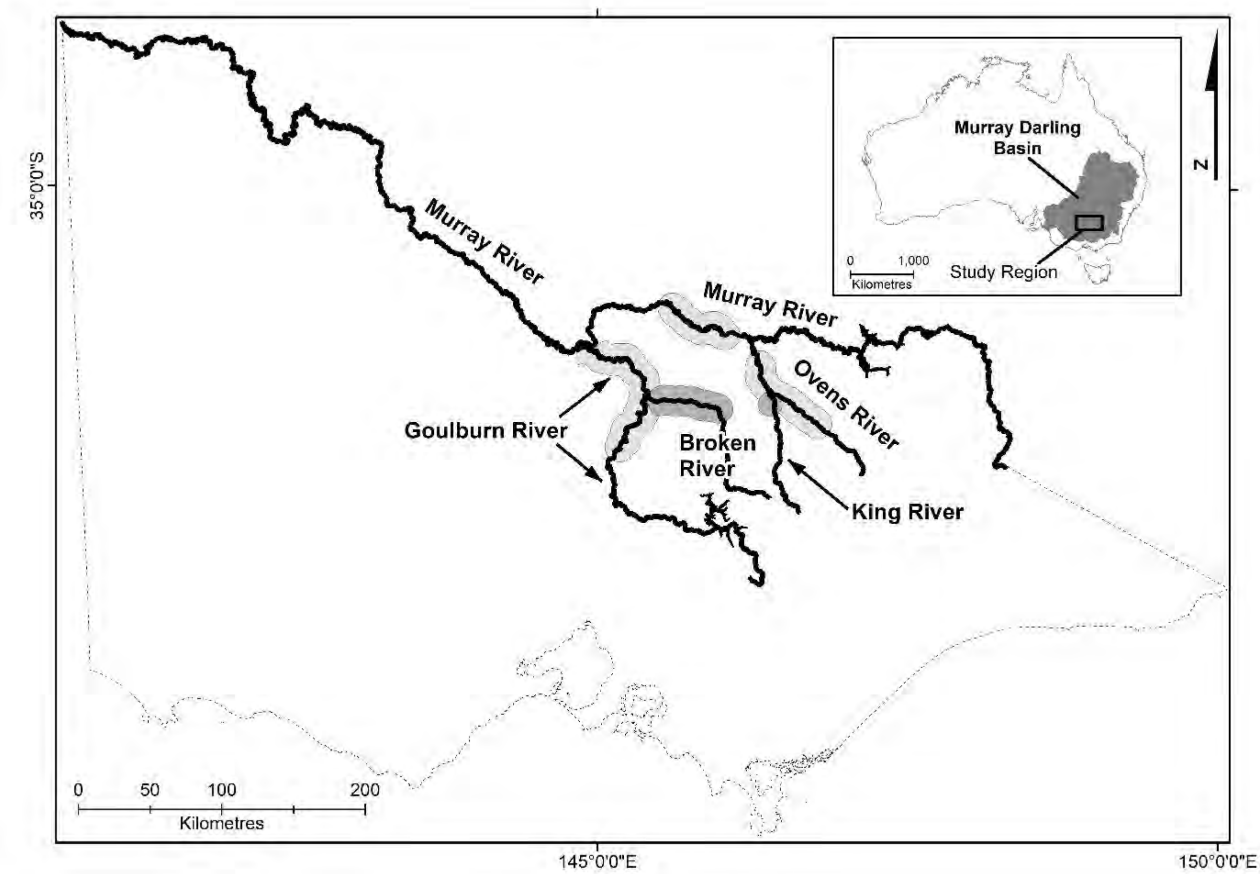



Figure 2.5.2 Location of each of the five study rivers used for the assessment of Murray Cod recruitment dynamics in the south-eastern Murray–Darling Basin. The distribution of sites within each river is shown in grey polygons.

## 2.5.4 Results

- Although Murray Cod were recruited in most years, recruitment strength was highly variable between and within waterways across years (Figure 2.5.3). The Murray River exhibited the least variation in recruitment strength, and recruitment was generally greater than the values seen in the other waterways (other than the Ovens on occasion). Recruitment was most variable in the Ovens River, King River and, to a lesser degree, the Broken River. The Goulburn River had relatively stable levels of recruitment, albeit at much lower levels in comparison to the other rivers.

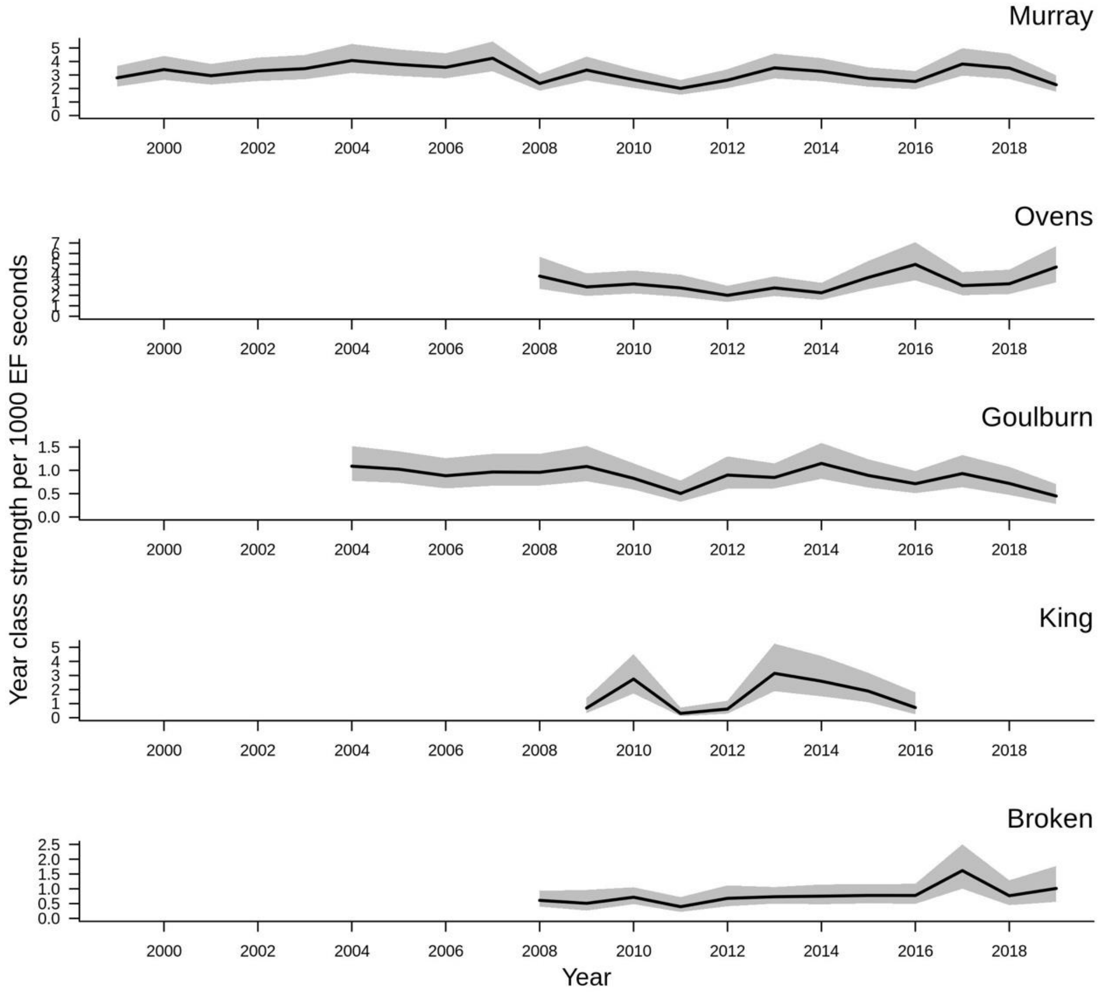



**Figure 2.5.3** Murray Cod year class strength (expected number of recruits) for each river based on the fitted catch curve and observed river flow conditions. Solid black lines are median estimates of the number of recruits detected per 1000 electrofishing seconds; shaded regions are 95% credible intervals. Predictions for each river are presented only for years when monitoring occurred.

We found support for the influence of all tested flow covariates on recruitment strength. All five flow hypotheses were supported for the Murray River, which contributed the greatest amount of data to inform the model. Specific examples of such links are as follows:

- Flow variability during the spawning period (hypothesis 1) had moderate to strong support for influencing recruitment, with a negative effect in the Murray and King rivers. Specifically, the model predicted that an increase in discharge equivalent to the long-term median over a three-day period would result in a 93% and 22% reduction in recruitment strength in the Murray and King rivers, respectively.
- Summer discharge had moderate to strong negative effects on recruitment strength in the regulated Murray, Goulburn, King and Broken rivers (hypothesis 4). For example, if discharge during summer were increased by their long-term annual median (e.g. from 889 to 1,778 ML $d^{-1}$ in the Goulburn River), the model predicted that recruitment strength for that year would decrease by 36% and 34% in the Goulburn and Murray rivers respectively (Figure 2.5.4).
- A positive association between recruitment strength and spring discharge (hypothesis 2) was strongly supported in the Murray River, with an increase in proportional spring discharge by 1 unit (approximately 10,000 ML $d^{-1}$) associated with an 25% increase in recruitment strength.
- The relationship between river discharge and Murray Cod recruitment strength was also variable across rivers. For example, we found negative associations between average summer discharge and recruitment strength in all rivers apart from the Ovens (Figure 2.5.4). Similarly, we found discharge during the first winter period following spawning were positively associated with recruitment strength in the Murray, Goulburn and King rivers, but found little support for this hypothesis in the Broken and Ovens.

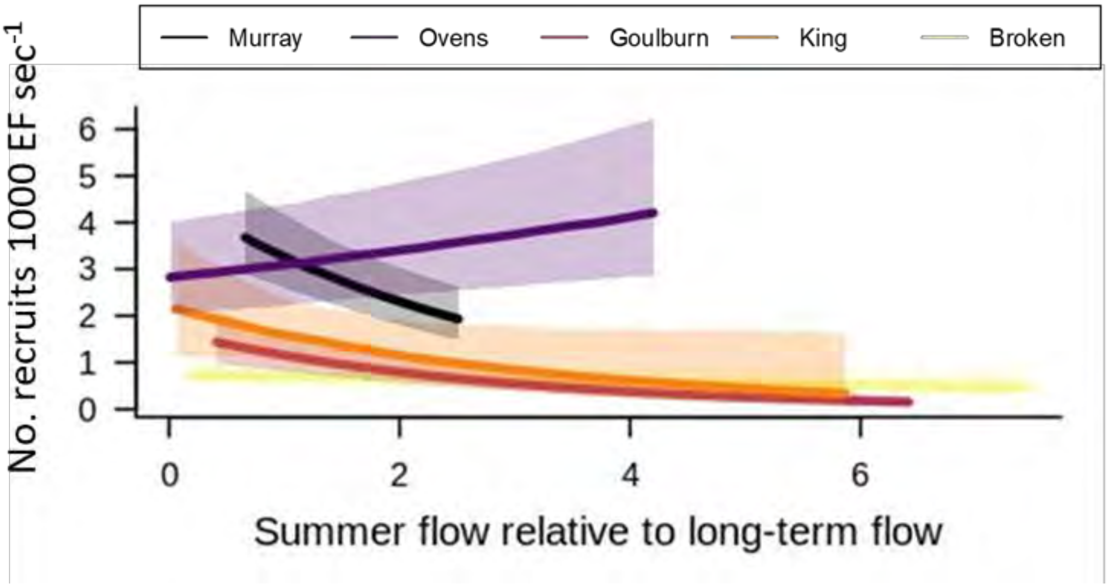



**Figure 2.5.4** Effects of summer discharge (proportion of the long-term annual median) on Murray Cod recruitment strength (survival to one year old) in the five study rivers. Lines are median expected catch in 1000 electrofishing seconds. Shaded regions are 95% credible intervals.

### 2.5.5 Conclusions and implications for flow management

To achieve recruitment outcomes for riverine fish, it is vital to consider the whole seasonal flow regime. For example, while spring flow conditions might be ideal for reproductive success of Murray Cod, these benefits can quickly be offset by subsequent adverse summer or winter flow conditions that impact new recruits. Broadly, our results provide robust quantitative support for managing flows in regulated rivers in accordance with the natural flow regime for species such as Murray Cod. Therefore, the management of flows in temperate regulated rivers should:

- be above the long-term annual average in winter and spring;
- transition to below the annual average levels through summer and autumn, while also maintaining suitable water quality;
- avoid overly variable rates of change in flows during the core egg and larval period for a species.

The varying relationships between river discharge and Murray Cod recruitment strength in different river systems is likely to be a result of both limitations in data availability for some systems or years and system-specific interactions between river flow, geomorphology and key habitat attributes. For example, while we found negative associations between average summer discharge and recruitment strength in our most regulated systems, we found moderate support for a positive association in the unregulated Ovens River. This result likely reflects how the seasonal reversal of flows in many regulated systems can alter the stressors experienced by fish. Under natural conditions, summer flows are almost always well below the long-term annual mean, and extremely low levels can make fish vulnerable to a multitude of stressors such as reduced water quality and habitat availability. Conversely, many regulated systems now experience above-average discharges over summer, which may reduce critical rearing habitats for juvenile fish or the prey they depend on.

Differing recruitment responses of Murray Cod to standardised river discharge at individual waterways highlights the need for careful consideration before transferring such information among systems. For example, had we only compiled data from the unregulated Ovens River, which showed a positive association between recruitment strength and summer flows, and applied it to the regulated Goulburn or Murray rivers, we would have predicted that higher summer flows would benefit the species. These differences among waterways are likely to be even greater in more diverse river reaches occupied by Murray Cod, including smaller irrigation creeks, upland reaches and lowland weir pool environments. It follows that any transfer of information should, where possible, be between waterways with similar characteristics, such as similar regulation or size. Our results could be further refined using reach-scale hydraulic models and assessment of food resources to predict how the different discharge rates influence critical habitat and prey associations, which might identify common processes that occur in rivers with markedly different flow regimes. This would allow greater transferability of results to other waterways where there are shortfalls in empirical data.

Because of the long-lived nature of Murray Cod, the impact of a poor recruitment year may be negligible for the population over one year, but the cumulative impacts (positive or negative) over multiple years are likely to be far more significant. To test this, the results from this study are being used to refine existing population models to assess likely long-term population outcomes from varying combinations of managed flow scenarios over multiple years (see Section 2.6 and Supplementary Material 8). In the longer term it will be important to complete this process for a range of species with differing life-history strategies.

Our results provide an important scientific basis for the credibility and implementation of flow management aimed at improving the recruitment of equilibrium fish species such as Murray Cod, Trout Cod and River Blackfish. The analytical approach used in this study can also be applied to other species where long-term monitoring data have been compiled and length-at-age relationships are established.

## 2.6 Assessing long-term trends in fish populations and responses to flow management in Victorian rivers (KEQ 4)

This work is a summary of the following three research projects presented in Supplementary material 7–9.

**Supplementary Material 7**: Amtstaetter, F. and Koster, W. (2020). VEFMAP Stage 6: Long term fish community monitoring in the Thomson and Glenelg rivers. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

**Supplementary Material 8**: Yen, J., Thomson, J., Lyon, J., Koster, W., Kitchingman, A., Raymond, S., Stamation, K., and Tonkin, Z. (2020). Flow attributes only partially explain long-term trends in fish populations. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

**Supplementary Material 9**: Todd, C., Koehn, J., Yen, J., Koster, W. and Tonkin, Z. (2020). Predicting long-term population responses by Murray Cod and Silver Perch to flow management in the Goulburn and Campaspe rivers: a stochastic population modelling approach. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 2.6.1 Context

Maintaining or enhancing native fish populations is a fundamental objective of the Victorian Waterway Management Strategy and is embedded in many Environmental Water Management Plans. Consequently, environmental flows are often intended to increase native fish population abundance, distribution or resilience. Since its inception, a key component of VEFMAP has been the establishment and continuation of a long-term fish population monitoring program at priority managed rivers across the state, to help track progress towards this fundamental objective.

Measuring the effects of flow management on population trends is challenging because many species respond to sequences of flow events occurring over multiple years, and population trends are further influenced by other modifiers such as exotic species, habitat availability and stocking (Figure 2.1.4). In south-eastern Australia, the combined influence of factors such as drought, invasive species, and restoration efforts (e.g. fish stocking and habitat rehabilitation) can make it difficult to identify the effects and outcomes of flow management on fish populations, especially for those that are long-lived or wide-ranging, such diadromous species.

This section addresses some of the challenges of measuring the effects of flow management on fish population trends across Victorian rivers. We have used one or a combination of long-term data collections from multiple rivers and used analytical techniques that partition the effects of flows from other modifiers. We refer to three separate studies (Supplementary Materials 7–9) that assess long-term trends in distribution and abundance, the relative influence of flow on these trends, and how current flow management has or can improve population outcomes. Importantly, each of these studies considered the new information collected from each of the KEQs (and other studies) that link flows to key population processes when assessing long-term population trends.

### 2.6.2 Aims

Each of the studies sought to report long-term trends in fish populations and relate those trends to river flows. We also aimed to forecast population trajectories and risks to populations in response to various flow management scenarios, to inform the delivery of environmental flows that enhance native fish outcomes. The specific studies and their general aims were:

1. *Coastal rivers population trends*: Report population trends of Tupong, Common Galaxias and Australian Grayling in the Glenelg and/or Thomson rivers and relate these changes to managed river flows in each system.

2. *Northern Victorian population trends:* Assess population trends of six species across northern Victorian rivers and relate these long-term trends to key attributes of the flow regime. Our overarching goal was to identify population trends and identify how much of these patterns could be explained by flows compared to flow-independent factors.
3. *Stochastic population modelling:* Assess long-term predictions of the dynamics and risk to populations of Murray Cod and Silver Perch in the Goulburn and Campaspe rivers under a range of managed flow scenarios, while accounting for other influential intrinsic modifiers (e.g. fecundity) and extrinsic modifiers (e.g. stocking and angling).

### 2.6.3 Methods

*Coastal rivers population trends*

For the coastal rivers we used long-term, standardised data (catch-per-unit-effort, CPUE) from bank-mounted electrofishing for three diadromous fishes (Tupong, Common Galaxias and Australian Grayling) to determine population trends. Sampling was completed annually from 2005 to 2020 in the Thomson River and 2009 to 2020 in the Glenelg River. Changes to environmental water delivery in the Glenelg River provided the opportunity to test for the effectiveness of the new flow regime in increasing the abundance of the Tupong and Common Galaxias populations (Australian Grayling are very rarely captured in the Glenelg River). Specifically, summer and early autumn environmental flow deliveries have established higher baseflows and one to two fresh releases each year since 2017. Tupong were captured in sufficient numbers, allowing for a before-after-control-impact (BACI) design, using the Glenelg River as the impact site (changes to environmental water delivery), and the Thomson River as the control (where the same changes in flow management did not occur). However, very few Common Galaxias are captured in the Thomson River, so the analysis on this species could not include a BACI design. We used a generalised mixed effects model and a general additive model for Tupong and Common Galaxias, respectively (both with negative binomial distributions) to determine whether the number of Tupong and Common Galaxias increased in the Glenelg River (relative to the Thomson River) following the increases in environmental water use.

*Northern Victorian population trends*

For the regional-scale assessment of populations in northern Victoria, we studied long-term trends in fish populations using standardised capture data (CPUE) for six species: Murray Cod, Trout Cod, Golden Perch, Silver Perch, Murray–Darling Rainbowfish (*Melanotaenia fluviatilis*) and Carp. These species have a variety of life-history strategies. Capture data included total abundance (counts) and total biomass (weights) and were collected in annual electrofishing surveys from 1999–2019 in the Murray, Goulburn, Broken, Ovens, King, Campaspe, and Loddon rivers. These seven rivers span a gradient of flow conditions across northern Victoria, from unregulated to highly regulated and flow stressed, which should provide a detailed insight into the effects of environmental water under a range of conditions.

We estimated population trends with an advanced modelling method that included linear and nonlinear trends in CPUEs. This explicitly separated noise from trends and estimated the amount of trend explained exclusively by flow. In addition, this approach allowed for differences in trends among rivers, and accounted for additional variation among reaches and sites. We used seven key attributes of the flow regime to quantify the flow regime in these rivers and years: spring flows, summer flows, winter flows, flow variability during spring, number of days with low flows, antecedent flows, and water temperature. We standardised all metrics except water temperature by dividing by the median daily discharge in each river from 1991 to 2019.

*Stochastic population modelling*

We modified stochastic population models previously developed (e.g. Todd and Koehn 2008; Koehn and Todd 2012) to predict long-term trends and risk to populations of Murray Cod and Silver Perch in the Goulburn and Campaspe rivers under a range of managed flow scenarios. The Murray Cod population model is a single river models due to the species completing all its life cycle within a single reach. Conversely, the model developed for Silver Perch is a metapopulation model with connections to the lower connected Murray River with immigration and emigration to and from the Goulburn and Campaspe rivers as well as other reaches of the Murray River and Lower Darling River. The models incorporate the quantified links between flow and key population processes generated in KEQs 3 and 4, with other influential intrinsic (e.g. fecundity) and extrinsic (e.g. stocking and fishing) modifiers to compare population trends and risk in each population from 2004 – 2019 under of the following scenarios:

- current flow and stocking as they have occurred (Actual);
- current flow without the environmental water allocation - EWA (No EWA);
- current flow recommendations, had they been implemented each year (Current EWA Recs);

- current flow with the recent levels of summer inter-valley trade - IVT - observed: 9 in 15 years of summer IVT (IVT) and 13 in 15 years of summer IVT (High IVT);
- current flow and no stocking (No Stocking).

### 2.6.4 Results

*Coastal rivers population trends*

- The catch of Australian Grayling in the Thomson River was at its lowest for three years from 2009 to 2011 (Figure 2.6.1). Otherwise, there are no apparent trends in the catch of this species since sampling began in 2005.
- The catch of Tupong in the Thomson River has been variable but shows no distinct trends since sampling began in 2005 (Figure 2.6.1). The number of fish captured is reflective of the recruitment success of this species. For example, peaks in catch typically followed large recruitment years when YOY entered the rivers and these strong year classes made up most of the population for several subsequent years.
- Based on relatively high proportions of YOY Tupong in the catch, strong year classes (year of hatch) occurred in 2012, 2016 and 2017 in the Glenelg River. These were also strong year classes in the Thomson River.
- The catch of Tupong and Common Galaxias were, on average, higher after changes in environmental water management in the Glenelg River (Figure 2.6.1). The mean catch of Tupong and Common Galaxias increased 16.0 and 5.8 times respectively, since this change. The increase in the number of Tupong in the Glenelg River was significant relative to the catches in the Thomson River which had no such change in flow management ($z$ = –7.20; $p$ < 0.001). The increase in Common Galaxias was also significant, albeit without a control ($z$ = 2.40; $p$ = 0.017).

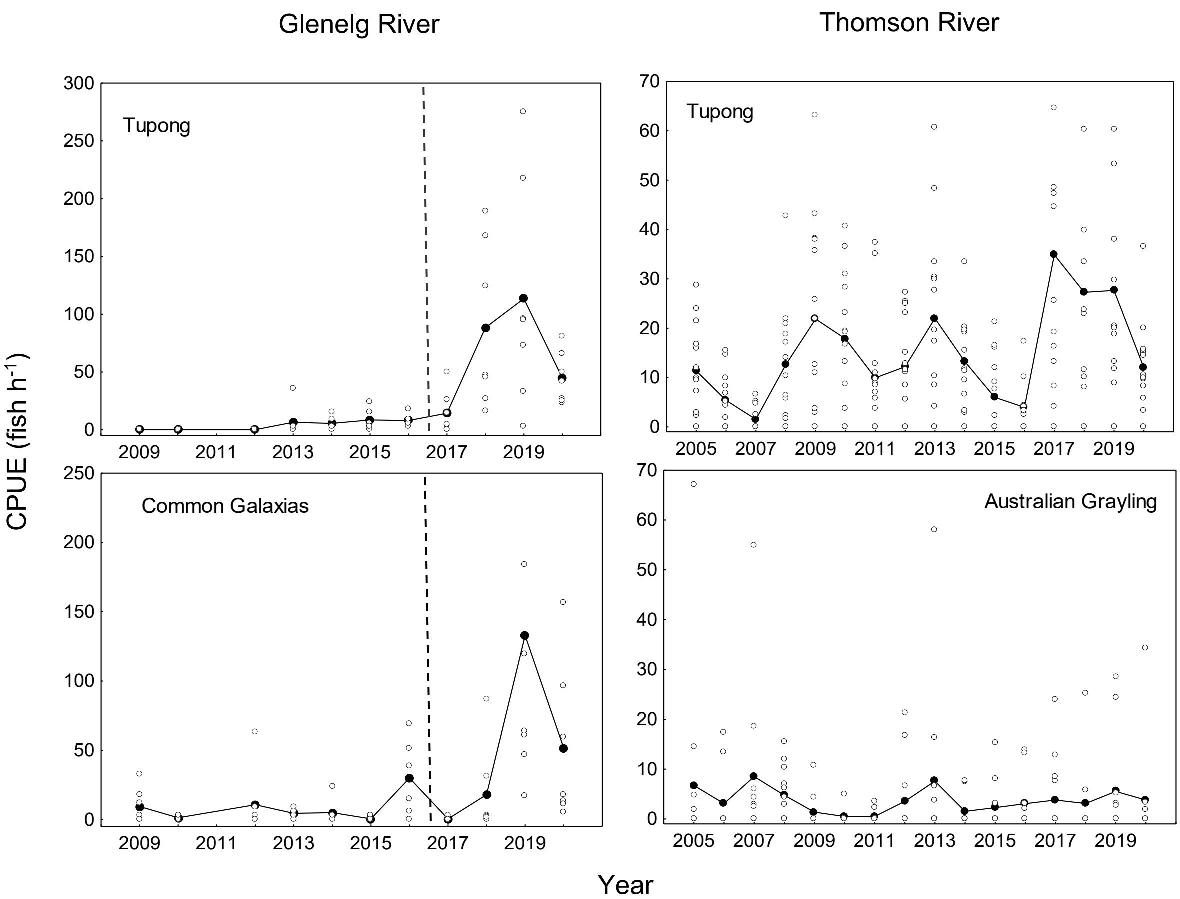



**Figure 2.6.1** Mean bank-mounted electrofishing catch-per-unit-effort (solid circles; CPUE) of three diadromous species captured in the Thomson and Glenelg rivers, 2005–2020. Open circles represent the raw data for each site and the dashed vertical line represents the timing of the change in environmental water management in the Glenelg River.

*Northern Victorian population trends*

- At a regional level, Murray Cod, Golden Perch, Murray-Darling Rainbowfish and Carp all declined in abundance and biomass in the early years of surveys, during the 'millennium drought'. This was followed by an increasing trend from 2007 to 2008 for Golden Perch and Carp, and from 2011 to 2012 for Murray Cod and Murray–Darling Rainbowfish (Figure 2.6.2). The abundance of Trout Cod declined from 1999 to 2010, increased from 2011 to 2015, and were stable or slightly lower from 2015 to 2019. Silver Perch abundances were steady or slightly lower through the entire survey period (1999-2019,) with evidence of slight increases in biomass since 2017.
- While most of these general trends were similar in all river systems (where the systems contained a common species), the magnitude of change, and in some cases direction, varied across systems. For example, the regional-scale increase in Murray Cod and Golden Perch after the millennium drought was greatest in the Campaspe and Ovens rivers, while the Loddon River had the lowest rate of increase or was stable during the same period.
- The seven flow metrics selected explained up to 33.1% of the long-term trends in abundances and up to 31.5% of the long-term trends in biomass. The amount of variation explained was relatively similar among species, with slightly less variation explained in biomasses of Murray Cod (17%) and Trout Cod (23.5%) than in other species (>25%).
- Flow attributes had the following associations with trends in abundances and biomasses:
    - Spring flow was positively associated with abundances and biomasses of Murray Cod, Trout Cod, Murray–Darling Rainbowfish and Carp, less clearly but generally positively associated in Golden Perch, and weakly or not at all associated in Silver Perch (Figure 2.6.3). These effects were strongest when daily spring flows were more than five times higher than the long-term annual average.
    - The number of days with low flows (less than the long-term 10th percentile) had generally negative associations with abundances and biomasses of all species except Silver Perch, with positive peaks at intermediate low flow values in Murray Cod, Trout Cod, and Golden Perch (see Supplementary Material 8).
    - Summer flows had negative associations with abundance and biomass of Murray Cod and with biomass of Trout Cod, while winter flows had positive associations with abundance and biomass of Golden Perch.

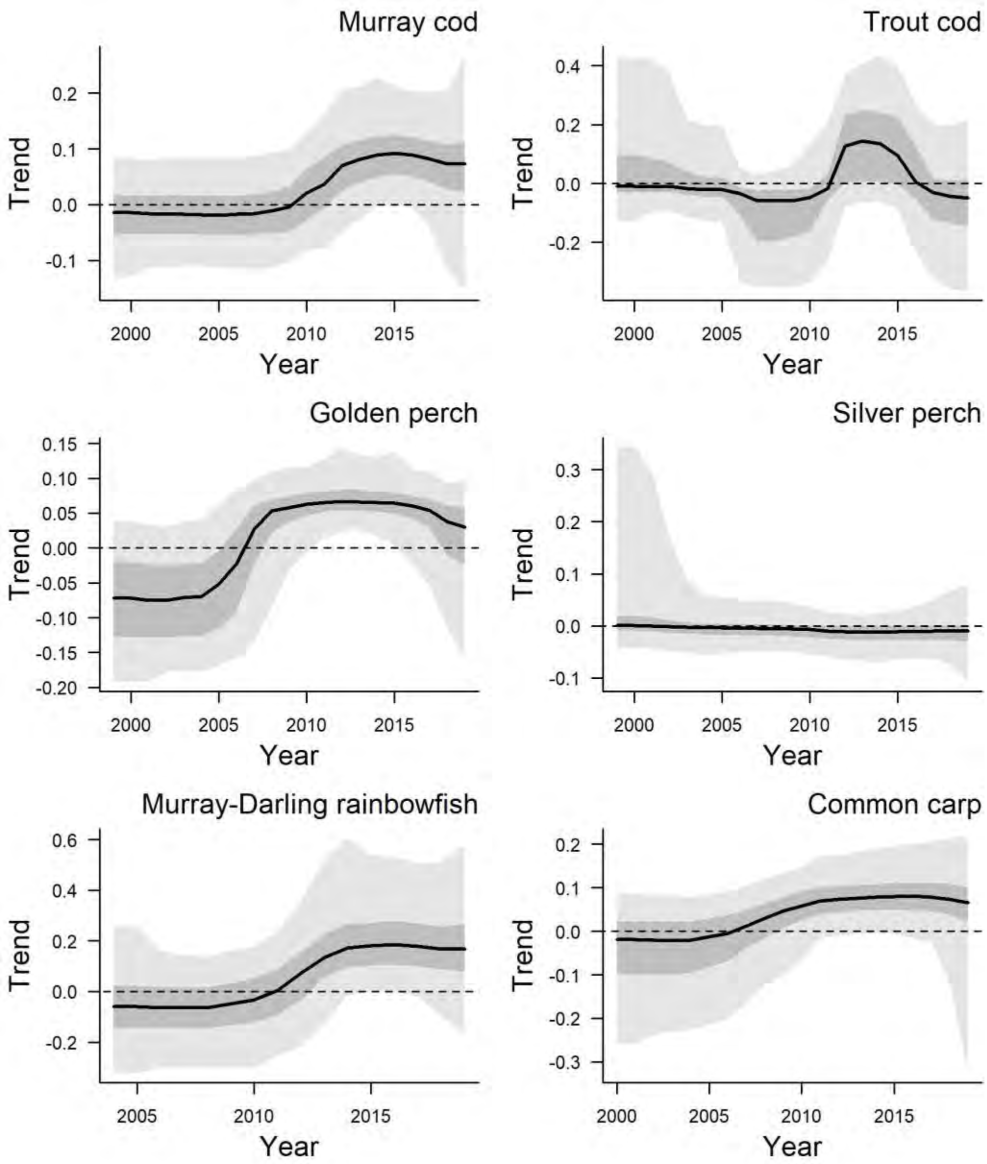



**Figure 2.6.2** Estimated temporal trends in regional abundance of each species. Values are proportional changes in abundance in each year (positive values indicate increases, negative values indicate decreases). Values are extracted from a temporal model without flow variables, so represent total changes in abundance due to flow and other (unmeasured) factors. Solid black lines are median fitted values, dark shading shows 50% credible intervals, and light shading shows 95% credible intervals.

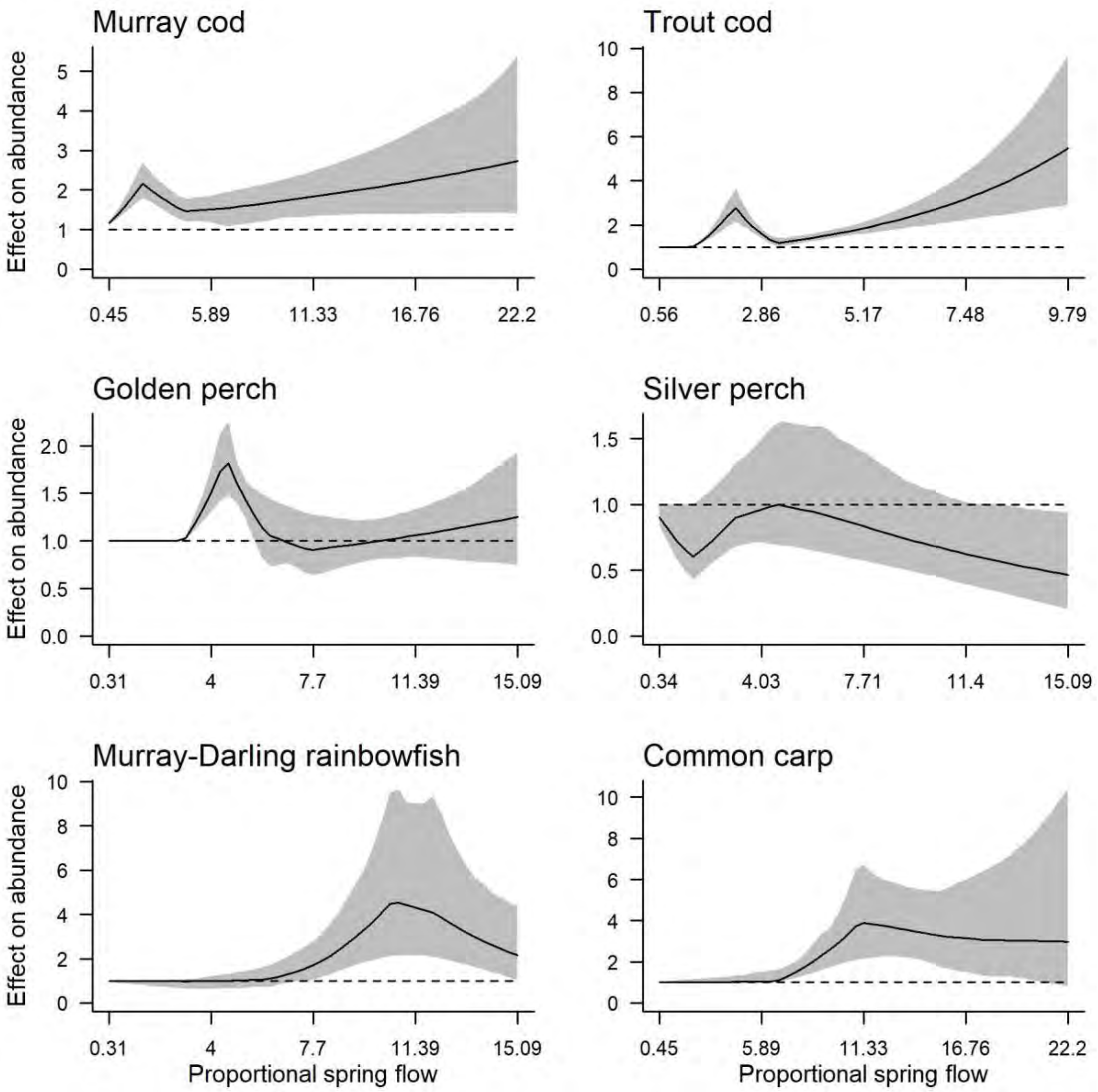
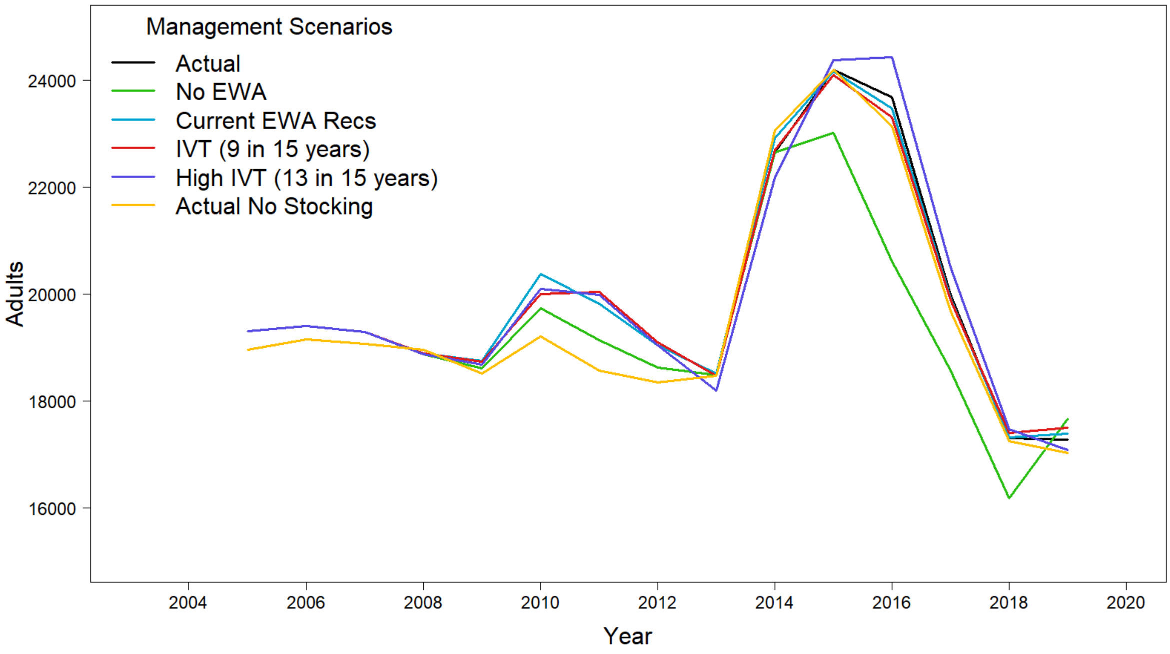



**Figure 2.6.3** Estimated effects of spring flow on the abundance of six freshwater fish species. Values are multiplicative effects, so that a value of one denotes no effect, values less than one are negative effects, and values greater than one are positive effects. Solid black lines are median fitted values and shading indicates 95% credible intervals.

*Stochastic population modelling*

- Our predictions for Murray Cod in the Goulburn River showed a highly stable population of adult fish since 2005 (Actual scenario; Figure 2.6.4a). We also found stocking made little difference to the population outcomes (Figure 2.6.4a; compare scenarios Actual – which includes stocking with Actual No Stocking) pointing to the modelled system being highly regulated by density dependence. Moreover, the population seemed to fluctuate close to the carrying capacity of 20,000 adult fish set for the Goulburn River, with minor decline during the millennium drought and some recovery observed in 2014-2016 in response to ‘good’ years of recruitment in 2010-2012 (Figure 2.6.4a).
    - Of the scenarios tested for the Goulburn River, there was little to separate the outcomes, in terms of average trajectory, except possibly the No EWA scenario (Figure 2.6.4a) with the risk to the population almost indistinguishable among scenarios over the 15-year flow sequence (Figure 2.6.4b). The scenario that excluded the environmental water allocation produced marginally lower outcomes from 2010 onwards (Figure 2.6.4a) however, these differences are minor with no discernible difference in the associated risk curves (Figure 2.6.4b).

a)




b)

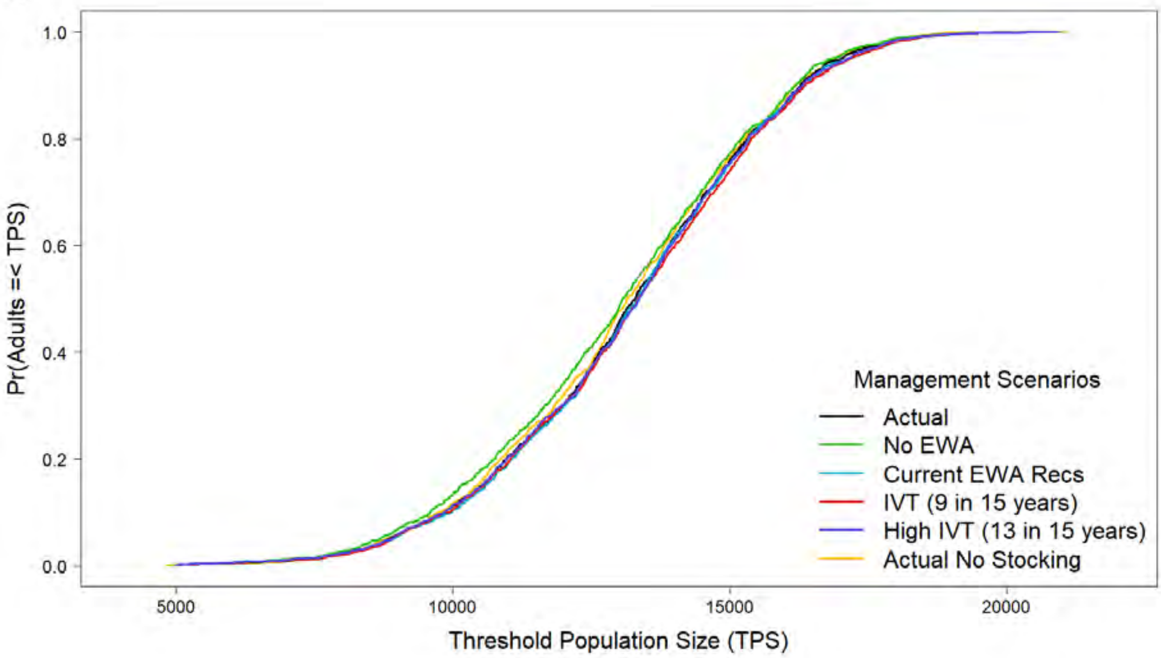



**Figure 2.6.4** Population model outputs for Murray Cod in the Goulburn River estimating a) the average adult population size trajectory for each of the management scenarios; and b) risk curves associated with each scenario for the period 2005-2019. Scenarios were: Actual = actual flow, temperature and stocking values; No EWA = actual temperature, stocking and flow values minus the environmental water allocation; Current EWA recs = actual temperature, stocking and flow values modified to meet current flow recommendations for each year; IVT = actual temperature, stocking and flow values modified to a 9 in 15 year summer intervalley trade at an average of 2,853 ML day$^{-1}$; High IVT = actual temperature, stocking and flow values modified to a 13 in 15 year summer intervalley trade at an average of 2,853 ML day$^{-1}$; Actual No stocking = actual flow and temperature values without stocking.

- Our predictions for Murray Cod in the Campaspe River showed a general increasing trend since 2009, however with greater differentiation among scenarios tested compared with those for the Goulburn River (Figure 2.6.5a). The system appears to be less driven by density dependence and more driven by response to flow. This was seen by the clear difference between the Actual scenario (includes stocking) and the Actual No Stocking scenario identifying that the system has capacity to respond to the additional stocked fish between 2009 and 2013.
  - The scenarios tested separated into 2 groups: those scenarios where the adult population increased substantially from 2009 in response to strong recruitment and stocking from 2005 onwards; and those scenarios that did not or had no stocking. Under the current flow recommendations in the Campaspe River the population is predicted to outperform other managed flow scenarios in most years and the size of the adult Murray Cod population is predicted to increase by an average of at least 7% above other scenarios from 2009.
  - The IVT scenarios did not produce a population response in the same manner post 2009 as the other scenarios, remaining largely stable except by a recruitment response to the flows in 2012-2014 (as reflected by a population response 5 years later; Figure 2.6.5a). These differences are reflected in the associated risk curves where the IVT scenarios risk curves are closer to zero representing higher risk as is the No Stocking scenario (Figure 2.6.5b). For example, the probability of the adult population falling below 600 individuals over the time period was up to 66% higher for the IVT scenarios in comparison to the current flow recommendations (Figure 2.6.5b).
- Our predictions for Silver Perch in the Goulburn River showed an adult population in decline through the Millennium Drought, followed by an increase, small decline and then final increase again due to the floods of 2016 (Figure 2.6.6a). The Goulburn River Silver Perch population is sustained through both local recruitment and immigration, where the general pattern broadly mirrors the dynamics of the lower connected Murray River.
  - Of the scenarios tested there is little to separate the outcomes, in terms of average trajectory (Figure 2.6.6a). It is worth noting that the Actual and No Environmental Water Allocation scenarios produce marginally higher risk outcomes compared with the other scenarios (Figure 2.6.6b) over the 15-year flow sequence. This includes IVT years. For example, the probability of the adult population falling below 7,000 individuals over the time period was 0.51 (Actual) and 0.49 (No EWA) compared with the next best of 0.39 (Current EWA Recs), 0.36 (High IVT) and 0.34 (IVT) (Figure 2.6.6b).
- Our predictions for Silver perch in the lower Campaspe River followed a similar pattern to that of Silver Perch in the Goulburn River, with the population in decline through the Millennium Drought, followed by two increases in the year after major floods (Figure 2.6.7a). We found the Campaspe Silver Perch population is sustained through immigration only, and therefore, the general patterns in dynamics broadly mirror the dynamics of the connected mid-Murray River.
  - Of the scenarios tested High IVT produced the best results though the differences in the average trajectory were marginal differences with the pattern for all scenarios remaining the same (Figure 2.6.7a). It is worth noting that the Current EWA Recs scenario produced higher risk outcomes compared with the other scenarios and the High IVT scenario produced lower risk outcomes (Figure 2.6.7b) over the 15-year flow sequence. For example, the probability of the adult population falling below 2,500 individuals over the time period was 0.70 (Current EWA Recs), 0.53 (Actual), 0.5 (No EWA), 0.46 (IVT) and 0.3 (High IVT) (Figure 2.6.7b).

a)

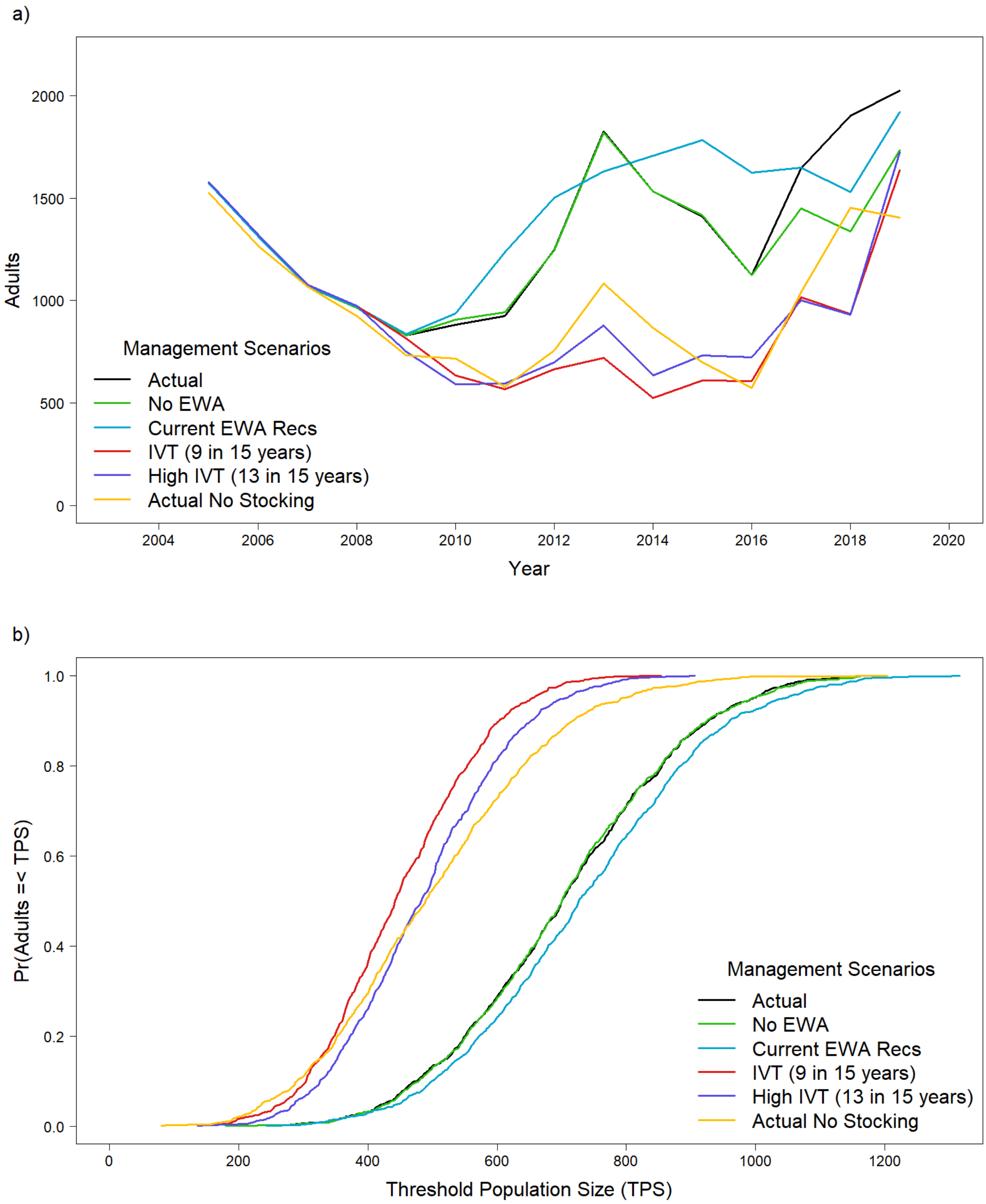



**Figure 2.6.5** Population model outputs for Murray Cod in the Campaspe River estimating a) the average adult population size trajectory for each of the management scenarios; and b) risk curves associated with each scenario for the period 2005-2019. Scenarios were: Actual = actual flow, temperature and stocking values; No EWA = actual temperature, stocking and flow values minus the environmental water allocation; Current EWA recs = actual temperature, stocking and flow values modified to meet current flow recommendations for each year; IVT = actual temperature, stocking and flow values modified to a 9 in 15 year summer intervalley trade at an average of 200 ML day$^{-1}$; High IVT = actual temperature, stocking and flow values modified to a 13 in 15 year summer intervalley trade at an average of 200 ML day$^{-1}$; Actual No stocking = actual flow and temperature values without stocking.

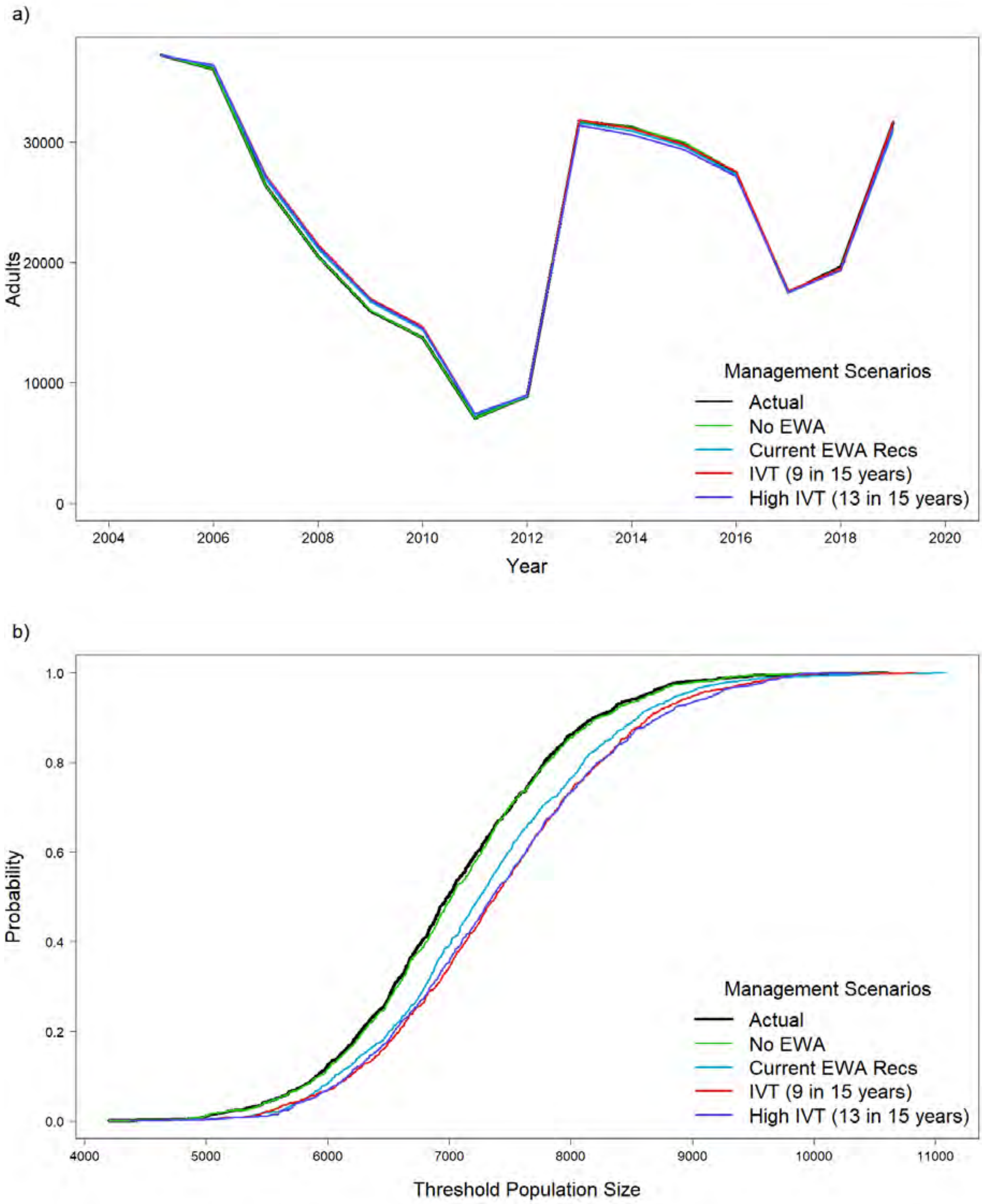
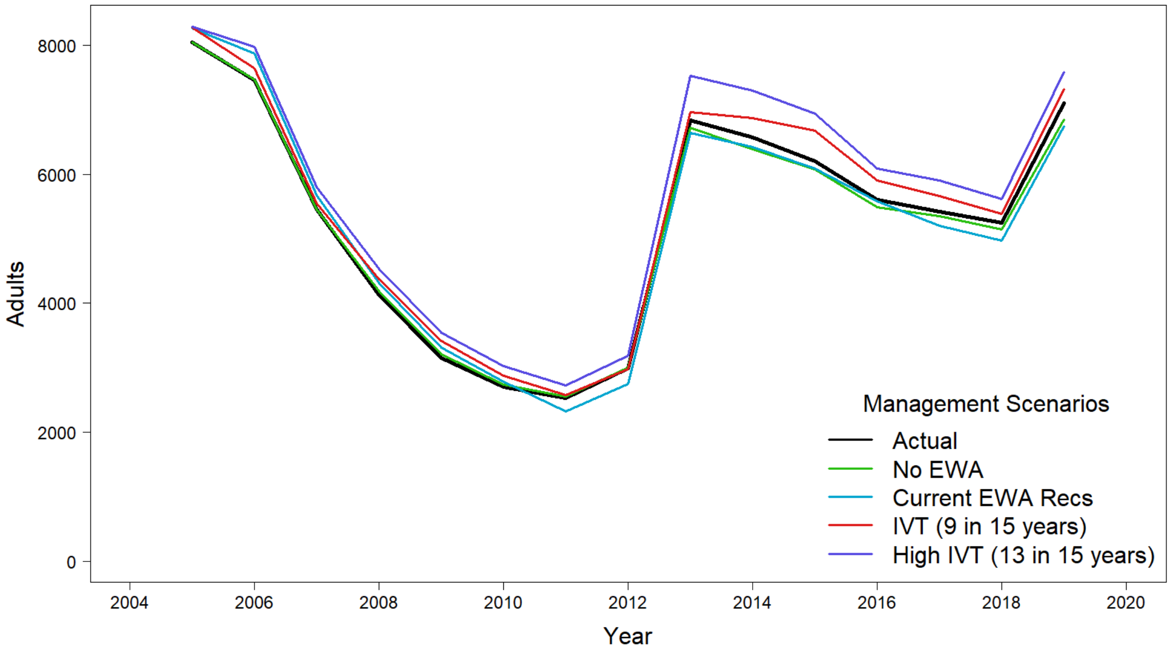



**Figure 2.6.6** Population model outputs for Silver Perch in the Goulburn River estimating a) the average adult population size trajectory for each of the management scenarios; and b) risk curves associated with each scenario for the period 2004-2019. Scenarios were: Actual = actual flow, temperature and stocking values; No EWA = actual temperature, stocking and flow values minus the environmental water entitlement; Current EWA recs = actual temperature, stocking and flow values modified to meet current flow recommendations for each year; IVT = actual temperature, stocking and flow values modified to a 9 in 15 year summer intervalley trade at an average of 2,853 ML day-1; High IVT = actual temperature, stocking and flow values modified to a 13 in 15 year summer intervalley trade at an average of 2,853 ML day-1; Actual No stocking = actual flow and temperature values without stocking.

a)




b)

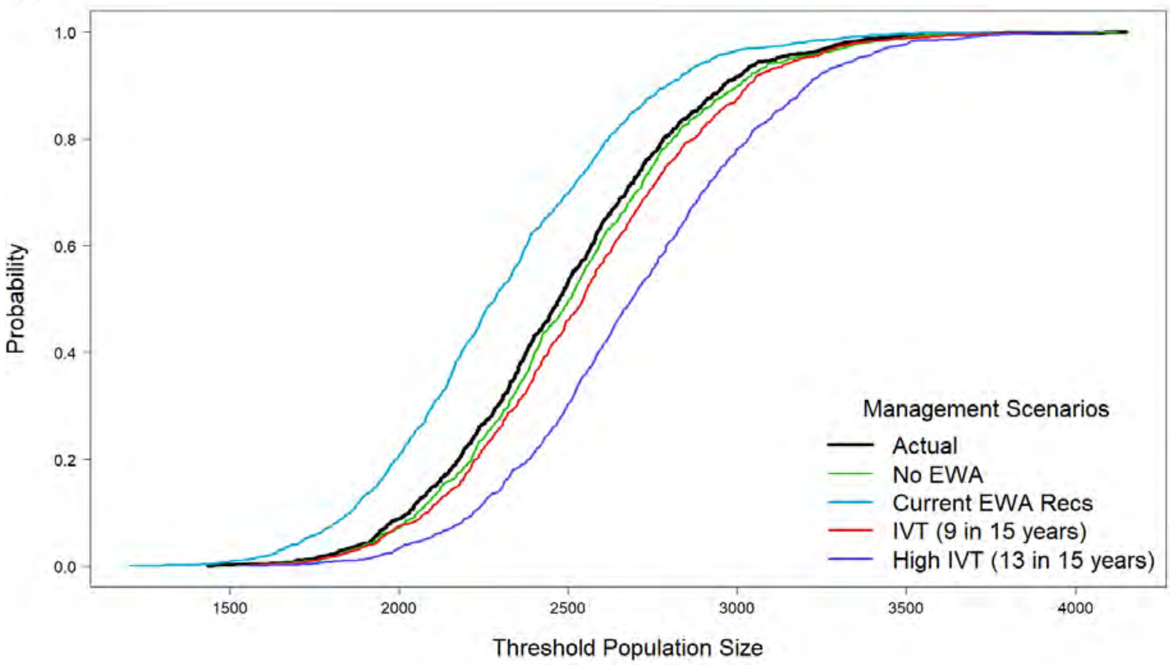



**Figure 2.6.7** Population model outputs for Silver Perch in the Campaspe River estimating a) the average adult population size trajectory for each of the management scenarios; and b) risk curves associated with each scenario for the period 2004-2019. Scenarios were: Actual = actual flow, temperature and stocking values; No EWA = actual temperature, stocking and flow values minus the environmental water entitlement; Current EWA recs = actual temperature, stocking and flow values modified to meet current flow recommendations for each year; IVT = actual temperature, stocking and flow values modified to a 9 in 15 year summer intervalley trade at an average of 200 ML day-1; High IVT = actual temperature, stocking and flow values modified to a 13 in 15 year summer intervalley trade at an average of 200 ML day-1; Actual No stocking = actual flow and temperature values without stocking.

### 2.6.5 Conclusions and implications for flow management

At a broad level, populations of most species assessed showed a declining trend through the millennium drought, then increasing or stabilising trends once flows returned due to both natural flows and an increase in use of environmental water. There were some variations to this trend between systems and species. The following are specific examples of these results:

*Coastal rivers population trends*

- The catch of Tupong in the Thomson River has been variable through time, with peaks in catch resulting from periodic, strong recruitment. This level of stability may be the result of relatively consistent baseflows from winter to early summer over the period of the study. These periods correspond to the timing of Tupong spawning migrations and spawning, immigration into coastal rivers and upstream dispersal, which are key life-history processes for diadromous fishes. Environmental flows have been used in the Thomson River to increase river discharge during spring and summer since 2011.
- Low catches of Australian Grayling from 2009 to 2011 may be the result of dry conditions at the end of the millennium drought. River discharge during late April and early May (the spawning period for Australian Grayling in the Thomson River) were at their lowest in 2005 and 2007 to 2009, which may have impacted the 2008 to 2010 year classes. Environmental flows of around 800 ML $d^{-1}$ have been used successfully to enhance spawning of Australian Grayling in most years since 2011.
- Tupong and Common Galaxias numbers increased in the Glenelg River over the same period when changes were made to summer and early autumn environmental flow deliveries (higher baseflows and one to two fresh releases each year since 2017), indicating the successful reinstatement of a flow regime better suited to diadromous fishes.

*Northern Victorian population trends*

- Regional-scale patterns in population trends were similar for Murray Cod, Golden Perch, Murray-Darling Rainbowfish and Carp. These species all declined in abundance and biomass during the Millennium drought but subsequently had increasing trends thereafter. These patterns varied across species and systems. For example, increasing trends in Murray Cod and Golden Perch after the millennium drought were greatest in the Campaspe and Ovens rivers, while the Loddon River had the lowest rate of increase or was stable during the same period. Our results support current flow management approaches already being used at some rivers to enhance populations of species such as Murray Cod, Golden Perch, and Murray-Darling Rainbowfish.
- There is a need to consider the role of flow on specific population processes, particularly recruitment and dispersal capacity. If immigration and recruitment are restricted, we will not see these positive responses to flow regardless of investment.
- Because a large proportion of the variance in population trends is not explained by our flow metrics, any assessment of population trajectories should also consider other drivers, such as stocking, genetic stocks and habitat restoration. These drivers and their possible interactions with flow may offset any benefits of flow management or overshadow our ability to detect responses to flow.
- Carp responses were similar to those of other species, so flow management might also benefit Carp, which have known negative ecological effects.
- Recommendations for flow managers:
    - Deliver flows during spring that are more than five times the long-term daily average in the system.
    - Minimise the number of low-flow days (fewer than 40 days per year below the long-term 10th percentile).

*Stochastic population modelling*

- Model predictions for Murray Cod show a generally stable adult population that fluctuates with gross flow patterns (lagged for adults) in the Goulburn River, whereas for the Campaspe River the adult population shows an increasing trend since 2009. This aligns with the general trends observed in the monitoring data and associated analysis.
- Of the scenarios tested for Murray Cod in the Campaspe River, the current flow recommendations produced the best population outcomes and the least risk to populations. Conversely, in the Goulburn River all the management scenarios were virtually indistinguishable. Both IVT scenarios in the Campaspe River performed poorly for Murray Cod. This highlights the risk of multiple years of elevated summer flows to long-lived species.
- Model predictions for Silver Perch in both rivers broadly reflected the dynamics of the broader mid-Murray River metapopulation. For the Goulburn River all the management scenarios were virtually indistinguishable (as per the Murray Cod predictions in the river). The results were, however, different in the Campaspe River, where the High IVT produced the best results. This was due to the sustained higher summer flows enhancing immigration of juvenile fish into the lower reaches of the river.
- We recommend further refinement of our population model construct with the help of waterway managers to test other flow scenarios. Extending the temporal scales of modelling (30–50 years) and a broader range of managed flow scenarios when exploring opportunities to modify current recommendations is also recommended.
- This first attempt to apply these models that incorporate flow-driven population processes to environmental flow scenario testing is highly novel. Continuing to focus on process-explicit models that directly identify the key biological processes and how these are influenced by flow or other factors presents a powerful tool for flow management. As our understanding of both ecosystem processes and model constructs evolve, we will be able to ask more complex questions and test a diverse range of hypotheses with which to manage native fish populations. Extending these analyses to include other and multiple species, including interactions among species (population modelling or otherwise) will be of considerable value.

Collectively, these results highlight the value of long-term monitoring data, which help programs such as VEFMAP track their progress towards the fundamental objective of maintaining or enhancing native fish populations. Long-term population monitoring data for taxa such as fish, with their cultural, economic and conservation value, also provide a powerful communications tool, not just to demonstrate outcomes, but also to highlight shortfalls and need for investment.

The statistical approaches used here are novel and should be extended to other species and rivers where data exists. Of course, the approaches used are currently single-species models, which can present a challenge when managing entire ecosystems while balancing the needs of many taxa. Species interactions complicate this challenge because interactions can fundamentally alter how species respond to management actions, potentially with unintended or adverse outcomes. An example in Victorian waterways is the exotic Carp, which can benefit from some management actions targeting native species, strengthening the already negative impacts that Carp have on those native species. Conversely, species and biota interactions may enhance the benefits of management actions when one species positively affects another. For example, management actions targeting aquatic macrophytes can benefit macroinvertebrates, thereby increasing the availability of habitat and food resources for fish (see Section 3.7). Understanding how species interact, and when these interactions will affect responses to management actions, is key to developing management strategies that maximise biodiversity benefits while minimising the risk of unexpected outcomes. We therefore recommend expanding the population modelling approach to forecast responses of interacting species, and ideally taxa, to flow management.

## 2.7 Summation of findings

### 2.7.1 Outcomes

Combining event-based intervention monitoring and condition monitoring during VEFMAP Stage 6 has provided a major step forward in identifying and quantifying key pathways that link attributes of river flows to the processes governing native fish population dynamics in Victoria. Establishing and quantifying links between river flows and population processes within our KEQ framework has provided much needed empirical evidence to support environmental water delivery aimed at enhancing native fish populations. Most notably, our assessments of fish movement in response to specific flow events generated overwhelming evidence and support for the use of environmental flow delivery as an effective management tool to enhance migration, dispersal and subsequent populations of native fish species in coastal rivers such as the Glenelg (Section 2.3) and inland rivers such as the Campaspe, Loddon and Goulburn (Section 2.4).

More broadly, several studies provided empirical evidence to support some of the conceptual links between river flows and the processes and dynamics affecting native fish populations. These results not only support some components of existing flow regimes, but also provide a strong base to support modifications and testing of different flow regimes in the future. For example, flow recommendations for many northern Victorian rivers have an objective for enhancing Murray Cod populations, yet until this study little empirical data existed to support such actions. Our assessment of recruitment dynamics for Murray Cod has provided robust quantitative support for managing flows in regulated rivers in accordance with the natural flow regime (Section 2.5). Similarly, our findings that show the enormous spatial range and diverse array of habitats used by Silver Perch have helped change the way flows are managed for this species— most notably, shifting from a single reach or river scale to a whole-of-catchment scale when considering flows and habitat availability to support all life history requirements (Section 2.4).

The long-term condition monitoring underway at priority managed rivers in Victoria since 2007 has provided vital information to help track progress towards the fundamental objective of improving native fish populations. Our analysis of data from this monitoring showed that for most species assessed, there was a declining trend in fish abundance through the millennium drought, with increasing or stabilising trends once flows returned as a result of both natural flows and an increase in environmental flows. Species and systems that typified this trend include Murray Cod, Murray-Darling Rainbowfish and Golden Perch in the Campaspe and Broken rivers; and Tupong and Common Galaxias in the Glenelg River. There were, however, some variations to this general trend between systems and species.  For example, unlike most other systems in the period following the millennium drought, the Loddon River fish population had the lowest rate of increase or remained at low stable levels, most likely because the extreme low flows limited the survival and retention of fish (Section 2.4).

Our analysis of long-term data also partitioned the effects of flows from other modifiers, finding that a large proportion of variation in population trends was not explained by flows. Any assessment of population trajectories should therefore also consider other drivers, such as stocking, baseline genetic stocks and habitat restoration. For example, our assessment of natal origin for Murray Cod and Golden Perch (e.g. Section 4.6; Supplementary material 10: Harris et al. 2020) found that, in some river reaches, stocked fish make up a large proportion of the population, and therefore stocking is likely to be a key management action governing the observed increases in abundance. Thus, assessing the role of flows in governing recruitment or survival in these reaches must also consider stocking, as has been done recently in two collaborative projects that have accessed data and otolith samples for Golden Perch collected during the VEFMAP program (Tonkin et al. 2017; Price et al. 2019).

Finally, our application of the stochastic population modelling for Murray Cod and Silver Perch has made significant progress towards predicting how flow management will influence long-term population trends under a range of management scenarios. Importantly, the approach incorporates the quantified links between river flows and population processes generated in our event-based monitoring (such as recruitment and migration), as well as accounting for many of the key intrinsic (e.g. fecundity) and extrinsic (water temperature, stocking and recreational fishing) factors in addition to river flows. Of the scenarios tested for Murray Cod, the current environmental water recommendations showed the best population outcomes and produced the least risk to populations in the Campaspe River. Conversely, despite components of the flow regime influencing the recruitment strength of Murray Cod, predictions from our population model for the Goulburn River found little evidence of any such benefits of the current flow recommendations. Our model predictions also suggest that high inter-valley transfers during summer present a high risk to populations of Murray Cod and can offset benefits gained from environmental water delivery.

### 2.7.2 Is Environmental water management making a difference?

Based on the results generated during Stage 6, it is clear that environmental watering is influencing key processes and populations of native fish, but the extent of this influence is often species or system specific. For example:

*KEQ 1: Can environmental flows promote immigration by diadromous fishes in Victorian coastal rivers?*

We found a positive association between spring river discharge and abundances of four species of juvenile diadromous fishes. The greatest benefits of environmental water on juvenile diadromous fish immigration can be achieved by providing spring flow pulses in rivers and years of low spring discharge (as was demonstrated for the Werribee River). The timing of environmental flows must also consider peak immigration times for each species.

*KEQ 2: Do environmental flows enhance dispersal, distribution and recruitment of diadromous fishes in Victorian coastal rivers?*

Our results showed strong support for enhanced upstream dispersal of three species of juvenile diadromous fish in response to environmental flow releases during summer and early autumn. For one system, this response was limited to a single species (Short-finned Eel) that could be better able to traverse several barriers in the system. We recommend that environmental flows be used to enhance the upstream dispersal of diadromous fish recruits in the lower reaches of rivers where there are no restrictions to fish passage and where sufficient flows exist to maintain suitable water quality and habitat for survival and maturation through summer. Environmental flows may provide the greatest population level benefits in years when the abundance of new recruits is relatively high and summer discharge is low.

*KEQ 3: Do environmental flows support immigration of native fish into, and dispersal throughout, northern Victorian rivers?*

Our analyses of data collected from three studies clearly demonstrates the importance of flows as a key driver of movement throughout river networks, with environmental flows playing an important role to enhance this process in flow-stressed regulated rivers. For Silver Perch, we found that river discharge and time-of-year are important drivers of movement within and between habitats, with environmental flow releases contributing to these movements. In the Loddon system, acoustic telemetry and fishway trapping revealed that upstream movement of fish of all sizes increased substantially during environmental flow releases.

*KEQ 4: Does environmental flow management used for large-bodied species enhance: (i) survival and recruitment, (ii) abundance and (iii) distribution throughout northern Victorian rivers?*

Our analyses of long-term monitoring data collected as part of VEFMAP and other programs found strong evidence that flows influence Murray Cod recruitment and the population dynamics of this species as well as Golden Perch, Silver Perch and Trout Cod. The contribution of environmental water to fish population outcomes is river, species and process specific. For example, based on our monitoring data and subsequent model estimates, environmental flows have clearly enhanced recruitment, survival and subsequent population dynamics of Murray Cod in the Campaspe River. These same environmental flows do not appear to have enhanced recruitment of Golden Perch in that system, but rather, the survival and distribution of stocked fish. Conversely, despite empirical evidence linking components of the flow regime to recruitment strength of Murray Cod and immigration and spawning of Silver Perch, predictions from our population models for the Goulburn River found little evidence of any such benefits from the existing flow recommendations for populations of either species.

### 2.7.3 Overarching recommendations

The approaches used for the Fish theme during VEFMAP Stage 6 have enabled significant advances in understanding fish population responses to flow management by testing process-specific responses to environmental water delivery and monitoring population trajectories of fish throughout Victoria. Our results have provided an important scientific basis for the credibility and implementation of flow management aimed at achieving population outcomes for native fish. We recommend that the program continues the approach applied during Stage 6, using a combination of:

- event-based intervention monitoring of specific population processes
- condition monitoring, consisting of annual electrofishing surveys of priority river reaches
- long-term population modelling to test specific flow recommendations.

The approach of combining event-based and long-term monitoring, as well as population modelling for fish, has now been adopted as part of the Commonwealth Environmental Water Office's Monitoring and Evaluation Framework.

Continuing to use the event-based monitoring will further embed this program into the adaptive management framework of the Victorian Waterway Management Strategy. This will enable researchers and managers to continuously test and refine environmental flows aimed at achieving outcomes for native fish populations. The KEQs developed in Stage 6 should be reviewed in relation to the outcomes and objectives of waterway managers (embedded in SWPs), to prioritise the objectives to be tested for Stage 7. This review should include whether the KEQs tested during Stage 6 should be continued, and if so, how they could be refined. For example, while we found strong evidence that environmental flows influence the dispersal of juvenile diadromous fish, our assessment was limited to just two systems and very similar fresh events. Continuing to monitor these events at different times, discharge magnitudes and in other river systems would provide greater transferability and help refine environmental flow delivery to enhance diadromous fish populations in many Victorian coastal rivers.

The continuation of long-term condition monitoring using annual electrofishing surveys of priority river reaches would help monitor progress towards the fundamental objective of enhancing native fish populations. A review of the data collected thus far would be required to assess the value of refining the information collected (such as expanding or discontinuing the suite of rivers and sites surveyed). Using an analytical approach like that used for the Murray Cod recruitment on these long-term datasets would also be valuable for other species (e.g. River Blackfish). This would help quantify flow links and refine environmental flow delivery for future testing, as well as facilitate long-term projections in a population modelling framework (as in our Murray Cod and Silver Perch approach).

Finally, our first attempt in using population models parameterised using key results from the KEQ research, has provided an important tool to help predict the long-term population outcomes from a variety of managed flow scenarios. These included existing flow recommendations, inter-valley transfers and other interventions such as stocking. We propose to continue to update and use these models for the existing species and others, as well as for interactions between species and taxa. Validating these model outputs using empirical data collections will also be important.

# 3 Vegetation theme: Monitoring responses to environmental water

## 3.1 Introduction

Riparian zones are significant for the ecosystem services they provide, including biomass production and carbon sequestration, climate regulation, habitat provision as well as substantial aesthetic, cultural and education services (Capon et al. 2013; Capon and Pettit 2018; Riis et al 2020). Riparian vegetation, in particular, serves multiple socio-ecological functions (Dufour et al. 2019) and is a critical ecosystem component that delivers a remarkable range and a disproportionally large number of ecosystem services, relative to its extent in the landscape (Riis et al. 2020). Despite the enormous number of environmental, ecological and anthropogenic benefits riparian systems deliver, they are also some of the most severely degraded and transformed ecosystems globally (Capon et al. 2013), with vegetation clearing, livestock grazing, pollution, exotic species (flora and fauna) as well as alteration of natural flow regimes being some of the most severe threats to riparian vegetation (Palmer and Ruhi 2019). The impacts of river regulation through altered flow regimes on riparian vegetation and subsequent ecological and biochemical processes is a key research theme globally and has been recently described as a frontier research topic (Palmer and Ruhi 2019).

There has been a considerable investment in managing riparian ecosystems for environmental, cultural, social and economic purposes in Victoria. Environmental water is a significant part of that investment, and environmental flows need to be carefully managed to achieve the desired objectives stated within the MDBP, EWMPs and SWPs. These vegetation objectives are underpinned by a series of conceptual models described by various programs. For VEFMAP, detailed conceptual models were initially developed in Stage 2 (Chee et al. 2006), and these have been built on and further developed throughout VEFMAP. A summary of the key processes for linking vegetation population outcomes with environmental water management is provided in Figure 3.1.1. Within this model, the key drivers of the effects of environmental water on vegetation are the availability of surface and ground water resources, the physical process of bank inundation, and the provision of flowing water to influence the key population processes of longevity/growth, recruitment and dispersal. An expansion of this overarching model that relates the current understanding of vegetation responses and mechanisms to specific environmental flow components has been refined throughout VEFMAP Stage 6 and is provided in Figure 3.1.2. This model shows that many of the different flow components have a similar set of functional influences on vegetation populations, but the specific responses will vary for species and sites. This detail has been the focus of Stage 6 monitoring.

Evaluating the effects of environmental flows on waterways is difficult because of the paucity of information directly relating environmental flows to ecological outcomes (Sanderson et al. 2012), combined with the highly dynamic and site-specific nature of these responses (Poff and Zimmerman 2010). Additionally, the general understanding of flow-ecology relationships has traditionally been hampered by a focus on single response variables, without considering other correlated or confounding factors (Davies et al. 2014) such as rainfall, other flow attributes, livestock grazing, soil properties, exotic species and previous disturbance (Poff and Zimmerman 2010) (Figure 3.1.1). In Victoria, river regulation (including water extraction), livestock grazing and exotic species continue to have serious negative impacts on all major waterways, and vegetation monitoring and evaluation needs to consider these interactions.

VEFMAP Stage 6 vegetation monitoring can be used to determine how environmental flows influence the spatial distribution, foliage cover and species diversity of riparian vegetation at a given location, while considering interacting or confounding factors.

The broad objective for vegetation monitoring in VEFMAP Stage 6 was to examine the effectiveness of flow deliveries in achieving their desired vegetation objectives (outlined in EWMPs and SWPs).

Supplementary objectives included:

- Identify if vegetation responses to flow management vary within or among rivers or regions.
- Assess if vegetation responses to flow management are dependent on or enhanced by complementary management interventions (e.g. livestock exclusion).

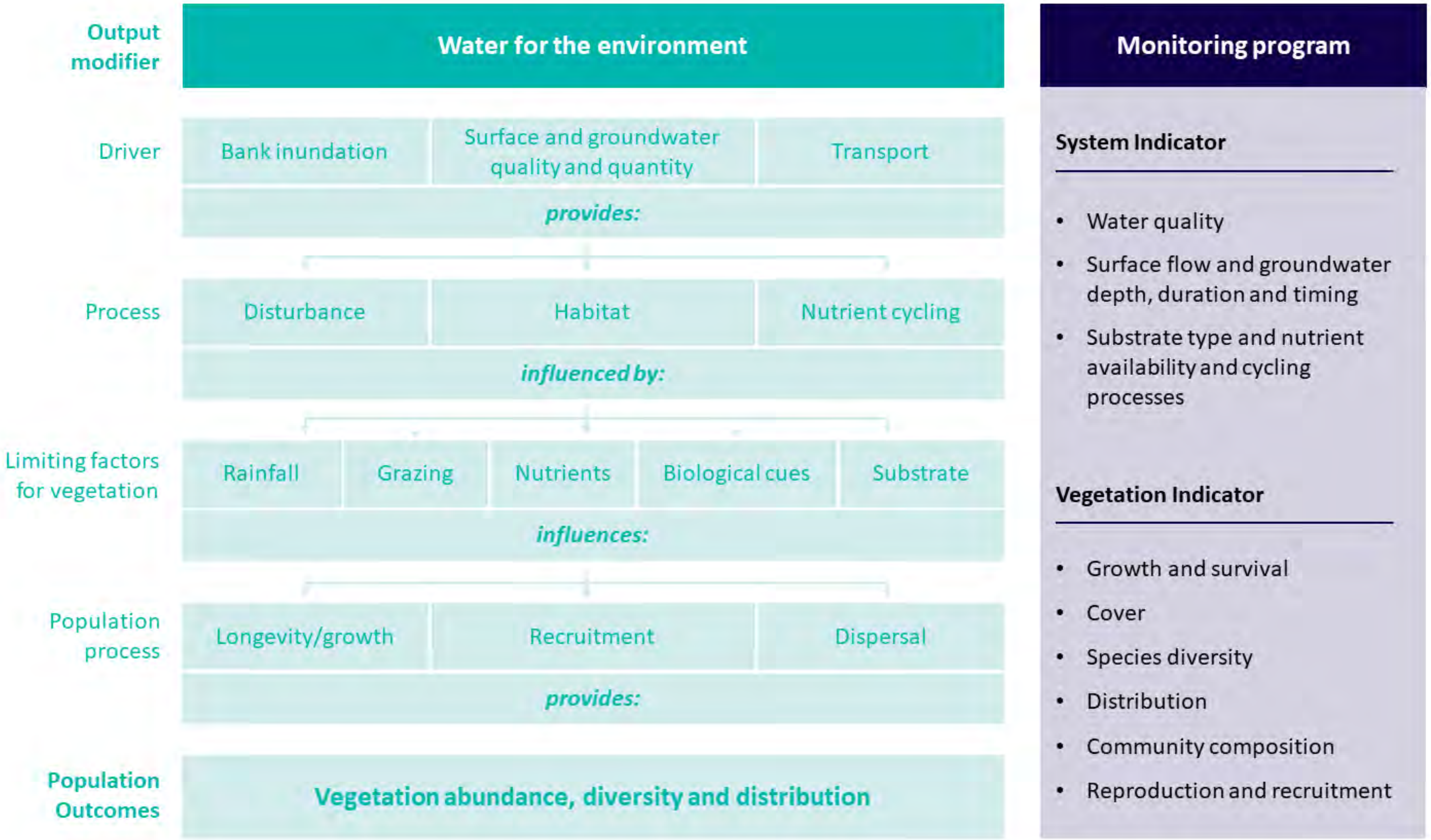



**Figure 3.1.1** Overarching conceptual model underpinning the key pathways and processes linking water for the environment (management output) to vegetation population outcomes. Examples of indicators used to monitor these processes are shown, as well as existing monitoring underway within VEFMAP across Victoria recording these indicators.

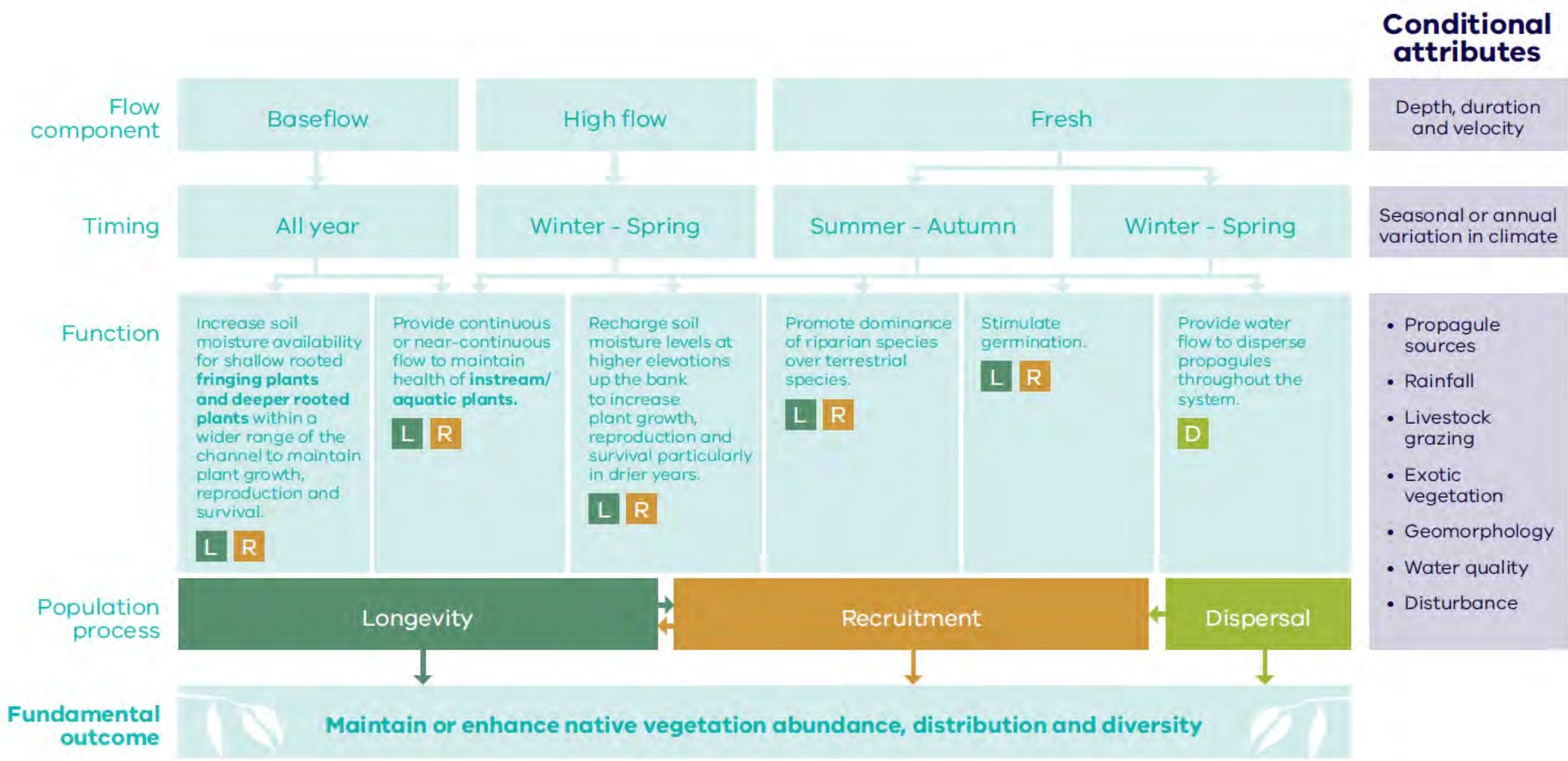



**Figure 3.1.2** Conceptual model depicting how environmental water is currently managed to influence key processes governing population dynamics of vegetation species in Victorian rivers

These conceptual models also highlight some of the key system and vegetation indicators, as well as conditional attributes that are required to understand vegetation responses to environmental flow management. In general, different plant species respond differently to the same conditions (e.g. management or threats), but the responses are typically more similar within specific functional groupings or types. These types form a critical filter for each of the vegetation indicators to evaluate broadly applicable trends. Different resolutions are commonly used in vegetation groupings; the finest (highest) resolution is used for individual species; an example of moderate resolution is the Wetland Plant Functional Groups (WPFG, sensu Brock and Casanova 1997); and low resolution is used for broad vegetation types such as aquatic, emergent and fringing (Figure 3.1.3). Broadly speaking, aquatic species persist only in water, and may be submerged or floating; emergent species typically have an erect habit and require at least some soil surface inundation each year, but may tolerate extended dry periods if sufficiently deep-rooted; fringing species tolerate submergence but can survive out of water for months or years if rainfall is sufficient; and terrestrial species do not require any inundation and usually have low inundation tolerance. This broad definition of riparian and terrestrial types forms the primary grouping level for VEFMAP Stage 6 (see Appendix 1 for full species list and grouping), although finer resolutions are used where relevant.

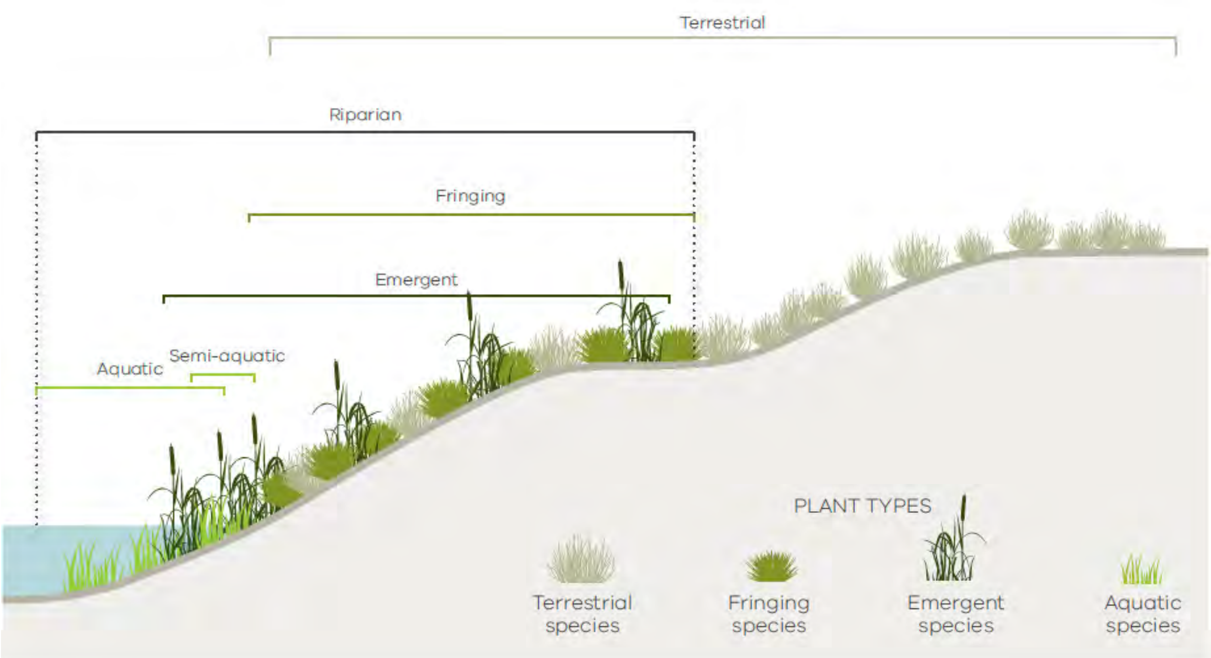



**Figure 3.1.3** A schematic river cross-section indicating the vegetation type categorisation, and their approximate distributions, primarily used within VEFMAP Stage 6.

Based on the conceptual understanding of how vegetation responds to managed flows (e.g. Figures 3.1.1 and 3.1.2) and the various management plan objectives identified by collaboration between DELWP's Environmental Water team, ARI, CMAs and researchers from The University of Melbourne, five target KEQs were identified for the Vegetation theme in Stage 6:

KEQ 1: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of aquatic and semi-aquatic vegetation at a sub-reach scale?

KEQ 2: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of emergent vegetation at a sub-reach scale?

KEQ 3: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of fringing herbaceous vegetation at a sub-reach scale?

KEQ 4: How does environmental flow discharge influence the recruitment and establishment of emergent, fringing herbaceous, and woody vegetation at a sub-reach scale?

KEQ 5: How are vegetation responses to environmental flow discharge influenced by additional factors such as grazing, rainfall, soil properties, and season?

The first four KEQs broadly reflect an interest in how existing riparian vegetation responds to flows. For some catchments specific target plant species were identified, but for other catchments a more general understanding of broad vegetation responses to environmental flows was considered most valuable. Species-specific responses are particularly useful for understanding why common problematic weeds or sensitive target native species persist at sites. Insights into how these species interact with altered flow regimes may be useful for determining management actions for target plant species within a region. Additionally, plant functional grouping of species-level data can be a powerful tool in understanding how suites of species respond more generally throughout reaches and across rivers. As a consequence, VEFMAP Stage 6 aimed to collect quantitative estimates of plant species cover, richness, recruitment, growth and survival, distribution, and composition. For this purpose we used broad-scale mapping of vegetation to inform large changes in species composition and distribution, and fine-scale transect and quadrat surveys to record the magnitude of changes in foliage cover and germination at a species level in relation to seasonal and hydrological changes (including inundation and soil moisture availability).

KEQ 5 reflects the importance of understanding the effect of other environmental factors on flow-ecology relationships. Factors such as rainfall, livestock grazing, Carp, exotic plant competition and availability of soil moisture were considered important factors for many rivers in Victoria. Consequently, in addition to quantitative measurements of vegetation responses to flow interventions, VEFMAP Stage 6 has incorporated complementary data collection and experimentation to specifically assess the additional impact of these factors. For example, vegetation monitoring involved common vegetation survey techniques as well as field and ex-situ experiments and the evaluation of key physical processes such as soil moisture monitoring (Figure 3.1.4). These factors have been either experimentally manipulated or measured across the VEFMAP Stage 6 survey sites which span across a wide temperature and rainfall gradient in Victoria and across seven CMAs.

**Figure 3.1.4** Measuring soil moisture in a livestock grazing exclosure on the Campaspe River (NCCMA).

The monitoring program for the Vegetation theme of VEFMAP Stage 6 has pursued a participatory and collaborative approach to research and monitoring, which has included regular and extensive communication and collaboration with waterway managers of surveyed waterways, valuable and productive collaborations with university researchers and students, and many critical collaborations with consultants to provide additional high-level expertise on various project components.

On-site and ex-situ experiments were undertaken to target aspects of all five KEQs relating to growth and survival of riparian vegetation, and we studied other environmental and management actions that may interact with environmental flows to influence riparian vegetation condition. On-site livestock grazing and Carp exclosure experiments were conducted, as well as ex-situ seedbank and nursery experiments in collaboration with students and researchers at The University of Melbourne.

Due to limitations with data availability and quality from earlier stages of VEFMAP, this report summarises vegetation findings entirely from data collected in Stage 6. The Stage 6 data have been used to answer specific KEQs, and to provide insights into factors influencing the health and persistence of riparian vegetation on managed waterways in Victoria. The studies completed in Stage 6 make significant progress in evaluating the influences of environmental water, demonstrating outcomes, directly informing management decisions, and addressing key knowledge gaps. Each study is linked, but contains a distinct set of aims and hypotheses that are evaluated with data and the outcomes used to address Stage 6 objectives.

Unlike the fish theme, the vegetation KEQs do not equate to discrete units that are effectively evaluated independently, i.e. one focus study per KEQ. Instead, because many vegetation types co-occur (e.g. Figure 3.1.3) and have similar responses that are most effectively evaluated together, many of the study components are relevant to multiple KEQs. However, each study has a primary focus on a particular KEQ, and the vegetation theme sections are correspondingly ordered in sequence (Table 3.1.1). The order is not based on the level on importance or the size of the study, but the links to vegetation types via KEQs.

**Table 3.1.1 Structure of the Vegetation theme sections in this report and their relevance to Stage 6 KEQs.**

| Section | Primary KEQ | Relevant KEQs | Title |
|---|---|---|---|
| 3.2 | 1 | 2, 3, 5 | Drivers of the distribution and community composition of aquatic vegetation in regulated rivers of Victoria |
| 3.3 | 1/5 | 2, 4 | The impacts of European Carp on aquatic vegetation in a regulated river |
| 3.4 | 1 | 2, 3, 5 | Environmental flows help structure fish and vegetation communities in a regulated intermittent stream system in a semi-arid landscape |
| 3.5 | 2, 3 | 1, 4, 5 | Evaluating the influence of environmental flows on emergent, fringing and terrestrial vegetation within regulated Victorian rivers |
| 3.6 | 2, 3 | 4 | Responses of herbaceous plants to experimental inundation: testing the effects of inundation duration, season and water temperature to inform flow management |
| 3.7 | 4 | 1, 2, 3, 5 | Vegetation recruitment in river channels and the role of environmental flows on plant germination |
| 3.8 | 4 | 2, 3 | Native riparian species dominate the soil seedbank of in-channel geomorphic features of a regulated river |
| 3.9 | 5 | 1, 2, 3, 4 | Riparian vegetation responses to livestock grazing and grazing exclusion in regulated rivers |
| 3.10 | 5 | 2, 3, 4 | Understanding the links between environmental flows and soil moisture in regulated waterways to improve vegetation condition |

## 3.2 Drivers of the distribution and community composition of aquatic vegetation in regulated rivers of Victoria

KEQs 1, 2 & 3: aquatic, emergent and fringing vegetation, and 5: other factors

This section is a summary of the following co-authored project, presented in Supplementary Material 11.

**Supplementary Material 11**: Vivian, L., Jones, C.S., Kitchingman, A., Mole. B (2020). Drivers of the distribution and community composition of riparian vegetation in regulated rivers of Victoria. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 3.2.1 Context

Flow regime is a primary driver of the distribution, abundance and diversity of riparian vegetation (Poff et al. 1997; Casanova 2011). Riparian plants are exposed to different flow regimes depending on their position within the riparian zone, resulting in a gradient of species types from the river channel to the bank. This reflects their ability to respond to the flow regime, including the duration, frequency, timing, and depth of inundation. Aquatic species within the channel have traits that allow them to survive long periods of full submergence or partial inundation, whereas emergent and fringing species on the margins and lower banks are less frequently fully submerged and often have adaptations to fluctuating water depths.

In Australia, aquatic species in rivers have been generally less well studied than those in wetlands and lakes (Mackay et al. 2003; Mackay and James 2016). Riparian vegetation studies often focus more on species in the zone that experiences fluctuating wet–dry conditions (i.e. emergent and fringing species) than aquatic species that reside mostly permanently in water (e.g. Catford and Jansson 2014). This may reflect the fact that relatively few species are considered to be true aquatics that depend on the presence of permanent surface water (Mackay and James 2016).

In this study we focused on aquatic species in Victorian rivers and explored the key drivers of their distribution and abundance. These drivers include flow magnitude and flow variability; aquatic species often become less abundant with increased flow magnitude, velocity and frequency of high flow events, and high levels of flow variability (Riis and Biggs 2003; Riis et al. 2008) (Figure 3.2.1). However, other non-hydrological drivers can also have a strong influence, including water quality and turbidity, shading from surrounding vegetation, substrate type, exotic plant and animal species (e.g. Carp) and grazing by introduced stock (Madsen and Adams 1989; Biggs 1996; Mackay et al. 2003; Bornette and Puijalon 2011) (Figure 3.2.1). We compared the response of aquatic species to a range of these key drivers with those of emergent and fringing species to understand how different factors may influence different riparian plant types, and how management actions, including environmental flows, may need to be tailored to achieve positive outcomes for each.

This study was based on vegetation mapping data instead of fine-scale transect data. The mapping data provide a rapid assessment of vegetation diversity and extent (not cover) during one snapshot in time, as well as a broad site-based context within which to embed the finer scale quantitative transect data. These approaches are also better suited to aquatic species that are difficult to assess by transect or quadrat approaches.

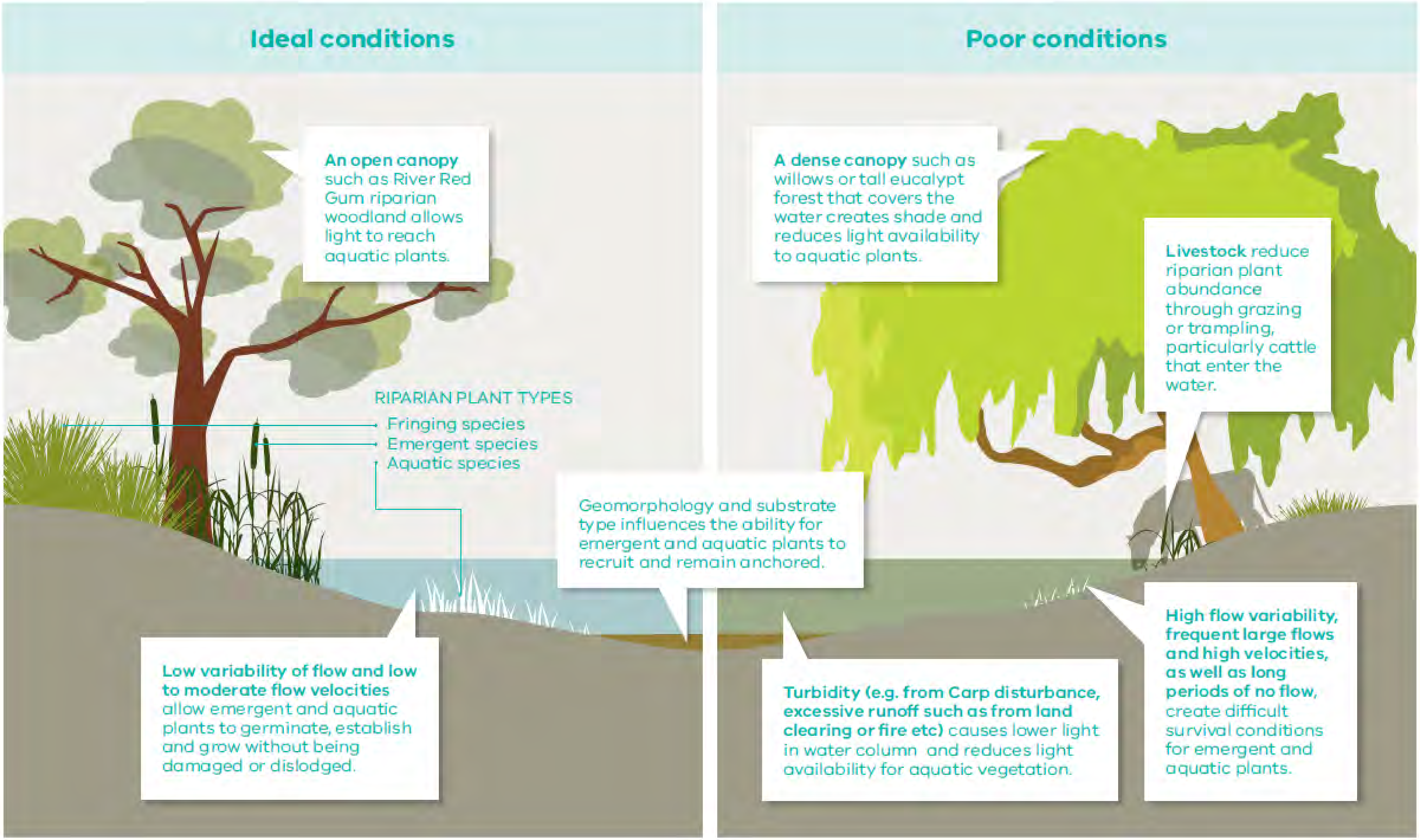



**Figure 3.2.1** Conceptual model showing the role of river flows and other key drivers of the distribution and abundance of riparian vegetation.

### 3.2.2 Aims and hypotheses

Our aim was to investigate the distribution and abundance of riparian plants across flow-regulated rivers in Victoria, with a particular focus on aquatic species. We tested a series of hypotheses predicting the relationship between aquatic species and key hydrological and environmental drivers:

- *Flow magnitude and variability* — Aquatic species cover and richness will have an inverted-U-shaped response to flow magnitude and variability. Specifically, cover and richness will be highest at moderate levels of flow magnitude and flow variability, but will decline with increasing flow magnitudes and flow variability as well as at the lowest flow magnitudes (i.e. prolonged dry periods of no flow).
- *Shade* — Aquatic species cover and richness will decline with increasing levels of overstorey shade.
- *Grazing* — Aquatic species cover and richness will be lower at sites grazed by livestock compared to ungrazed sites.

We also hypothesised that the responses of emergent and fringing species to the hydrological and shade variables will differ to those of aquatic species due to their occurrence in the wet-dry ecotone rather than in the more permanently wet riverbed.

### 3.2.3 Methods

*Site locations*

Our study area was seven major river systems in Victoria. Within this area we surveyed 44 sites across 30 distinct reaches in 15 different waterways (Figure 3.2.2–3.2.4). The sites span a latitude of about 38°10′S – 35°50′S and a longitude of 141°20′E – 147°10′E, covering a wide temperature and rainfall gradient and six catchment management authorities.

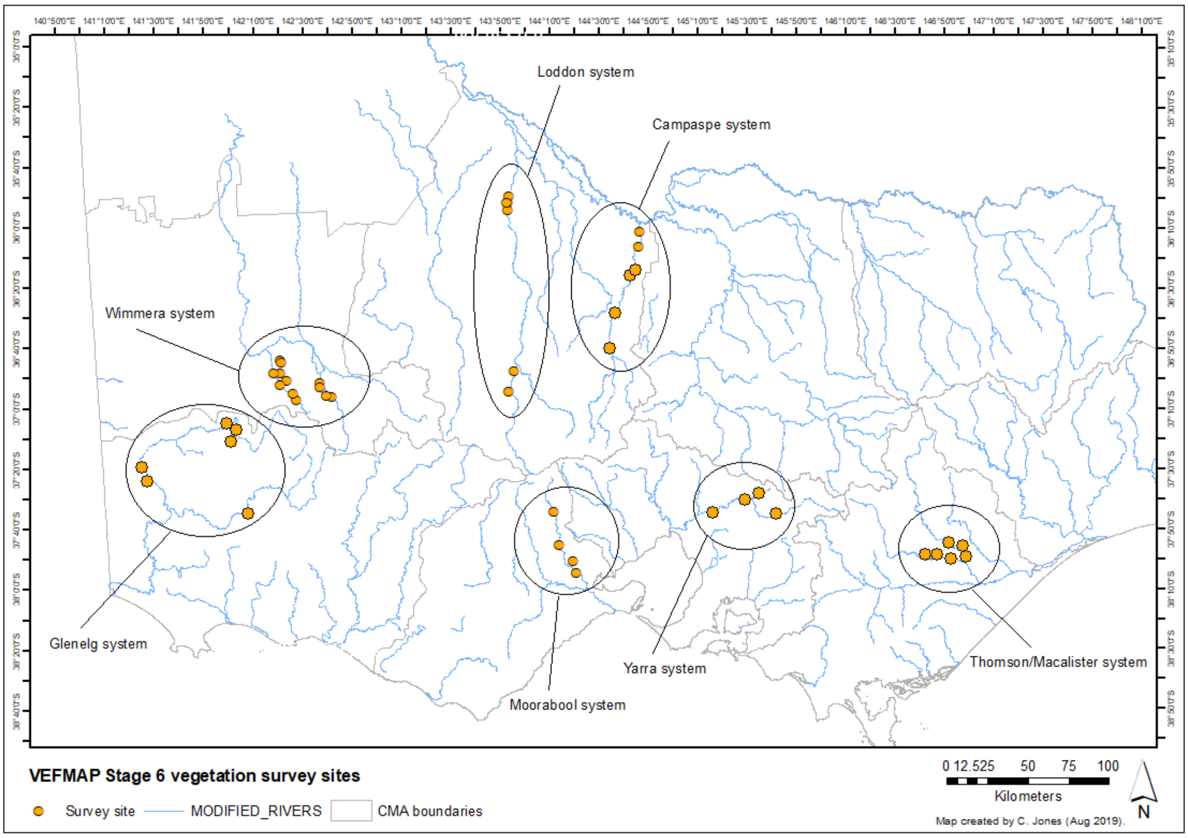



Figure 3.2.2 Location of study sites.

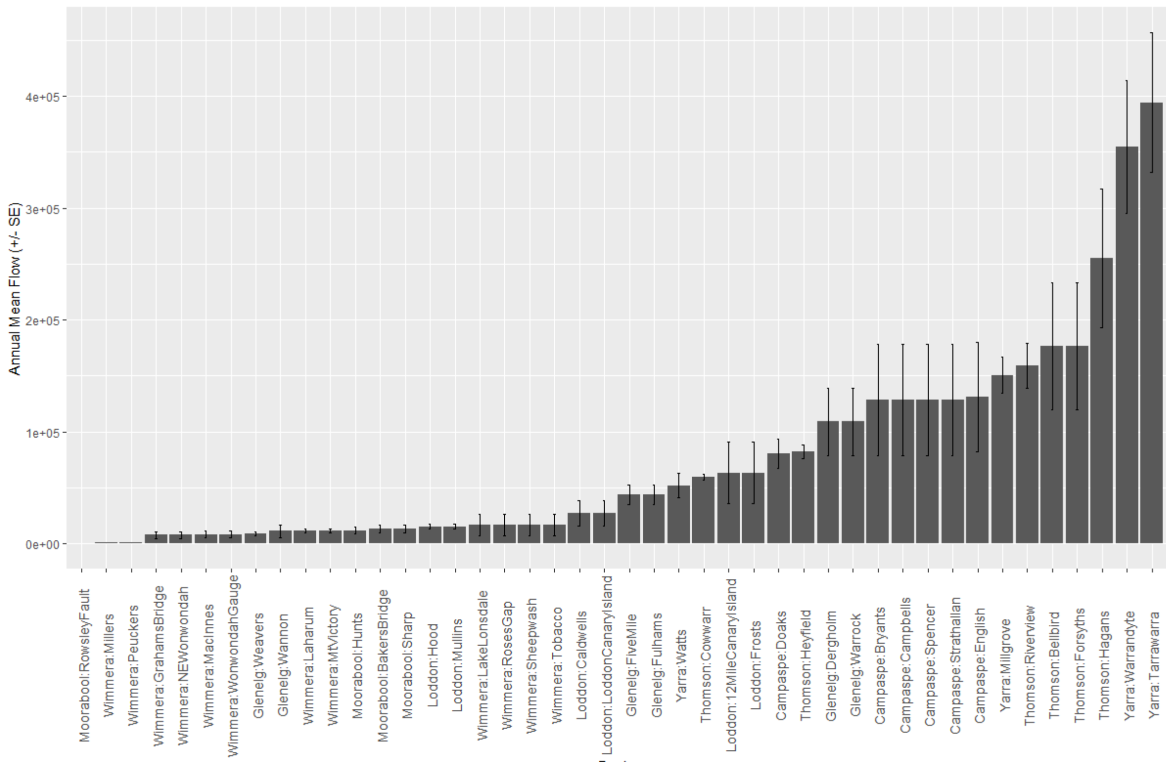



**Figure 3.2.3** Mean annual flow (2011–2018) at sites in this study, taken from the closest flow gauge to each site. Error bars show standard error across the time period.

*Vegetation sampling*

During each survey, all aquatic, emergent and fringing species on both sides of the river were mapped by drawing polygons around patches of individual species onto tablets loaded with aerial images. A full list of species categorisations across Stage 6 is provided as Appendix 1. The length of the sites ranged from 65 m to 640 m. Full details of mapping methods are available in DELWP (2017a). At each site the vegetation mapping was divided into two sides (left and right of the waterway centreline) to enable an analysis of grazing and canopy shade, which often differed between banks. Predictor variables related to each hypothesis were:

- flow magnitude: annual mean flow, daily mean flow, and mean annual number of zero flow days
- flow variability: daily flow coefficient of variation, and the mean frequency of events in a year that exceeds seven times the median daily flow (FRE7; a measure of the frequency of high flow events) (Riis and Biggs 2003)
- light availability: canopy shade (measured as the percent of canopy cover over each bank side, digitised from recent aerial images) and overstorey type
- grazing: presence or absence of stock grazing.

Values for flow variables were derived from the closest river flow gauge for each site and calculated for the period 2011 to 2018 (after the millennium drought), and some gauge data were assigned to more than one site. Three sites with very low to no flow were assigned estimated values for annual mean flow and the mean annual number of zero flow days, based on local knowledge of the sites.

Two response variables were calculated for each site bank side: species richness and summed percent extent. The latter represents vegetation cover and was calculated as the length of each species polygon (on each site) divided by site length, with totals able to exceed 100% if more than one species was present. Both variables were calculated for aquatic, fringing and emergent species separately.

More comprehensive statistical analyses are provided in Supplementary Material 11.


**Figure 3.2.4** Two contrasting systems with aquatic vegetation present: (left) the Moorabool River, with *Cycnogeton procerum*, and (right) the Campaspe River, with patches of *Vallisneria australis* and *Potamogeton sulcatus*.

### 3.2.4 Results

*General patterns*

- A total of 21 aquatic, 62 emergent and 29 fringing species was recorded across the 44 sites. The majority of sites had no (11 sites) or only one (29 sites) aquatic species present.
- The sites with the highest richness of aquatic species were Weavers in the Glenelg system, with 6 species, and three sites with 5 species (Five Mile in the Glenelg system, and Doaks and English in the Campaspe system). McInnes in the Wimmera system had the largest extent of aquatic species, because of the presence of three species that extended along almost the entire site (*Cycnogeton procerum*, *Myriophyllum simulans* and *Gratiola peruviana*).
- The Glenelg had the highest total richness of all types of species: 10 aquatic, 22 emergent and 22 fringing (Figure 3.2.5). The Loddon had the lowest aquatic and fringing species richness (2 and 3 species respectively) but a relatively high emergent species richness (16 species). Low aquatic species richness was also recorded in the Yarra (2 species), West Gippsland (Thomson and Macalister) (3 species) and Wimmera (4 species) systems.
- The most frequently recorded species overall were the aquatic species *Cycnogeton procerum*, which was recorded at 30 sites (68% of sites), and the emergent species *Juncus amabilis* (27 sites; 61% of sites) and *Phragmites australis* (24 sites; 55% of sites).
- The species with the largest extent (assessed across site banks) were *Cycnogeton procerum*, *Juncus amabilis, Phragmites australis* and *Carex tereticaulis* with mean summed percentage extents across banks of 31.6%, 21.5%, 18.6% and 7.2% respectively.

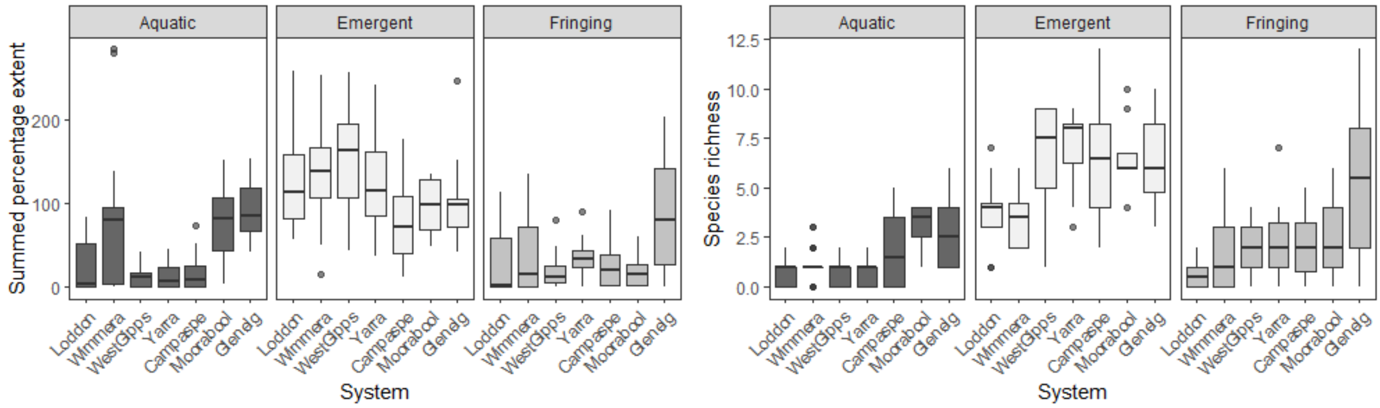



**Figure 3.2.5** Summary boxplots of aquatic, emergent and fringing species across each system by summed percentage extent (left) and species richness (right). Systems are ordered by ascending overall species richness.

*Flow magnitude*

- At sites with high annual mean flow, the summed percentage extent and richness of aquatics was generally low, although there were few sites at this end of the flow magnitude gradient. At sites with low annual mean flow, aquatic summed percentage extent and richness ranged from zero to the highest values recorded (Figure 3.2.6). A similar pattern was evident in relation to daily mean flow (not shown). No clear relationship was evident for emergent species, although fringing species showed a similar response to aquatics.
- Sites with the highest mean number of days per year with no flow (200 days or more) all had very low extent of, or no, aquatic species (Figure 3.2.6). Patterns for emergent and fringing species were not evident.

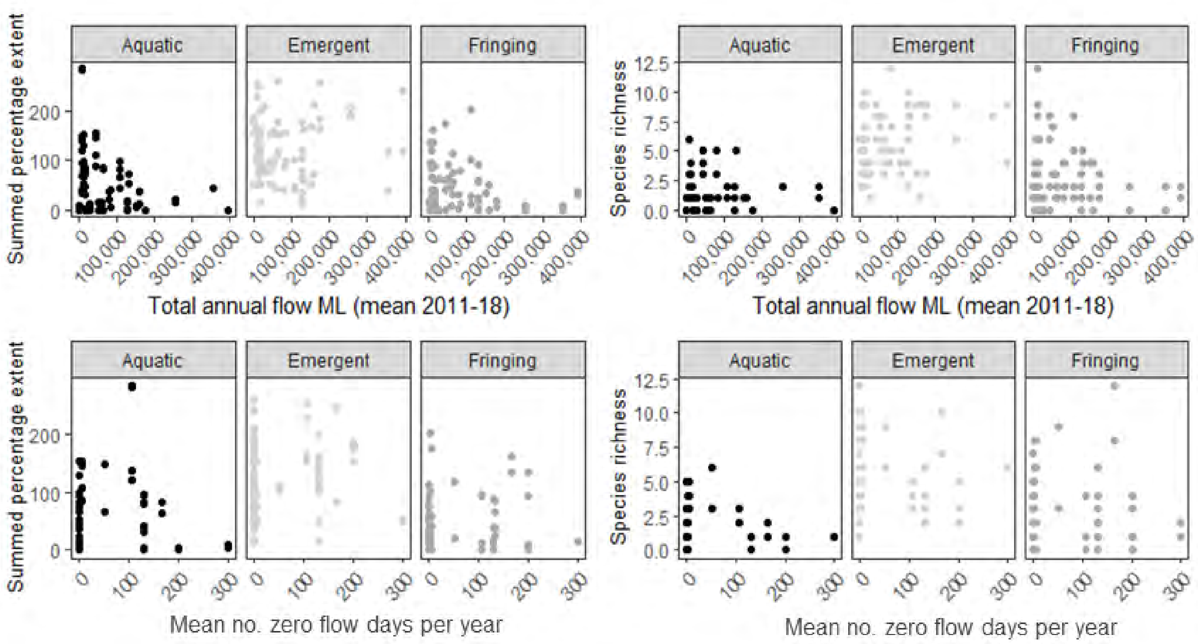



**Figure 3.2.6** Scatter plots of aquatic, emergent and fringing species showing summed percentage extent (left) and richness (right) along site banks in relation to annual mean flow (top row) and mean number of zero flow days per year (bottom row).

*Flow variability*

- Aquatic species summed percentage extent and richness was generally highest at sites with intermediate values of daily flow coefficient of variation (Figure 3.2.7). At the sites with the lowest values (Cowarr and Heyfield in the West Gippsland system, and Millgrove, Tarrawarra and Warrandyte in the Yarra system), summed percentage extent and richness was generally very low, ranging from 0 to 45% in extent and 0 to 2 species. However, at the four sites with the highest daily flow coefficient of variation values (those on Mt William Creek in the Wimmera) the summed percentage extent ranged between 0 and 100%.
- The relationship of aquatic species to FRE7 was less clear. The highest summed percentage extents were at intermediate FRE7 sites. However, at both the lowest and highest FRE7 sites the summed percentage extent varied from 0 to over 100%. The highest values of aquatic species richness were at sites with lower FRE7, but values at sites with low FRE7 were also variable, ranging from 0 to the highest values of richness observed (Figure 3.2.7).
- Fringing and emergent species did not show a clear relationship with either measures of variability.

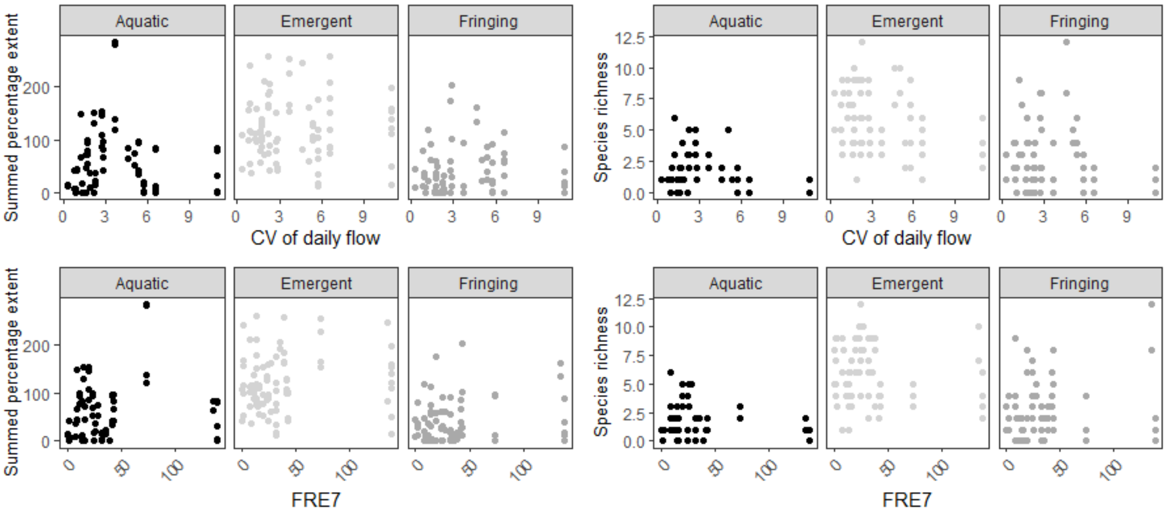



**Figure 3.2.7** Scatter plots of aquatic, emergent and fringing species between site banks, showing summed percentage extent (left) and richness (right) along site banks in relation to the daily flow coefficient of variation (top row) and the mean frequency of events in a year that exceeds seven times the median daily flow (FRE7) (lower row).

*Grazing*

- There was no clear difference in the summed percentage extent or richness of any species type between grazed and ungrazed site banks when examined across all sites (Figure 3.2.8). This is because the effect of grazing is dependent on many additional factors. For example, grazing effects can only occur where the flow and shade levels are sufficient to support aquatic plants. Where aquatic vegetation does occur, grazing impacts can occur only if grazers have access to the water, i.e. where the water is shallow and the banks are not too steep, which is often variable within a site. So assessments of grazing impacts at a site scale are insufficient to fully evaluate livestock impacts.

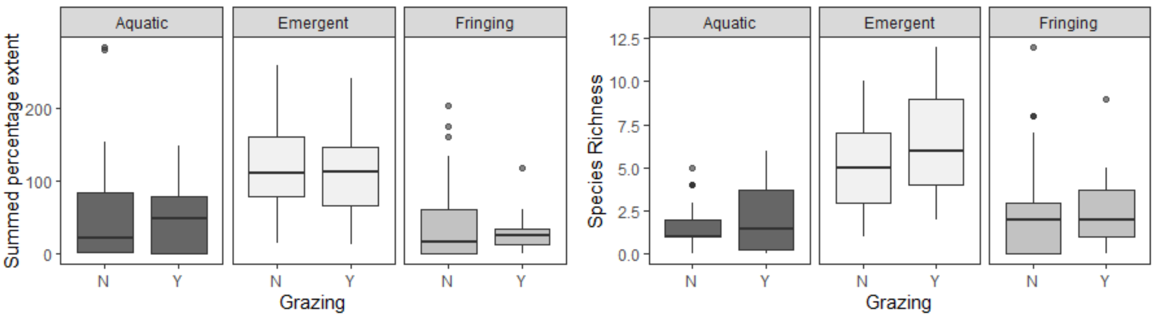



**Figure 3.2.8.** Comparison of extent (left) and richness (right) of aquatic, emergent and fringing species between site banks with and without a history of grazing.

*Shade*

- The summed percentage extent of aquatic species was generally highest in the sites dominated by River Red Gum (*Eucalyptus camaldulensis*) with an open or shrubby understorey, compared to sites dominated by open or closed forest or by shrubs only (Figure 3.2.9). The River Red Gum open and shrubby understorey sites generally have a more open canopy compared to forested sites (DELWP 2020). However, there are likely to be interactions with other drivers associated with the patterns observed at the forested and shrubby sites, particularly as there was very low replication in these categories. For example, forested sites were only in the Yarra system and had high annual mean flow and low variability of flow, and the previous results showed that high annual mean flow in particular is associated with low aquatic species cover. Similarly, shrubby sites were only in the West Gippsland system in a heavily modified agricultural landscape where the original overstorey at these sites has been largely cleared, so they may be overall more degraded than other sites where other disturbances may have reduced aquatic species.
- There was no clear trend between the summed percentage extent or richness or any species type and shade when calculated as percent cover from aerial images (not shown).

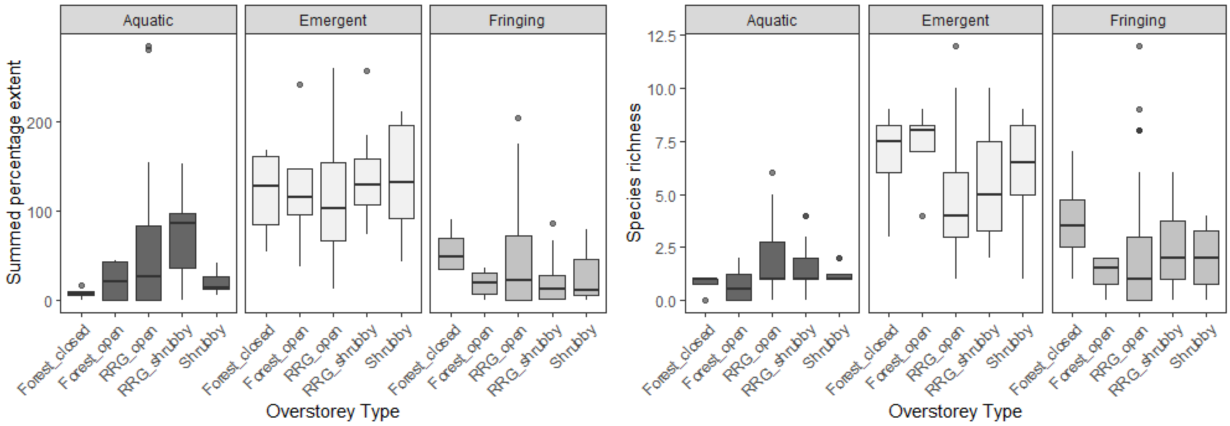



**Figure 3.2.9** Comparison of summed percentage extent (left) and richness (right) of aquatic, emergent and fringing species between site banks classified by overstorey type. RRG = River Red Gum.

## 3.2.5 Conclusions and implications for flow management

- Aquatic species richness was generally very low across all sites. However, some of the recorded species can have large extents within a site and have a very wide distribution across Victoria, e.g. *C. procerum*, which was the most frequently recorded species in this study. Given that a few key species make up a significant proportion of the richness and extent of the total Victorian aquatic vegetation assemblage, detailed species-specific knowledge on their ecology and flow requirements would be valuable. However, it is also important to understand how and why the more uncommon aquatic species may differ from the common species.
- Waterways in our study (i.e. regulated lowland rivers that receive environmental flows from upstream dams) with moderate to low flows have the greatest hydraulic capacity to support aquatic species. In contrast, lowland waterways with the highest flow or the driest river reaches are unlikely to have high aquatic species extent or diversity, because very high or low flow rates provide poor hydraulic habitats for most vascular aquatic plants. Where the flow rate is already high, environmental flows cannot improve the hydraulic habitat for aquatic plants. Conversely, along the driest river reaches, such as those where there are extended periods of no flow, or where low flows persist, environmental flows may substantially benefit aquatic plants by providing adequate baseflows to reduce the duration of dry periods (provided other conditions are suitable for establishment and growth). Understanding these conditions is important for setting appropriate management expectations and objectives for improving the condition of aquatic plants.
- There was limited evidence of a relationship between the extent and richness of aquatic species and flow variability, shade, or grazing, despite strong published or anecdotal evidence of their impacts. This may be due to several factors:
    - The low resolution of some of the environmental and hydrological data. The use of more site-specific measures, as well as measurement of local hydrological conditions such as velocity, is likely to help resolve these relationships.

    - The assessment of grazing as a binary variable. A more nuanced measure of grazing intensity is likely to have a stronger relationship with riparian vegetation condition. In addition, grazing often has the greatest impact on vegetation cover, rather than extent, with only the latter measure used in this study. Grazing impacts also occur at the sub-site level, so finer scale assessments are required.
    - The distribution of sites used in the study across these gradients. For example, there were few sites with either very low or very high levels of shade, and it is possible that the tolerable threshold for aquatic species' shade tolerance is at a level higher than examined here, such as under very dense willow or forest cover. However, these conditions are uncommon along regulated river reaches in Victoria.
- Carp are also likely to influence the distribution and abundance of aquatic plants. However, Carp are present in most of the sites surveyed, so this study was unable to investigate their effect due to a lack of sites without Carp. Section 3.3 examines the potential direct impacts of Carp on aquatic vegetation through a case study and the use of Carp exclosure plots.

This study provides a valuable contribution towards increasing our understanding of the drivers of aquatic species presence and extent in Victoria's regulated rivers. This is particularly important because our knowledge of aquatic species is generally less than our knowledge of other riparian plants. Management strategies targeted specifically at maintaining and improving aquatic plant condition should consider the particular requirements and tolerances of this group of plants, including the hydraulic and environmental conditions that provide the most suitable habitat. Although hydraulic habitat for aquatic vegetation is optimal in reaches with intermediate levels of flow, environmental flows are likely to have the largest benefits to aquatic plants where they can provide essential baseflows and freshes in drier systems, particularly by reducing the duration of dry periods. However, their effectiveness will also depend on other factors that can limit aquatic plant occurrence and abundance, including high turbidity, livestock grazing, canopy conditions, channel form, and other flow variables.

## 3.3 The impacts of European Carp on aquatic vegetation in a regulated river

KEQs 1: aquatic vegetation, 2: emergent vegetation, 4: recruitment and 5: other factors

This project was conducted as a case study for the effects of Carp on aquatic vegetation. This case study is fully summarised here and is not expanded upon further in the Supplementary Material.

### 3.3.1 Context

European Carp (*Cyprinus carpio*), known as Carp in Australia, are a significant pest of many Australian waterways (Koehn 2004). Carp influence aquatic and emergent vegetation directly because of their feeding method, and indirectly through the alteration of water attributes such as turbidity (e.g. Das et al. 2009, Weber and Brown 2009). It is likely that the presence of Carp in many Victorian waterways is adversely affecting aquatic and emergent vegetation abundance and diversity. Evaluating the effect of Carp on waterway health, particularly vegetation, was identified as a potential KEQ during the development of Stage 6. However, it is difficult to quantify these impacts and estimate the magnitude and rate of aquatic and emergent vegetation recovery and expansion if Carp were removed from these systems. This challenge is particularly difficult because most regulated river systems in Victoria have Carp populations.  Waterfowl herbivory could be another confounding factor. Although waterfowl herbivory may also adversely affect aquatic and emergent vegetation, waterfowl are vectors for the spread of aquatic and emergent plant propagules and may provide population benefits for some of these species (e.g. Raulings et al. 2011).

A recent study in Reedy Lagoon in Gunbower Forest, through The Living Murray initiative, evaluated the effect of Carp exclosures on aquatic vegetation (Bennetts et al. 2018). That study, and a follow-up study in which all Carp were removed from the lagoon, showed strong evidence for large increases in aquatic vegetation cover and richness in the absence of Carp. This indicates that the potential benefits of flow management and environmental flows on aquatic vegetation may be severely compromised where Carp are present. This is critical information for waterway managers who are aiming to improve aquatic vegetation diversity or extent through water management, because the presence of Carp could mean that their objectives are unachievable.

Because of the large impact of Carp in many aquatic systems, the interest in this knowledge by water managers, and the recent investment in understanding the potential impacts of Carp control measures, it was valuable to conduct a case study into the impacts of Carp exclusion in a river system that builds on the work at Reedy Lagoon. In this pilot study we used a set of similar Carp exclosures on the Campaspe River to test the applicability of such a study in a flowing system, as well as getting some preliminary evidence of the potential impacts of Carp (and Carp control) on aquatic and emergent vegetation. This information can be combined with the broader evaluations of vegetation responses in Section 3.2 to provide a quantitative assessment of the impacts of different factors on aquatic and emergent vegetation.

### 3.3.2 Aims and hypotheses

The aim of the study was to seek evidence about the potential direct impact of Carp on aquatic and emergent vegetation, which would allow us to fully understand the potential benefits and limitations of environmental flows in systems occupied by Carp. The potentially confounding effects of waterfowl were considered but evaluating the impacts of waterfowl specifically was outside the scope of the study. The indirect effects of Carp on water quality attributes were not addressed in this study, as these factors could not be controlled by the treatments.

Our study was designed to test the following hypotheses:

- Control plots with either unrestricted Carp and waterfowl access, and exclosures with Carp access and waterfowl exclusion, are likely to have limited growth and establishment of aquatic and emergent vegetation compared to plots that exclude Carp.
- Exclosures with Carp access but waterfowl exclusion will have different responses to control plots with Carp and waterfowl access, because of the different effects of each animal on various plant species.

### 3.3.3 Methods

Eight exclosures with paired unfenced controls were installed in December 2018 along a 200 m section of the Campaspe River at Barnadown, in north-central Victoria (Figure 3.3.1). The site was chosen because it had (a) no livestock access, (b) clear evidence of Carp presence and impacts, and (c) a diversity of vegetation within the river channel and bathymetry.

After we found that waterfowl herbivory was impacting the unfenced controls, the control plots were fenced with modified exclosures containing slots allowing Carp access but restricting waterfowl; these were installed in December 2019. Two control plots could not be fenced because of woody obstructions, so new controls were added for those and were called 'ControlB' exclosures. Exclosures were positioned with one of the corners pointing upstream in the direction of flow to reduce the amount of debris catching on the walls. All exclosures were 2.4 m × 2.4 m in area and 1.2 m high, and were made from the following materials:

- rectangular hollow section (25 × 25 × 1.6 mm) steel frame
- galvanised weld mesh (50 × 50 mm netting)
- 4 steel posts 2.1–2.4 m long, embedded in the corners.

**Figure 3.3.1** Carp and waterfowl (treatment) exclosures and carp only (control) exclosure fences on the Campaspe River.

Surveys were undertaken in December 2018, March 2019, June 2019, December 2019 and April 2020, and will continue in future years.

During each survey, each plot was photographed from fixed photo points at the side and above, and the area and number of patches of each plant species present within the plot were mapped on paper.

The maps were subsequently digitised into polygons (Figure 3.3.2) and the percentage extent of each species in each plot was calculated using *ImageJ* (Schindelin et al. 2012). The total extents were then summed to give a total summed extent across all species.

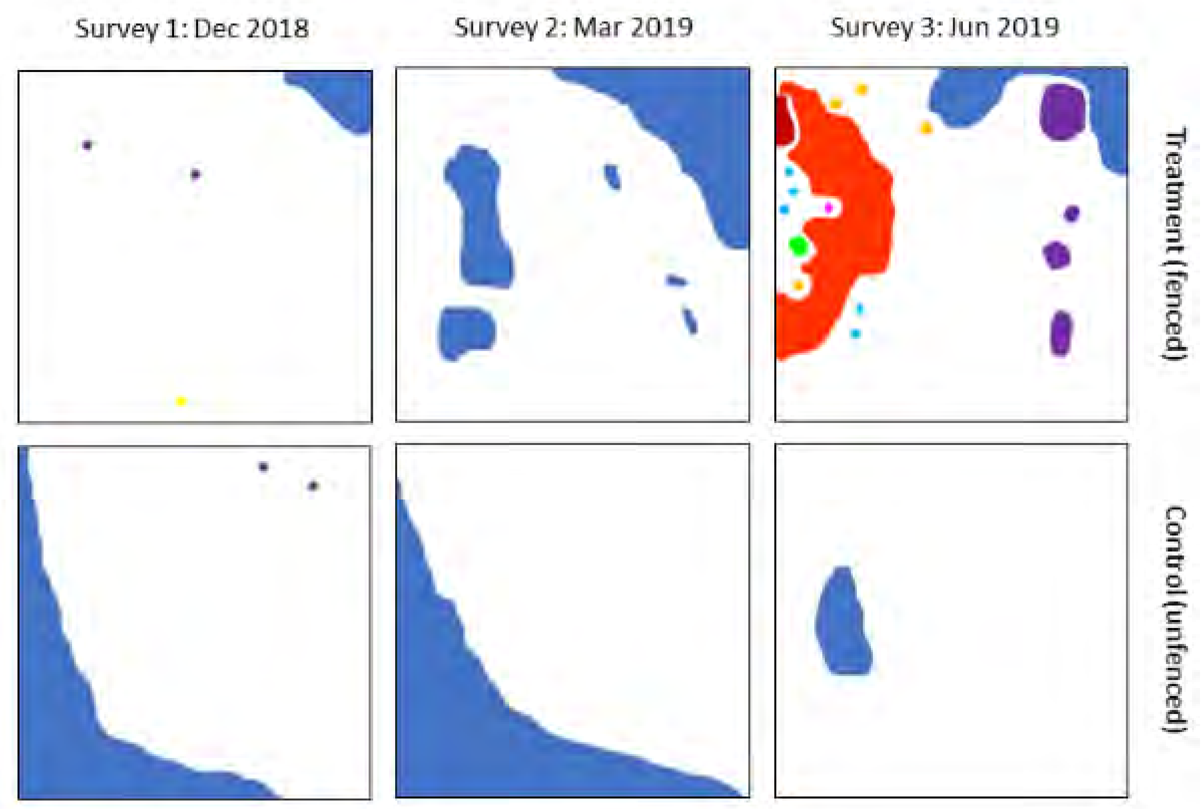



**Figure 3.3.2.** Vegetation monitoring of an exclosure and its paired control plot in the Campaspe River. Each colour represents a different species.

### 3.3.4 Results

There was a large variation in vegetation extent changes between exclosure plots. While there was a trend in some of the exclosures indicating a strong increase in extent and density (i.e. recovery) of vegetation to the exclusion of Carp, other exclosures showed very little response. Density responses were not quantified through surveys but were recorded through photographs. Vegetation trends were clearly influenced by waterfowl herbivory (recorded by field observations) and the variation in initial extent and diversity of species in each exclosure, which confound the responses to Carp exclusion and lead to analytical challenges. The introduction of new exclosures to exclude waterfowl but allow Carp access should overcome this problem, but it is too early to show any trends because of the slow recruitment and growth of many aquatic species. Despite this, the results outlined below indicate that there has been an overall positive change in aquatic and emergent vegetation extent and species richness in response to Carp and waterfowl exclusion. There is also a possibility that the exclosure itself influences the results by changing flow dynamics but this has not appeared to be significant and the installation of control exclosures should mitigate any effects.

*Percentage increase in vegetation extent*

With the exception of Exclosures 5 (deep water/silt substrate) and 8, an increase in vegetation extent was observed in all treatment exclosures in the first year to December 2019 in comparison to controls (Figure 3.3.3). After waterfowl exclusion from controls, the patterns were similar apart from a large increase in the control plot eight, with the mass recruitment of plants on the exposed soils. In general, shallow exclosures showed a trend for a greater percentage increase than moderate depth exclosures, irrespective of substrate type, i.e. shallow exclosures with both silt (exclosure two, Figure 3.3.4) and gravel (exclosure seven, Figure 3.3.5) substrates. The largest changes were observed in extremely shallow plots where the soil surface was periodically exposed (exclosure two treatment, and exclosure eight, control and treatment).

*Vallisneria australis* was the most abundant species but was also heavily impacted by waterfowl grazing that impacted vegetation extent and density. Although the vegetation extent for exclosure three (both treatment and control) remained relatively constant, there was an observable increase in the density of vegetation within the exclosure plot (Figure 3.3.6) that was not captured by the data that only recorded extent. There was little to no observed increase in vegetation extent for the controls, with exclosures one, two, three, four, six and seven remaining relatively constant. Control exclosure eight was the only control to have an increase in vegetation extent, which was also the shallowest and had the most exposed soil.

*Species richness*

Twenty-four unique species or taxa were recorded within the control and exclosure plots on at least one occasion during the study. These were dominated by fringing (littoral) and emergent species that colonise the fringing areas of the bank toe, but also included four aquatic (submerged and floating) species: Water ribbons (*Cycnogeton procerum)*, Millfoil (*Myriophyllum* sp.), Curly pondweed (*Potamogeton crispus)*, Pondweed (*Potamogeton sulcatus)*, Hornwort (*Ceratophyllum* sp.), alga (*Characeae* sp.)  and Eel grass (*Vallisneria australis*). No species considered fully terrestrial was recorded in any plot during the study.

All treatment exclosures showed an increase in species richness in the first year to December 2019 with Carp and waterfowl access to controls (Figure 3.3.3). After waterfowl exclusion from controls, richness only increased in newly fenced controls in plots two and eight, i.e. the plots with the most exposed soil. In general, treatment exclosures that were shallow showed a greater increase in species richness than moderate to deep exclosures, with the deep exclosure showing no increase in species richness. No more than five plant recruits were recorded in any plot that had no soil exposure, compared to hundreds of seedlings in exposed plots. Although plant recruitment in exposed soil was dominated by fringing and emergent species, aquatic species were recorded germinating in exposed soil and shallow water within the plots.

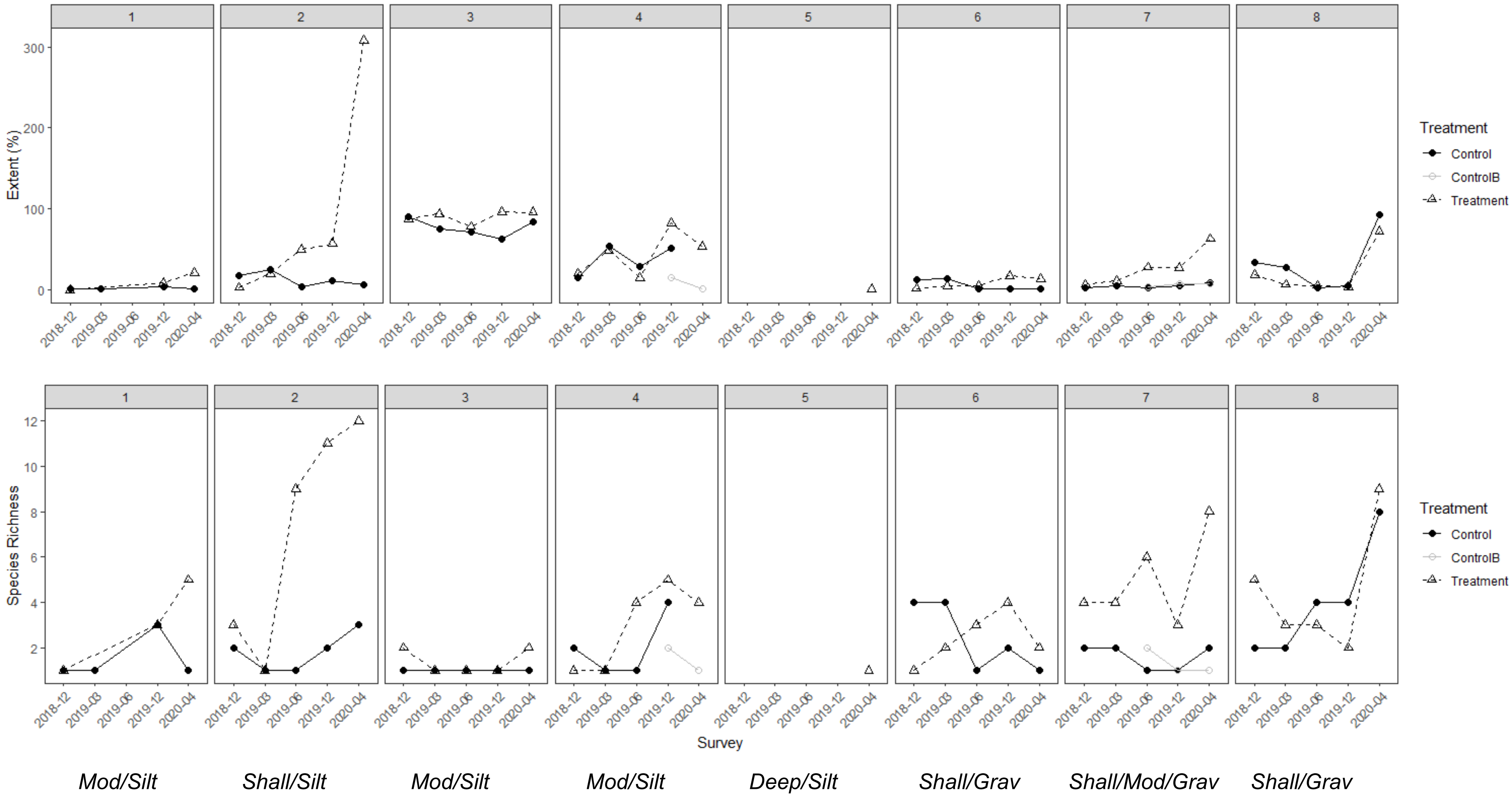



**Figure 3.3.3** Summed vegetation extent (%) for all species and the total species richness within control and exclosure plots surveyed. Exclosure basic characters (apply to treatment and controls unless stated). 1. Depth moderate (15–30 cm), substrate silt; 2. Depth shallow (< 15 cm), substrate silt; 3. Depth moderate (15–30 cm), substrate silt; 4. Depth moderate (15–30 cm), substrate silt; 5. Depth deep (> 30 cm), substrate silt; 6. Depth shallow (< 15 cm), substrate gravel; 7. Depth shallow (< 15 cm), substrate gravel (Control7B is moderate 15–30 cm deep); 8. Depth shallow (< 15 cm), substrate gravel.

**Figure 3.3.4** Exclosure 2 (the shallowest exclosure), showing fringing and aquatic species colonising the seasonally and shallowly inundated depths. First photo June 2019, second in December 2019, third and fourth photos in May 2020.

**Figure 3.3.5** Exclosure 7 in December 2018 (left) and May 2020 (right), showing the expansion of emergent *Schoenoplectus tabernaemontani* and *Cycnogeton procerum*.

**Figure 3.3.6** Exclosure 3, a deeper plot dominated by *Vallisneria australis*, showing a dense cover inside the exclosure (right) and very little cover outside (left) in June 2019 and again in December 2019.

### 3.3.5 Conclusions and implications for flow management

The following general trends were observed:

- A year after the treatments were applied, exclosures with no Carp or waterfowl access generally had greater vegetation extent and richness than controls.
- The vegetation responses following waterfowl exclusion were influenced by the season and the short duration, but the control plot with the most exposed soil (Exclosure 8) had a substantial increase in vegetation extent and richness.

The following trends in the rate of vegetation recovery were also observed:

- The initial extent of vegetation present affected the rate of vegetation recovery and expansion, but the patterns were inconsistent. Many species were recruited only at sites where the soil was exposed, so they were only present in deeper plots if they were present at the start of the study.
- Control plots with *V. australis* showed large declines in density (Figure 3.3.6), although this impact could be attributed to both Carp and waterfowl.
- The depth of water influences species composition; shallower exclosures were likely to have greater species richness than deeper exclosures. Vegetation extent was less influenced by water depth, but long-term trends may see changes in slower-growing plants. Deeper water does not necessarily prevent the growth of aquatic vegetation, but it is likely to be more difficult and rates of recovery and colonisation are likely to be slower.

Many additional factors not evaluated in this study, such as flow rate, are also likely to impact recovery rates, as slower water is more conducive to rapid recovery than faster water. This case study suggests that responses were not dramatically different between different substrate types, but further information is needed to clarify this effect.

Although this study involved a small number of samples and the findings may not be representative of other locations, it nevertheless provides valuable insights into this important problem, both from a methodological and outcomes perspective. The implications for waterway management are that the Campaspe River, and probably other waterways, would be expected to have an increased local extent and diversity of vegetation within the river channel if Carp were reduced or eliminated. Flow management to increase soil exposure within the river channel during natural low-flow periods is also likely to have significant impacts on aquatic vegetation recruitment. However, more information regarding the vegetation responses to different Carp densities and the interaction with waterfowl is needed to confidently attribute causes and magnitudes of responses.

## 3.4 Environmental flows help structure fish and vegetation communities in a regulated intermittent stream system in a semi-arid landscape

KEQs 1, 2 & 3: aquatic, emergent and fringing vegetation

This chapter is a summary of the following co-authored project, presented in Supplementary Material 12.

**Supplementary Material 12**: Jones, C.S., Sharley, J., Ayres, R.M., Raymond, S., Hackett, G., Just, K., Mole, B., Vivian, L., Fletcher, G. and Tonkin, Z. (2020). Environmental flows help structure fish and vegetation communities in a regulated semi-arid intermittent stream system. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 3.4.1 Context

Intermittent streams are dynamic systems in which physical and biological processes depend on the degree of flow intermittency. Water management such as river regulation and extraction can alter intermittency by making the flow regime more permanent or even more intermittent, and this affects taxa composition and interactions. Environmental flows are increasingly used to preserve ecological values, but evidence for the outcomes from these actions in intermittent systems is limited. The management of regulated intermittent streams requires an understanding of the role of the flow regime in shaping species assemblages as a result of species' traits that determine lifespan, reproduction and dispersal potential. There are many existing ecological models that describe community assemblage patterns in relation to disturbance or resources, such as the intermediate disturbance hypothesis (Connell 1978) and *r*- and *K*-selection (Macarthur and Wilson 1967). This understanding should also consider interactions or dependencies between taxa. These interactions are often overlooked but are important; for example, vegetation providing critical breeding habitat for fish, frogs and invertebrates.

To address the need for evaluating interactions between vegetation and fish and understanding the role of river regulation and environmental flows in naturally intermittent streams, we conducted a case study that paired data collection of vegetation and freshwater fish in a subset of sites. This approach enabled us to investigate an increased level of ecological complexity in flow monitoring research while directly addressing the program KEQs. The study will also enable us to integrate fish and vegetation monitoring in future research.

The study area was five hydrologically distinct reaches spanning three regulated tributaries of the Wimmera River. Each of these waterways is naturally intermittent, but flow regulation and, more recently, environmental water delivery, has created a series of novel regimes on a spectrum of strong intermittence to semi-permanence. These waterways historically supported a unique and diverse assemblage of species that have been greatly restricted since European occupation. These include the native River Blackfish (*Gadopsis marmoratus*) and Southern Pygmy Perch (*Nannoperca australis*), both in decline through much of their former range; and the critically endangered Wimmera bottlebrush (*Callistemon wimmerensis*) that is restricted to riparian channels and floodplains.

### 3.4.2 Aims and hypotheses

We predicted that different categories of recent intermittence — near-perennial (few flow gaps), short intermittence (brief gaps in flow) and long intermittence (long gaps in flow) (Table 3.4.1) — would result in different fish and vegetation species communities, based on various models and assumptions about community structure and processes in relation to flow alteration. For both fish and vegetation, we hypothesised the following:

- More perennial reaches, maintained in recent times by environmental water, will have a greater relative abundance and broader distribution of fish species that have a shorter recruitment window and are longer-lived compared to intermittent reaches. The same would apply for longer-lived vegetation species. These dominant longer-lived species are often relatively large.
- Reaches with short intermittence, which have also relied on environmental water to provide some connectivity and maintain refugia, will favour fauna that are shorter-lived, have a protracted reproductive window, or have a high tolerance to reduced water levels and adverse water quality, particularly high temperature and low dissolved oxygen. Aquatic vegetation will be spatially patchy with pools and lower lying areas having higher cover, but mature emergent and fringing species will persist throughout.
- Reaches with long intermittence that receive little environmental water will have a low relative abundance and narrow distribution of all fish and aquatic plant species because of limitations to colonisation and survival of mature plants and new recruits. Fringing and emergent plant cover will be restricted to large mature plants that can access deeper soil moisture reserves and tolerate dry periods, as well as ephemeral species in wetter years.

We discuss our finding in relation to the role of river regulation and more recently, environmental flow delivery aimed at restoring the fish and vegetation community structure in intermittent stream ecosystems. These findings relate to assessments of understanding fish populations in regulated Victorian waterways (such as Section 2.6) and directly to vegetation KEQs 1-3 (primarily aquatic species). Based on our findings, we construct a conceptual model of the response of fish and vegetation abundances in intermittent streams with regulated flows and discuss how we expect this to change into the future if the current management regime is maintained and under climate change.

### 3.4.3 Methods

The Wimmera River catchment has been extensively modified from its historical state and is considered one of the most highly regulated and stressed river systems in Victoria. Regulation of waterways in this region began in the 1860s, when 17 500km of earthen channels were constructed to create the Wimmera–Mallee channel system to harvest and divert water from rivers and creeks. The Wimmera–Mallee Pipeline, completed in 2010, replaced these channels to save water, but in doing so reduced river flows in the system in comparison to the pre-2000 conditions. The timing of the construction and operation of the pipeline coincided with the end of the millennium drought, which dried much of the study region, as well as the commencement of environmental water allocation and delivery in the system.

The study area encompasses the MacKenzie River, Burnt Creek and Mount William Creek, which are three tributaries of the Wimmera River (Figure 3.4.1). Within these tributaries we studied five distinct reaches, differentiated by flow regulation regimes and infrastructure (Table 3.4.1). These streams are naturally intermittent, with flow commonly ceasing in summer and autumn. During no-flow periods, water refuges are available in deeper pools within each reach, but their size, depth, and longevity are highly variable.

Fish were surveyed at five to eight sites per reach using single-pass electrofishing. Backpack electrofishing (Smith-Root LR20B) was used at MacKenzie River and Burnt Creek, and bank-mounted electrofishing (Smith-Root 7.5 Kva) was used at Mount William Creek to maintain sampling efficiency because of the elevated electrical conductivity in the reach in comparison to the other reaches. Surveys were undertaken during spring 2017 and autumn 2018 to assess species abundance and richness, community composition and recruitment following the spring and summer reproductive period.

The distribution of understory riparian vegetation species was mapped at 12 sites, including at least two sites per study reach, and in each case corresponding with a fish survey site. Vegetation was mapped on two occasions in spring 2017 and autumn 2018 to detect seasonal or transient species, but data were subsequently merged because of a lack of variation between sampling periods. Vegetation data collected during surveys included polygon data for patches of individuals and point location data for one or a few individuals. All riparian species were mapped and then grouped into three categories, based on a gradient of water dependence: emergent, fringing and terrestrial (see Section 3.1). Flow regime classifications were assigned to each reach (Table 3.4.1).

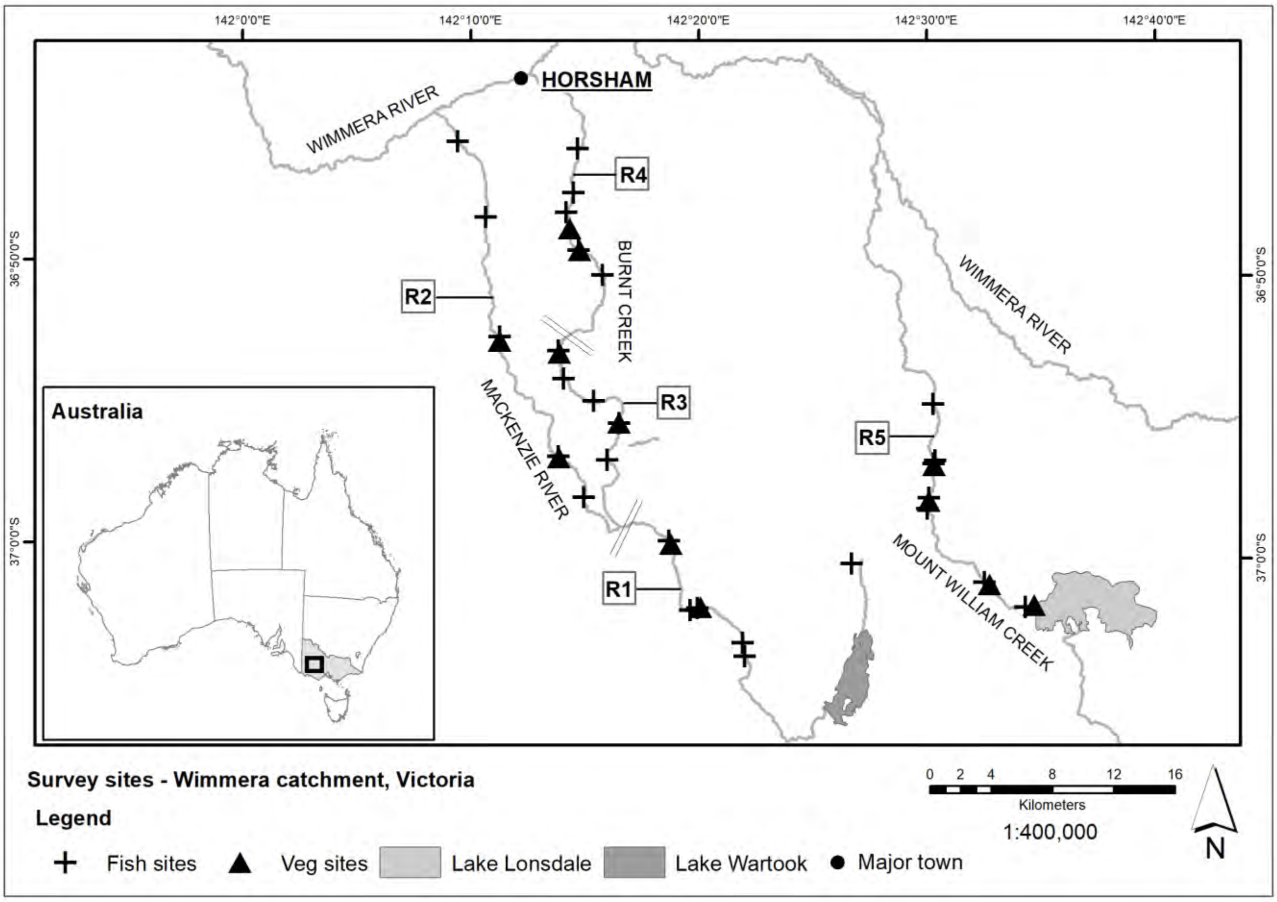



**Figure 3.4.1** Map of the study area in the Wimmera river catchment, including the five study reaches (R1–R5) and the fish and vegetation survey sites.

**Table 3.4.1** Description of five study reaches, including the current flow regime (regulated with environmental water delivery), their flow regime classification and a site image typifying the reach. All photos taken in April 2018.

| Reac h | Waterway | Present regime | Flow regime classification | |
|---|---|---|---|---|
| R1 | MacKenzie River (upper) | Relatively stable baseflows throughout the year with small winter/spring freshes. Flows maintained largely by environmental water. | Perennial |  |
| R2 | MacKenzie River (lower) | Reduced intermittence with small winter/spring freshes and low summer baseflows. Refugia maintained by environmental water. | Short intermittence |  |
| R3 | Burnt Creek (upper) | Relatively stable baseflows throughout the year with small winter/spring freshes. Flows maintained largely by environmental water. | Perennial |  |
| R4 | Burnt Creek (lower) | Intermittent (dry/wet) with very low winter/spring freshes. Little to no environmental water. | Long intermittence |  |
| R5 | Mt William Creek | Reduced intermittence with small winter/spring freshes and low summer baseflows. Refugia maintained by environmental water. | Short intermittence |  |

## 3.4.4 Results

- Fish abundance and vegetation extent varied between reaches and were positively correlated with reach discharge. In general, the two most perennial reaches (reaches 1 and 3; Table 3.4.1) had the highest abundance of fish and aquatic vegetation extent (Figure 3.4.2). The abundance of fish in these reaches also increased from spring to autumn, a reflection of successful spawning and recruitment throughout spring and summer. Fish abundance and aquatic vegetation extent were lowest in the long intermittence reach (reach 4) which had the lowest discharge and longest cease to flow periods. This was the only reach where fish abundance declined from spring to autumn, indicating poor survival during the extended summer cease to flow period. Riparian vegetation within the long intermittence reach was dominated by perennial emergent species that can tolerate extended dry periods such as *Carex tereticaulis* (Poong'ort) and *Juncus amabilis* (Gentle Rush).
- Species richness for both fish and vegetation was poorly correlated with flow classification (Figure 3.4.2). Fish species richness was in general, similar across the reaches although the greatest value, which included a diverse spread of native and exotic species, was detected in the spring survey of the driest reach (4). Aquatic vegetation species richness was very low in general, and the majority of all instream vegetation extent consisted of Water Ribbons (*Cycnogeton procerum*). Emergent species had the greatest richness in perennial reaches, but the pattern was inconsistent across flow classifications. Fringing species richness was highest in reach 2, where short-intermittence flows are carefully managed to support riparian species.

- While fish and aquatic vegetation population attributes were broadly correlated with reach discharge, interactions between fish and vegetation and season were also observed (Figure 3.4.3). The abundances of fish and aquatic vegetation were positively correlated ($R^2 = 0.44$, $p < 0.002$) and fish abundance was lower in spring (Figure 3.4.3a). Fish abundance was poorly correlated ($R^2 = 0.02$, $p > 0.2$) with emergent vegetation (Figure 3.4.3b) and fringing vegetation ($R^2 = –0.05$, $p > 0.7$) (Figure 3.4.3c).
- The fish community composition differed across the reaches. For species displaying more equilibrium type life-history strategies, such as Southern Pygmy Perch and River Blackfish, abundance and distribution (proportion of sites detected) were greatest in reaches with perennial regimes (reaches 1 and 3) and one of the short intermittence regimes (reach 2). As hypothesised, the abundance and distribution of species with opportunistic type life-history strategies (Australian Smelt, Flat-headed Gudgeon and Carp Gudgeon) was highest in reach 5 (short intermittence). There were no distinct trends in the abundance or distribution of exotic species between reaches. Aquatic vegetation community composition was dominated by a single species, Water Ribbons in all reaches, and was only different in the perennial reaches 1, 3 and the long-intermittence reach 4 because of the presence of Amphibious Water-milfoil (*Myriophyllum simulans*), Small-fruit Pondweed (*Potamogeton cheesemanii*) and Austral Brooklime (*Gratiola peruviana*). Emergent vegetation was greater in richness than aquatics and was highest in the perennial reaches, while fringing species richness was highest in the short-intermittence reach 2 (see Supplementary Material 12 for further details).
- 

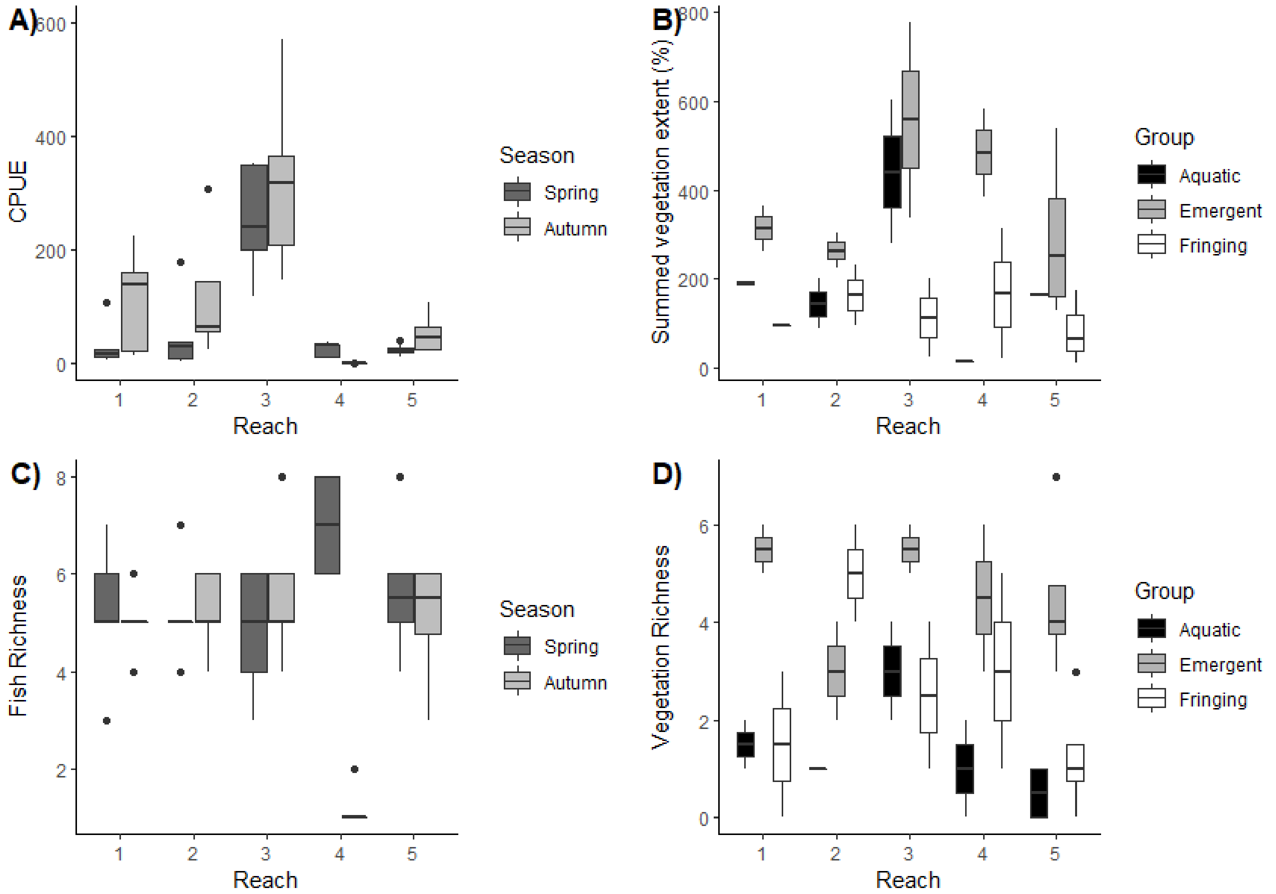



**Figure 3.4.2** Box plots of fish and vegetation abundance and richness per reach: (A) native fish abundance (CPUE): (B) vegetation abundance (summed vegetation extent %); (C) all fish species richness; (D) vegetation richness. Vegetation measures are indicated per group (aquatic, emergent or fringing) across both seasons given little change between sampling events. Error bars for fish indicate the 95% confidence intervals across sites within reaches. Error bars are not displayed for vegetation because only two values contribute to each bar.

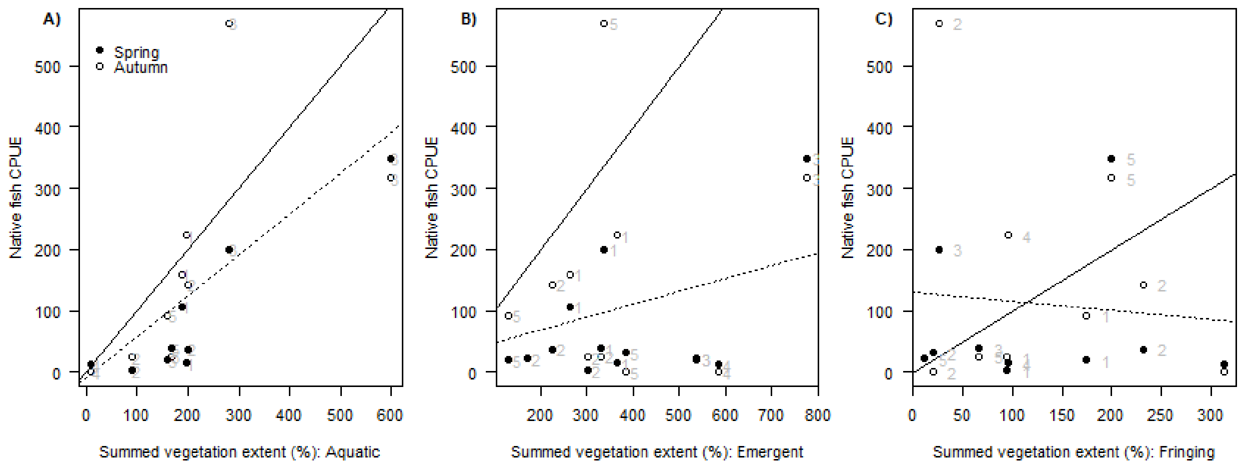



**Figure 3.4.3** Pairwise linear regressions for the abundances of native fish (fish native CPUE) and vegetation (summed vegetation extent%) for three vegetation groups: (A) aquatic, (B) emergent, and (C) fringing. Each point represents a site surveyed in spring (closed circles) or autumn (open circles). Numbers indicate the corresponding reach. Dotted lines show the linear regression for the points, solid lines indicate a 1:1 relationship.

### 3.4.5 Conclusions and implications for flow management

Our study has shown that alterations to stream intermittency, either through regulation or environmental water delivery, can have a strong influence on fish and vegetation communities. Cleary distinct population patterns were observed between the five reaches:

- Fish surveys within these systems revealed that perennial systems were dominated by larger or longer-lived species with short reproductive periods. Vegetation extent was much greater in perennial systems, although not necessarily more diverse.
- Short-intermittence systems supported a higher richness of long-lived and short-lived fish species, which had highly variable abundances and a wide range of preferred habitat conditions because the conditions are not optimal for any to dominate for long periods. Short-intermittence systems did not have greater aquatic plant richness, but the lower banks had a greater total plant diversity because aquatic and emergent species co-occurred.
- The long-intermittence system had a very low abundance and distribution of fish and aquatic vegetation. Fish species were mainly introduced species, and vegetation was dominated by perennial, deep-rooted, emergent and fringing native species that can persist in extended dry conditions (see Supplementary Material 12).

Based on these results, we constructed a simple conceptual model of taxon responses to managed flows in intermittent systems that can guide management of environmental flows to achieve desired ecological outcomes (Figure 3.4.4). The systems in our study are at various stages of progression in these general models, as some processes take many years to establish after the end of the drought; for example, the as re-establishment of long-lived fish and vegetation species in the more perennial reaches, and the re-establishment of aquatic, emergent and fringing plants in short-intermittence systems that are sustained by careful environmental flow delivery. This process has been particularly slow in the Wimmera because of continued periodic drought conditions since 2010. Long intermittence can cause declines in abundance from wetter conditions until a stable state is reached, or in the case of the study sites, they can increase from drought to stability.

The correlations between stream discharge, fish abundance and aquatic vegetation also suggest dependencies between taxa. This appeared particularly evident for Southern Pygmy Perch and the aquatic plants Water Milfoil and Austral Brooklime, which have very different physical form from the dominant Water Ribbons and may provide critical habitat for spawning, feeding or refuge from predation.

Since the construction and operation of the Wimmera–Mallee Pipeline the delivery of environmental flows has had a strong influence on native fish communities in the MacKenzie River, upper Burnt Creek and upper reaches of the Mount William Creek. Environmental flows have enhanced habitat availability and connectivity in the upper MacKenzie River and Burnt Creek, resulting in the establishment of an abundant and wide distribution of fish species such as Southern Pygmy Perch and an increase in the extent of aquatic vegetation. Environmental flows have also been crucial in maintaining a diverse fish community and aquatic vegetation extent in the short-intermittence reaches of the lower MacKenzie and Mount William Creek, by providing opportunities for the dispersal of recruits and propagules during fresh events, maintaining soil moisture for aquatic plant survival, and providing critical refuge pools during cease to flow periods.

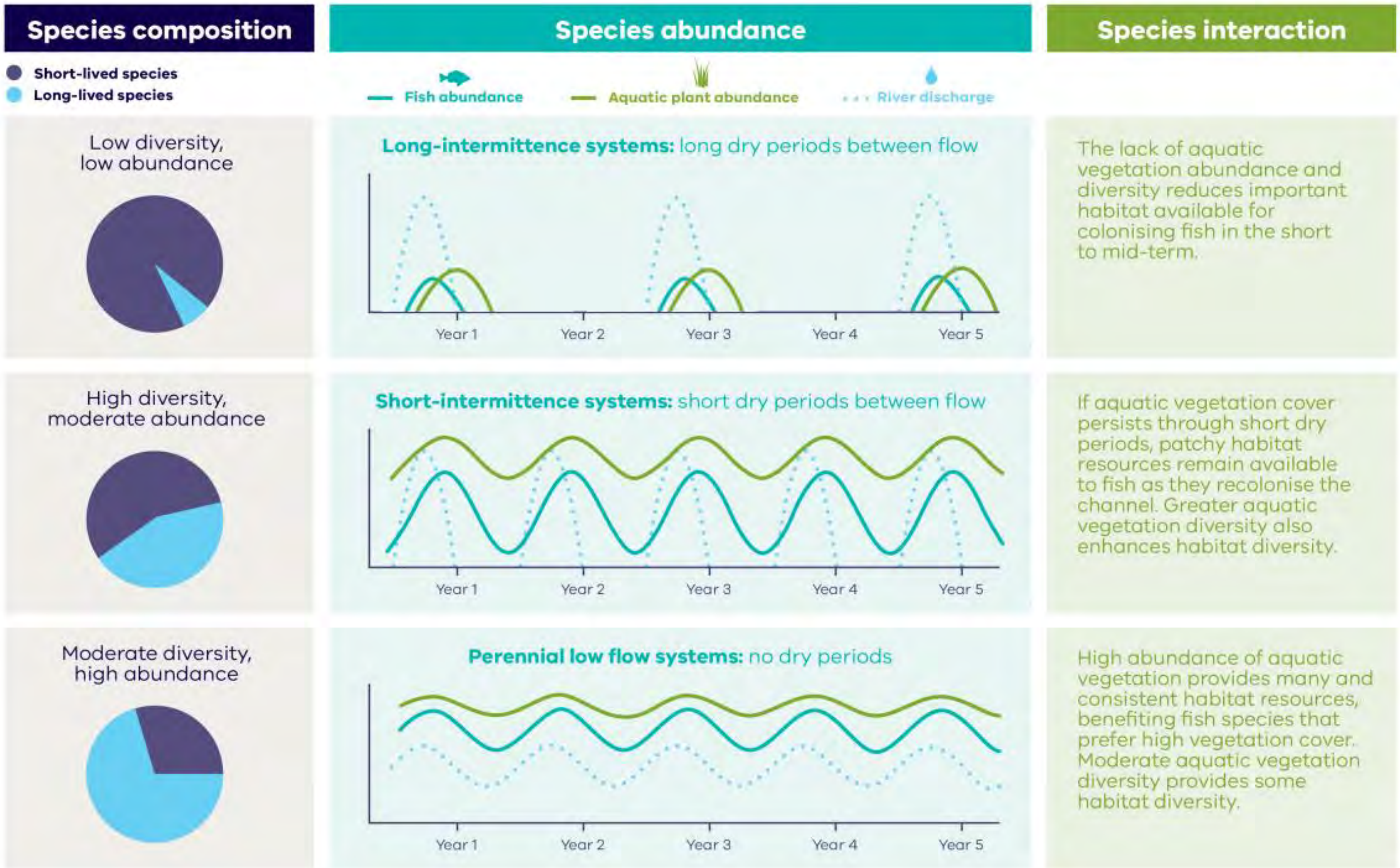



**Figure 3.4.4. Conceptual model showing the role of flow intermittence in governing the abundance and composition of aquatic vegetation and fish communities.**

## 3.5 Evaluating the influence of environmental flows on emergent, fringing and terrestrial vegetation in regulated Victorian rivers

KEQs 1–5: vegetation, recruitment and other factors

This work is a summary of a co-authored paper currently in preparation for submission, presented in Supplementary Material 13.

**Supplementary Material 13**: Jones, C.S., Vivian, L., Mole, B., Thomas, F.M., Backstrom, A., Just, K., Gould, E., Caffrey, L., and Brooks, J. (2020). Evaluating the influence of environmental flows on vegetation in regulated rivers. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 3.5.1 Context

Riparian vegetation is severely degraded in many waterways globally. Vegetation clearing, livestock grazing, pollution, exotic species (flora and fauna) and the alteration of natural flow regimes are some of the most severe threats to this vegetation (Palmer and Ruhi 2019). Environmental flows aim to mitigate or reverse the degradation caused by many of these threats, particularly river regulation. In some cases, environmental flows may be able to restore vegetation condition in degraded waterways, but in some cases environmental flow management may be insufficient.

Two of the most commonly delivered environmental flow components that aim to benefit riparian vegetation are baseflows (to sustain water levels and quality) and spring freshes (to replicate natural rainfall peak discharge events). Both of these flow components are often reduced or prevented by regulating structures such as reservoirs. Evaluating the benefits of these flow components (among others) is a high priority for waterway managers who need to determine the value from these flows and how to manipulate their delivery to maximise the value of environmental water entitlements.

Baseflows and spring freshes are intended to provide benefits to various groups of riparian vegetation, particularly emergent and fringing species. Native emergent and fringing species compete directly with many exotic riparian and terrestrial species for resources. Because of this, native emergent and fringing species are major beneficiaries of environmental flow management as well as key indicator species to evaluate flow effectiveness.

Evaluating the effects of environmental flows on waterways is difficult because of the highly dynamic and site-specific nature of these responses (Poff and Zimmerman 2010). There is a need to evaluate the isolated impacts of specific flow events (short-term responses) as well as the impacts of successive flows, environmental or otherwise, within a broader flow regime (medium to long-term responses). This evaluation also needs to consider other major drivers of vegetation, such as rainfall, other flow attributes, livestock grazing, soil properties, exotic species and previous disturbance (Poff and Zimmerman 2010).

In south-eastern Australia, river regulation (including water extraction), livestock grazing, and exotic species continue to have serious negative impacts on all major waterways, despite major government investment into waterway management. While some valuable information has been acquired for some locations, site-specificity makes prediction and extrapolation very difficult within and between waterways. Therefore, large-scale data showing vegetation responses within and between waterways is important for a state-wide understanding and to enable sufficient understanding to inform management in all regulated waterways.

### 3.5.2 Aims and hypotheses

In this study, we conducted a large-scale, multi-year vegetation survey to evaluate the effects of key environmental flow components on emergent and fringing vegetation. Additionally, we sought to test how additional factors such as livestock grazing or exotic species influenced native vegetation responses to flows. Specifically, we aimed to:

- describe detailed site-specific vegetation trends associated with season, flow, rainfall and other factors, such as livestock grazing and exotic vegetation across rivers in Victoria
- quantify short and medium-term vegetation responses to individual flow events and regimes
- provide clear implications and guidance for waterway management based on findings.

Our hypotheses were as follows:

- Emergent and fringing vegetation have higher cover on bank elevations where bank flows and spring freshes reached.
- Terrestrial species have reduced cover on bank elevations where baseflow and spring freshes reached.
- Exotic riparian species and native riparian species directly compete for resources and are negatively correlated, and benefits of environmental flows are prevented or reduced by high exotic riparian species cover.
- Livestock grazing reduces vegetation cover and prevents or reduces benefits of environmental water.

### 3.5.3 Methods

*Study locations across a rainfall and temperature gradient*

We selected seven major river systems in Victoria and surveyed 44 sites across more than 20 distinct river reaches repeatedly over one to four seasons from 2016 to 2019 (Figure 3.5.1). Surveys were conducted before and after environmental flow events in spring, summer and autumn and were timed depending on specific flow deliveries within each system (Figure 3.5.2). Each site was surveyed 3 to 10 times, totalling 222 site surveys.

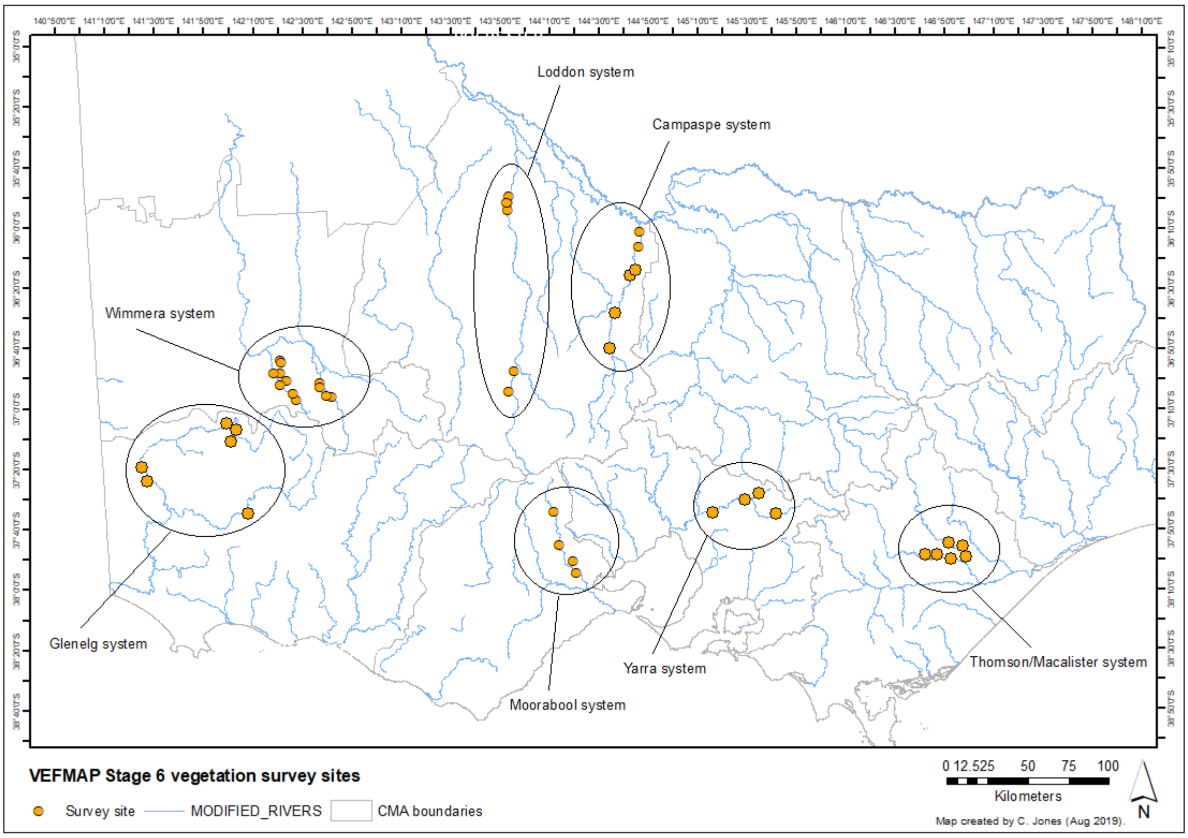



Figure 3.5.1 Study sites for evaluating the influence of environmental flows on emergent, fringing and terrestrial vegetation in regulated Victorian rivers.

The 44 sites surveyed span a latitude of approximately S38°10′S to 35°50′S across Victoria and a longitude of 141°20′E to 147°10′E (Figure 3.5.1), across a wide temperature and rainfall gradient. The highest rainfall and most temperate sites occur in the South-Eastern region captured by the Thompson/Macalister and Yarra systems. The lowest rainfall and hottest sites were in the Loddon and Wimmera systems. Figure 3.5.2 shows examples of daily rainfall and river flows for high and low rainfall sites, and how before and after sampling was used to capture the effect of specific environmental flow events.

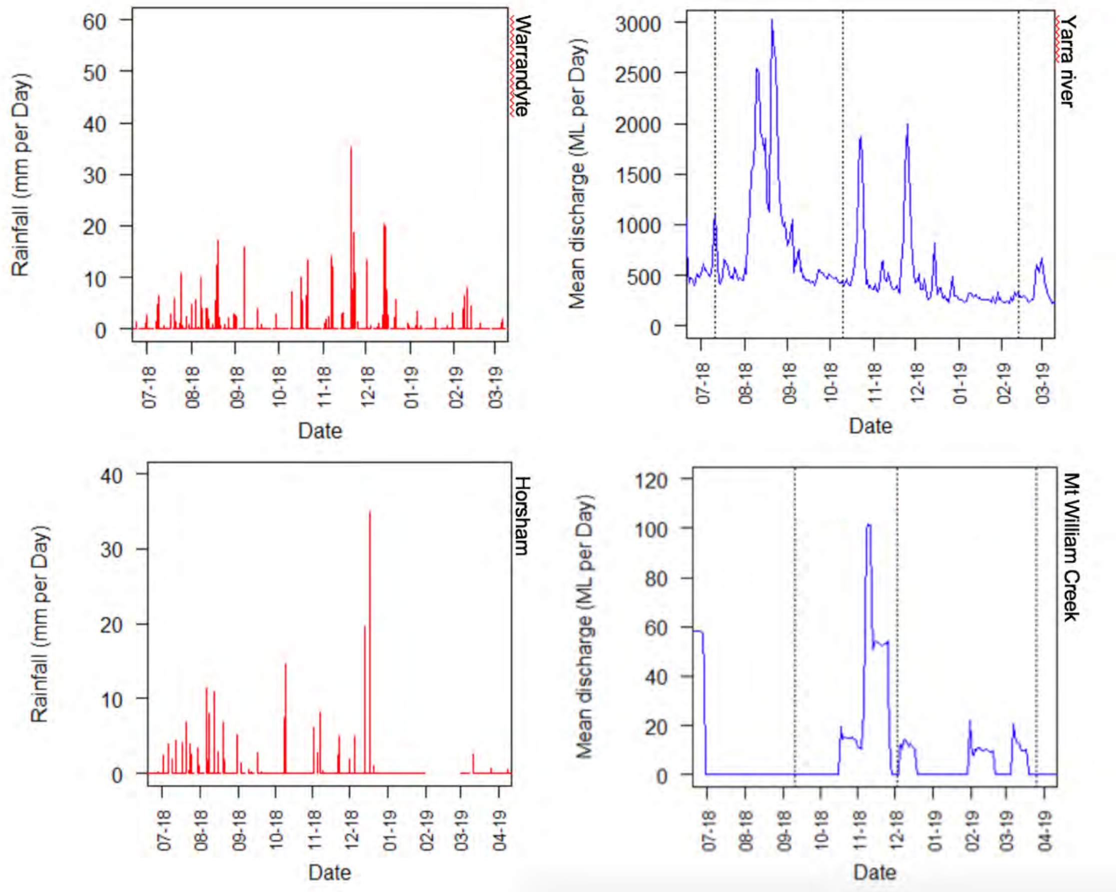



**Figure 3.5.2** Daily recorded rainfall at relatively high rainfall sites near Warrandyte and associated river flow and sampling on the Yarra River for 2018/2019. Daily recorded rainfall at relatively low rainfall sites near Horsham in the Wimmera and associated river flow and sampling on Mt William Creek for 2018/2019. Black dotted lines indicate VEFMAP sampling periods.

*Vegetation sampling*

The vegetation survey approach is described in detail in DELWP (2017a). In each survey, 5 to 10 permanent transects were established perpendicularly to the flow of the river, from the low-flow water margin to a designated location up the bank, depending on the site (Figure 3.5.3). On each transect, a series of sub-transects were positioned every metre, perpendicular to the transect (parallel to the waterway). Along each sub-transect, point quadrat samples were taken at 10 cm intervals to record both the substrate type (water, bare ground, log, rock, litter) and the species identity of any plant that occupied the vertical point quadrat space up to 5 m from the ground. Species recorded were classified by origin (native or exotic). A full list of species and their classifications is provided in Appendix 1.

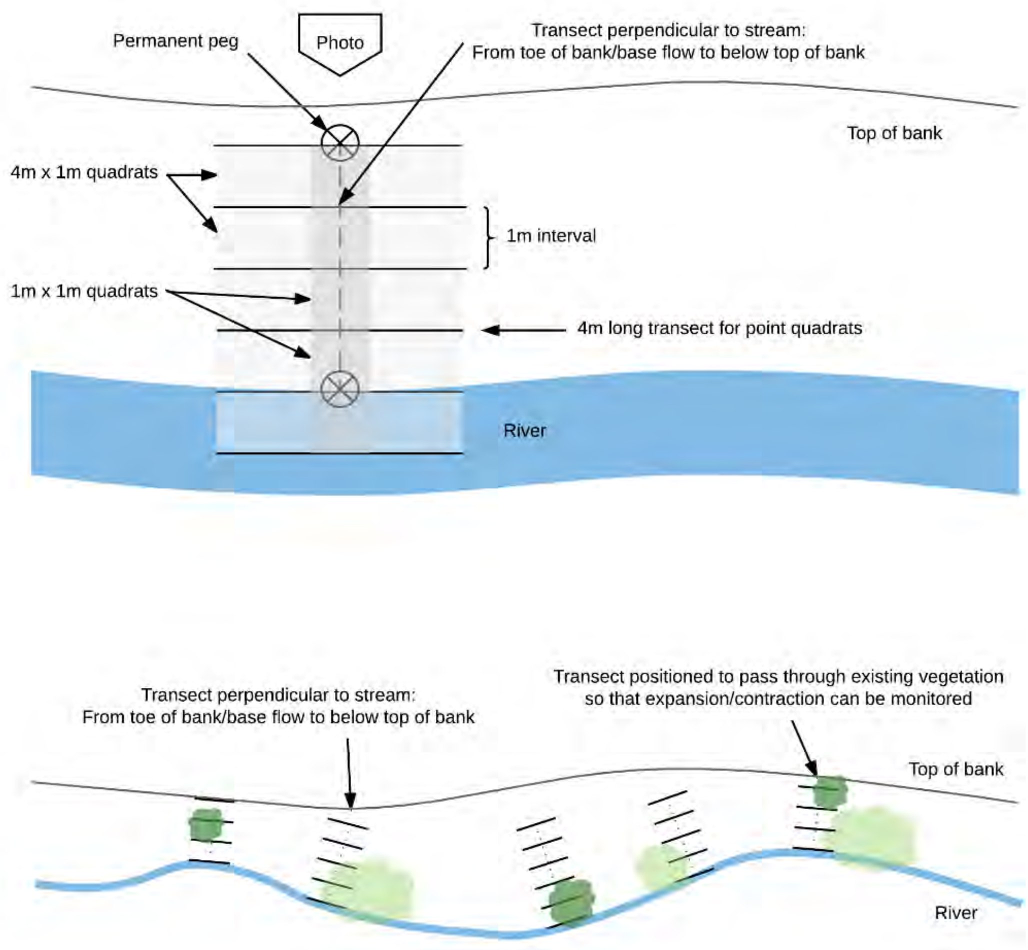



**Figure 3.5.3** Vegetation sampling layout used in the VEFMAP. Source: DELWP 2017a

*Livestock grazing*

Livestock grazing was recorded as present (*n* = 9) or absent (*n* = 34) at each site. The identity of the livestock (sheep or cattle) was recorded but no data on stocking densities or durations were available. At a subset of the grazed sites, grazing exclosures were installed to evaluate the effects of grazing removal. A detailed summary of these exclosures is provided in Section 3.9. The ungrazed sites and exclosures within grazed sites were aggregated for this study.

*Stream flow data*

Hydrological surveys provided information about the flow height (elevation up the bank) and the duration of that height change. This information was used to evaluate vegetation responses to flows at different locations up the bank, and to compare positions that did or did not get inundated, how deeply they were inundated and for how long. Continuous stream flow elevation was used to develop hydrology metrics for individual flow events or regimes. Flow elevations for each site were generated by various means, depending on the availability of data, which was processed by Streamology. Data sources used included:

- VEFMAP collected data, collected from Troll loggers for short periods of time (up to two years between 2017 and 2020). Some loggers were levelled into AHD, and these data were provided and used where possible.
- Water Measurement Information System (WMIS) data: Hydrographic data collected under the DELWP Water Monitoring Partnership, accessible via the WMIS website (http://data.water.vic.gov.au/).
- Water Data Online: The Bureau of Meteorology's (BOM) web portal that displays all hydrographic site data provided to the BOM (http://www.bom.gov.au/waterdata/).
- Melbourne Water website: The Melbourne Water website displays and allows extraction of hydrographic data collected at sites managed by Melbourne Water (https://www.melbournewater.com.au/water/rainfall-and-river-levels#/).

- Data held by State Rivers and Waterways (SRW): Hydrographic data collected by SRW were provided by Ventia after approval from SRW.
- AHD and Zero Gauge Height (ZGH) values. The AHD dataset collected from a DELWP project to survey partnership sites was used. This data set was provided by Ventia. AHD values for the Melbourne Water sites were provided by Phillip Dorward of Melbourne Water. AHD values for VEFMAP loggers were provided by Chris Jones.

For each site, the available data were collated and then allocated a data tier, reflecting its relative quality. Sites that were correlated were done so by Ventia following the methodology described in Supplementary Material 19. An effort was made to collate the highest quality data for all sites using existing data sets. Although the quality of the existing data sets is reliable, fully quantified uncertainties were not possible because they were collected and quality-checked by a third party.

*Data analysis*

Data were analysed for target species groups to determine the effect of spring freshes on vegetation within different bank elevation zones. Bank zones were defined by bank elevation relative to baseflow and spring fresh levels, as follows:

- Zone 1: Below baseflow levels
- Zone 2: Between baseflow and spring fresh levels
- Zone 3: Above spring fresh levels.

Our analysis calculated the effect of spring freshes on a total count of plant hits per sub-transect within each zone in the survey periods. All data compilation and analyses were conducted using R version 3.6.0 (R Core Team, 2019) through R-Studio (RStudio Team 2015).

Generalised additive mixed models (GAMM) with a negative binomial family specification were used. A standard value of 1 was added to all datapoints to enable fitting of 0 values. Survey period (before and after), bank elevation zone (1–3) and treatment period (years 1, 2 and 3 of the study), and their interactions, were included as fixed factors, while transect identity was included as a random effect. We ran the model using the gam function in the *mgcv* package (Wood 2011).

Post hoc contrasts between treatment factors were conducted on the GLMM using the emmeans function in the *emmeans* package (Lenth 2020) to fit pairwise contrasts between each of the fixed factors. The exponentiated coefficient estimates provided the proportional increase in the response for that treatment after compared to before, which was then centred on zero and converted to a percentage. Significance is defined by the threshold of $p < 0.05$ and is visually approximated by confidence intervals not overlapping with zero. Confidence intervals (95%) were calculated as the exponentiated lower and upper bounds, estimated as the coefficient ± two times standard error.

### 3.5.4 Results

*Temporal and spatial influences on waterway hydrology*

The regulated flows on all rivers monitored over the three years of sampling showed regimes altered from the typical natural flow regime based on pre-regulation flow data. This is schematically represented in Figure 3.5.4 where altered flow regimes are characterised by reduced flow overall, punctuated by pulses of spring and summer freshwater release. For each river system, there is a discernible ‘baseflow’ level, ‘low flow’ level, the point at which water in the river channel typically reaches its lowest point during the year and a ‘high flow’ or ‘spring fresh’ level, the point at which water in the river channel typically reaches its highest point during the year.

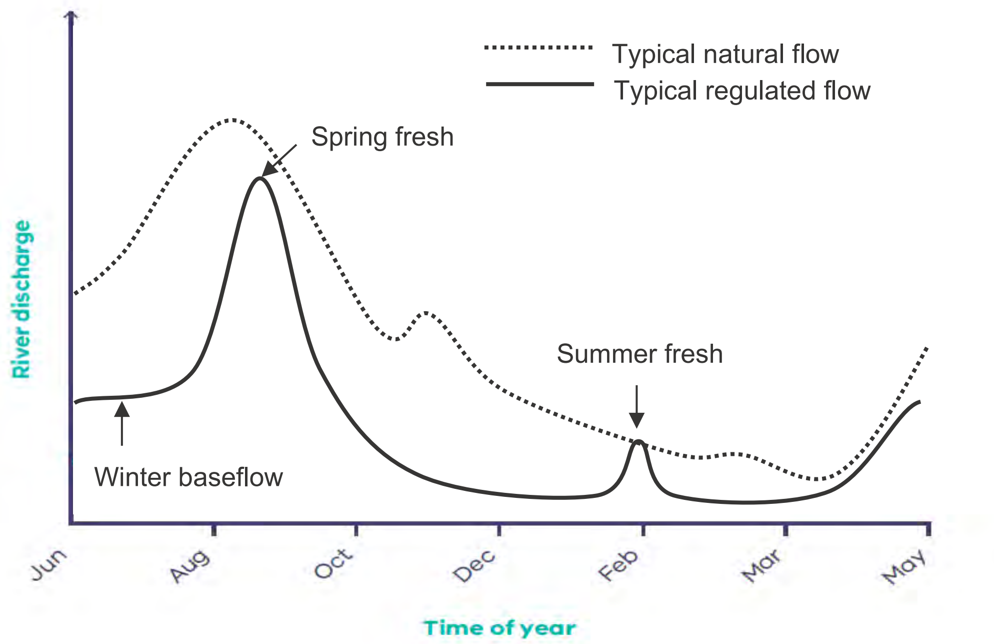



**Figure 3.5.4** A schematic representation of a typical natural flow regime and regulated flow regime experienced across the study sites.

*Plant species cover varies with bank elevation and spring fresh levels*

Species-specific elevation distributions within channels were apparent in most river systems and varied substantially between rivers. Species distributions along channel banks indicated distinct relationships between flow regimes, soil moisture and species tolerance. Individual flow events differentially influenced species health and persistence along the bank. Figure 3.5.5 shows the common elevational distribution above the spring fresh line of an exotic terrestrial forb, *Oxalis pes-caprae* (Soursob). This species typically has high percentage cover above the spring fresh mark (the highest flow point) then cover drops to close to 0% below the spring fresh, closer to the river edge. In comparison, the high fringing grass, *Poa labillardierei* (Common Tussock-grass) has a broader distribution centred around the spring fresh level, whilst the low fringing species *Alternanthera denticulata* (Lesser Joyweed) typically can persist only at low elevations in areas frequently inundated. The emergent species, *Phragmites australis* (Common Reed) shows a broad elevation distribution which reflects a broad tolerance to inundation and drying.

Species-specific responses are useful particularly in order to understand how common problematic weedy species or sensitive target native species persist at sites. Insights into how these species interact with altered flow regimes may be useful to determining management actions for target plant species in a region. VEFMAP Stage 6 undertook controlled experiments to specifically understand inundation tolerance for common riparian species, see Section 3.6 for further information.

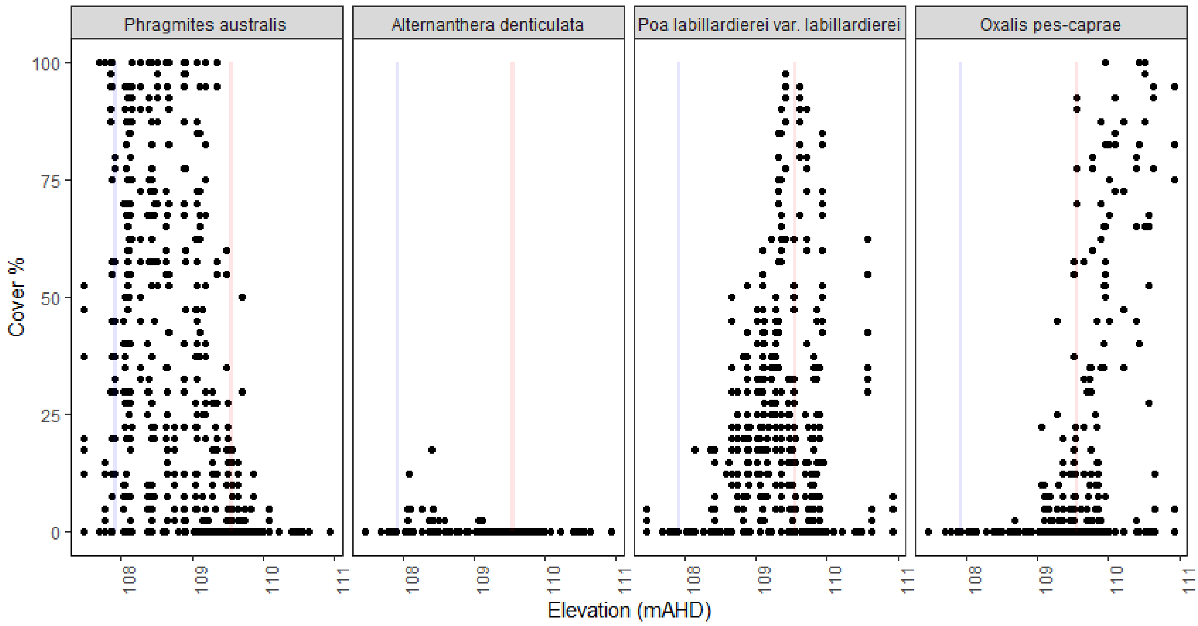



**Figure 3.5.5** Four common plant species distributions in relation to elevation and flow events at a single site on the Campaspe River. Blue lines indicate baseflows, and red lines indicate spring fresh levels.

*Plant function group cover varies with bank elevation, spring fresh levels and between native and exotic species within rivers*

Plant functional groupings are very useful for understanding how suites of species respond throughout reaches and in different river systems. In general, all river channels we monitored were dominated by emergent, fringing and terrestrial species, with fewer aquatic species present (Figure 3.5.6,Figure 3.5.7).

Rainfall benefits vegetation by promoting growth and reproduction when water resources are otherwise limited. Although the seven major river systems monitored during Stage 6 span a rainfall and temperature gradient, some individual river reaches also spanned climatic gradients. For example, the Campaspe River southern reaches are near Bendigo, which has a mean summer rainfall is 33.3 mm and temperature of 30.2°C, whereas the northern reaches are near Echuca, which has a mean summer rainfall of 27.0 mm and temperature of 31.0°C. Areas with higher rainfall have more native and exotic vegetation overall and tend to have a higher cover of inundation-tolerant terrestrial exotic species (Figure 3.5.6, Figure 3.5.7). Generally, the riverbank vegetation is dominated by either exotic or native species, and terrestrial plants are dominated by exotic species, with more native species being represented in aquatic, emergent and fringing vegetation (Figure 3.5.6, Figure 3.5.7).

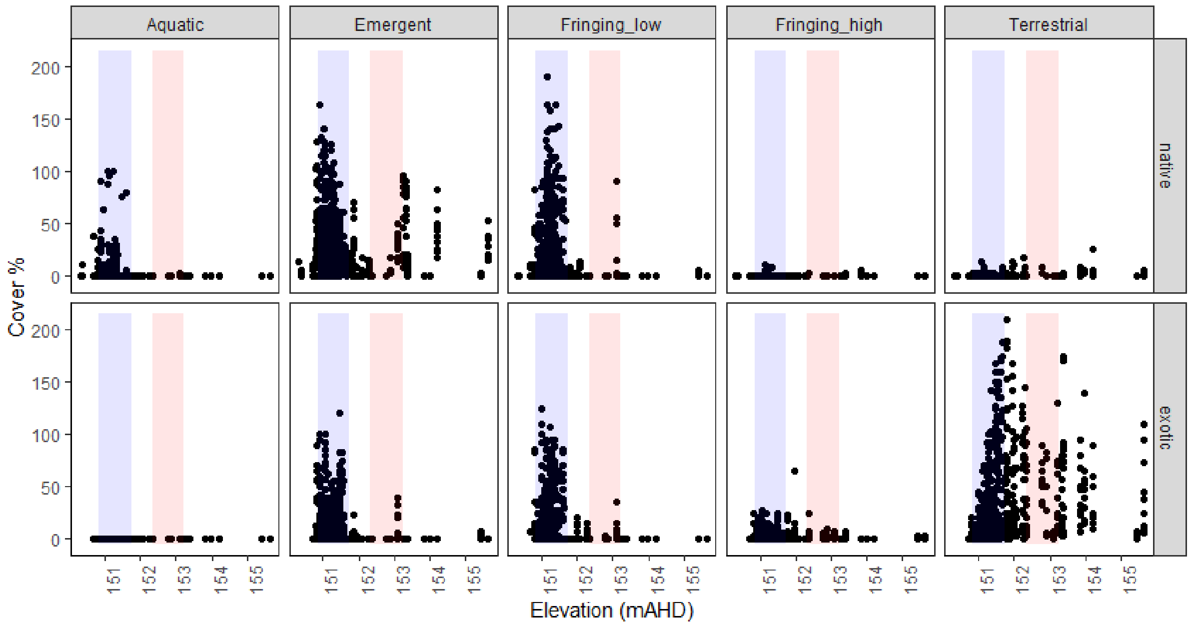



**Figure 3.5.6** Plant function group distributions in relation to elevation, baseline (blue line) and spring fresh (red line) flows at the southern end of the Campaspe River at the Doaks site. The width of the vertical bars represents the variability in the elevation reached by baseflows (blue) and spring freshes (pink).

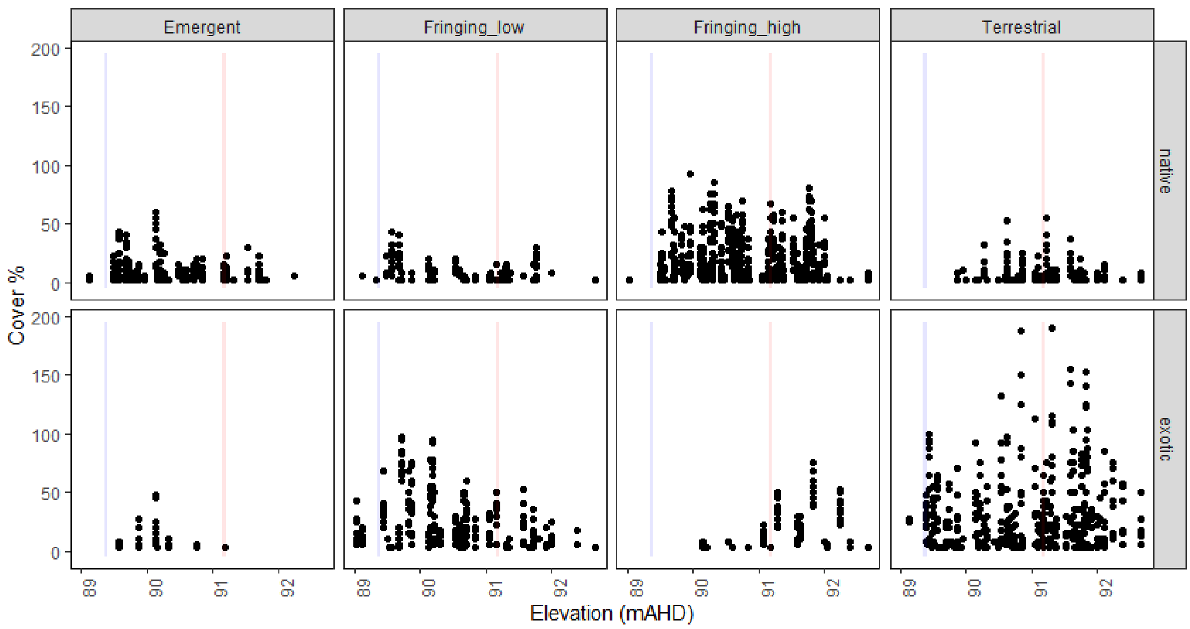



**Figure 3.5.7** Plant function group distributions in relation to elevation, baseline (blue line) and spring fresh (red line) flows at the northern end of the Campaspe River at the Spencer site. The width of the vertical bars represents the variability in the elevation reached by baseflows (blue) and spring freshes (pink).

*Plant function group cover varies spring fresh levels and between native and exotic species across rivers*

Exotic plant species dominate the terrestrial functional group across all river systems with native species having more cover in the emergent and fringing functional groups (Figure 3.5.8). There is wide variation in the cover of both exotic and native plants between sites within river systems.

Across all river systems plant species richness within functional groups was either equivalent or higher for native plants in emergent and fringing vegetation, but there were always greater numbers of species in terrestrial exotic vegetation (Figure 3.5.9).

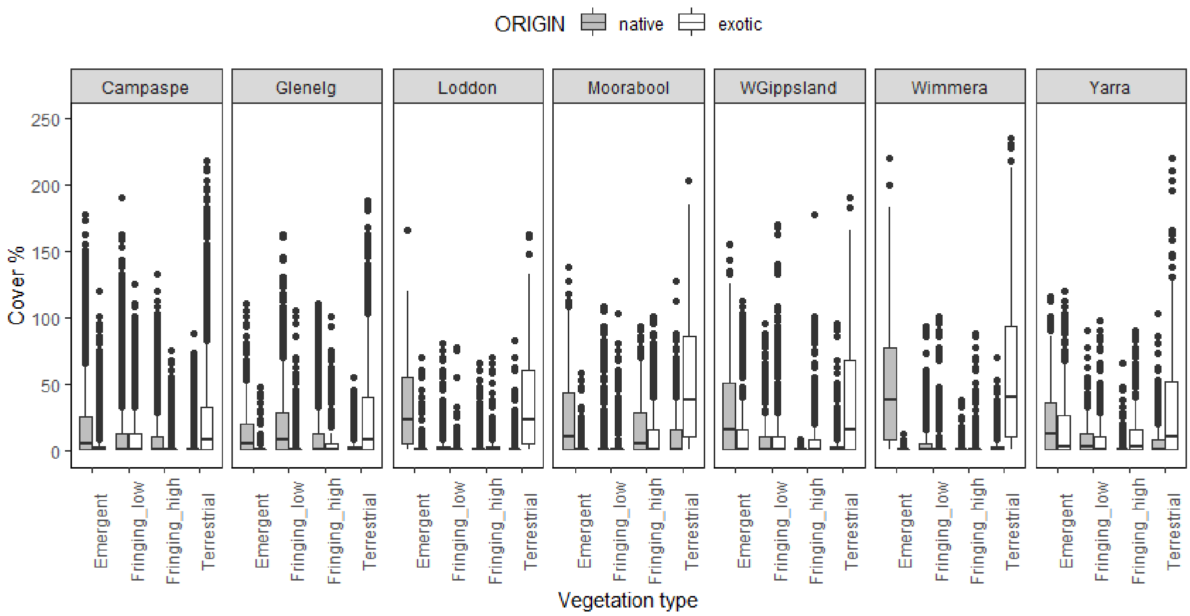



**Figure 3.5.8** Box plots displaying the percentage cover of plant function groups, separated by origin (exotic white bars, native grey bars) across all rivers. For each boxplot, the box indicates the range between the first and third quartiles of the data, the whiskers extend up to 1.5 x the inter-quartile range, and outliers occur as points beyond those limits.

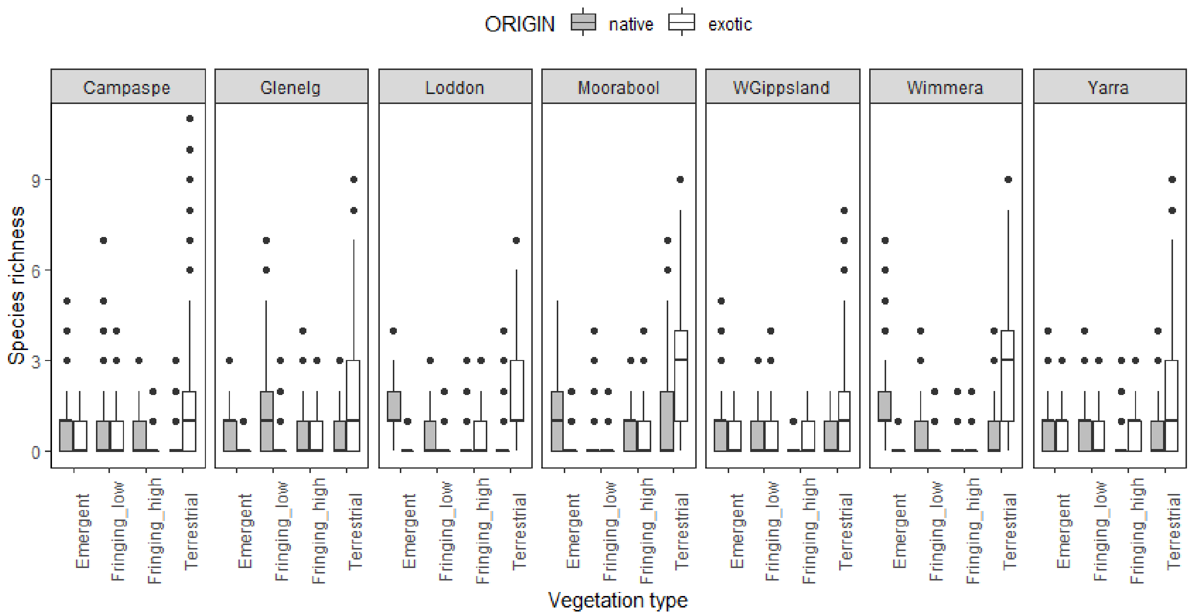



**Figure 3.5.9** Box plots showing the species richness of exotic plants (white bars) and native plants (grey bars) in all rivers. For each boxplot, the box indicates the range between the first and third quartiles of the data, the whiskers extend up to 1.5 x the inter-quartile range, and outliers occur as points beyond those limits.

*All vegetation is negatively affected by livestock grazing*

Grazing more strongly suppresses native vegetation, which results in high exotic plant species cover at sites (Figure 3.5.10). Native vegetation cover was slightly lower across all sites with livestock grazing in all systems except in West Gippsland (Thomson and Macalister) with one partially grazed site only, and the Wimmera with no grazing. Exotic vegetation was largely unaffected by grazing across all systems apart from the West Gippsland system which had slightly higher cover in ungrazed sites. The data presented here are pooled across functional groups and across all 44 sites, however further fine scale results (including comparison of paired transects inside and outside grazing exclosures) is presented in Section 3.9 of this document.

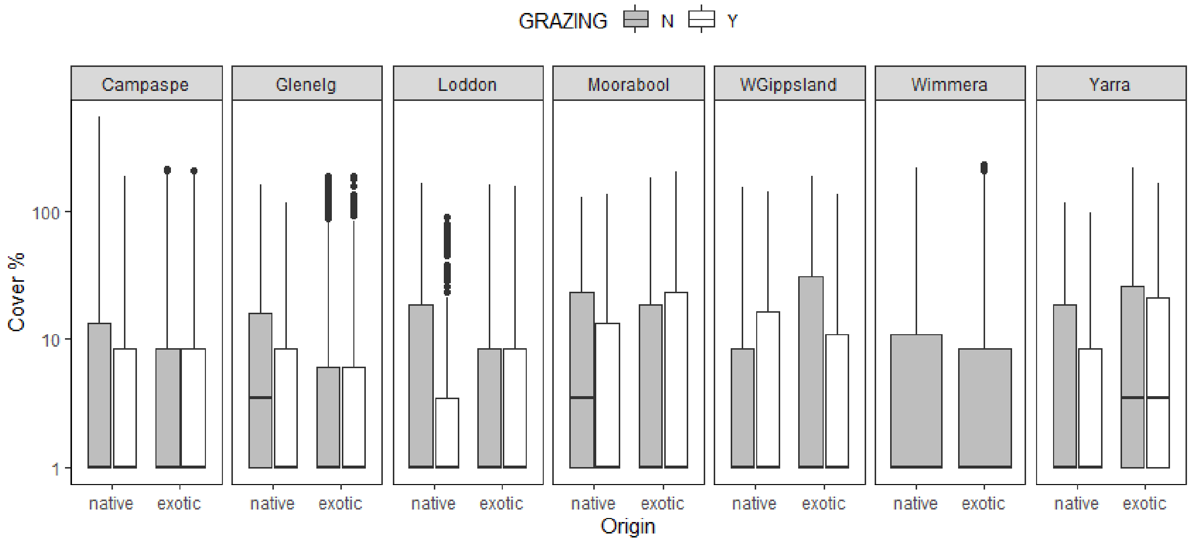



**Figure 3.5.10** Box plots showing livestock grazing influences plant species cover in all river systems. This data is for all functional groups and all sites. Sites the Wimmera system were not grazed. For each boxplot, the box indicates the range between the first and third quartiles of the data, the whiskers extend up to 1.5 x the inter-quartile range, and outliers occur as points beyond those limits.

*Native and exotic competition*

In general, where there is high exotic species cover there is low native species plant cover and most systems are dominated by cover of exotic terrestrial plants species (Figure 3.5.8, Figure 3.5.11, Figure 3.5.12). Drier sites (for example, waterways in the Wimmera, Figure 3.5.11) have lower cover of both native and exotic vegetation but tend to have higher cover of native vegetation across all plant functional groups, particularly lower riparian groups.

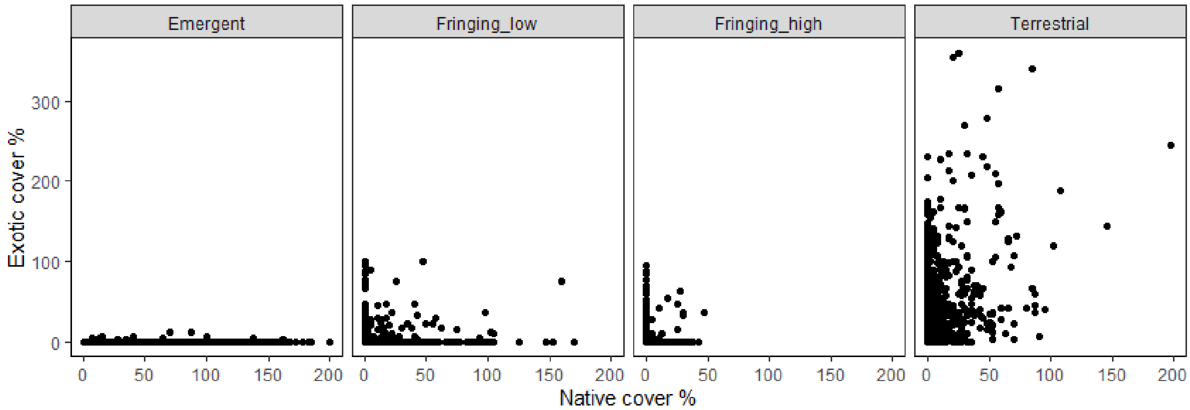



**Figure 3.5.11** Exotic versus native percentage cover for plant functional groups in all sites in the Wimmera region. Data are pooled across all surveyed sites in the system.

Intermediate rainfall areas (demonstrated here with data from the Campaspe River, Figure 3.5.12) have relatively high covers of both exotic and native emergent and fringing vegetation, with exotic terrestrial species dominating native terrestrial species cover.

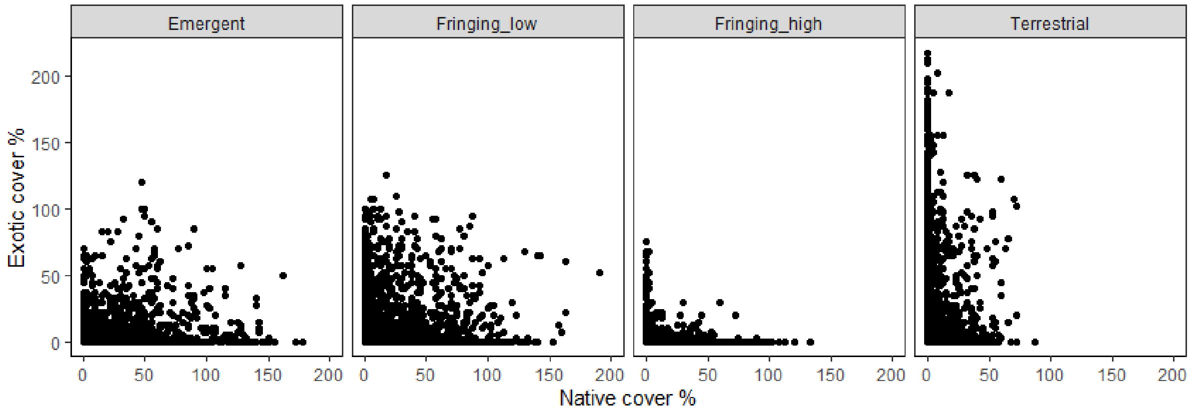



**Figure 3.5.12** Exotic versus native percent cover for plant functional groups across all sites on the Campaspe River. Data are pooled across all surveyed sites in the system.

In high-rainfall areas, exotic species dominate each plant function group. Exotic species are particularly dominant in the higher elevation areas (high fringing and terrestrial), probably because the higher rainfall enables inundation-tolerant exotic species to dominate (Figure 3.5.13).

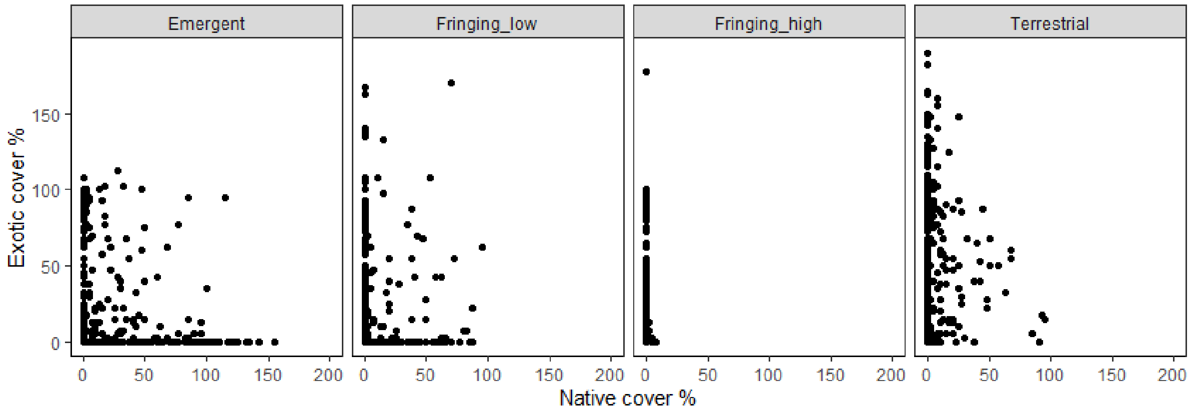



**Figure 3.5.13** Exotic versus native percentage cover for plant functional groups at all sites on the Thompson and Macalister rivers. Data are pooled across all surveyed sites in the system.

*The influence of spring and summer fresh environmental flows on vegetation*

Here we present findings from the Campaspe River looking specifically at the effects of three spring fresh periods across all six sites. Analyses for other systems is provided in Supplementary Material 13.

The effect of spring freshes on vegetation cover was initially evaluated by comparing cover levels before and after spring fresh events within bank zones that were or were not inundated (Figure 3.5.14). The ‘before’ surveys were conducted in late August or early September in each of the three years, but the ‘after’ survey varied depending on the fresh timing (Jan, Nov and Dec respectively). Zones 1 and 2 are directly impacted by surface water during spring freshes, while zone 3 may be influenced by changes in soil moisture. Zone 2 is the primary response zone for the effects of spring freshes. Emergent species (native and exotic) increased in zone 2 in the first and third years (2017–18 and 2019–20), but less so or not at all in the second year (2018–19) (Figure 3.5.14A). Emergent species are most likely to grow during an inundation period because their tall habit allows for greater access to air and light.

Fringing species are more likely to be totally submerged by freshes, which reduces growth rates in the short term (see Section 3.6). Low-fringing species (native and exotic) also increased in zone 2 in a similar pattern to emergent species, but native species increased by a similar amount in the second year (Figure 3.5.14B). The reduced growth in the second year is likely due to the earlier second survey, i.e. reduced period of growth between surveys. The increase in native species cover of low fringing species in zone 3 was dominated by species such as *Persicaria prostrata* (Creeping Knotweed) that have a high tolerance of dry conditions, a wide elevation distribution, and seasonal growth cycles. High fringing species were weakly influenced by spring freshes, apart from exotic species in 2019–20 (Figure 3.5.14C). So, in the short term, spring freshes do not consistently increase fringing plant growth more than plants not inundated by the fresh and exotic fringing species tend to benefit most. However, they are less affected than terrestrial species.

The spring fresh period corresponds with a decreased in the cover of exotic terrestrial species in all zones (Figure 3.5.14D). The reduction is likely to be due to a combination of effects of spring freshes and the natural senescence of exotic annual species in summer, although large reductions were still observed in 2018–19, the year with the earlier resurvey (November, compared to December or January) when many annual species have not yet senesced. It appears that current spring fresh durations on the Campaspe River cause variable decreases in terrestrial plant cover in the short term.

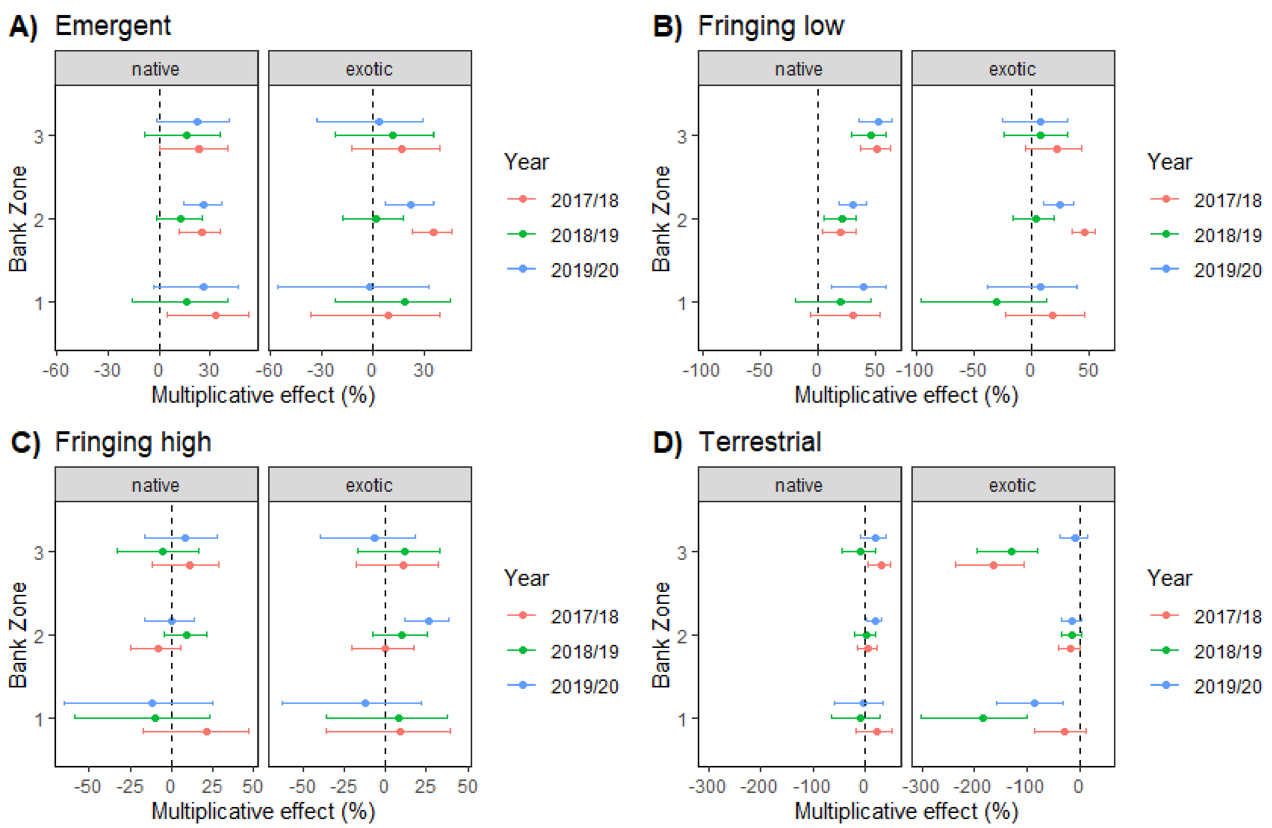



**Figure 3.5.14** The multiplicative effect of spring fresh periods on native and exotic vegetation cover in different bank elevation zones across all six study sites on the Campaspe River. Data are mean effects from statistical models and post-hoc contrasts, with error bars indicating the 95% CI. The vertical dashed line at zero indicates no effect.

### 3.5.5 Conclusions and implications for flow management

The methods employed here aimed to gather data to address the short-term influence of environmental flows on riparian vegetation by using an 'event-style' approach to monitoring, while also considering multi-year trends. Multiple rivers, reaches and sites were monitored across a rainfall gradient in Victoria to provide information about the influence and interaction of base-level rainfall on rivers receiving environmental water. This study has highlighted several key patterns in relation to our initial hypotheses that can be used to guide management of flows:

- The commonly prioritised and delivered environmental flow components (baseflows and spring freshes) influence vegetation abundance and composition on the riverbanks. Some species showed tighter relationships with environmental flow patterns than others, but broad vegetation groups were correlated with flow levels.
- Individual spring freshes appear to have beneficial effects on native and exotic emergent species cover and less negative effects on fringing species than on terrestrial species cover, which results in cumulative competitive growth advantage to riparian species.
- Environmental flows appear to have greatest impacts in lower rainfall areas where water resources are more limited, which in Victoria is generally in the north and west.
- Environmental flows have limited effectiveness in areas that are heavily grazed by livestock, have extremely damaging flows (e.g. prolonged high summer flows), or have high inundation-tolerant exotic species cover (usually higher rainfall areas). Livestock grazing needs to be excluded or heavily reduced in riparian zones to allow sustainable riparian vegetation populations to develop, and to realise the potential benefits of environmental flows. Exotic riparian species need to be managed where they are abundant enough to exclude native riparian species.

Waterway managers are already working to plan environmental flow deliveries strategically to ensure that beneficial flow events are maximised, and detrimental flow events are limited or avoided. The information provided here (and in the other sections) should help to inform these decisions by providing alterations or confidence to existing decision processes. Waterway managers also need to consider environmental flows as one of many tools that need to be managed together to maximise outcomes for waterway health, such as weed control, livestock grazing removal and revegetation. Given climate change predictions of drying climate and lower river flows, environmental flows are likely to be increasingly important in the future.

## 3.6 Responses of herbaceous plants to experimental inundation: testing the effects of inundation duration, season and water temperature to inform flow management

KEQ 2: emergent and KEQ 3: fringing

This work is a summary of three independent studies conducted to address specific research questions related to VEFMAP Stage 6. Two of these studies were undertaken as part of Masters degrees of students at The University of Melbourne, Vanja Kitanovic and Alanna Main, supervised by Joe Greet (University of Melbourne) and Chris Jones (ARI). All three studies were conducted in collaboration with Joe Greet at the Burnley Campus of The University of Melbourne. The content of this summary is based on two research publications currently in journal review and a Masters thesis:

**Supplementary Material 14**: Kitanovic, V., Greet, J., McKendrick, S., Jones, C.S. (2020) Grasses in riparian zones display unexpected tolerance to cool-season inundation. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

**Supplementary Material 15**: Vivian, L., Greet, J., Jones, C.S. (2020) Responses of grasses to experimental submergence in summer: implications for the management of unseasonal flows in regulated rivers. *Aquatic Ecology*. https://doi.org/10.1007/s10452-020-09788-4

**Supplementary Material 16**: Main, A. (2020) Effects of water temperature on the inundation tolerance of herbaceous riparian plants. A research thesis as part of the Masters of Environment at The University of Melbourne.

### 3.6.1 Context

In regulated rivers in south-eastern Australia, environmental flows are often released in late winter and spring to mimic the natural timing of peak flows. These flows are important for maintaining and improving the condition of riparian vegetation, as their life history stages, including growth, flowering, seed dispersal and recruitment, are often timed with patterns of natural seasonal flow patterns (Poff et al. 1997; Greet et al. 2011). While seasonal peak flows in winter and spring are expected to benefit riparian plants, the impacts of environmental flows on different species remain poorly quantified, and many knowledge gaps remain around the tolerances of plants and how this varies between species or groups. For example, spring fresh events may be expected to simultaneously benefit riparian species while disadvantaging terrestrial species, but the inundation tolerances of these two major plant groups to these events are poorly understood.

Prior to river regulation, high flows in summer were infrequent, and any that did occur were likely to be of short duration. However, high summer flows are increasingly common in many rivers in the region, driven by the delivery of short duration environmental flows (summer freshes) as well as longer duration flows to meet downstream demands (e.g. irrigation water or water traded and delivered to another system downstream (inter-valley transfer, or IVT). These unseasonal flows can result in the riparian zone becoming inundated at a time of year that would have naturally (i.e. pre-regulation) experienced low flows, potentially negatively impacting plants. Understanding the effects of such flows on riparian plants is particularly important if there are ongoing negative impacts that compromise the positive benefits of seasonal environmental flows.

The planning and management of both seasonal and unseasonal flows to benefit riparian vegetation and reduce the risk of potential negative impacts requires an understanding of how plants respond to inundation at different times of year and under different conditions. This includes understanding the duration of inundation that can be tolerated by plants that occur on different parts of the riverbank, as this can assist in planning appropriate flow durations and magnitudes. For example, it is currently unclear whether the delivery of IVT in summer as pulsed flows of shorter durations is more tolerable to inundated vegetation than single large events (Morris 2019). Key knowledge gaps include the tolerance and growth response of terrestrial and riparian species to individual inundation events in different seasons, and in relation to factors such as water temperature, turbidity and light availability.

To address some of these knowledge gaps, we conducted a series of experiments using outdoor tanks to investigate the responses of various herbaceous plant species to inundation during different seasons (Figure 3.6.1). Three separate experiments were conducted at different times of the year: (1) late winter/early spring; (2) mid-spring; and (3) late summer/early autumn. We also examined the effects of shading (experiments 1 and 3) and increased water temperature (experiment 2), on plant responses. Each experiment included inundation treatments that represented realistic potential scenarios for delivering winter/spring environmental flows (experiments 1 and 2) and irrigation flows in summer and autumn, including flows delivered in pulses compared to single continuous flows (experiment 3). Species-specific responses are useful particularly in order to understand how common problematic weedy species or sensitive target native species persist at sites.

### 3.6.2 Aims and hypotheses

The experiments aimed to investigate the responses of plant growth and survival to various treatment combinations of inundation duration across different seasons, shading and water temperatures. The specific hypotheses of each experiment were:

*Experiment 1 (late winter/early spring)*

- Inundation response will vary between species, with the differences between species becoming more apparent at longer inundation durations.
- Survival and growth of inundated plants will be reduced in shaded compared to unshaded conditions.
- Seedlings will be more sensitive to inundation than established plants.

*Experiment 2 (mid-spring)*

- Inundation response will vary between species, with the differences between species becoming more apparent at longer inundation durations.
- Survival and growth of inundated plants will be reduced in artificially warmed water compared to un-warmed conditions.

*Experiment 3 (late summer/early autumn):*

- For inundated plants, their survival and growth will be greater in response to two-week inundation pulses compared to continual inundation.
- Survival and growth of inundated plants will be reduced in shaded compared to unshaded conditions.

### 3.6.3 Methods

Experiments were conducted in tanks in a covered outdoor area at the Burnley campus of The University of Melbourne (Figure 3.6.1). Experiments 1 and 3 focused on the response of a selection of terrestrial grasses commonly found in riparian zones of south-eastern Australia. These included both native and exotic species spanning an expected continuum of tolerance to inundation. Experiment 2 included a broader selection of plant species, including three grasses common to all three experiments (*Bromus catharticus, Poa labillardierei* and *Rytidosperma caespitosum*), as well as a range of riparian non-grass species (Table 3.6.1).

Each experiment had a different structure (Table 3.6.1). Experiments 2 and 3 each involved a single large experiment, whereas Experiment 1 comprised three individual experiments, hereafter referred to as experiment 1a, 1b and 1c:

- <u>experiment 1a</u>: established (i.e. adult) plants inundated for nine different durations
- <u>experiment 1b</u>: established plants grown in three treatments of shaded-wet, shaded-dry and unshaded-dry conditions for 53 days (Figure 3.6.1a)
- <u>experiment 1c</u>: seedlings inundated for six different durations (Figure 3.6.1b). Seedlings were those that emerged from soil seed bank samples collected in the field.

Experiment 2 tested the effects of five different inundation durations (0 [control], 9, 18, 27 and 36 days) and water heating (heated vs unheated) on established adult plants. Experiment 3 tested the effects of four different inundation scenarios (0 weeks inundation [control], two 2-week wet/dry pulses, 4 weeks continuous inundation, and 8 weeks continuous inundation) and shading (shaded vs unshaded) on established plants.

**Table 3.6.1** Summary of each experiment. Asterisks indicate exotic species.

| Experiment | 1: Late winter/early spring | 2: Mid-spring | 3: Late summer / early autumn |
|---|---|---|---|
| Timing | August – September | October – November | February - April |
| Length of experiment | 35 days (Experiment 1a)<br>53 days (Experiment 1b)<br>25 days (Experiment 1c) | 44 days | 56 days |
| Treatment factors | Experiment 1a: Inundation duration with nine different durations of 0, 1, 2, 5, 7, 10, 15, 25 and 35 days (established plants only)<br>Experiment 1b: Three combinations of shading and inundation (shaded–wet, shaded–dry, unshaded–dry) one single duration of 53 days (established plants only)<br>Experiment 1c: Inundation duration with six different durations of 0, 1, 2, 5, 10 and 25 days (seedlings only) | Inundation duration with five different durations (0, 9, 18, 27 and 36 days) and two different water temperatures during inundation (heated vs unheated) (Figure 3.6.1c) | Four different inundation scenarios (0 weeks, two 2-week wet/dry pulses, 4 weeks continuous, 8 weeks continuous) and two levels of shading (shaded vs unshaded) |
| Species | *Bromus catharticus**<br>*Lachnagrostis filiformis*<br>*Lolium multiflorum**<br>*Phalaris aquatica**<br>*Poa labillardierei*<br>*Rytidosperma caespitosum* | *Bromus catharticus**<br>*Cyperus eragrostis**<br>*Juncus pauciflorus*<br>*Oxalis pes-caprae**<br>*Phyla nodiflora**<br>*Poa labillardierei*<br>*Ranunculus repens**<br>*Rytidosperma caespitosum* | *Bromus catharticus**<br>*Dactylis glomerata**<br>*Lolium perenne**<br>*Poa labillardierei*<br>*Rytidosperma caespitosum* |
| Tank water temperatures | 12.85°C (average) | Unheated: 17.9°C (average)<br>Heated: 22.9°C (average) | 17.1°C (measured in week 5 of experiment)<br>23.1°C (measured in week 7 of experiment) |

Experimental plants were grown from seed either sourced from a commercial seed supplier or collected in the field. After establishment, plants were allocated to tanks depending on the particular combination of treatments and level of replication used in each experiment (Table 3.6.1; Supplementary Materials). Inundation was simulated by decreasing or increasing water depths in each tank with tap water.

Plants were measured at regular intervals for height and/or cover, depending on the growth form. At the end of the experiment plants were harvested for biomass measurements. Full details of the methodology, including experimental designs and statistical data analyses, are available in Supplementary Materials 14-16.

The results below present the summaries of the analyses from each experiment, with detailed statistical results (e.g. p-values, model results) also available in Supplementary Materials 14-16.

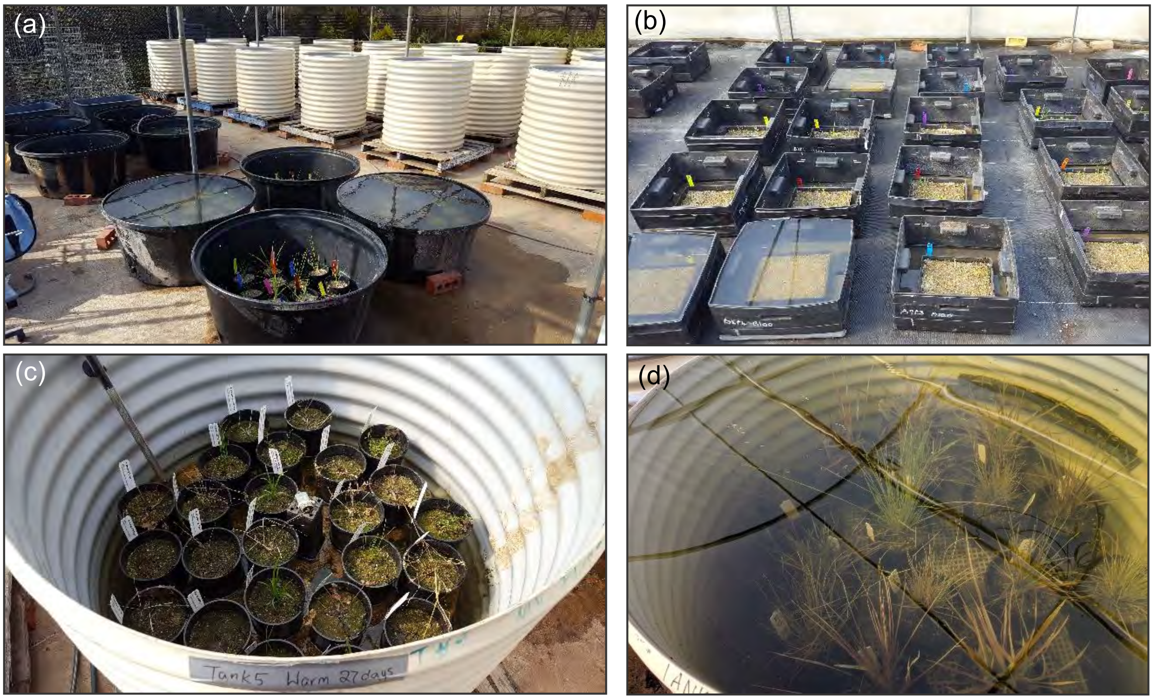



**Figure 3.6.1** Examples of the three experiments. (a) Outdoor tank arrangements: tall white tanks in background used in all three experiments, black tubs in the foreground also used in experiment 1 to test the effects of shade x inundation; (b) inundation of seedlings emerging from the soil seed bank in experiment 1; (c) inside of a tank in experiment 2 showing arrangement of plants and water heater; (d) inside of a tank in experiment 3 showing plants in an inundated treatment.

## 3.6.4 Results

*Experiment 1 (late winter/early spring)*

- *Experiment 1a (established plants):* Five of the six species had a 100% survival rate across all inundation durations; *B. catharticus* had a lower survival rate (50%) in the longest duration inundation treatment (35 days). Growth declined with increasing inundation duration for all species (Figure 3.6.2).
- *Experiment 1b (established plants)*: Plants in the shaded–dry treatment grew rapidly throughout the experiment. In contrast, growth rates of plants in the shaded–wet and unshaded–dry treatments were either low, stable or in decline, depending on the species. After 53 days, the survival rates of *B. catharticus* and *Phalaris aquatica* in the shaded–wet treatment were 17% and 92% respectively, while the remaining species had a 100% survival rate.
- *Experiment 1c (seedlings)*: Ten grass species with a total of 272 individual seedlings emerged from the soil seed bank. Their tolerance to inundation was generally high across all inundation durations, with only eight seedlings dying in both short and long-duration inundation treatments.

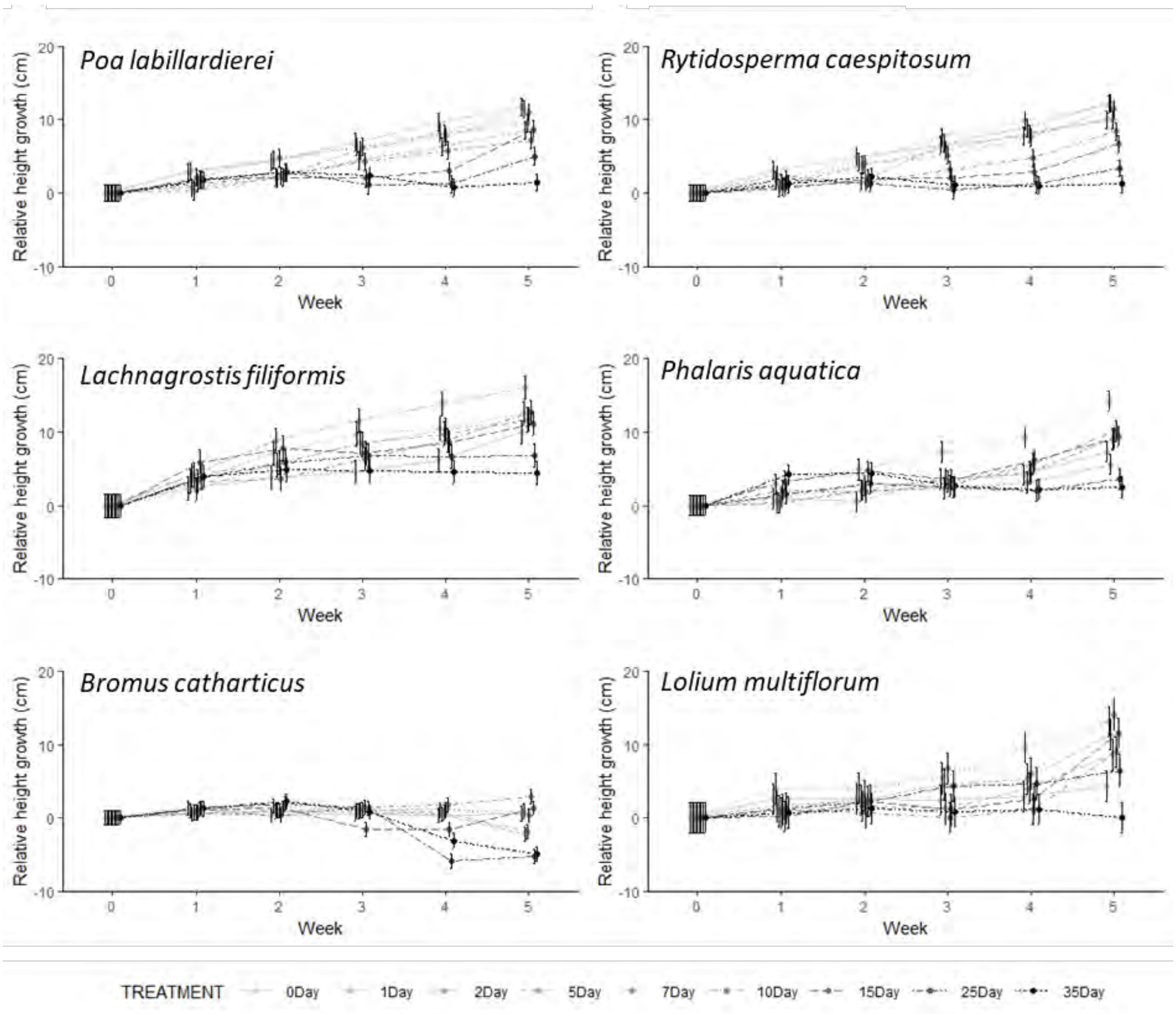



**Figure 3.6.2** Relative height growth of established adult plants in response to different inundation durations in Experiment 1 (winter/early spring); values are modelled mean ± standard error. All plants survived with the exception of *B. catharticus*, which had a survival rate of 50% in the 35-day inundation treatment.

*Experiment 2 (mid-spring)*

- There was a clear gradient of inundation tolerance across the species. The riparian species *Cyperus eragrostis, Juncus pauciflorus* and *Phyla nodiflora* exhibited 100% survival rates, and either increased or maintained height, across all inundation duration and temperature treatment combinations. *Ranunculus repens* and *P. labillardierei* were intermediate in their responses, with some plants dying, and growth rates declining, in the longer-duration treatments. In contrast, the terrestrial species *B. catharticus*, *R. caespitosum* and *Oxalis pes-caprae* exhibited more rapid rates of death and declines in growth while inundated, particularly at longer durations (Figure 3.6.3).
- Water heating had no or minimal effect on the growth rates of the tolerant riparian species *C. eragrostis, J. pauciflorus* and *P. nodiflora.* For the remaining species, plants in the heated tanks generally exhibited more rapid death rates and higher mortality compared to those in the unheated tanks, particularly at longer inundation durations (Figure 3.6.3), although there was little effect on plant growth.
- Warm water treatments additionally reduced biomass growth in only the shortest inundation treatments but not in the longer inundation treatments.

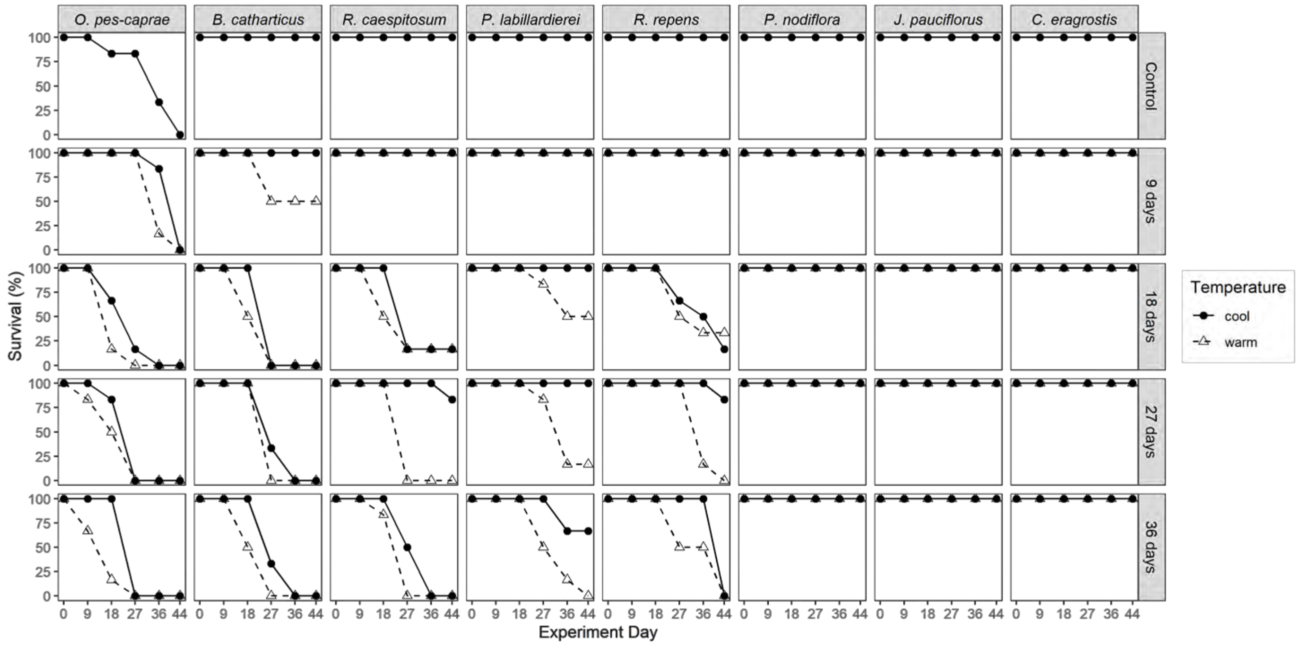



**Figure 3.6.3** Survival rates of plants in relation to different inundation durations in Experiment 2, including the effect of water temperature, controlled by heaters, on inundated plants. Control plants were not inundated.

*Experiment 3 (late summer/early autumn)*

- All inundation treatments, including the two-week pulse, resulted in complete mortality in three of the five species *(B. catharticus, D. glomerata* and *R. caespitosum*) by eight weeks. In the two-week pulse, although survival rates of these species were 100% at the end of the first two-week inundation period, survival declined during the following two weeks while plants were emerged.
- There was also complete mortality of *L. perenne* in the eight-week continuous inundation treatment. However, survival rates were 67% and 50% in the unshaded two-week pulse and unshaded 4-week treatments respectively. It was the only species to show some degree of increasing survival rates under unshaded conditions when inundated, but only in the two shorter inundation periods.
- Heights of *B. catharticus, D. glomerata, R. caespitosum* and *L. perenne* declined with increasing inundation duration (Figure 3.6.4).
- For non-inundated plants, shading generally resulted in an increase in plant height (Figure 3.6.4) and a decrease in total biomass.
- *Poa labillardierei* largely survived all treatments irrespective of inundation or shading with 100% survival rates except for the shaded 4-week treatment where one plant died. It was the only species to maintain relatively stable heights and biomass across all inundation treatments.

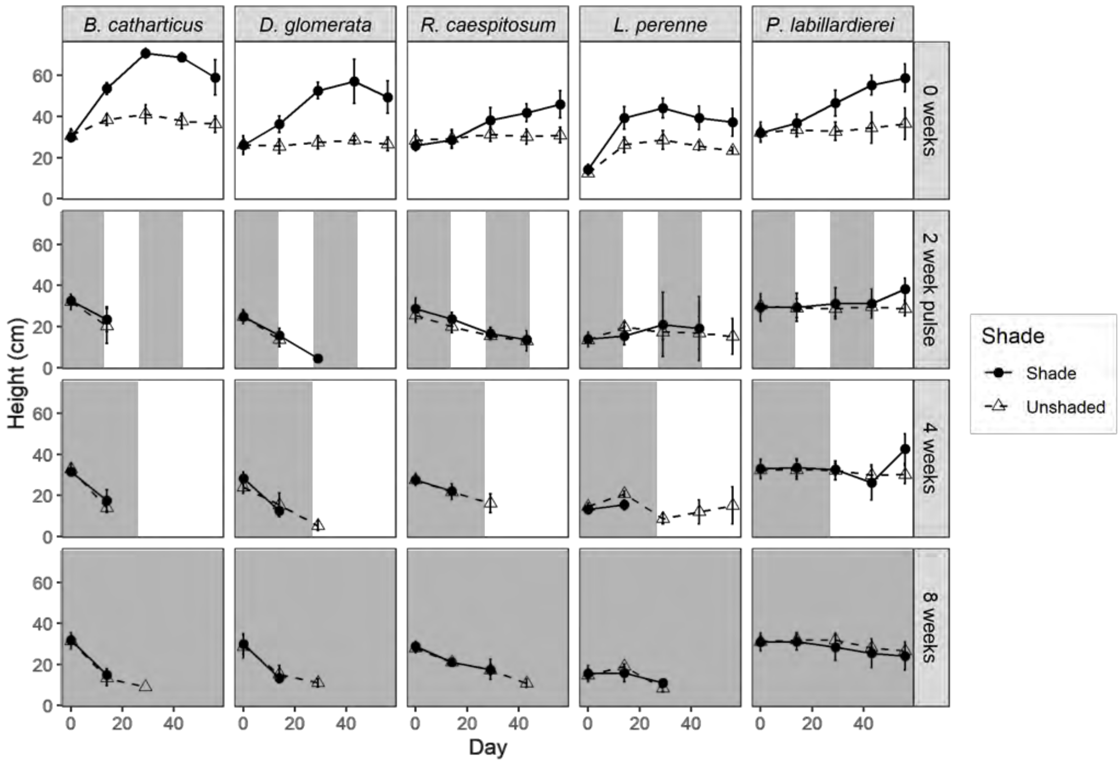



**Figure 3.6.4** Heights of plants assessed as alive (measured as the height of the longest section of green leaf) during Experiment 3; values are means (excluding dead plants) ± 95% CI. Grey shading indicates periods of submergence. The premature end of lines before the end of the experiment indicates that no plants were left alive in that treatment.

### 3.6.5 Conclusions and implications for flow management

- Across the three experiments there was a continuum of inundation tolerances. The most tolerant species had high rates of survival and growth irrespective of inundation duration, the season of inundation, or water temperature. Less tolerant species, including both adults and seedlings, were able to survive long inundation in late winter – early spring with no mortality, although growth rates were reduced, with the exception of the least-tolerant *B. catharticus*. However, the survival and growth of these species declined across the seasonal gradient to mid-spring and late summer – early autumn, and with increasing inundation duration.
- The degree of inundation tolerance of the species largely matches their observed distribution in the riparian zone. For example, riparian species that occur lower on the bank and experience more frequent inundation, such as *J. pauciflorus* and *C. eragrostis*, were the most tolerant, while terrestrial grasses such as *B. catharticus* and *R. caespitosum*, which are most likely to occur on mid to upper banks where inundation is less frequent, were the least tolerant.
- Possible factors driving the decline in inundation tolerance of some species with season include the timing of inundation in relation to plant life history stages, with summer flows potentially inundating plants during their peak growing season when metabolic demands are greatest (Crawford 2004); and the impact of warmer water temperatures, which can exacerbate inundation stress for plants due to higher respiration rates, accelerated carbohydrate utilisation, and more rapid leaf decay (van Eck et al. 2005). In experiment 2, the effect of water temperatures was explicitly investigated. The results indicated that warmer water can reduce the survival rates of species that are less tolerant of inundation, although growth rates and biomass production appeared to be less affected. A possible exception may be the native grass *P. labillardierei*, which appeared highly tolerant of long-duration inundation at both extremes of the seasons examined (late winter/early spring and late summer/early autumn) yet had lower survival rates in heated water compared to unheated water in mid-spring. We expect that the influence of artificial warming may be even greater if the warming experiment were conducted a few months earlier, in winter/spring. Any potential negative effect of warmer water temperatures is also relevant for

understanding plant responses to inundation (including environmental flows) under future climate change scenarios, depending on the likelihood of climate change to increase river water temperatures either directly or indirectly via altered flow regimes, including seasonality (e.g. van Vliet et al. 2013).

- Despite the reduction of light by approximately 80%, shade appeared to have little influence on the response of species to inundation, with the possible exception of *L. perenne,* suggesting that the abundance of light is not an important driver of responses, although photoperiod was not tested.
- Inundation of plants in late summer/early autumn indicated that even two-week periods of inundation at that time of year may reduce growth and cause the death of some riparian grasses. This suggests that the delivery of longer duration unseasonal summer and autumn flows, such as those delivered to meet downstream consumptive demands, in pulses of two weeks with a two-week break to allow plants to recover in between flow events, rather a continuous single four-week block, will not necessarily reduce plant mortality. However, flows of shorter duration, such as typical summer freshes, may result in lower plant mortality, although any potential longer-term impacts of repeated short-duration summer inundation on plant responses requires further study, particularly for processes such as flowering and seed set.
- This series of experiments has provided important evidence that the seasonal timing of flows and water temperature can influence how plants respond to inundation. Many species are highly tolerant of cool temperature inundation during late winter and early spring, including terrestrial species found growing in riparian areas, supporting the use of environmental flows to mimic seasonal peaks for improving overall riparian vegetation condition. However, given that this includes exotic species, environmental flows in late winter and spring are unlikely to control undesired plants; rather, they will benefit the suite of species present in the riparian zone irrespective of their native or exotic status. These patterns match field observations, with only two winter/spring events during Stage 6 causing mass mortality of plants, one being the very large natural floods in 2016. In contrast, inundation by warmer water or inundation in summer and autumn can result in reduced survival and growth for many species, particularly those that are more sensitive to inundation in general, although more tolerant species may also be negatively impacted. Therefore, the delivery of unseasonal flows, including flows to meet downstream demands as well as summer freshes, may need to be carefully managed to reduce the impact on the riparian zone.

## 3.7 Vegetation recruitment in river channels and the role of environmental flows on plant germination

KEQ 4: recruitment

This chapter is a summary of the following co-authored project, presented in Supplementary Material 17, and is currently in preparation for journal submission.

**Supplementary Material 17**: Jones, C.S., Vivian, L., Mole, B., Backstrom, A. (2020). Vegetation recruitment in river channels and the role of environmental flows on plant germination. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 3.7.1 Context

Plant recruitment is a critical process for sustaining vegetation populations and communities. When vegetation recruitment is diminished, communities or populations can collapse as the adult plants senesce and die. This not only impacts threatened plant species and local biodiversity but can also be catastrophic for whole ecosystems due to the critical roles plants play in food and/or habitat provision for other biota, as well as many other ecosystem functions.

Riparian plant species possess a wide range of recruitment strategies (Table 3.7.1) although the most common and dominant mechanism is reproduction from seed. Seed can be dispersed via a range of pathways within and between waterways. Riparian soil seedbanks are particularly important for river health because stored seed enables vegetation to rapidly recover after a disturbance event such as flooding (Reid and Capon 2011; O'Donnell et al. 2015). Different species have many different seed dormancy strategies once a viable seed is produced and dispersed. Germination can be stimulated by several environmental cues, including rainfall, temperature, photoperiod, and flows. Germination is just one step in a broader process for the successful recruitment of a new plant from a seed to maturity.

In regulated waterways, environmental flows are increasingly being used to achieve a range of environmental benefits (e.g. DELWP 2017a). A possible benefit is the stimulation of seed germination (Reid and Capon 2011; Greet et al. 2012; Dawson et al. 2017), but the response patterns to managed flow among the alternative recruitment patterns are not well documented. An improved understanding of plant recruitment response to flows may have implications for best-practice environmental flow management.

**Table 3.7.1 Summary of the number of plant species or taxa with non-seed recruitment mechanisms, from all 500 taxa recorded in Stage 6.**

| Spore | Bulbil | Tuber | Bulb/ Corm | Rhizome | Stolon | Roots at nodes/ Adventitious roots | Sucker | Division |
|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 14 | 9 | 113 | 23 | 72 | 16 | 2 |

### 3.7.2 Aims and hypotheses

In this study we evaluated plant recruitment processes and rates in riparian zones, in relation to rainfall and flow conditions. We tested if environmental flows were successfully triggering plant germination, and what flow conditions were more effective for triggering germination in different broad plant groups (Figure 3.7.1). This information is targeted at directly informing flow management actions to maximise the environmental benefits provided by investment in environmental flows. We tested the following hypotheses:

- Mass germination events occur throughout the year in response to rainfall or flows.
- Environmental flows in regulated waterways will trigger plant germination.
- For perennial plants in a functional group triggered by low flows (G1a: aquatic and emergent species), the most effective germination response is triggered by low-flow conditions in early to mid-autumn.
- For annual and perennial plants in a functional group triggered by rain (G1b: terrestrial and fringing), the most effective germination response is triggered by rain in late autumn.
- For perennial plants in a functional group triggered by high temperature and high flows (G2: fringing), the most effective germination response is triggered by flows in late spring to early summer.

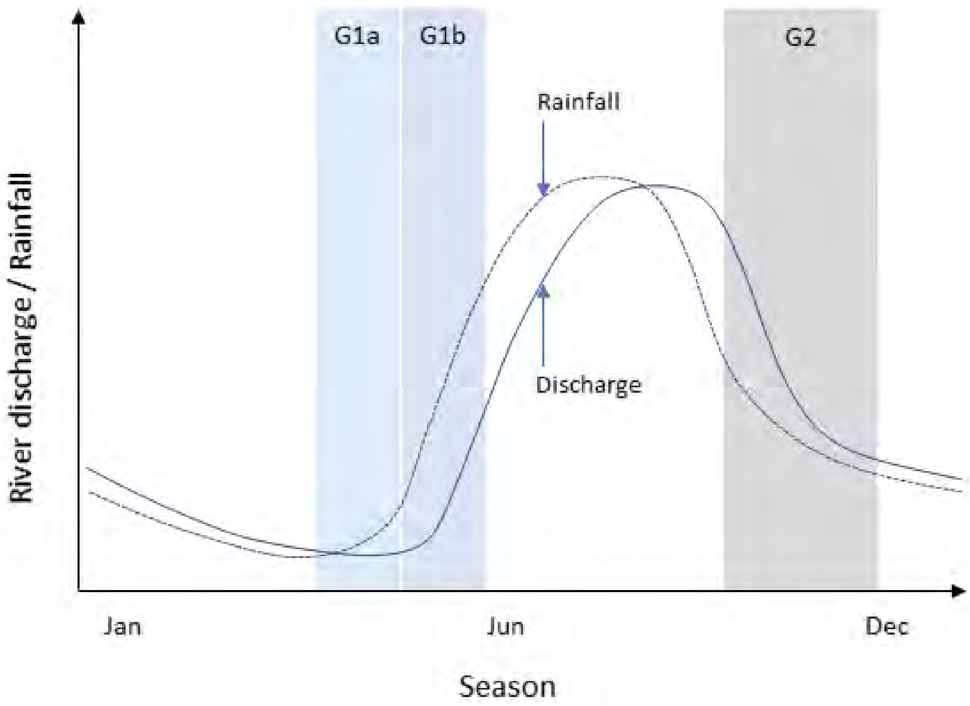



**Figure 3.7.1** Conceptual germination model. G1a = Low-flow triggered (aquatic and emergent); G1b = Rainfall triggered (terrestrial and fringing); G2 = temperature and high-flow triggered (fringing). Source: Jones and Vivian 2019.

### 3.7.3 Methods

We conducted recruitment surveys at 44 sites across 12 regulated waterways over a four-year period in Victoria (Figure 3.7.2). Each site was surveyed on 3–12 occasions in different seasons.

Germination was assessed by counting the total number of seedlings of each species observed in a series of 1 × 1 m quadrats along transects spanning the elevation gradient of the bank of each waterway. The transect length (and subsequently the number of quadrats) varied according to the size of the channel and ranged between 3 and 20 quadrats. The number of transects varied at each site but ranged between 5 and 10. Seedlings were counted at each visit over the four-year period, and counts were recorded continuously from 0 to 10, then categorically from 11–50, 51–100 and 100+. Unidentified germinants were recorded and subsequently identified in later surveys if the plants could be reliably relocated.

Given that our data are counts of seedlings, the survey timing does not correspond with the germination event. In this case, the number of seedlings recorded in a particular period is an indicator of germination within the period prior to the survey, i.e. May–September surveys indicate autumn–winter germination, October–January surveys indicate spring germination and February–April indicate summer germination.

Data were evaluated in regard to two key flow levels (baseflow and spring fresh) that indicate common environmental flow priorities for vegetation management. Flow levels were derived from a combination of in-situ data loggers and permanent gauges calibrated against surveyed water level elevations at each site. A few sites for which full flow data were not available were not compared to flow elevation (see Section 3.5.3 for more detail).

Recruitment data were plotted initially against survey month to determine temporal patterns and counts per quadrat were pooled across years when multiple years of surveys were completed. Subsequent data summaries show seedling counts against elevation of quadrat position up the bank. Elevation comparisons need to be conducted separately for each site because of the variation in elevation between sites, the changes in channel profile, and the variation in flow patterns at each site. More comprehensive statistical analyses are provided in Supplementary Material 17.

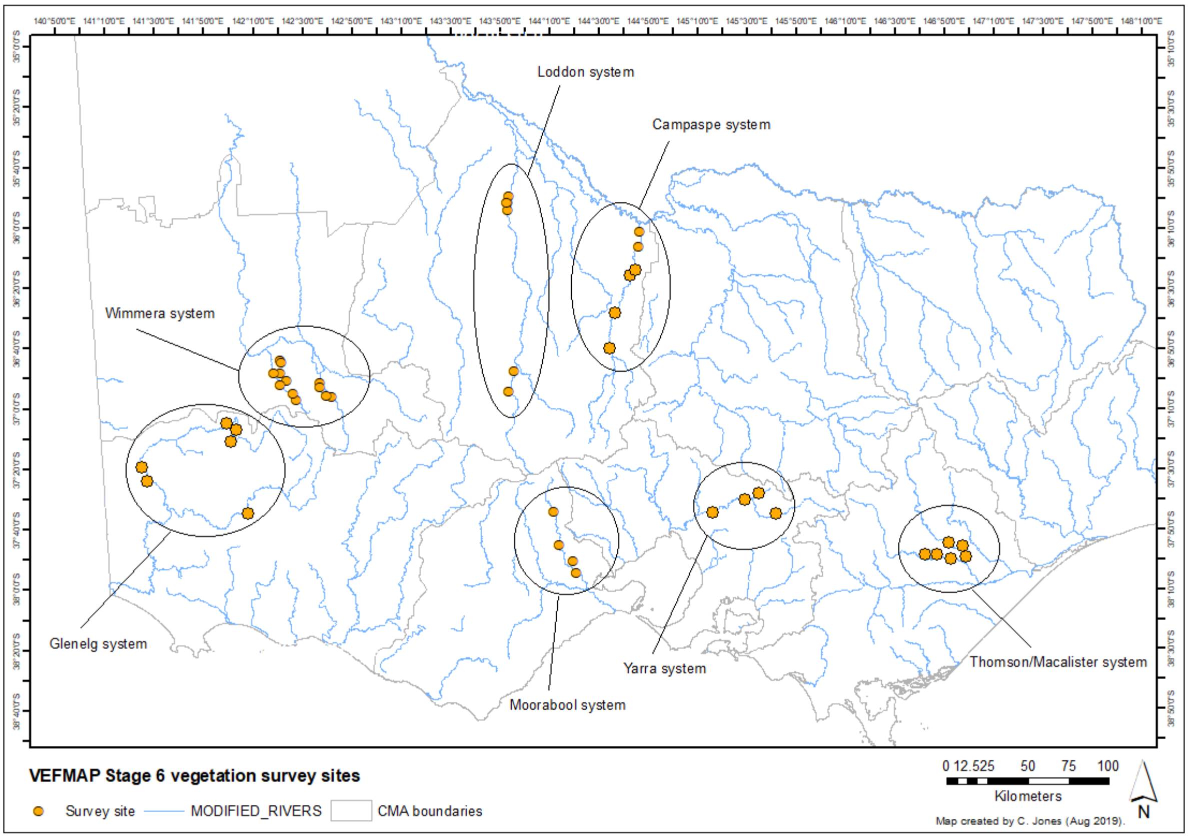



**Figure 3.7.2** Locations of sampling sites in Victoria. Each system is labelled and named by its major waterway.

## 3.7.4 Results

Overall, seedling abundance was relatively low for many riparian species groups, whereas low fringing and terrestrial species were the most abundantly recorded (Figure 3.7.3). Aquatic vegetation was uncommon, which reflects the low rate of germination of this group but also the sampling design, which focused on the channel bank. Seedling abundance was generally highest in spring for most functional groups. This pattern was particularly strong for terrestrial species. Because there is a delay between germination and detection, the cohort of spring seedlings represents germination prior to the survey. We conducted very few surveys in winter so in most cases the germination window prior to the spring surveys includes seedlings from late autumn to early spring. This is the dominant period for plant germination, and seedlings tend to show slow cool-season growth. Various survey events conducted during Stage 6 clearly showed that autumn-germinated seedlings survived large spring freshes and contributed to plant cover (Section 3.5).

Most vegetation groups had some continuous record of recruitment throughout the year across all systems and all species. Seedlings of aquatic and emergent species appeared to be more prevalent in summer and autumn, compared to high fringing and terrestrial species.

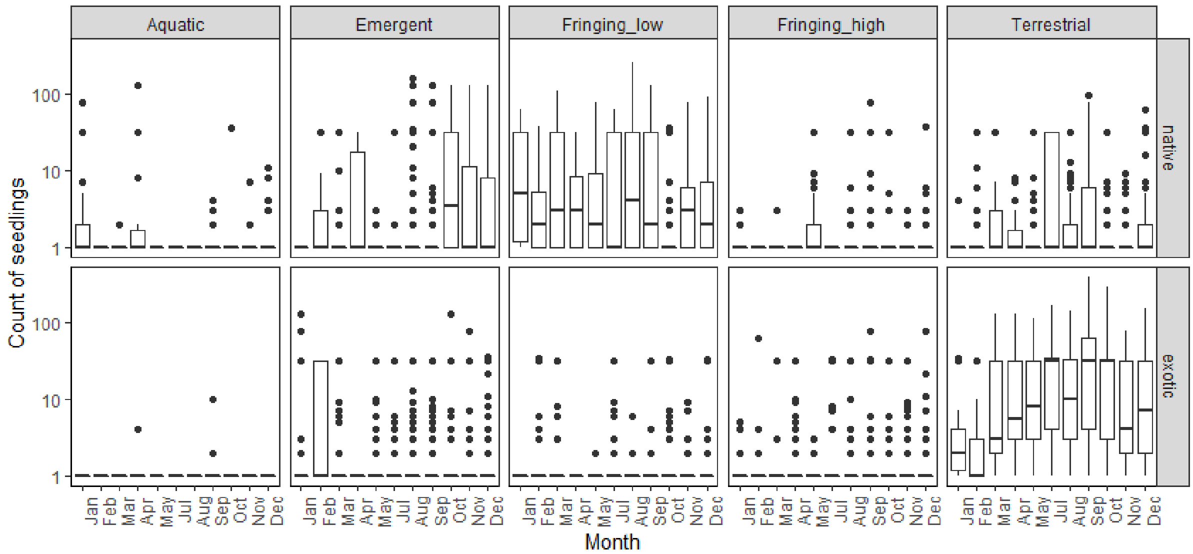



**Figure 3.7.3** Counts of seedlings per quadrat in the five target vegetation groups. Data are pooled across all 44 sites. The *y*-axis is log-scaled for clarity. Boxplots show the median and the range between the first and third quartiles of the data; whiskers extend to 1.5 times the inter-quartile range.

At the individual site level we were able to evaluate the seedling abundance at different elevations on the bank and in relation to key flow levels (Figure 3.7.4 to 3.4.7). Figure 3.7.4 and Figure 3.7.5 show the seedling counts at different elevations at the most upstream site (Doaks) and most downstream site (Campbells) respectively.

The Doaks site has a greater fall in river height over the span of the sampling transects, which is indicated by a greater range in baseflows and spring freshes. This site had a high proportion of emergent and low fringing vegetation at the lower bank elevations. The highest seedling abundances were recorded in surveys 1 (winter/spring) and 2 (spring/summer), with low abundances in survey 3 (summer germination).

In contrast, the Campbells had a much lower proportion (and discrete distribution) of emergent and low fringing species, and the mid-bank elevations had a much greater proportion of high fringing riparian species such as native tussock grasses. These higher-fringing species were much more prevalent in summer up to the spring fresh level, which may indicate post-fresh germination.

Both of these Campaspe River sites had a high abundance of exotic terrestrial species, typically dominated by pasture species and cosmopolitan weeds. Many of these patterns were common to other systems in the study.

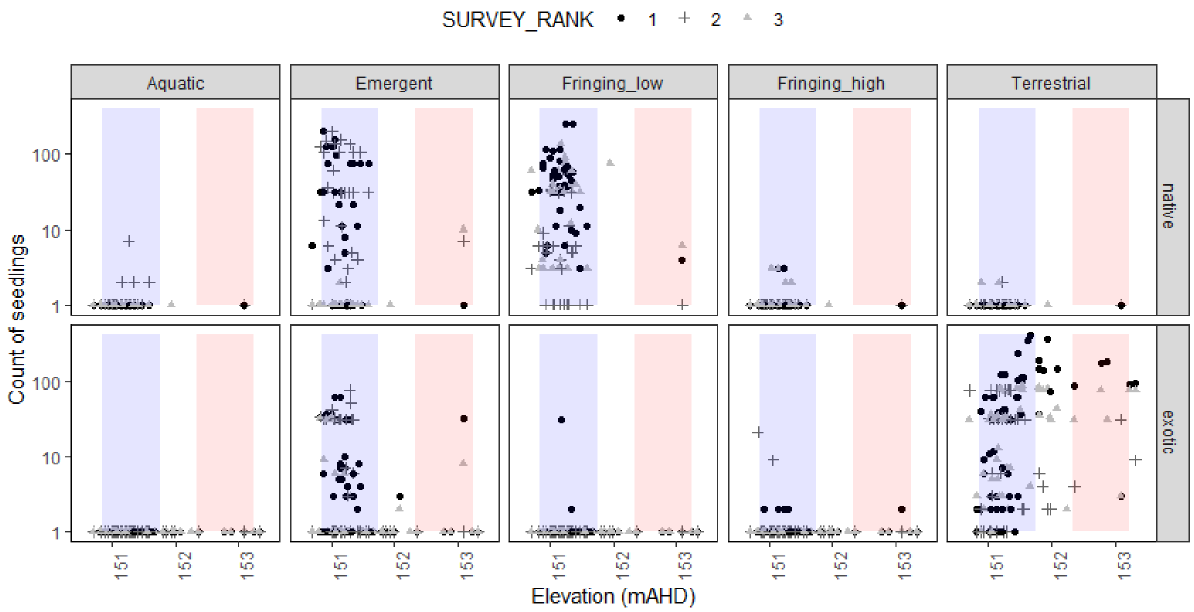



**Figure 3.7.4** Seedling abundance at survey elevations in the Doaks site on the Campaspe River (NCCMA). Points are coloured and shaped according to the survey rank within a sampling year: 1 winter–spring, 2 spring–summer, 3 summer–autumn. Coloured rectangles show the range of target flow levels at that site across the sampled locations for baseflow (blue) and spring fresh (red).

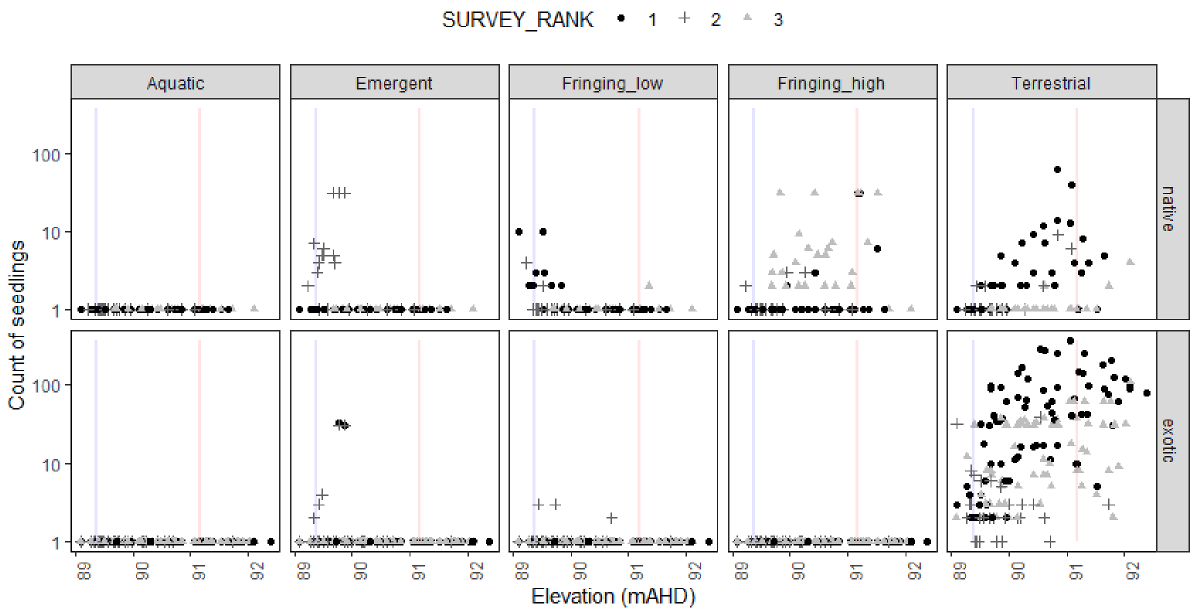



**Figure 3.7.5** Seedling abundance at survey elevations in the Campbells site on the Campaspe River (NCCMA). Points are coloured and shaped according to the survey rank within a sampling year: 1 winter–spring, 2 spring–summer, 3 summer–autumn. Coloured rectangles show the range of target flow levels at that site across the sampled locations for baseflow (blue) and spring fresh (red).

Two contrasting examples of recruitment are shown below in Figure 3.7.6 and Figure 3.7.7. Figure 3.7.6 shows the seedling counts within a naturally intermittent system where flow regulation has reduced flow volume and duration on the lower Burnt Creek in the Wimmera CMA. The lack of flow and long periods of cease-to-flow result in very low recruitment densities, apart from terrestrial species that are typically stimulated to germinate from seasonal rainfall.

At the other end of the spectrum, the Yarra River is in a relatively high rainfall catchment with large flow volumes. Very high seedling abundances were recorded at the Tarrawarra site in the emergent and low fringing vegetation groups in the first two surveys (Figure 3.7.7). These higher rainfall sites typically have a much higher proportion of exotic vegetation, particularly riparian or inundation-tolerant species, which are a significant threat to these systems. As with many other sites, the high fringing species pool is very low.

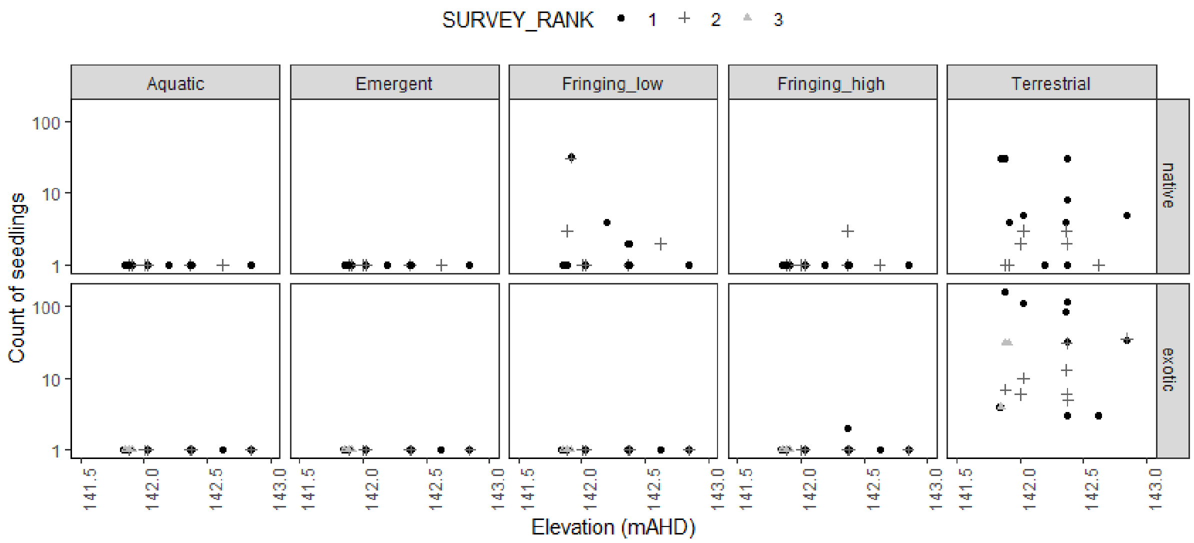



**Figure 3.7.6** Seedling abundance at survey elevations within the Millers site on the Burnt Creek (WCMA). Points are coloured and shaped according to the survey rank within a sampling year: 1 winter–spring, 2 spring–summer, 3 summer–autumn. No coloured rectangles are shown because this reach does not receive regular baseflow or spring fresh flows.

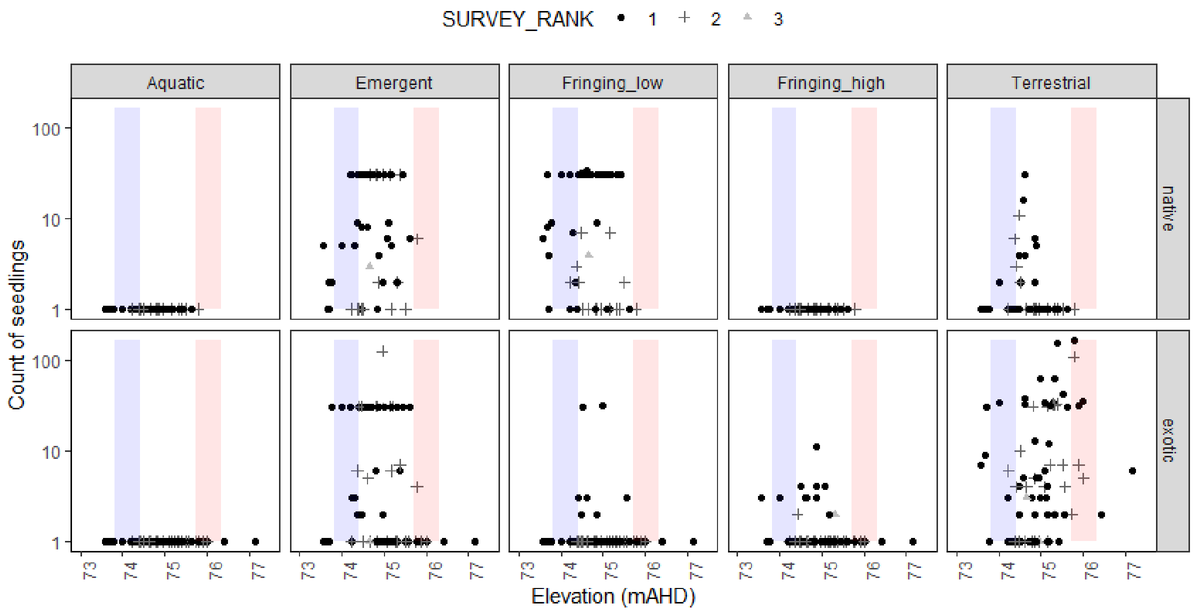



**Figure 3.7.7** Seedling abundance at survey elevations within the Tarrawarra site on the Yarra River (PPWPCMA/Melb. Water). Points are coloured and shaped according to the survey rank within a sampling year: 1 winter–spring, 2 spring–summer, 3 summer–autumn. Coloured rectangles show the range of target flow levels at that site across the sampled locations for baseflow (blue) and spring fresh (red).

## 3.7.5 Conclusions and implications for flow management

Our results indicate that flow management and environmental flows can play a significant role in further improving benefits to riparian vegetation through the germination of riparian species. The timing and duration of these flows can have a significant impact on the extent of germination and the range of species, but generally, germination of riparian species is maximised by flows in spring and low flows in autumn. Rainfall remains a significant driver of many species in the riparian zone, so with forecast hotter and drier climate conditions in the future, the role of environmental flows in maintaining riparian vegetation populations may become increasingly important.

Successful germination events do not necessarily result in successful recruitment events. Successful plant recruitment is only achieved if germinants survive and continue to establish. Many plants (including terrestrial species seedlings) are highly tolerant of extended cool season inundation (Kitanovic et al. 2020; see Section

3.6), and our results indicate that many autumn germinants survived subsequent winter flows and spring freshes. It appears that mass mortality of autumn germinants generally only occurs if flows are high for a very long time, or later in the growing season. Although we did not track seedling growth to maturity explicitly, our observations and data show many examples of seedlings progressing to maturity in many different systems.

Our results (expanded in Supplementary Material 17) have allowed us to further develop the conceptual model (Figure 3.7.1), summarised below in a revised concept model for germination in regulated waterways of Victoria (Figure 3.7.8). This model, which is likely to be relevant for many systems in south-eastern Australia, indicates three primary germination periods in waterways with different triggers:

- Germination triggered by elevated flows and the subsequent exposure as flows recede. This period favours riparian species but will stimulate many vegetation groups.
- Germination triggered by low flows throughout summer and autumn (depending on the system flow and rainfall, i.e. drier sites will have earlier germination) that occurs on the lower bank margin and within the channel bed in any shallow or exposed areas. This period favours riparian species and is particularly important for aquatic species that will have low germination rates if elevations remain high.
- Germination triggered by rainfall in late autumn (depending on when rainfall increases within a given year). This period favours terrestrial species but will stimulate the germination of a wide range of species.

This information can help to guide management decisions for riparian vegetation that incorporates recruitment processes explicitly. This study has made substantial gains in understanding how riparian plant recruitment corresponding with KEQ 4, but further examination and monitoring will help pinpoint the timing, rate and variation of species responses to flows.

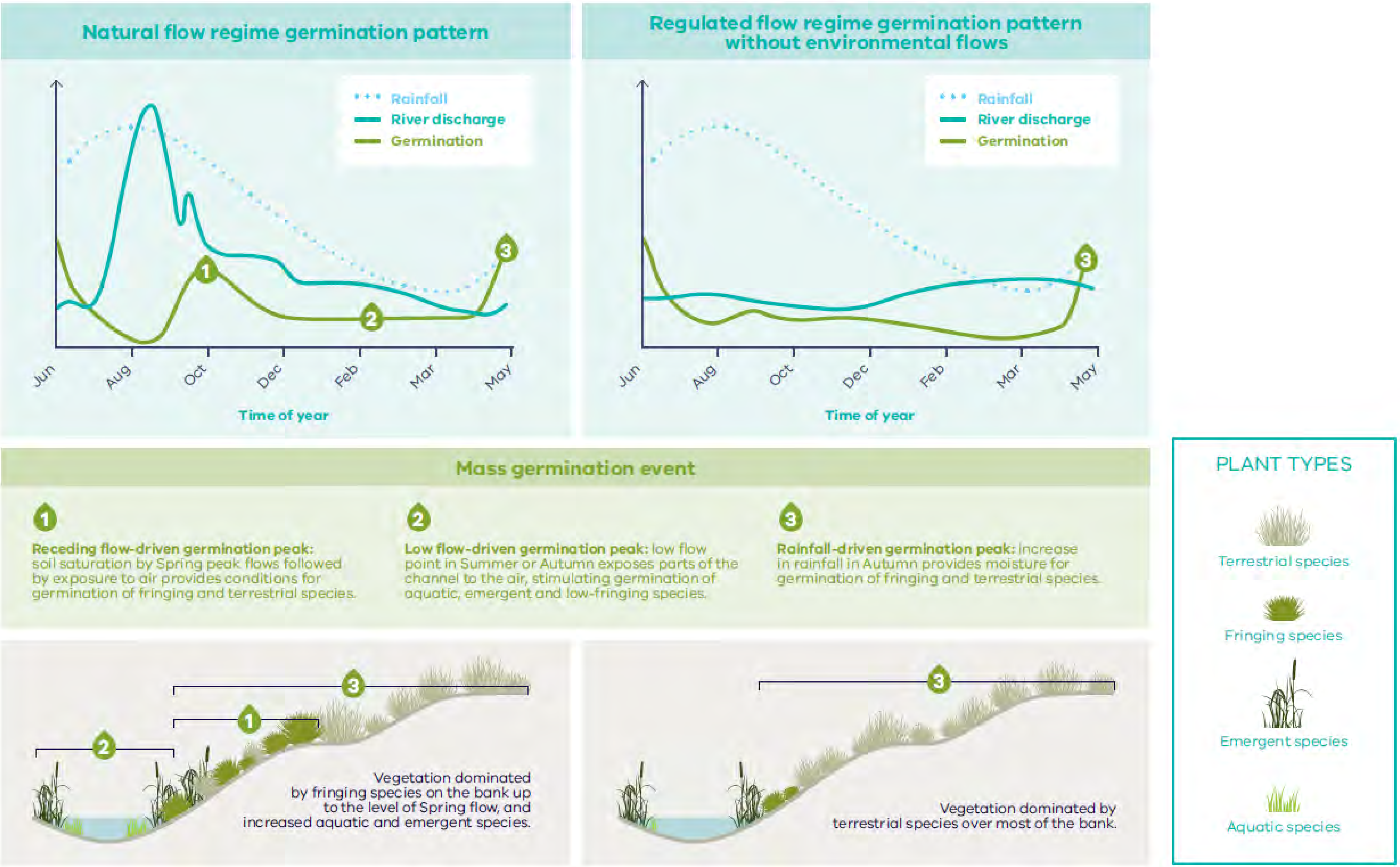



Figure 3.7.8 Revised concept model based on VEFMAP Stage 6 findings and the broader literature.

## 3.8 Native riparian species dominate the soil seedbank of in-channel geomorphic features of a regulated river

KEQ 4: recruitment

This work is a summary of the research conducted for a University of Melbourne Master's thesis by Marjorie Pereira, supervised by Joe Greet (University of Melbourne) and Chris Jones (ARI). The research has also been compiled into a manuscript and is currently in review.

**Supplementary Material 18:** Pereira, M., Greet, J., Jones, C.S. (2020) Native riparian plant species dominate the soil seedbank of in-channel geomorphic features of a regulated river. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

### 3.8.1 Context

Environmental flows are widely used to help manage riverine environments and mitigate the impacts of flow regulation (Arthington et al. 2006). They may also benefit native riparian vegetation by promoting plant recruitment from soil seedbanks. However, successful recruitment of native riparian plants from the seedbank is dependent on seedbank composition, particularly the presence of native seed and a limited abundance of seed of exotic species (O'Donnell et al. 2015), as well as appropriate environmental flow volume, frequency and duration.

The dynamic nature of river flows means that riparian soil seedbanks are particularly important for river health, since soil-stored seed enables vegetation to recover rapidly after a disturbance such as flooding (Reid and Capon 2011; O'Donnell et al. 2014). However, riparian soil seedbanks tend to consist mainly of early-stage colonisers such as rushes and sedges, and the lower abundances of other types of plants (e.g. woody perennials) could limit the usefulness of soil seedbanks in restoration (Thompson and Grime 1979; Greet 2016). A predominance of exotic species may even mean that soil seedbanks are a hindrance to restoration, particularly along degraded rivers in agricultural landscapes (O'Donnell et al. 2015). An understanding of the species composition of soil seedbanks in riparian systems is therefore an important aspect of understanding how these systems might respond to environmental flows. This study sought to improve our understanding of the composition of soil stored seedbanks for a number of in-channel geomorphic features in a regulated northern Victorian river.

### 3.8.2 Aims and hypotheses

Our study was conducted on the Campaspe River, as a case study of a highly regulated river within a cleared agricultural landscape. Specifically, we aimed to investigate patterns in soil seedbank composition associated with gradients in flooding frequency represented by different geomorphic features (bars, benches and floodplains), from frequently flooded (bars), to infrequently flooded (floodplain). We tested the following hypotheses:

1. Soil seedbank composition differs between geomorphic features.
2. There is a higher prevalence of flood tolerant species in the soil seedbanks of in-channel features (bars and benches) compared to floodplains.
3. There is a higher prevalence of native species in the soil seedbanks of in-channel features (bars and benches) compared to floodplains.

### 3.8.3 Methods

Soil seedbank sampling was conducted at six sites along the Campaspe River, between Lake Eppalock and Echuca (Figure 3.8.1). Soil seedbank samples were taken from three river channel features (bars, benches and floodplains) at each of the six sites. These geomorphic features (Figure 3.8.2) represent a gradient in elevation and thus flooding frequency from frequently flooded (bars) to infrequently flooded (floodplain). Seedbank samples were 'grown out' in a glasshouse, and seedlings were identified and classified according to taxa, flood tolerance (tolerant or intolerant) and origin (native or exotic).

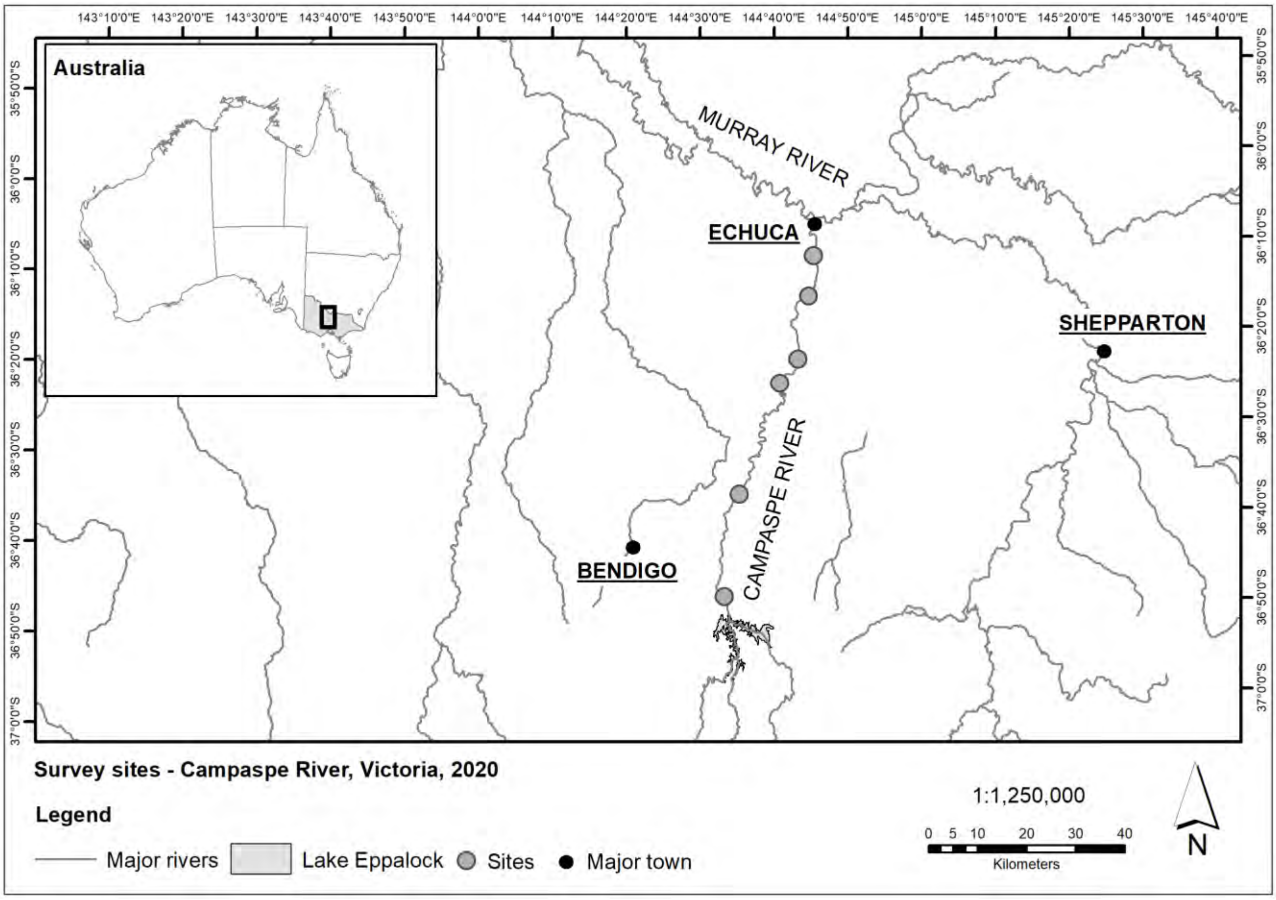



**Figure 3.8.1** Map of the Campaspe River, Victoria, with the six sampling sites indicated.

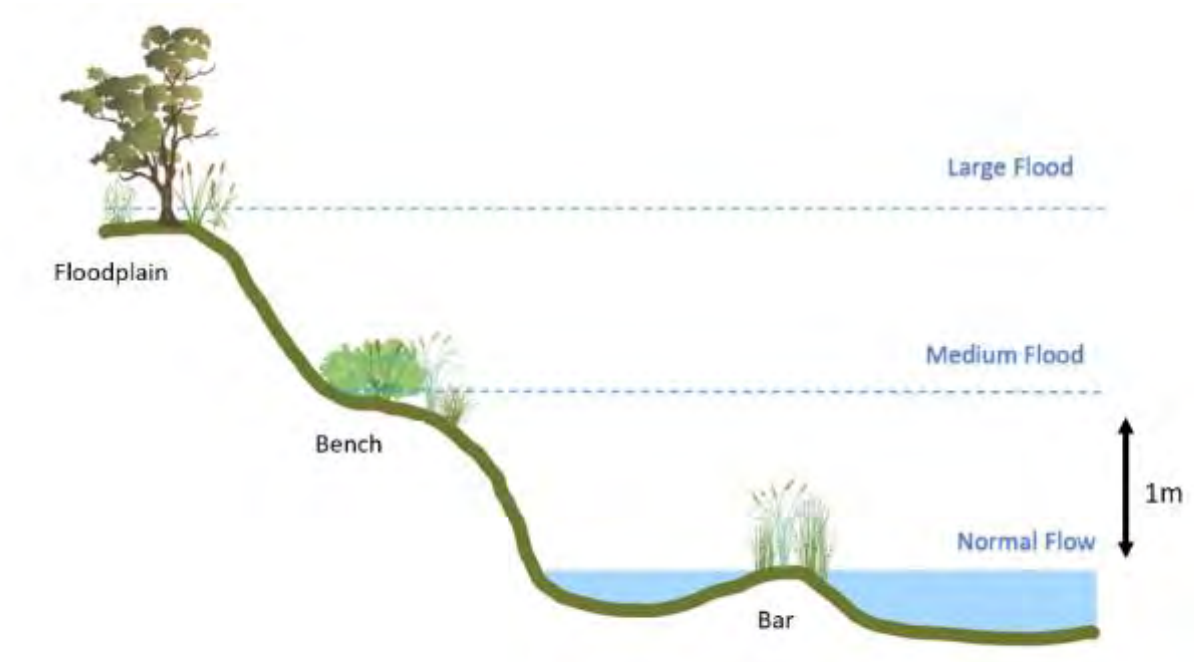



**Figure 3.8.2** Stylised cross-section of a river channel, indicating the three geomorphic features where soil seedbanks were sampled.

Statistical analyses were conducted to:

- compare species composition differences between geomorphic features
- determine species associations with different geomorphic features
- compare differences in seed abundance and taxa richness between geomorphic features
- compare differences in seed abundance and taxa richness between geomorphic features in combination with plant origin or flood tolerance.

### 3.8.4 Results

A total of 6515 seedlings were identified across all features and sites. These comprised 55 different taxa, 27 of which were native and 28 exotic (Table 3.8.1). Of the native taxa, 16 were flood-tolerant and 11 flood-intolerant. The opposite trend was found for exotic species: only 7 exotic taxa were flood-tolerant and 21 flood-intolerant.

Monocots were the most common taxa present. Tall native perennial rushes, grouped as *Juncus* spp. because of their phenotypical similarity, accounted for 59% of all seedlings. This group consisted of *Juncus amabilis* and *Juncus usitatus*, both of which have been commonly recorded in the extant vegetation (Jones and Mole 2018). Two sedge taxa, *Carex* spp. and the exotic *Cyperus eragrostis*, were also notably abundant (16%), as were grasses such as the native *Lachnagrostis filiformis* (9%). Very few tree or shrub seedlings were recorded (Table 3.8.1).

**Table 3.8.1** Summary of growth form, origin, flood tolerance and seedling abundances of seedbank taxa.

| Growth form | No. of taxa | Origin | | Flood tolerance | | Total abundance of seedlings |
|---|---|---|---|---|---|---|
| | | Native | Exotic | Tolerant | Intolerant | |
| Grass | 12 | 4 | 8 | 5 | 7 | 1024 |
| Sedge | 2 | 1 | 1 | 2 | 0 | 1061 |
| Rush | 2 | 2 | 0 | 2 | 0 | 3840 |
| Forb | 37 | 18 | 19 | 12 | 25 | 579 |
| Shrub | 1 | 1 | 0 | 1 | 0 | 1 |
| Tree | 1 | 1 | 0 | 1 | 0 | 10 |
| **Total** | **55** | **27** | **28** | **23** | **32** | **6515** |

The results also showed the following:

- The species composition of the soil seedbank samples differed between geomorphic feature ($p < 0.001$), but not between sites ($p = 0.078$). Soil seedbank samples from bar and bench features were more similar to each other than to floodplain samples, which were least similar to bar samples.
- Flood-intolerant terrestrial species including the native *Rytidosperma* spp. and the exotic species *Bromus carthanticus*, *Trifolium repens* and *Ehrharta longiflora* were more common within floodplain samples. Indicator species analyses identified the native sedges *Carex* spp., and native flood tolerant forbs *Persicaria lapathifolia* and *P. prostrata* to be best associated with bar samples, and the native flood-tolerant grass *Lachnagrostis filiformis* to be best associated with bench samples.
- There was no evidence of a difference in overall taxon richness of the soil seedbanks between the different geomorphic features ($p > 0.05$). A mean of 5 ± 1 (mean ± SE) taxa was recorded for bar samples, 7 ± 1 for bench samples, and 6 ± 1 for floodplain samples.
- Seedling abundances of the soil seedbank samples differed between geomorphic features ($p < 0.001$), with highest abundances recorded for bench samples (91 ± 20 seedlings), intermediate abundances for bar samples (74 ± 17 seedlings) and lowest abundances for floodplain samples (27 ± 6 seedlings).

- In general, there was a close similarity between vegetation responses based on origin (exotic versus native) or flood tolerance (tolerant or intolerant) because many of the tolerant species were native. There were differences in flood-tolerant and flood-intolerant taxon richness by geomorphic feature (Figure 3.8.3). Significantly more flood-tolerant than flood-intolerant taxa were recorded for bar samples: 4 ± 1 vs 2 ± 0. Similar numbers of flood-tolerant and flood-intolerant taxa were recorded for bench samples: 4 ± 1 vs 3 ± 0. Conversely, floodplain samples contained fewer flood-tolerant taxa than flood-intolerant taxa: 2 ± 0 vs 4 ± 1.
  There were greater abundances of flood-tolerant than flood intolerant-seedlings overall ($p < 0.001$). There was also a significant interaction between feature and tolerance ($p < 0.001$). Much greater abundances of flood-tolerant than flood-intolerant seedlings were recorded for bar (70 ± 15 vs 5 ± 1) and bench (85 ± 19 vs 5 ± 2) samples, while abundances for floodplain samples were similar (15 ± 3 vs 13 ± 3).

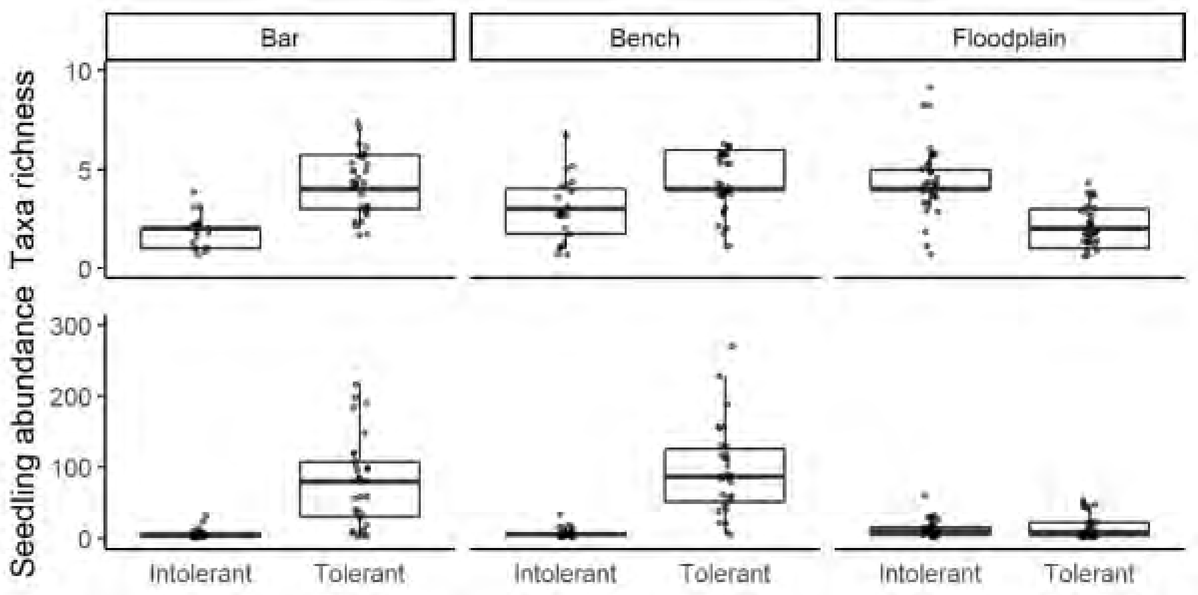



**Figure 3.8.3** Boxplots of flood-intolerant and tolerant taxa richness (top) and seedling abundance (bottom) and per sample for each of the three geomorphic features (pooling across all sites). Bold lines represent median values, boxes indicate the interquartile range (25th to 75th percentiles) and whisker lengths are 1.5 times the interquartile range.

### 3.8.5 Conclusions and implications for flow management

As hypothesised, we found that propagules of native flood-tolerant taxa dominated the seedbanks of in-channel features in a heavily regulated river subject to environmental flows. Conversely, exotic pasture grasses and other terrestrial species were less common in the soil seedbank of in-channel features. In summary, our results indicate that:

- Soil seedbanks were larger in frequently flooded geomorphic features than in less frequently flooded features.
- While the species richness of the soil seedbank across these geomorphic gradients were similar, species-level patterns differed. Frequently flooded sites were dominated by highly abundant annuals and small-seeded monocots (particularly sedges and rushes), while perennial grasses were more common at infrequently flooded sites.
- Flood-tolerant taxa were more common in the soil seedbanks of in-channel features than in floodplain soil seedbanks.
- Native taxa predominated in the soil seedbank of in-channel features.
- Exotic species were generally associated with areas that had less frequent flooding (i.e. floodplains).

These findings imply that the environmental flows currently used to discourage the growth of terrestrial exotic species within the channel appear to be successful, and that they may also be helping to maintain some level of resilience of the native riparian vegetation populations by reducing competition. Furthermore, strategic increases to the frequency, depth, duration and further consideration of the timing of flow releases may help to encourage the establishment of native riparian vegetation, particularly within the channel of systems with a soil seedbank dominated by native flood tolerant species. Conversely, the majority of exotic taxa identified in this study were flood-intolerant, so increases in environmental flows may further decrease the extent of such species and, ideally, confine them to the floodplain (Miller et al. 2013).

## 3.9 Riparian vegetation responses to livestock grazing and grazing exclusion in regulated rivers

KEQ 5: other factors (livestock grazing)

This project was conducted as a case study for the effects of livestock grazing on waterway vegetation. The proof of concept design was important to determine the logistics of installing and maintaining structures within a flowing water system and to determine recovery processes with known exclusion treatment. This case study is fully summarised here and is not expanded upon further within the Supplementary Material, but the data from within these transects are incorporated into the study summarised in Chapter 3.5.

### 3.9.1 Context

Grazing by livestock remains one of the greatest threats to the health of waterways in south-eastern Australia, causing substantial direct and indirect impacts to vegetation and ecosystem functions (Robertson and Rowling 2002; Hansen et al. 2019). Livestock can impact riparian vegetation through the consumption of plants as well as trampling, leading to shifts in plant community composition towards domination by exotic species, declines in overall vegetation cover and an increase in bare ground, and reductions in native species recruitment (Robertson and Rowling 2002; Jones and Vesk 2016). The degree of impact depends on a range of factors, including livestock density, the timing and duration of grazing, livestock access to watering points and shade, and the species of grazer, as well as local environmental factors such as site productivity and rainfall (Jansen and Robertson 2001; Robertson and Rowling 2002; Lunt et al. 2007; Jones and Vesk 2016).

In Victoria, most waterways have some areas of frontage with livestock access. For example, on the Campaspe River approximately 25% of the total frontage between reaches 1 and 5 is covered by a grazing licence (Darren White, NCCMA, pers. comm.). In waterways where environmental flows are delivered to improve and maintain the health and function of riparian vegetation, a key knowledge gap is the effectiveness of these flows where livestock grazing is present. Additionally, it is unclear how riparian vegetation in a regulated waterway responds if grazing pressure is removed. As part of the vegetation component of VEFMAP Stage 6, these knowledge gaps have been investigated through the installation of grazing exclosures at a number of sites along regulated rivers that receive environmental flows and where livestock grazing is present.

This section describes the field experiments for grazing exclusion in Stage 6 and presents results illustrating rates and magnitude of vegetation recovery once livestock are excluded. A broader analysis of how environmental flow responses are influenced by livestock grazing across many sites where livestock grazing is present or absent is provided in Section 3.5.

### 3.9.2 Aims and hypotheses

The aim of the study was to identify how livestock grazing may be impacting the response of riparian vegetation in regulated waterways to environmental flows. We tested a series of hypotheses using grazing exclosures installed at sites with current livestock grazing:

- Sites with livestock access will have higher riparian vegetation cover inside the exclosure compared to outside.
- The difference between riparian vegetation cover inside and outside of exclosures will be greater at sites with higher levels of grazing intensity or higher productivity (rainfall or flow).
- Native riparian vegetation cover will not increase on banks that receive environmental flows and have livestock grazing present.
- The relative recovery of native or exotic vegetation within exclosures will depend on the initial vegetation conditions of the site.

### 3.9.3 Methods

We installed ten grazing exclosures across five sites on three waterways, with each grazing exclosure plot paired with an adjacent control plot (Figure 3.9.1). Each plot contained one survey transect. The methods for vegetation surveys following DELWP (2017). Grazing intensity for each site was recorded on a relative scale from low to very high based on discussion with waterway managers and landholders (Table 3.9.1), because quantifying grazing pressure in a more explicit way was beyond the scope of this study.

Three surveys per water year were conducted at each site, each roughly corresponding to spring, summer and autumn. For sites with multiple years of surveys, the timing of the surveys was repeated for each year.

**Table 3.9.1.** Details of the grazing exclosures.

| Waterway | Site | Mean annual rainfall | Number of exclosure pairs | Date installed | Number of surveys | Grazing intensity | Grazer |
|---|---|---|---|---|---|---|---|
| Campaspe River | Strathallan | 441.9[A] | 2* | Dec 2016 | 11 | Very high | Sheep |
| Campaspe River | Doaks | 441.9[A] | 2 | Dec 2016 | 12 | Light | Cattle |
| Campaspe River | English | 441.9[A] | 2 | Nov 2017 | 11 | Light | Cattle |
| Glenelg River | Weavers | 652.0[B] | 2 | Nov 2018 | 5 | DS: High<br>US: Moderate | Cattle<br>Cattle |
| Yarra River | Tarrawarra | 741.8[C] | 2 | Nov 2018 | 3 | High | Cattle |

* The fencing of one of the exclosure plots at Strathallan was destroyed by a falling tree between November 2017 and January 2018, after which the exclosure pair was no longer surveyed. Rainfall stations: [A] Rochester, [B] Casterton, [C] Healesville (Badger Creek Sanctuary).

The exclosures were designed to prevent grazing by livestock, deer, macropods and rabbits. However, discussions with waterway managers and landholders around each site suggested that livestock grazing pressure was by far the most significant grazing pressure at the study sites, which also corresponded with our field observations of herbivory and scats. Exclosure size ranged from about 8 × 8 m to 15 × 10 m, depending on the space available at each site.

**Figure 3.9.1** Grazing exclosure on the Yarra River in 2018.

### 3.9.4 Results

*Campaspe River*

Native vegetation cover at the very heavily grazed Strathallan site increased inside the exclosure over time from a baseline of about 15% at the commencement of the study (Figure 3.9.2, Figure 3.9.3). By the final survey, this difference in cover between the exclosure and the control plot was maintained across the elevation gradient surveyed. In the control plot there was no noticeable increase in native vegetation cover across the section of bank watered by the spring fresh (Figure 3.9.2).

Although some exotic species were present, the vegetation inside the exclosure continued to be dominated by native vegetation throughout the survey period (Figure 3.9.2). This exclosure was on a relatively steep bank and therefore has much less surface soil moisture retention than other sites.

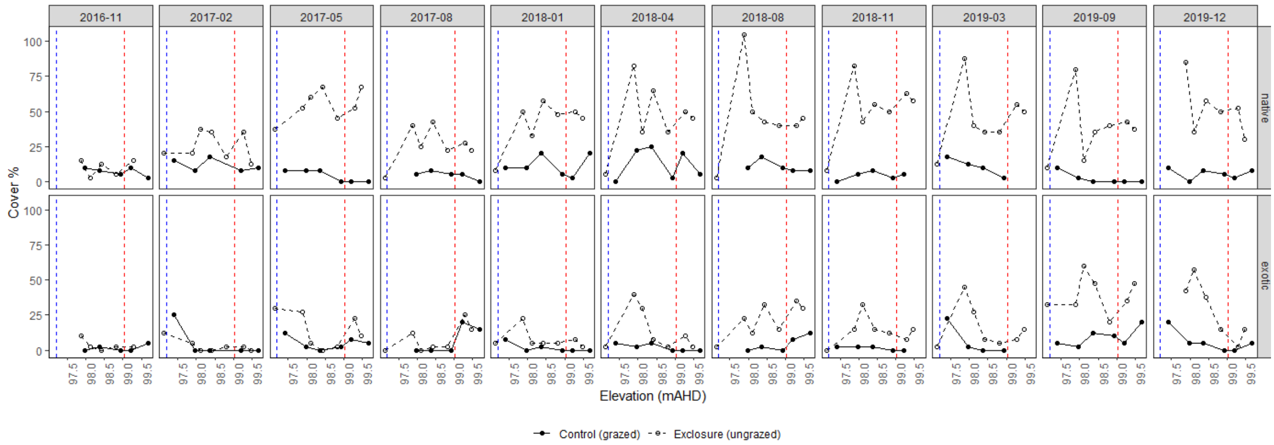



**Figure 3.9.2** Change in vegetation cover of native and exotic species at Strathallan, comparing trends across each survey date for the exclosure (ungrazed) and control plot (grazed). Vertical red dotted lines indicate the levels of spring freshes, and vertical blue dotted lines indicate the levels of baseflows.

**Figure 3.9.3** Comparison of vegetation between the inside and outside areas of the exclosure at Strathallan in December 2020, three years after installation.

At the more lightly grazed Doaks site, native species cover inside and outside of the upstream grazing exclosure remained similar (Figure 3.9.4, Figure 3.9.5). Exotic species cover increased in the exclosure along some parts of the elevation gradient surveyed from September 2017 onwards, although this difference was less evident in the most recent surveys.

At the downstream grazing exclosure, where the gradient of the bank slope is initially very flat, native species cover increased inside the exclosure compared to the control plot, although the degree difference varied between surveys and elevation along the bank. *Acacia* spp. (Wattles) that colonised the sandy bar at the second exclosure were subsequently killed by inundation, given that they are not sufficiently tolerant of inundation. In contrast, *Eucalyptus camaldulensis* (River Red Gum) seedlings that recruited in the same locations survived the same inundations and are now well-established saplings (in the upstream, Figure 3.9.5, and downstream exclosures at this site).

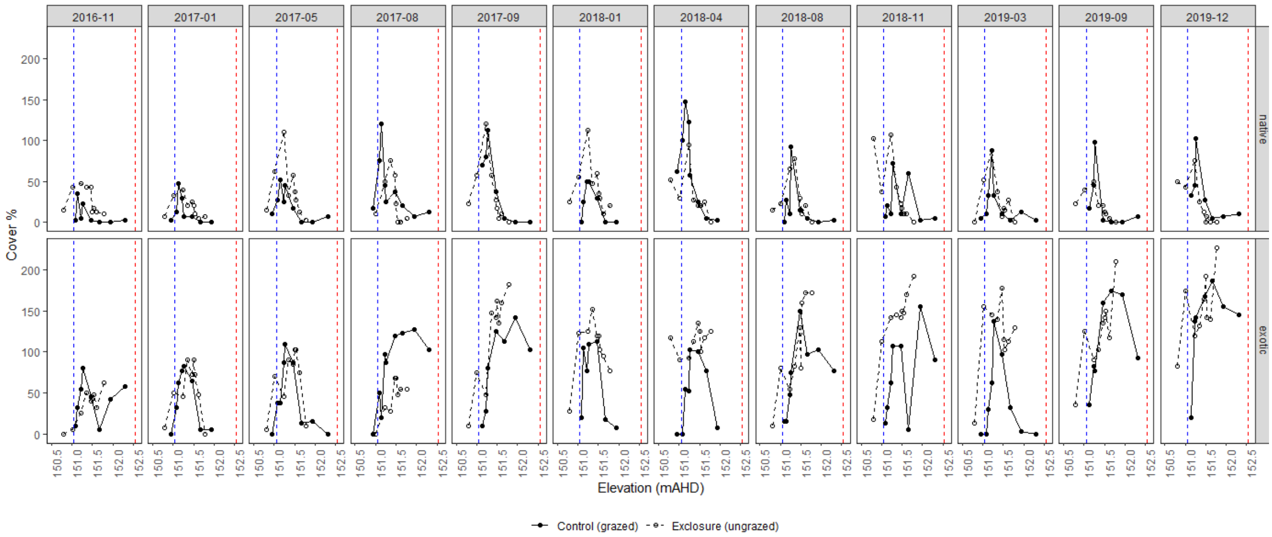



**Figure 3.9.4** Change in vegetation cover of native and exotic species at Doaks (upstream), comparing trends across each survey in the exclosure (ungrazed) and control plot (grazed). Vertical red dotted lines indicate the levels of spring freshes, and vertical blue dotted lines indicate the levels of baseflows.

**Figure 3.9.5** Comparison of vegetation between the inside and outside areas of the exclosure at the Doaks upstream site in December 2020, three years after installation.

At the English site, which was also lightly grazed, native species cover remained at similar levels inside and outside the upstream grazing exclosure (Figure 3.9.6). Although there was an increase in native species cover within the exclosure at the highest elevations surveyed during two surveys (December 2018 and September 2019), the differences were not consistently different from the controls. In contrast, from the January 2018 survey onwards, exotic species cover increased dramatically inside the exclosure at the higher elevations surveyed and to a lesser extent the same outside (Figure 3.9.6). Being above the fresh level, this vegetation was dominated by terrestrial species.

In comparison, the downstream exclosure at this site had a much greater increase in native species cover inside the exclosures, because of colonisation by native riparian species. Large increases in exotic species also occurred at the higher elevations, mostly dominated by terrestrial species (not shown).

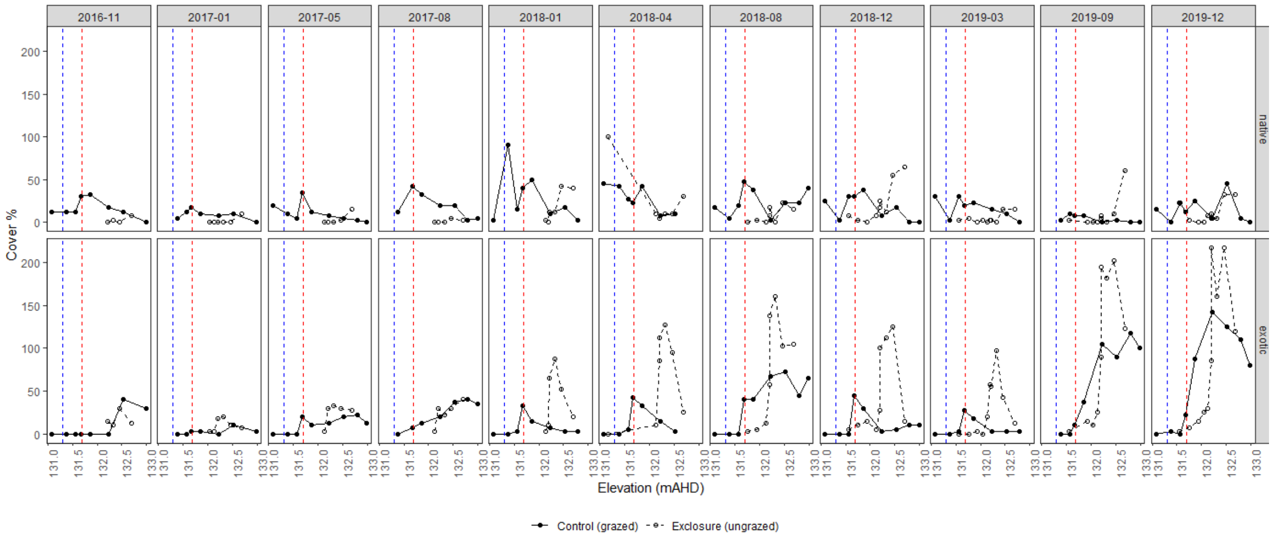



**Figure 3.9.6** Change in vegetation cover of native and exotic species at the English upstream site, comparing trends across each survey in the exclosure (ungrazed) and control plot (grazed).

*Glenelg River*

At the Weavers site there was no clearly consistent difference in native species cover between the exclosure and the control plot at the more heavily grazed downstream site, although during the last survey exotic species cover was higher in the exclosure at higher elevations (Figure 3.9.7). However, by the third survey there were already signs of plant expansion in the upper elevations (*Rytidosperma* sp. and *Hemarthria uncinata*) and colonisation of the bank on the water margin by the emergent *Typha domingensis* (Figure 3.9.8). These patterns are only mildly represented in the data within survey 5 but we expect the subsequent growth of these species to be far greater in the next 6-12 months now that colonisation has occurred. At the more moderately grazed upstream exclosure pair, there was no clearly consistent difference in either native or exotic species cover at this early stage of recovery (not shown).

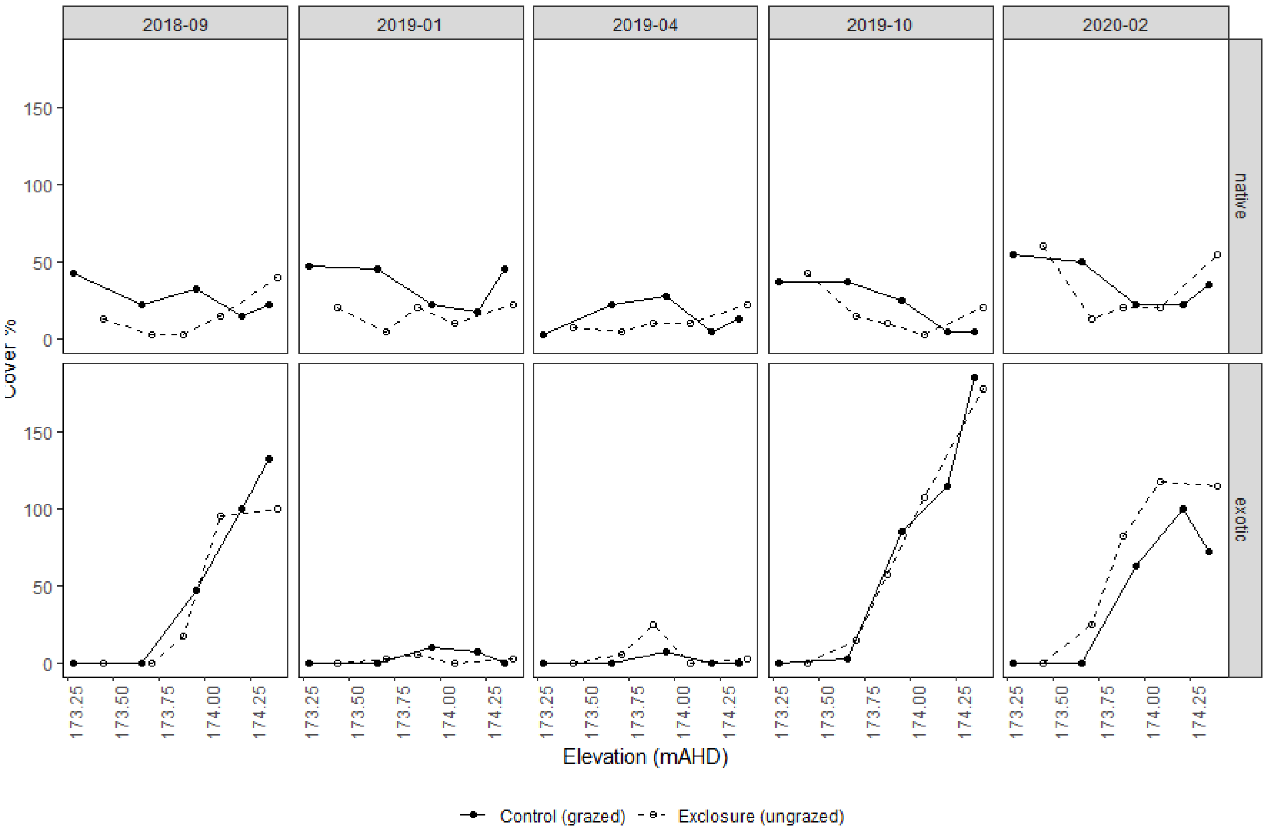



**Figure 3.9.7** Change in vegetation cover of native and exotic species at Weavers (downstream), comparing trends across each survey inside the exclosure (Treatment) and outside the exclosure (Control). No flow level data was available for this site.

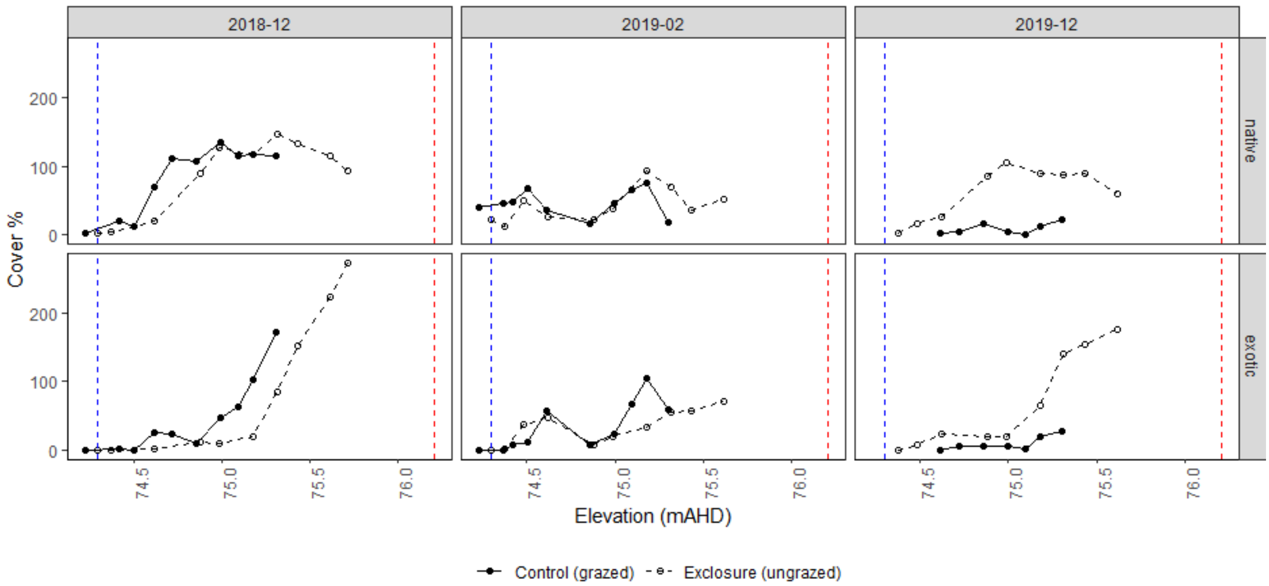
**Figure 3.9.8** Colonisation of native emergent vegetation (*Typha* and *Juncus*) inside the exclosure at the Weavers downstream site in December 2020, 15 months after installation.

*Yarra River*

At the heavily grazed Tarrawarra sites, native species cover in the upstream control plot increased over the survey period, while native species cover inside the exclosure remained at similar levels, resulting in a divergence in cover values in the third survey (Figure 3.9.9A). A similar pattern was evident in exotic species cover at the highest elevation surveyed. The second survey (autumn) showed a natural, seasonal decline in plant cover compared to the growth seasons in spring and summer.

At the downstream site, by the third survey native species cover was higher inside the exclosure than the adjacent control plot but only in the middle portion of the transect surveyed (Figure 3.9.9B). In contrast, exotic species cover was consistently higher inside the exclosure compared to the outside control plot across the entire portion of the transect surveyed (Figure 3.9.9B). The corresponding decline in exotic cover where native cover was highest suggests competitive interactions at this location.

**A (upstream)**




**B (downstream)**

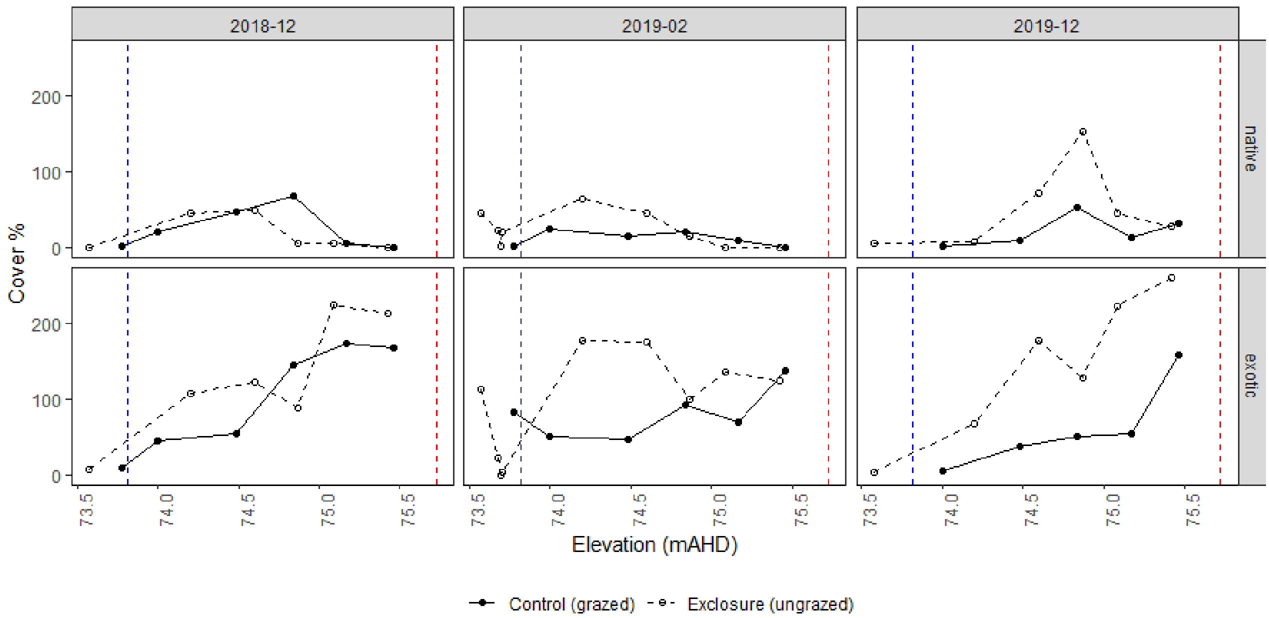



**Figure 3.9.9** Change in vegetation cover of native and exotic species at Tarrawarra (a) upstream and (b) downstream, comparing trends across each survey inside the exclosure (Treatment) and outside the exclosure (Control). Exclosures were installed on the second survey after the first survey had taken place.

### 3.9.5 Conclusions and implications for flow management

- This study presents data showing that high livestock grazing pressure is detrimental to native vegetation condition (represented here by cover). Environmental flows are unlikely to provide positive outcomes for native vegetation at sites with high livestock grazing pressure. However, environmental flows can have an important role in vegetation recovery if grazing is removed. Environmental flows are also likely to support riparian vegetation condition in areas with light grazing intensity.
- The varied responses in native versus exotic vegetation recovery following grazing exclusion suggests that the response trajectories are dependent on the productivity (rainfall), flow and initial vegetation condition. Drier catchments may be more likely to have native riparian vegetation dominance, where the dominant exotic species are terrestrial and sensitive to inundation. In these catchments, environmental flows can play an even greater role in native vegetation recovery.
- Data from higher rainfall catchments (Tarrawarra sites on the Yarra River) suggest that areas with higher productivity may have a greater response rate to livestock exclusion, but also a high pressure of exotic species. Large numbers of plant recruits have been observed at these sites and we expect subsequent changes to be rapid and large.
- Where livestock grazing is excluded above the level of environmental flows, there is a high likelihood of exotic terrestrial vegetation colonisation in disturbed river frontages. Below the environmental flow levels, exotic species that are tolerant of floods can dominate frontages, particularly in higher rainfall catchments. In these cases, additional management actions may be needed to help guide native vegetation recovery, particularly actions that provide conditions for native species to regain competitive advantages over exotic species. For example, a staged reduction in livestock density and/or duration, with periods of access timed to detrimentally impact weed species (i.e. to prevent them from flowering and/or setting seed), may result in a better outcome for any remaining indigenous vegetation. Ongoing monitoring coupled with an adaptive management program is an essential part of this process.
- This case study lends support to all four of our hypotheses on the effect of grazing on riparian vegetation cover. However, differences in native and exotic species cover between the exclosures and control plots were not clearly evident or consistent at all sites. This may be due to these sites having a lower grazing intensity and therefore reduced impacts on vegetation cover. However, recovery of riparian vegetation after stock exclusion can take years to decades (Robertson and Rowling 2002), and differences may therefore become more evident with time.

Overall, these results suggest that with appropriate environmental flows and reducing livestock access, particularly where grazing intensity has been high, Victoria could have large and widespread riparian vegetation gains. In many places riparian vegetation gains would be dominated by native species, but in others additional management actions may be required to reinstate native species to degraded sites. Expanding this study to include more replicates across a broader selection of sites with a range of quantifiable grazing intensities would help to determine the generality of these findings.

## 3.10 Understanding the links between environmental flows and soil moisture in regulated waterways, to improve vegetation condition

KEQ 2: emergent and KEQ 3: fringing and KEQ 5: other factors (soil moisture)

This section is a summary of a distinct part of the VEFMAP vegetation monitoring plan to evaluate soil moisture responses to flow and to then draw preliminary implications for vegetation condition. The project includes contributions by students and researchers at The University of Melbourne and staff at Jacobs. This summary is based largely on the collaborative research study between ARI, Jacobs and waterway managers, as well some preliminary investigations done by three different student research projects.

**Supplementary Material 19**: Jones, C.S., Unland, N., Hoxley, G., Lovell, D., White, D., and Fletcher, G. (2020) Understanding the links between environmental flows and soil moisture in waterways to improve vegetation condition. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Hao, F., Huang, D. and Lilburne, P. (2017). A preliminary investigation into the modelled impact of environmental flows on soil moisture content of stream banks in the Wimmera region, Victoria. The University of Melbourne, Masters research project thesis, Australia.

Hu, K., Lin, A. and Liu, C. (2017). Soil analysis and modelling of soil moisture response to environmental flow in the riparian zone of the Campaspe River. The University of Melbourne, Masters research project thesis, Australia.

Zhou, L., Luo, H., and Zuo, D. (2018) Understanding Soil Moisture Changes in Riparian Zones. The University of Melbourne, Masters research project thesis, Australia.

### 3.10.1 Context

One of the primary objectives for environmental flows is to provide water to parts of the channel that are not inundated by low flows, such as higher banks, instream benches and, in some cases, floodplains. Higher flows such as freshes may simultaneously provide a surface water disturbance/resource and a groundwater disturbance/resource. Surface water can have direct effects on biota, depending on the depth and duration of flow, as discussed in earlier sections of this report. But the influence of flows on groundwater in or immediately adjacent to the waterway channel and the subsequent influences on biota are poorly understood – despite being commonly stated as an environmental management objective for riparian vegetation. Indeed, ground water is a critically important resources for ecosystem processes, particularly in drylands (e.g. Robinson et al. 2008). The provision of ground water (or more generally, soil water) as a vegetation management objective is aimed at reducing the risk of plant mortality due to drying, stimulating germination and to increase the available resources for plant growth and reproduction. Groundwater and soil water act as a critical store of water for vegetation. Through slow flow processes groundwater can also be a store for future stream flow via floodplain recharge and bank return flows (e.g. Unland et al. 2014).

To understand the influence of flows on vegetation through groundwater changes, it is useful to understand how the waterway flows and the delivery of environmental flows influences soil moisture within the channel at depths accessible to vegetation. Recent advances in technology has made this type of research increasingly possible, particularly at the point scale (Robinson et al. 2008). However, this technology is rarely used for evaluating environmental responses to managed flows and a vast set of knowledge gaps remains for these processes.

Once we have an understanding of how flows influence groundwater levels, it is possible to evaluate how flows may influence vegetation via groundwater provision. Recent research has provided valuable insights into the water use of deep rooted trees in relation to river flows or floodplain inundation (Doody et al. 2015), but little is known about how groundwater and soil water changes may influence understorey (ground layer) vegetation that relies on soil moisture closer to the surface.

### 3.10.2 Aims and hypotheses

To address these knowledge gaps, we conducted a study to directly monitor and quantify responses of soil moisture in river channels in relation to environmental flows and used this to evaluate the potential influences of flows on vegetation through ground water changes. We aimed to develop an understanding of the soil moisture responses to environmental conditions in the riparian zone (such as stream flow, rainfall and evapotranspiration) to form an assessment of how flows may influence plant recruitment and the growth of shallow-rooted riparian plants.

Our specific questions were:

- How does river flow (particularly environmental flow events) alter the soil moisture levels in the adjacent riverbank, with regard to infiltration, evaporation, saturation, persistence, etc.?
- Given the soil moisture responses to flows, what are the implications for managers seeking to improve vegetation condition through flow management and environmental flow allocations?

Our hypotheses were:

- Soil moisture responses to environmental flows will vary between sites, depending on soil attributes, flow attributes, seasonal conditions and other factors.
- Soil moisture provided by flows will increase the available water resources to shallow rooted plants, in a way that is beneficial to plant health or populations.
- Flow manipulation may be used to increase the potential benefits of soil moisture provision to vegetation.

### 3.10.3 Methods

*Study sites*

Soil moisture data were recorded for different durations at nine sites within Victoria from 2016 to 2020 (and ongoing) through VEFMAP Stage 6. The sites were located on the Campaspe River, Goulburn River and three tributaries of the Wimmera River (Table 3.10.1). Site selection was based on existing or previous VEFMAP vegetation survey sites, and sites were stratified to cover a range of soil and flow conditions in the northern, lower rainfall region of Victoria and the most southern part of the Murray–Darling Basin.

**Table 3.10.1** Soil moisture recording sites during VEFMAP Stage 6.

| Site | Waterway | CMA | Period |
|---|---|---|---|
| Doaks Reserve | Campaspe River | NCCMA | Dec 2016 – ongoing |
| Bryants Lane | Campaspe River | NCCMA | Dec 2016 – ongoing |
| Strathallan Road | Campaspe River | NCCMA | Dec 2016 – ongoing |
| McCoys Bridge | Goulburn River | GBCMA | Dec 2016 – ongoing |
| Loch Gary | Goulburn River | GBCMA | Dec 2016 – 2018 |
| Roses Gap | Mt William Creek | WCMA | Jun 2017 – Dec 2017 |
| Peuckers Road | Burnt Creek | WCMA | Jun 2017 – ongoing |
| Wonwondah Gauge | Burnt Creek | WCMA | Dec 2017 – ongoing |
| NE Wonwondah Rd | MacKenzie River | WCMA | Mar 2019 – ongoing |

*Soil moisture data monitoring*

Soil moisture probes were installed in array pairs at each site, one at a low bank elevation and one at a high bank elevation (Figure 3.10.1). Sixteen arrays were installed at eight sites at any one time but some were shifted or were damaged and required repair. Array locations were recorded with high-accuracy GPS measurements of vertical and horizontal position. Monitoring used 90 cm long Sentek Drill & Drop Probe arrays that recorded soil moisture and temperature every hour, at 10 cm intervals, from 5 to 85 cm depth. Data were recorded using a data logger and manually downloaded at 3–6 month intervals. Raw data were processed using the IrriMAX10 software program. Unfortunately, technical errors with some of the probes in 2018 meant that part of the soil moisture data collection are missing across all three systems.

Flow levels were derived from a combination of in situ data loggers and permanent gauges calibrated against surveyed water level elevations at each site. Sites where full flow data were not available were not compared to flow elevation (see Section 3.5.3 for more detail).

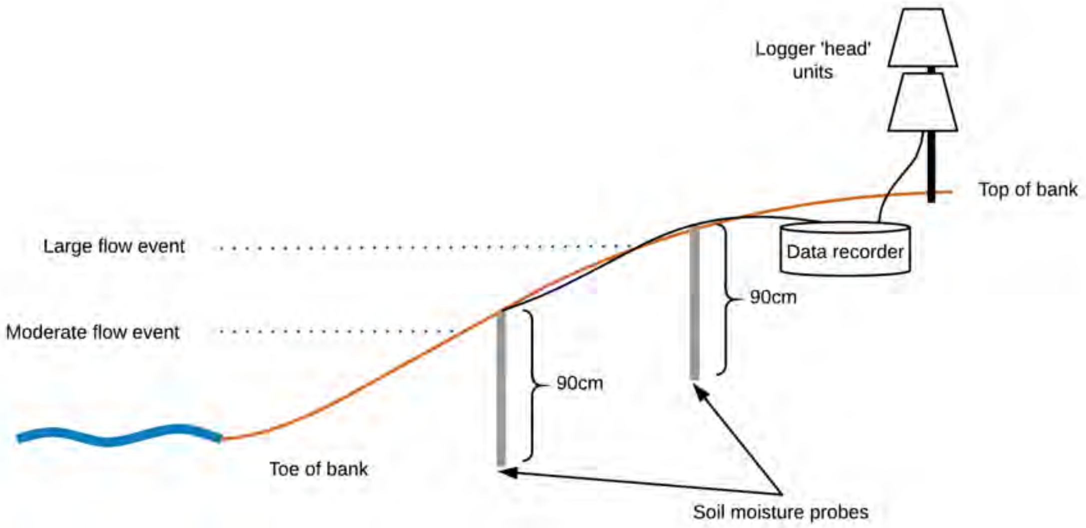



**Figure 3.10.1** Arrangement of soil moisture probe arrays on a waterway cross section in relation to hypothetical flow levels.

*Grain size and soil texture analysis*

Grain size and soil texture information was collected by student research groups from The University of Melbourne under the supervision of Justin Costelloe. Soil data were collected at all three Campaspe River sites but was not collected at monitoring locations within the Goulburn River catchment. Grainsize and soil texture classification was undertaken on soil samples collected at two locations on Mt William Creek and Burnt Creek in the Wimmera River Catchment.

Soil analysis processes are described in Hu et al. (2017), based on standard methods. Soil samples were collected immediately adjacent to the soil moisture probe locations. Grain size distribution, bulk density and porosity of soils were evaluated at 10 cm depth intervals to match the soil moisture sensors. Soil types were based on the analysis of grain size in soil cores collected at each site, as defined by Marshall (1947).

Full soil evaluation data are available in Hu et al. (2017) and Hao et al. (2017), and a summary of the results is provided in the Supplementary Material 19. At a coarse summary level here, the grain size classifications indicated that sandy loams were pervasive at all arrays on the Campaspe River and Wimmera River tributary sites, with additional gravels at Doaks.

*Data interpretation*

Prior to the analysis of soil moisture trends, soil moisture monitoring data (recorded as % moisture content) were corrected to % saturation. The % saturation value was calculated by dividing the recorded moisture content by the saturated water content (known as theta saturation or $\theta_s$) for the soil type at each monitoring point. The $\theta_s$ value for each monitoring point was subsequently calculated using water retention curves, as described by van Genuchten (1980). The saturation values used for each site are detailed in Supplementary Material 19.

In many monitoring records the saturation exceeded 100%. This does not appear to be related to inaccuracies in grain size analysis, as the maximum potential $\theta_s$ value for even heavy clays is 0.51 and would have been exceeded by the maximum moisture content recorded, resulting in saturation values over 100%. Instead, it is possible that saturation values over 100% are related to errors in the monitoring equipment at higher moisture content values. Alternatively, it is possible that disturbance of the soil profile upon installation created voids near the soil moisture probe, resulting in higher moisture content readings when the voids were filled upon saturation. For the purpose of this study, % saturation values of 100 or greater were treated as fully saturated.

Trends in soil moisture data at each site were then compared to environmental factors including rainfall and evapotranspiration (ET) to provide an assessment of the dominant factors driving soil moisture responses. Rainfall and evapotranspiration data were sourced from Bureau of Meteorology monitoring stations relevant to each river catchment.

### 3.10.4 Results

A summary of the findings for each monitoring site is provided below. Further information is provided in Supplementary Material 19. The terms Upper and Lower refer to the array positions higher and lower on the bank respectively.

*Campaspe River*

**Doaks**

- Soil moisture data at Doaks indicated that the soil profile below 15 cm depth at the lower probe array and 35 cm at the upper array was perennially saturated (Figures 3.10.2, 3.10.3). Since the elevation of these probes were below that of the stream level at this site, it is likely that the saturated probes were below the watertable.
- The upper 15 cm of the soil profile at the upper site was generally less than 20% saturated in January and June during 2017. However, at these depths, saturation increased to over 100% rapidly over hours to days during wetting events, before falling to pre-wetting saturation levels over a similar timeframe.
- Very shallow saturated conditions would mitigate against the development of deeper-rooted perennial plants, such as trees or shrubs unless highly tolerant of saturated soils. This is supported by the recruitment of *Acacia* species and River Red Gums at lower bank elevations but only River Red Gums surviving, e.g. Section 3.8.
- It is likely that there is active concentration of salts in surface soils, as the watertable is well within the capillary fringe and most likely within evaporative reach.
- Soil moisture is most likely not limiting vegetation establishment or growth at this site and enhanced flooding or inundation is not likely to result in significant change to the vegetation assemblage through the provision of groundwater resources.

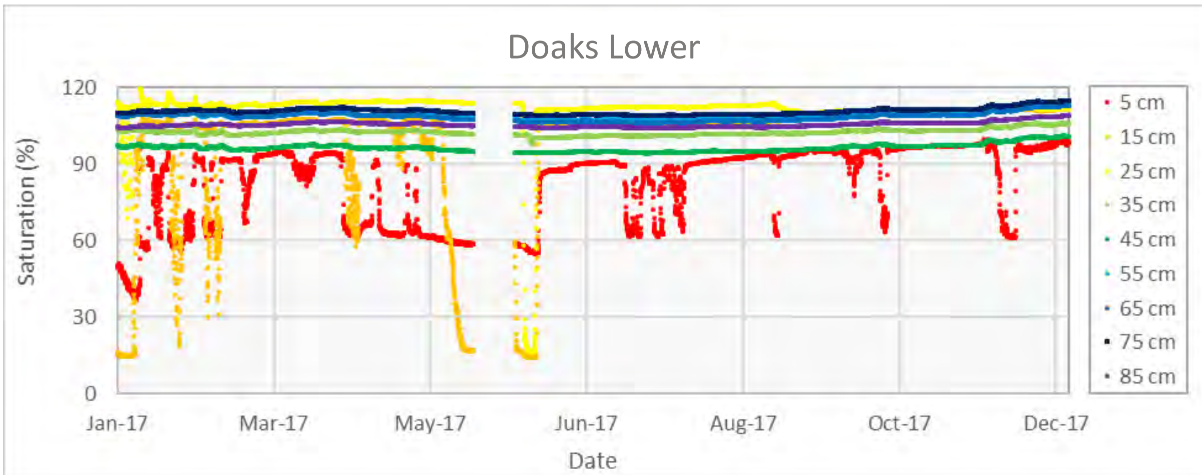



Figure 3.10.2 Soil moisture trends at Doaks Lower. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

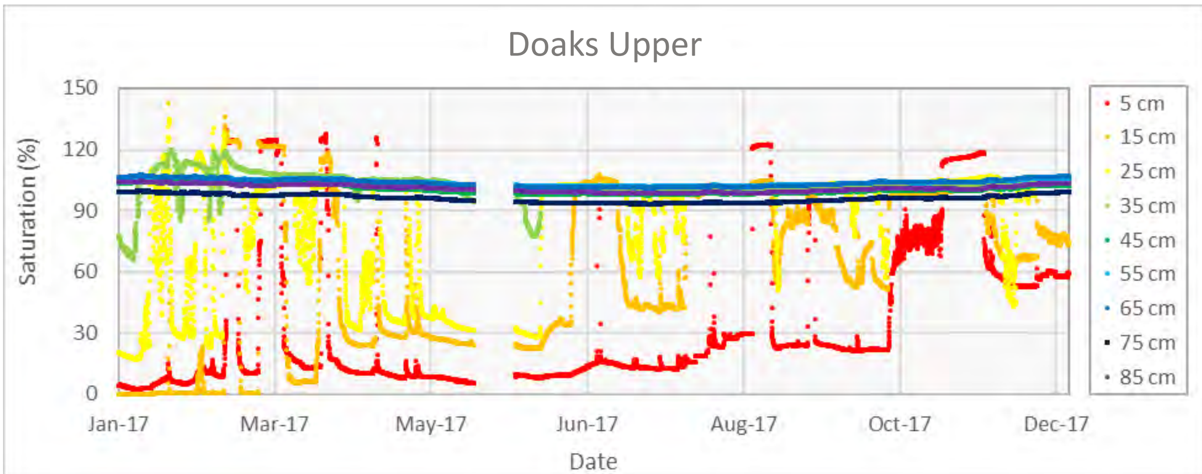



Figure 3.10.3 Soil moisture trends at Doaks Upper. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

**Bryants**

- There was adequate soil moisture available for use by most shallow-rooted vegetation over most of the monitored period.
- There were only short periods when the soil profile dried off in response to vegetative water use.
- At the upper site, the top of the profile was generally quite dry, and recharge events provided transient wetting.
- There was strong evidence that plants lower the deep soil moisture levels.
- Soil moisture is most likely not limiting mature vegetation growth at this site, but young or shallow-rooted plants may benefit from temporary resources (such as freshes) in drier periods.

**Strathallan**

- Very shallow saturated conditions would mitigate against the development of deeper-rooted perennial plants, such as trees or shrubs that are not adapted to saturated soils at the lower site.
- It is likely that there is an active concentration of salts at the surface or in surface soils, as the watertable is well within the capillary fringe and most likely within evaporative reach.
- At the upper site there is a persistent area of low moisture in the middle of the profile. This indicates that floods may not easily penetrate the surface clays at this site. As such, plants that are unable to develop roots to access the deeper water (> 80 cm deep) may struggle during dry conditions. Therefore, establishing a population of deep-rooted perennial species may be difficult at this site, but once developed they would be far more tolerant of drier conditions.
- Soil moisture is most likely not limiting vegetation establishment or growth at the lower site, but at higher elevations flows can be valuable to young or shallow rooted plants. These may not survive long periods between flows, so freshes may be important in years with high germination.

*Goulburn River*

**McCoys Bridge**

- Soil moisture levels at the deeper profiles retain elevated saturation levels in spring for 1–2 months, whereas the shallower profiles wet and dry much more rapidly, i.e. days to weeks (Figure 3.10.4).
- The soil profile at the Upper site was generally drier than at the Lower site, with soils averaging 41% saturation over the monitoring period compared to 78% saturation at the Lower site (Figure 3.10.5).
- Soil moisture profiles did not appear to dry out, and there appeared to be water available to plants at all points in the profile across the monitored period (e.g. Figure 3.10.4). This is interpreted to be the effect of capillary rise from the relatively shallow watertable.
- The soil profile responds relatively quickly, with wetting and drying events occurring rapidly. It appears that the soil moisture response is dominated by drainage and not by plant water uptake.
- Flows in this area may provide relatively modest benefits to plants.

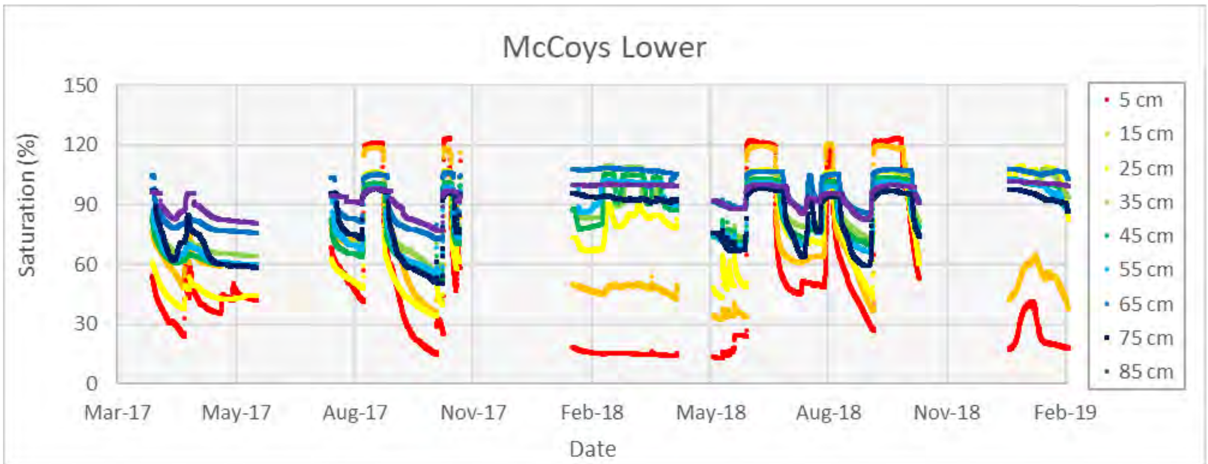



**Figure 3.10.4** Soil moisture trends at McCoys Bridge Lower. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

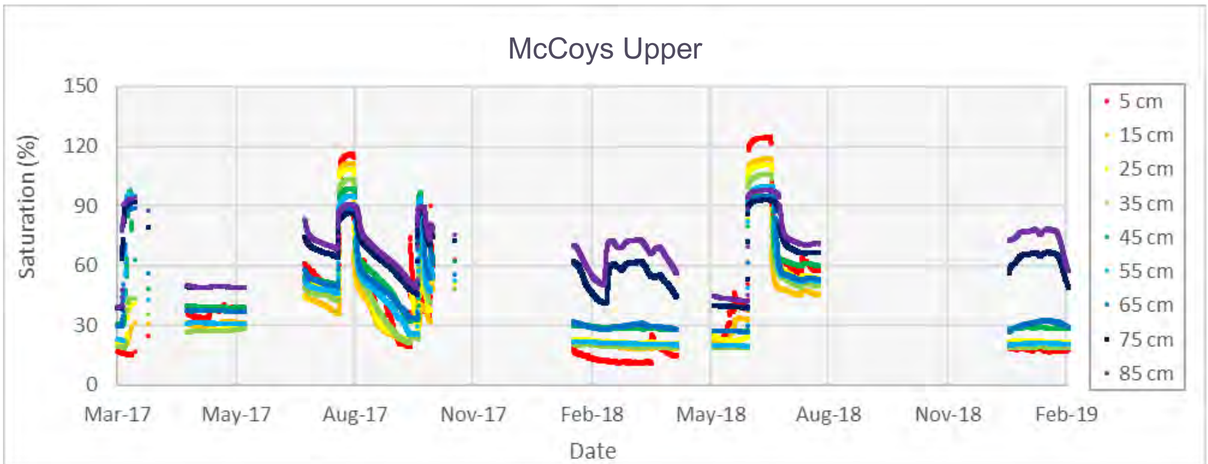



**Figure 3.10.5** Soil moisture trends at McCoys Bridge Upper. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

**Loch Gary**

- There is a large difference in the vegetation cover and composition between the McCoys Bridge and Loch Gary sites on the Goulburn River, with high cover at McCoys and very low cover at Loch Gary.
- Given the apparent fine-grained nature of the profile, it appears that there is very slow water penetration or drainage. Soil moisture declines slowly over time after flows, which indicates that there is potential availability of moisture for plants over many months. However, these soils may provide only a relatively small volume of accessible water in the root zone, so regular flows may assist plant persistence.
- This site may benefit from regular flows to keep plant-available water at high levels, but it appears that flows do not penetrate easily to depth and that the slow response of the deeper profile moisture might be related to wicking upward in response to higher plant root use.

*Wimmera River tributaries*

**Burnt Creek: Peuckers**

- It appears that there is very slow water penetration or drainage at this site. Soil moisture declined slowly over time after flows, which indicates that there is potential availability of moisture for plants over many months due to the semi-permanent pool near the probe (Figures 3.10.6 and 3.10.7). However, these soils may only provide a relatively small volume of accessible water in the root zone.
- The surface soils are very dry, but at shallow depth (15 cm) there is reasonable soil moisture, so that deep-rooted plants, once established, are likely to persist during dry conditions.
    - Short flow periods (several weeks) provide only short moisture availability in spring. Flows may be important for the establishment of young plants.

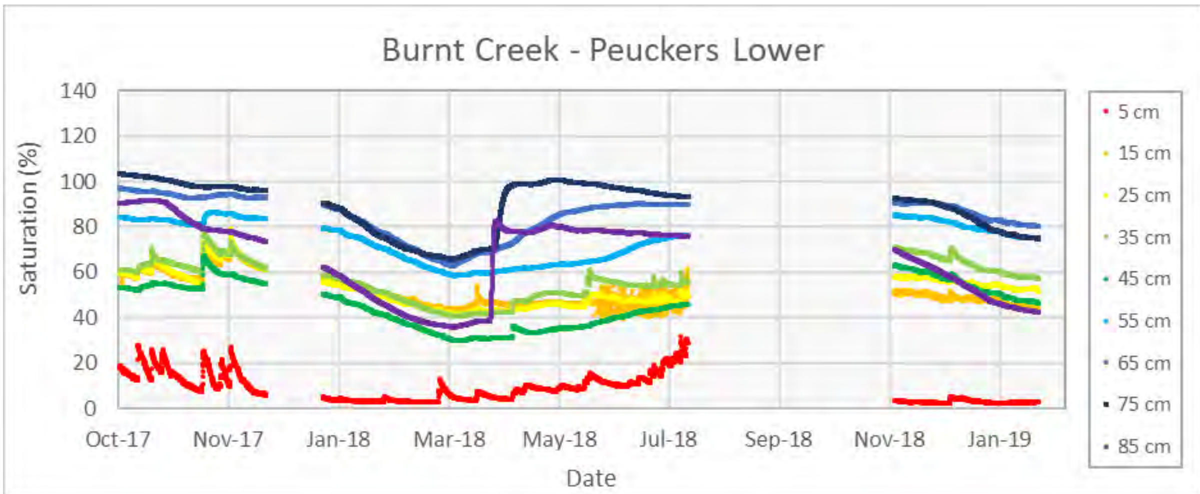



**Figure 3.10.6** Soil moisture trends at Burnt Creek – Peuckers Lower. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

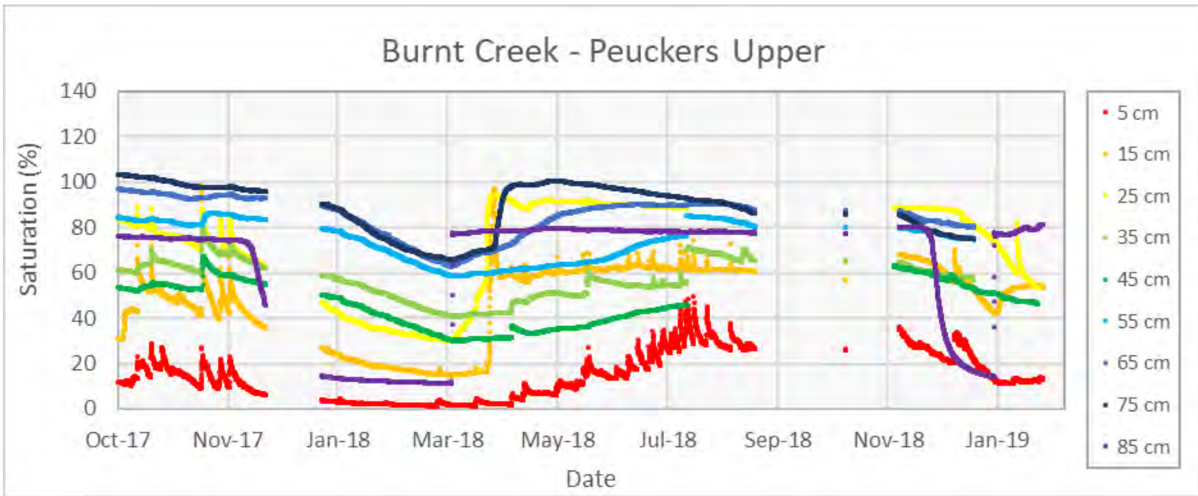



**Figure 3.10.7.** Soil moisture trends at Burnt Creek – Peuckers Upper. Each line indicates the saturation level at a different probe in the array at different depths from 5 to 85 cm below the soil surface.

**Burnt Creek: Wonwondah Gauge**

- The Lower site appears to show mid-profile water use that is drying the profile while a shallow wetting event is occurring, which may be influenced by the high proportion of shrubs with roots down to moderate depths.
- Short flow periods provide only short moisture availability in spring. Flows may be important for the establishment of young plants.

**Mt William Creek: Roses Gap**

- Because of the short span of monitoring data at the Mt William Creek site, soil moisture trends could be assessed only for summer conditions.
- The upper part of the profile is very dry because of a very high sand content. Combined with the steep bank position, this makes it very difficult for plants to become established and for environmental flows to provide sufficient soil moisture benefits.

## 3.10.5 Conclusions and implications for flow management

Overall, these results indicate that there are mixed responses of soil moisture to flows on each of the waterways, which can be explained in most cases by soil type, vegetation abundance, rainfall, season and depth of watertable. While vegetation at some sites and bank elevations stand to gain little benefit from soil moisture increases provided from flows, some sites and vegetation types may benefit considerably from increased soil moisture. In particular, young shallow-rooted plants may benefit at many sites by the short-term provision of soil moisture in spring or summer as rainfall levels decline. While this may not influence annual management at some sites, waterway managers may consider additional short-term freshes (spring or summer, depending on rainfall) in years with large recruitment events, such as after natural floods. Careful consideration of the potential negative effects of regular inundation need to be considered as well as the need for some flow components to be of a sufficient duration for other purposes, e.g. fish migration. Summer flows need to be very brief because of the high sensitivity of plants to summer inundation (Vivian et al. 2020) and the potential negative impacts on plant reproduction.

Importantly, these influences consider only the effects of groundwater on plants, not the simultaneous influences of surface flows that may be providing other benefits or disturbances to vegetation. For example, a summer fresh event or irrigation flow may simultaneously provide below ground water resources that may be scarce (benefit), while damaging the plant leaf material and potentially reproductive output (disbenefit) as described in Section 3.6. These competing influences are expanded upon more fully in the Supplementary Material and will be further investigated in the next stage of VEFMAP.

## 3.11 Summation of findings

### 3.11.1 Outcomes

Monitoring approaches used in VEFMAP Stage 6 have provided a wealth of information regarding vegetation responses to stream flow management. Combining data collection in the short-term (< 1 year) in five systems and mid-term (2–4 years) in two systems, and timing surveys around flow events, has allowed evaluation of individual flow events and regimes of events that are essential for guiding flow management. Unfortunately, there was a paucity of long-term vegetation data with which to integrate Stage 6 vegetation data, due to limitations in data availability and quality from previous stages. However, the methods developed in Stage 6 were designed to provide data that can be collected in a repeatable, quantitative, comparable and targeted way for sustained long-term monitoring into the future. Importantly, the vegetation monitoring process comprised a wide range of approaches, including detailed objective and repeatable sampling of common target vegetation attributes (cover, extent and diversity), as well as spatial mapping data, in-situ and ex-situ experiments and logging of above and below-ground hydrology. This combination of approaches has provided a rich pool of data and observations that combine to enable a comprehensive understanding of vegetation responses to flow management and also identify remaining and emerging knowledge gaps.

Vegetation transects and quadrats from over 222 site surveys at 44 sites in seven river systems were used to collect quantitative data to link species level cover, abundance and presence on a gradient of bank elevations in relation to river flow. Sites were sampled before and after major flow events in an 'event-style' monitoring approach. Vegetation data at both this temporal and spatial scale is unique for rivers in Victoria and provides an extensive plant species level dataset to interrogate subtle species- and site-specific responses to environmental flows; additionally, the data can be pooled into broader categories, such as plant functional groups, to generalise throughout reaches and across rivers. The 44 sites across seven catchment systems span a wide climatic gradient, allowing insights into how vegetation, river flow and rainfall interact. These data provide crucial information for informing all five KEQs outlined for Stage 6 vegetation theme.

In addition to fine-scale quantitative data collection, broader-scale vegetation mapping was also conducted on stretches up to 1 km long in each waterway. These data enabled us to rapidly assess vegetation diversity and extent (but not cover) during one snapshot in time and provided a broad site-based context within which to embed the finer scale quantitative transect data. Vegetation mapping is a useful tool for identifying large areas of interest such as high-threat weeds, channel invasions of terrestrial species, and large hydrological features. Vegetation maps have limited application for some aspects of the KEQs, but they are an important source of baseline data that can be used for long-term comparisons that are cost efficient relative to the fine-scale data collection. Together with photo points, vegetation maps are also crucial communication tools that can be used to easily communicate the broad vegetation condition at sites to waterway managers and the public.

Where possible, we maximised collaboration between the fish and vegetation themes in Stage 6. The Wimmera sites provided an opportunity to evaluate interactions between fish and vegetation, by pairing fish and vegetation data in a subset of sites. This approach is valuable as it allows a new level of ecological complexity in flow monitoring research. These sites also provided a template for integrating fish and vegetation monitoring in future research.

On-site and ex-situ experiments were critical components of the Stage 6 vegetation theme. These experiments were used to specifically target aspects of all five KEQs relating to growth and survival of riparian vegetation as well as researching other environmental and management actions that may interact with environmental flows to influence riparian vegetation condition. On-site livestock grazing and Carp exclosure experiments were conducted, as well as ex-situ seedbank and nursery experiments in collaboration with students and researchers at The University of Melbourne. These experiments were a relatively small component of the overall vegetation program funding, yet added considerable value to this research, in part because of their very targeted nature but also because much of the ex situ work was integrated into student research projects.

Hydrology is a crucial component of any flow evaluation research, and there has been a focus on a variety of data collection methods to address hydrology in Stage 6. Combining hydrological modelling concerned with overbank flow with soil moisture probes targeted below ground hydrology, as well as monitoring rivers across wide natural temperature and climate gradients has proven to be a valuable approach for understanding flow management and associated physical processes. The rich hydrological data gathered underpins analyses relating to all KEQs and has also been useful for developing strong relationships and collaborations with CMA personnel, as they were actively engaged to collect and evaluate soil moisture data.

It is important for all scientific research to be reproducible and transparent, particularly so for publicly funded research. During Stage 6 we have formed a collaboration with university researchers to develop and implement best practice approaches for conducting reproducible and transparent science and data analysis. This work is contributing directly to help guide protocols for broader use within ecology as a global science through Elliot Gould's research and will be expanded upon in Stage 7.

### 3.11.2 Is environmental water management making a difference?

Based on the results generated during Stage 6, it is clear that, for some species (or species groups) and some systems, environmental watering is influencing key processes and populations of native vegetation. Environmental flows are an important tool for waterway managers to provide benefits to riparian plants in regulated waterways. Examples relating directly to our KEQs are as follows.

*KEQ1: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of aquatic and semi-aquatic vegetation at a sub-reach scale?*

For aquatic species, the benefits of environmental flows are highest for a specific set of waterways. Vegetation mapping data from 44 sites across Victoria have shown that many regulated waterways lack the hydraulic habitat conditions suitable for many aquatic species, with very high or low flow volumes a barrier to colonisation and growth. Our data showed that environmental flows are, however, able to have significant benefits to aquatic plants where they can provide essential baseflows and freshes in drier systems. We also found that alterations of flow patterns of higher flow systems to expose soils can to improve aquatic vegetation recruitment. Additionally, we quantified the effects of other factors such as high turbidity, livestock grazing, canopy cover, channel form, and other flow variables that alter the relative abundance, extent and diversity of aquatic vegetation. For example, Carp (*Cyprinus carpio*) exclusion experiments have highlighted the negative impacts of Carp and waterfowl on some aquatic species. Quantifying the impacts of these additional factors is critical for evaluating the effects of environmental flows on aquatic vegetation species when other factors are limiting, which is a significant knowledge gap for environmental flow research. These findings can be used to directly inform management of aquatic vegetation through the delivery of environmental flows, the manipulation of flows, the additional management actions required to address other confounding factors, and the specification of realistic objectives for management of aquatic and semi-aquatic vegetation in Victoria.

*KEQ 2: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of emergent vegetation at a sub-reach scale?*

Our extensive data collection and evaluation has shown that unlike aquatic species, emergent species do not require permanent water resources to survive along waterways. However, the provision of environmental flows or natural high flow events increases the growth and recruitment of these species. Specifically, individual spring freshes result in increased cover, spatial distribution up the bank and germination of emergent species. Baseflows are then important for increasing emergent plant growth and abundance. Environmental flows (in the form of freshes and baseflows) also help to inhibit terrestrial species, which then reduces competition with emergent species. These responses however vary between sites and within and between reaches based on flow regimes, species present, rainfall, livestock grazing and other factors. The most significant of these other factors for emergent vegetation appears to be livestock grazing and presence of exotic riparian species. Environmental flows are unable to benefit native emergent species where livestock grazing pressure is moderate to high or exotic riparian species dominate. In these locations, environmental flows will only provide benefits if grazing is dramatically reduced and exotic species removed.

*KEQ 3: How does environmental flow discharge influence the spatial distribution, foliage cover and species diversity of fringing herbaceous vegetation at a sub-reach scale?*

Data collected through VEFMAP Stage 6 provides some of the most conclusive evidence for vegetation responses to environmental flows in Victorian waterways, particularly for fringing riparian species. Fringing riparian species (e.g. grasses and herbs) are far less impacted by individual spring fresh deliveries than terrestrial species, which gives them a competitive growth advantage. This effect is cumulative, meaning that successive years of deliveries can reinforce and consolidate benefits from previous years to benefit riparian vegetation populations. Spring freshes broaden the distributions of fringing species to higher bank elevations and help to sustain healthy high-bank fringing populations by increasing fringing plant propagule dispersal and germination, and by providing temporary water resources to young or shallow-rooted species. This means that the riparian vegetation extent is much broader than it would be without environmental flows, which increases habitat resources, stabilises banks and increases overall plant community resilience to large flood events.

Similar to emergent species, the provision of appropriate baseflows also increases fringing plant growth and abundance, such that the absence of these flows would reduce the abundance of riparian cover on waterways. Additionally, our field and experimental studies have highlighted the critical role freshes have in mitigating the encroachment of terrestrial species (which are more susceptible to inundation and reduce vegetation community resilience to floods) to the lower bank elevations. Importantly, our data have quantified these effects and shown that most plants are highly tolerant of cool-season inundation, but much less tolerant as the season progresses and temperatures increase, such that only highly tolerant species can survive extended summer inundation. These results have already directly guided flow decisions around desirable spring fresh events and undesirable summer irrigation flows. As with the emergent species, environmental flows have little to no benefit for native fringing vegetation if the livestock grazing pressure is high or the bank is dominated by inundation-tolerant exotic species. In these locations, environmental flows will only provide benefits if grazing is dramatically reduced and exotic species removed. However, our grazing exclosure field experiments have shown that many sites recover quickly after grazing removal, a process that is aided by environmental flows.

*KEQ 4: How does environmental flow discharge influence the recruitment and establishment of emergent, fringing herbaceous, and woody vegetation at a sub-reach scale?*

Our field and nursery studies showed that environmental flows, particularly spring freshes, have a significant role in increasing riparian vegetation seed abundance and germination. While rainfall plays a large role in vegetation recruitment, particularly for terrestrial species, spring freshes are important for triggering germination and for dispersal of riparian species propagules to higher bank elevations. Germination patterns vary among species groups and within groups, but environmental flows that replicate the natural flow patterns change the distribution and composition of plant communities through recruitment to favour riparian species (over terrestrial species). Our studies also highlight the importance of low flows in late summer, which replicate natural conditions and play an important role in promoting germination of aquatic, emergent and low-bank fringing species. Riparian shrubs benefit from elevated environmental flows for germination and establishment, although those requiring overbank flows typically require rarer natural floods. While the dominant canopy species in most Victorian regulated waterways (River Red Gum) does not require environmental flows to germinate, seedling survival and establishment may be increased by environmental flows.

*KEQ 5: How are vegetation responses to environmental flow discharge influenced by additional factors such as grazing, rainfall, soil properties, and season?*

Effective evaluation of environmental flows cannot be done without understanding the impact of other factors on how vegetation responds to flows. Our findings showed that livestock grazing was correlated with reduced native vegetation cover in all systems, meaning the vegetation outcomes achieved using environmental water were in most cases being prevented or degraded by livestock access. Native riparian vegetation communities will only benefit from environmental flows if heavy grazing is dramatically reduced and exotic riparian species are controlled where they occur in high abundance, which is more common in higher rainfall parts of Victoria.

Results from our soil moisture monitoring found that the provision of soil moisture through managed environmental flows is critical in drier streams where baseflows and spring freshes can support aquatic species. In more permanent waterways, freshes are important for providing soil moisture to shallow-rooted or young plants on the stream bank in drier years or seasons, particularly where soil properties reduce groundwater connections. However, in many perennial waterways (most regulated streams) provision of soil moisture through delivery of environmental flow is not critical for deeper rooted riparian plants.

Given the lower abundance of exotic riparian species, the reduced flow availability and reduced soil moisture in lower rainfall areas, environmental flows generally provide a proportionally larger benefit to vegetation communities in lower rainfall areas. Since much of the state is predicted to have reduced rainfall under climate change, riparian vegetation will become more reliant on environmental water in the future.

### 3.11.3 Overarching recommendations

The vegetation monitoring theme of Stage 6 has made significant advances to VEFMAP through refined sampling approaches, expanded spatial distribution, targeted and more frequent temporal resolution of data collection, targeted experimental approaches, and broader lines of evidence. These factors have provided a successful model for VEFMAP vegetation monitoring. We therefore recommend that many of the elements used in Stage 6 be continued within the program, but we have also identified a range of ways to enhance the process further to deliver greater outcomes and take advantage of the longer-term data pool. The key elements to be maintained are as follows:

- Continue to monitor the majority Stage 6 vegetation sites, albeit with potential modifications to data collection approach and timing.
- Continue vegetation mapping but with a refined and more repeatable process.
- Continue targeted studies through both in-situ and ex-situ experiments.
- Continue a multi-method approach for understanding hydrological processes that combines above-ground (flow) and below ground (soil moisture) measurements.
- Continue to explore and implement best practice research methods for reproducibility and transparency.

In addition to minor refinements to the continued actions listed above, the following new elements are suggested for consideration for Stage 7:

- Develop a long-term monitoring approach that will balance data and resource needs.
- Consider additional sites not surveyed within Stage 6 to comprehensively cover spatial scales across the Victorian temperature and rainfall gradient.
- Develop predictive models for flow responses to test and extrapolate relationships.
- Expand the evaluation of interactions between plant taxa and fauna.
- Consider new areas of research currently not covered by VEFMAP or other monitoring programs.

Rapid but comprehensive data collection of vegetation attributes for long-term study remains an obstacle for vegetation monitoring. While electrofishing surveys of river sections can provide a relatively rapid, repeatable and comparable approach to assessment of fish populations and communities, an equivalent has not been established for vegetation. Our broad vegetation mapping approach is one potential way of doing this, but it has failings in being subjective and poorly captures changes in plant cover (density). Detailed transect data are objective, repeatable, high resolution and highly valuable for fine-scale spatial treatments (such as flows along bank elevations), but these approaches are time-intensive. As part of the development of Stage 7, we will propose refined survey methods that meet the required criteria to establish long-term data collection for vegetation. The proposed approach will likely include multiple methods to meet multiple needs, as per the Stage 6 approach. Importantly, the data will correspond with existing data so that long-term comparative analyses will be possible.

We will continue using KEQs to guide evaluation of objectives but will revise the KEQs and associated research questions corresponding with the updated understanding of vegetation responses and processes and the priority knowledge gaps. The use of event-style monitoring has been a valuable approach; however, this can be refined regarding timing and location of sampling to improve the evaluation of effects across a broader range of environmental conditions (flow, rainfall, elevation, substrate, regulation etc.).

VEFMAP Stage 6 has been successful in building strong and collaborative relationships with CMA personnel, which makes planning for future event-style monitoring programs easier and more efficient. The collaborative experimental approach adopted during Stage 6 has also established strong research relationships with riparian ecologists at The University of Melbourne, and there are multiple areas where new research projects can be integrated into VEFMAP Stage 7 to complement the field-based monitoring program.

The data collected and analyses conducted during VEFMAP Stage 6 have created a solid understanding of vegetation response to environmental flows, which has addressed the five KEQs collaboratively developed at the beginning of the project. The highly dynamic nature of riparian systems, combined with the susceptibility of riparian vegetation to a range of natural and anthropogenic disturbances, can make it difficult to link flow regimes directly to ecological outcomes. Incorporating measurements related to other drivers of vegetation change (e.g. grazing, soil moisture, inundation tolerances etc.) has allowed a broader understanding of the interactive effects of management actions on vegetation in riparian systems. This multi-faceted approach, combined with the large spatial and temporal extent of the data, also provides exciting opportunities to integrate predictive modelling techniques to evaluate flow scenarios, predict implications of future flow scenarios and test the transferability of knowledge gained to new plant species and to other river systems. For this reason, there is a need to continue to evaluate the relative effects of other drivers in addition to the various flow drivers for future VEFMAP sampling. Importantly, this also includes expanding the opportunities to sample interactions between taxa groups (fish, vegetation etc.) to understand more complex food web or ecosystem processes and links in Victorian rivers.

# 4 Communication and engagement

## 4.1 Background

Cottingham et al. (2014) noted that a greater emphasis should be placed on the use of stories and results in communication tools that promote the success of VEFMAP. At the commencement of Stage 5, ARI sought to establish close links with key stakeholders (i.e. CMA water managers) to:

- understand their views on the program to date
- increase the focus on communication and engagement
- understand what they wanted from VEFMAP to support their management of environmental water
- understand whether the locations and ecological objectives of VEFMAP were adequate to inform their environmental water management needs
- focus on developing outputs to meet their needs.

The communication and engagement plan developed at the start of Stage 5 placed a priority on, increasing confidence in VEFMAP across key stakeholders and scientists, supporting the needs of key stakeholders in CMAs to enable them to convey VEFMAP outcomes to their communities, and enhancing information flow to and from complementary environmental water programs.

During Stage 5, feedback was gathered from stakeholders through a questionnaire, as well as direct interactions at workshops and meetings and discussions. The October 2015 questionnaire provided significant insights that guided the approach taken in Stage 6. It highlighted several core areas needing focus: project and data management, rigorous science and use of findings to inform management, and communication and engagement. A summary of insights provided by key stakeholders which were specific to communication and engagement included:

- Ongoing, strong, regular communication with relevant stakeholders is fundamental.
- Internal communication between the program funder, project team, steering committee and the Independent Review Panel, as well as external communication with target audiences, are required.
- Clarity and agreement should be sought early regarding the program's aims, scope, and roles of all involved.
- Tight collaboration with key stakeholders should be sought to understand and focus on what they need.
- A mix of face-to-face meetings in Melbourne and regional areas should be provided, and where possible these should link in with existing meetings of key stakeholders to maximise efficiency.
- Regular email updates to key stakeholders should be provided to keep them up to date on progress and findings.
- A mix of outputs for key stakeholders should be developed, including easy to interpret, user friendly products.

Stakeholders also contributed directly to the development of regional and system-specific questions and approaches. The potential Stage 6 fish and vegetation questions were developed by ARI, DELWP, The University of Melbourne and CMAs. These questions were ranked in order of their importance using agreed criteria and then distributed to the CMAs for comment and clarification. This approach of participatory project design represented an advanced mode of communication, to maximise the likelihood of a strong collaborative program for Stage 6.

## 4.2 Approach

Communication and engagement were funded as a distinct component of VEFMAP Stage 6 from its commencement. A Communication and Engagement Plan was developed for Stage 6 to (a) provide clarity and direction for the development of key communication messages for VEFMAP findings, (b) create a framework to guide engagement approaches, and (c) support the VEFMAP project team in building stakeholder and community understanding of the benefits of VEFMAP and the provision of environmental flows. This plan was considered a 'living' document, which enabled regular reflection and adaptation, as Stage 6 progressed. A draft of the plan was circulated to CMAs for comments, which were then incorporated into the final working document.

The Stage 6 **engagement approach** sought to:

- continue to build confidence in VEFMAP across waterway managers and scientists
- enhance awareness of waterway managers of the approach taken and achievements for VEFMAP Stage 6, in a timely manner
- strengthen communication between those involved, including DELWP, CMAs (Environmental Water Reserve Officers (EWROs), waterway managers, others involved in river and riparian management), Melbourne Water, VEWH, consultants and scientists
- seek regular feedback from waterway managers regarding communication methods and outputs to meet their needs
- support the needs of waterway managers to enable them to convey VEFMAP outcomes to the community
- enhance information flow to and from complementary environmental flow programs.

Strong engagement with key stakeholders such as waterway managers was a priority to:

- regularly communicate plans, progress and results
- enable collaboration and inclusion of local advice on the timing and location of monitoring
- facilitate provision of advice to influence environmental water management planning
- provide opportunities for input and feedback on the program.

### 4.2.1 Key messages

In the early phases of Stage 6, key messages focused on:

- VEFMAP's scientifically rigorous approach, including the incorporation of intervention monitoring, the development of key evaluation questions, and the selection of monitoring methods and sites
- working closely with key stakeholders to make sure their information needs were met
- the aim to inform and support environmental water planning and implementation, and link with complementary programs.

There was a need to ensure that key stakeholders contributed to and had confidence in Stage 6 from the start. Building a solid understanding of the approach taken and emphasising the involvement of the Independent Review Panel also minimised risks of differing expectations about what the results of VEFMAP could demonstrate over time.

As Stage 6 proceeded, the focus of messages began to also incorporate progress, results, and how these could be interpreted. It was emphasised in the first years of Stage 6 that many survey results were preliminary and could provide useful insights, but that a more comprehensive picture would be obtained nearer the completion of this stage.

### 4.2.2 Target audiences

Five types of target audiences were identified (see Figure 4.2.1):

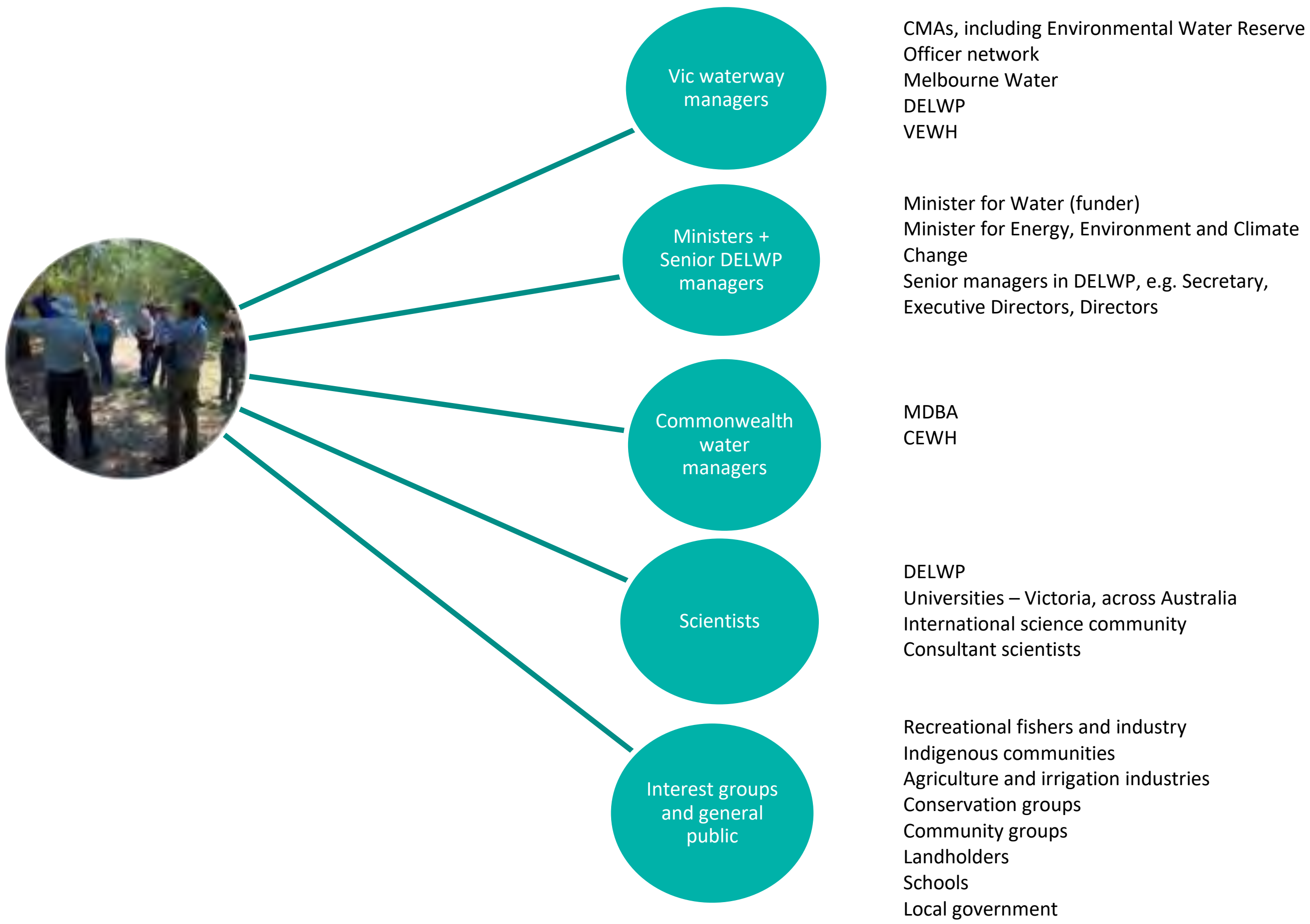



**Figure 4.2.1** Target audiences for VEFMAP Stage 6.

### 4.2.3 Activities and tools

A suite of activities and tools to engage with these audiences were identified and formed the basis for an action plan for their implementation (Table 4.2.1). A specific citizen science project with angler scientists was also undertaken (see Section 4.4). A communication register was set up at the start of Stage 6, to record activities on a monthly basis. The register was shared with team members monthly and discussed at each project team meeting, to ensure it captured efforts of the VEFMAP Project Team in a comprehensive way.

The following summary provides examples of how the different activities and tools were implemented and used (see also Figure 4.2.2).

- **Direct contact via phone and email**

VEFMAP team members regularly called and emailed key stakeholders, particularly EWROs, to liaise on planning of proposed surveys, share findings and interpretation of recent survey results, and provide advice to support or modify proposed environmental flow events. In early 2019 a field survey update template was created to share results with stakeholders after each survey via email. The Program Manager also sent Program progress updates to key stakeholders, approximately every six months. The distribution list for these updates included CMAs, VEWH, DELWP CWC&T, the Program Steering Committee, the IRP, MDBA, CEWO and Parks Victoria.

- **Face to face**

Numerous meetings and workshops occurred between VEFMAP team members and key stakeholders. These included:

- site visits to discuss monitoring methods, findings and proposed environmental flow events
- more formal meetings with CMAs, VEWH and regional environmental water advisory groups, to discuss Seasonal Water Plans and their content, and FLOWS studies and their content
- stakeholder workshops (Sept 2016, Oct 2017, Mar 2019) to discuss program progress and seek feedback
- Independent Review Panel meetings (May 2017, Aug 2019) to discuss program progress and seek feedback and advice
- Project Steering Committee meetings (multiple)
- VEWH and VEFMAP Communications Lead meeting (Jan 2020)
- DELWP and CEWO meeting to discuss alignment of environmental water programs (Feb 2018)
- regular interactions between the VEFMAP project team and members of other Victorian and Commonwealth environmental water programs (e.g. Melbourne Water monitoring, The Living Murray, Long-term Intervention Monitoring/MER).
- key stakeholder participation in field trips.

- **Presentations**

Presentations by VEFMAP team members provided overviews of the program in the early days, and then progressed to summarising progress and highlights of results and how these results could be interpreted to improve environmental water management. These included:

- EWRO network meetings (March 2018, September 2018, March 2019, June 2019)
- regional forums and events, including Getting Hooked on Flows Forum (with NCCMA and VRFish); discussion of Blackfish findings with Gunaikurnai Land and Waters Aboriginal Corporation (GLaWAC) and WGCMA, Science on Country – Echuca, Integrated Water Management Forum, Koondrook – World Fish Migration Day, Lake Boga Fish Habitat Day, Cohuna Fishing Classic, angling group meetings (fish ear bone project)
- ARI seminars (three in 2018) and DELWP events, such as the DELWP Biodiversity field trip along the Werribee River and the Hume regional biodiversity forum
- other organisation seminars and forums – VEWH Environmental Water Matter forum; MDBA Native Fish Forum; Wimmera Biodiversity Seminar; SWIFFT (Statewide Integrated Flora and Fauna Teams); River Basin Management Society seminars
- conferences (15 talks) including the International Conference on Fish Telemetry, Australian Society for Limnology/Australian Freshwater Sciences Society, Australian Society for Fish Biology, Australian Stream Management Conference (9ASM), Ecological Society of Australia, VicBioCon, and DELWP's Annual Water Science forum 'From Science to Application' (2019).

- **Documents and products**

A range of documents were prepared and shared each year to summarise VEFMAP progress and communicate results from monitoring. At the commencement of Stage 6 this included:

- two Monitoring Manuals: a) Program Context and Rationale, and b) Program Design and Monitoring Methods
- a program overview fact sheet
- a poster sent to each participating CMA and the VEWH.

Each year, products included:

- annual unpublished client reports, shared with key stakeholders
- draft annual reports circulated to key stakeholders for their input, following feedback after the first year of Stage 6
- progress fact sheets: four in 2016–17; six in 2017–18; seven in 2018–19.

Products were made available via emails to key stakeholders, the EWRO Yammer and ARI website (except unpublished client reports, which were only sent to key stakeholders).

The preparation of a brochure to summarise VEFMAP Stage 6 and its achievements will be a primary output of interest to ministers and senior DELWP managers.

- **Online content**

VEFMAP content was produced for the DELWP Water and Catchments and ARI's websites as well as other organisations.

The ARI website has a comprehensive overview of VEFMAP and its outputs. Via the subscriptions page, there are three online products that provided an opportunity to regularly promote VEFMAP and its progress:

- ARI enews (audience > 1500 people); VEFMAP highlighted nine times
- ARI Applied Aquatic Ecology Quarterly Update (audience > 1300 people); VEFMAP highlighted eight times
- ARI Applied Aquatic Ecology Quarterly Update Influence (audience > 650 people): VEFMAP highlighted three times.

The audiences for these online products incorporate most VEFMAP target audiences and represent a diverse and comprehensive mix of Commonwealth, State and local government staff, university scientists and students, interest groups, NGOs, consultants and the general public.

Content produced by other organisations related to VEFMAP:

- VEWH: annual reports titled 'Reflections' provided highlights of environmental water monitoring in Victoria. While the 2016–17 Reflections does not mention VEFMAP, it does outline seven examples of ARI monitoring related to VEFMAP and other programs. The 2017–18 Reflections mentions VEFMAP in general and for the Glenelg system. The 2018–19 Reflections incorporates a specific highlight for VEFMAP and WetMAP (DELWP's Wetland Monitoring and Assessment Program for environmental water), as well as the VEFMAP fish ear bone citizen science project, and Glenelg and Tarago river results. The VEWH website's 'News and Stories' section has periodically included VEFMAP highlights, associated with Reflections content.
- CMAs: each CMA varies in its online content regarding environmental water; many capture findings and work undertaken by VEFMAP, mainly via media releases, field days, annual actions and achievement reporting, videos, and links to other sites and information.

Other online sites and newsletters such as VRFish, Newstreams and Finterest occasionally shared and promoted VEFMAP content, and used findings of VEFMAP in their content.

Videos provide a simple tool to engage audiences and promote VEFMAP and its achievements.

- Two DELWP videos were produced:
  - 'Monitoring native fish and plant responses to environmental water (VEFMAP)' was released in early 2018 (458 views)
  - 'What can fish ear bones tell us? Benefits of water for the environment' was released in mid-2018 (529 views).
- Several CMAs have produced videos with VEFMAP content
  - 'Glenelg River – Victorian Environmental Flow Monitoring and Assessment Program' (>11 000 views via GHCMA YouTube and website) (June 2018), and November 19 about the VEFMAP vegetation monitoring
  - Campaspe River – drone trip (NCCMA)
- Journal articles

Over 15 journal articles covering VEFMAP findings are in various stages of completion. These will be promoted widely via DELWP and ARI; this includes providing links on the ARI website, highlighted in eNews, Applied Aquatic Ecology Updates and social media (when supported).

- Blogs and podcasts

While blogs and podcasts were identified as a potential avenue to share VEFMAP findings, they were not pursued. In recent times, DELWP has created a limited number of podcasts; this avenue for promotion of VEFMAP achievements will be investigated.

- **Social media and networking**

The EWRO Yammer network was identified as an effective avenue to share VEFMAP information with this key stakeholder group, and a substantial effort was made to post regularly. Over 50 posts were produced: 15 in 2017, 25 in 2018, 10 in 2019 and one in 2020. Readership of posts usually ranges from 30 to 40 people. These posts often initiated conversations within the network between stakeholders, including sharing further details, interpretation and highlights. EWROs also occasionally posted about participating in VEFMAP field trips.

Social media is a major way many people access and share information. DELWP has accounts on Facebook (statewide and regional), LinkedIn, Twitter and Instagram. Examples with VEFMAP content have included Facebook and Tweets about:

- the Loddon River fish going with the flow (February 2017)
- the discovery of the threatened *Cullen parvum* along the Campaspe River (February 2017)
- the large galaxiid haul on the Tarwin River (February 2019)
- insects needing streamside plants (September 2019).

The ability to progress and share external content through DELWP, including via social media and media releases can be constrained, because large government departments such as DELWP manage a significant and broad range of issues. Other circumstances (e.g. government caretaker mode, bushfires, Covid-19) also curtail opportunities.

CMAs and Melbourne Water have used social media, including Facebook and tweets, to publicise VEFMAP progress and highlights, including:

- the galaxiid haul in the Bunyip River (Melbourne Water, September 2017)
- grazing exclosure plots (NCCMA, September 2018)
- Carp exclosure plots (NCCMA, November 2018)
- Australian Grayling in the Glenelg River (GHCMA, February 2019)
- Broken River fish surveys (GBCMA, March 2019).

This has been a valuable avenue to share VEFMAP activities with local audiences. The VEFMAP project team has worked hard to build relationships with CMA staff involved in both management of environmental water and communication, so that it is notified of any social media planned that relates to VEFMAP. This has facilitated a collaborative approach and ensured that key messages are accurate and comprehensive, as well as allowing appropriate acknowledgement of all involved.

- **Internal DELWP online networking**

DELWP has several avenues to promote VEFMAP with internal staff:

- DELWP Yammer provides an efficient way to promote work and share highlights internally within DELWP with a potential audience of over 4500. Tagging participating staff, senior DELWP managers and funders can ensure these Yammers are noticed, and they are sometimes identified by DELWP Corporate Comms staff as providing good content for external media.
    - 10 VEFMAP-related posts were produced: *Cullen parvum* discovery (February 2017), Program context video (October 2017), galaxiid haul (August 2018), ear bones (October 2018 and November 2018), stakeholder forum (March 2019), DELWP ‘From Science to Application’ Water Award (August 2019), Australian Freshwater Sciences Society conference (December 2019), Murray Codference (December 2019), Quarterly Update Influence (April 2020). Readership of these posts usually ranges in the mid hundreds.
- Ada newsroom posts were a useful opportunity to engage with DELWP staff, and content is sometimes identified by DELWP Corporate Communications staff as providing good content for external media. VEFMAP was highlighted in a post about the ear bone project (June 2018) and for World Rivers Day (September 2018).
- Regular internal newsletters (Water and Catchments ‘Spill’ and Biodiversity ‘Yarn’) have also incorporated VEFMAP highlights.

- **Other media**

DELWP media releases provide an opportunity to share significant news. In 2017, several media releases were related to flow management and included VEFMAP content:

- Loddon fish going with the flow (February 2017)
- Co-ordinated flows in three rivers a boost for native fish (April 2017) and
- Murray Cod is gold and Perch is silver in the numbers game (May 2017).

CMA media releases have highlighted VEFMAP findings. The VEFMAP project team worked hard to build relationships with CMA staff involved in both management of environmental water and communication, so that media releases as well as other content could be prepared collaboratively. This has ensured that key messages are accurate and comprehensive, as well as allowing appropriate acknowledgement of all involved. Examples include:

- Getting hooked on flows (December 2017) NCCMA
- Flows target fragile native fish in Mt William Creek (January 2018) WCMA
- Silver lining for Broken River (March 2019) GBCMA
- Tupong love the Thomson (February 2020) WGCMA
- Fish surge up Glenelg River (May 2020) GHCMA.

Media releases are an effective way for stories to be subsequently picked up by a range of local newspapers, as well as radio and television. For example, the 'Loddon fish going with the flow' story led to radio interviews with ABC (Central Victoria and Mildura), and sharing across other online platforms e.g. Fishing Victoria Forum and Fishing Boating World.

Media interest was also generated by the release and promotion of journal articles relating to improved management of environmental flow. For example, 'From an irrigation system to an ecological asset: adding environmental flows establishes recovery of a threatened fish species' (Stuart et al. 2019) resulted in an interview for Nine Local News Central Victoria in September 2019.

**Table 4.2.1** Activities and target audiences.

| Activities | Victorian waterway managers | Ministers | Senior DELWP managers | Scientists | Commonwealth water managers | Interest groups and general public |
|---|---|---|---|---|---|---|
| **Direct contact** | | | | | | |
| Phone calls | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Emails and program updates | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Field survey update emails | ✓ | | | | | |
| **Face to Face** | | | | | | |
| Meetings | | | ✓ | ✓ | ✓ | |
| Workshops | ✓ | | ✓ | ✓ | ✓ | |
| **Presentations** | | | | | | |
| Regional forums and events | ✓ | | | ✓ | ✓ | ✓ |
| ARI seminars | | | ✓ | ✓ | ✓ | |
| External seminars e.g. RBMS | ✓ | | ✓ | ✓ | ✓ | |
| Conferences | ✓ | | ✓ | ✓ | ✓ | |
| **Documents and products** | | | | | | |
| ARI Technical Reports, client reports etc. | ✓ | | ✓ | ✓ | ✓ | |
| Annual progress reports | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Fact sheets | ✓ | | ✓ | | ✓ | ✓ |
| Posters and stickers | ✓ | | ✓ | ✓ | | ✓ |
| **Online content (websites, newsletters etc.)** | | | | | | |
| DELWP and ARI websites | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Other websites – VEWH, CMAs, CEWH, VFA, rec fishing sites, Finterest, etc. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ARI enews | ✓ | | ✓ | ✓ | ✓ | |
| ARI Applied Aquatic Ecology Quarterly Updates | ✓ | | ✓ | ✓ | ✓ | |
| ARI Applied Aquatic Ecology Quarterly Update Influence | ✓ | | ✓ | ✓ | ✓ | |
| Newsletter articles (VEWH, Finterest, RBMS, Basin News, Newstreams, ASFB etc.) | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Journal articles | ✓ | | ✓ | ✓ | ✓ | |
| DELWP and ARI Videos | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Blogs, podcasts etc. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

| Activities | Victorian waterway managers | Ministers | Senior DELWP managers | Scientists | Commonwealth water managers | Interest groups and general public |
|---|---|---|---|---|---|---|
| **Social Media and Networking** | | | | | | |
| EWRO Yammer | | | ✓ | | | |
| DELWP Facebook | ✓ | ✓ | | | | ✓ |
| DELWP Twitter | ✓ | ✓ | | ✓ | | ✓ |
| DELWP LinkedIn | | | | | | |
| DELWP Instagram | | | | | | |
| **Internal DELWP Online Networking** | | | | | | |
| Internal – DELWP Yammer | ✓ | ✓ | ✓ | ✓ | | |
| Internal – DELWP Ada | ✓ | ✓ | ✓ | ✓ | | |
| Internal – DELWP 'Spill' and 'Yarn' | ✓ | | ✓ | ✓ | | |
| **Other Media** | | | | | | |
| Media releases | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Newspaper articles | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Radio | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Television | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

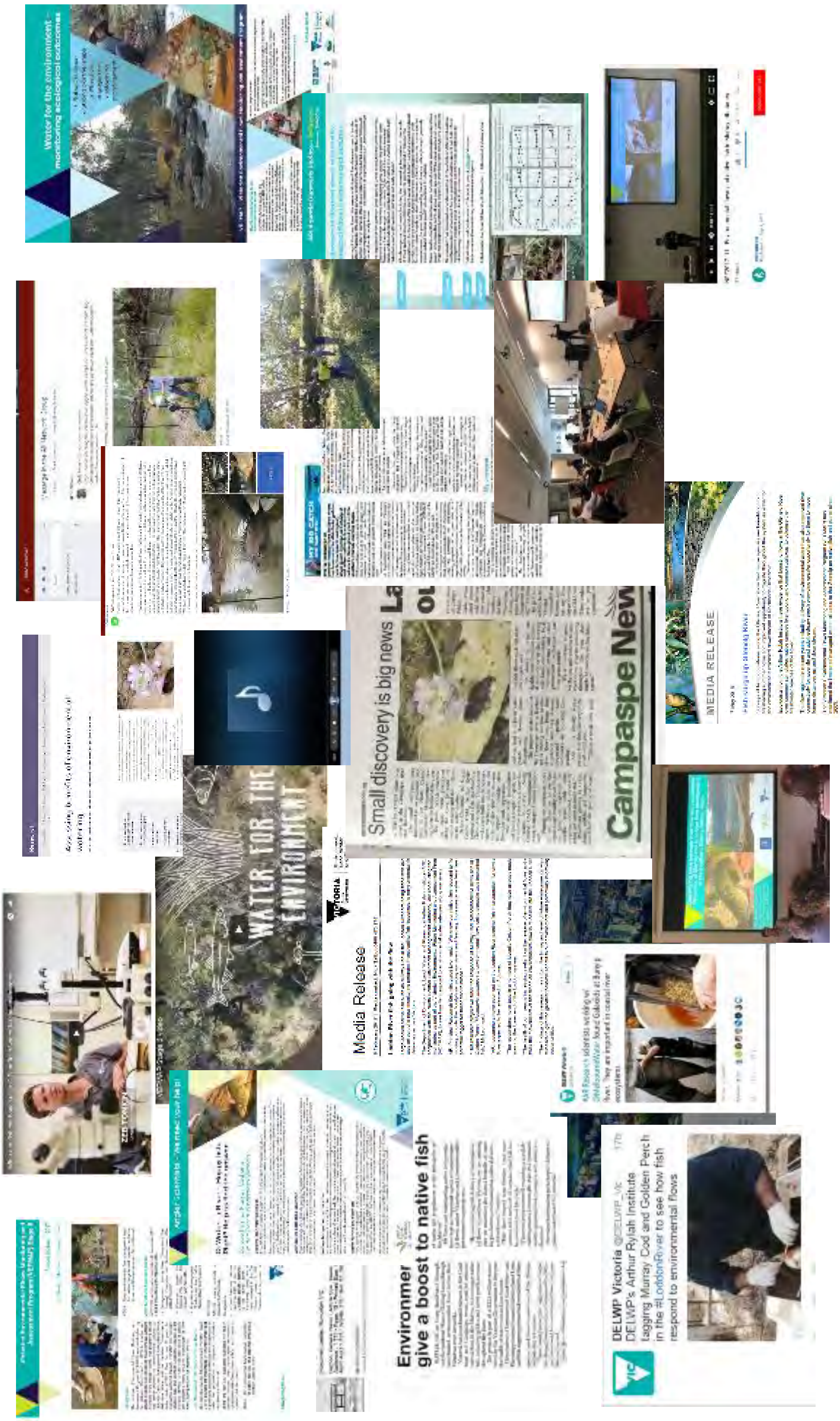



Figure 4.2.2 Examples of VEFMAP Stage 6 communication and engagement activities and tools.

## 4.3 Evaluation of communication and engagement

Stage 6 communication and engagement incorporated an adaptive model, allowing for modification of approaches as it progressed. The ongoing program evaluation included consideration of:

- communication and engagement **outputs**, in terms of undertaking identified activities and use of tools for target audiences, achievement of milestones and targets (e.g. number of flyers or publications produced, number of meetings, workshops attended)
- communication and engagement **outcomes**, their extent and quality (e.g. changes in awareness of VEFMAP, how attitudes towards the project has changed).

### 4.3.1 Communication and engagement outputs

Continual collation of communication and engagement activities enabled the project team to keep track of progress. Regular project team meetings and frequent strong communication across the team assisted in ensuring milestones could be met and enabled regular reflection on activities and tools to engage with target audiences.

A broad suite of activities and tools was used during Stage 6, with varying emphasis and frequency across audiences. The greatest emphasis was placed on engaging with waterway managers to (a) ensure a complete understanding of the Stage 6 approach and confirm support for the revised methods, (b) facilitate a collaborative effort, and (c) support and inform improved management of environmental water. Many insights have been gained regarding the effectiveness of activities and tools used during Stage 6 communication and engagement; these will prove valuable during the planning and implementation of Stage 7.

#### Activities and tools

***Phone and email***

Regular direct contact via phone calls and email updates between VEFMAP team members and the key stakeholders within CMAs were effective in building connections and providing advice to support or modify proposed environmental flow events. There was, however, some variation in the strength of these connections across all relevant CMAs, and options to ensure strong relationships across a broad range of staff should be pursued.

***Face to face***

There were consistent efforts to collaborate with many CMA staff via site visits and more formal meetings with CMAs and the VEWH to discuss environmental flow planning. There was, however, some variation in uptake of these meeting offers by the different CMAs and contributions to environmental water planning varied across regions. The opportunity to incorporate more structured input of VEFMAP staff to the development of Seasonal Watering Plans and FLOWs studies should be further investigated.

Stakeholder workshops, Independent Review Panel meetings and Project Steering Committee meetings provided useful opportunities to evaluate and review Stage 6 progress, including communication and engagement. The involvement of many VEFMAP staff in other Victorian and Commonwealth environmental water programs, and participation in workshops and meetings, contributed to the improved alignment of programs.

The participation of key stakeholders in field trips provided a useful method of building relationships and should be encouraged further.

Connections between the VEFMAP Communications Lead and CMA, VEWH and DELWP communication staff have been enhanced. Further efforts should be made to ensure this is maintained, particularly when there is a change in communications staff.

There have been efforts to connect with recreational anglers, particularly via the citizen science project (see Section 4.4). There have also been some efforts to engage with Indigenous groups via presentations (e.g. Science on Country), and a field site meeting about River Blackfish findings with Gunaikurnai Land and Waters Aboriginal Corporation (GLaWAC). Traditional Owners from Dja Dja Wurrung were also involved in establishing the grazing exclosures along the Campaspe River. Traditional Owner water cultural officers have expressed interest in participating in field trips, which would provide a valuable avenue of engagement and will be explored for future stages of VEFMAP.

### *Presentations*

Attending and presenting at EWRO meetings was a useful way of sharing VEFMAP progress and maintaining strong connections and should continue. A variety of presentations were given at regional forums and events, and VEFMAP team members should continue to liaise with CMAs to identify high priority events to focus on, to reach a diverse range of local audiences. Giving presentations at regional, state and commonwealth forums was also valuable. In Stage 7, consideration should be given to which events should be a priority, including engaging with target audiences that have not been the focus of concerted efforts.

ARI seminars provided a valuable opportunity to promote progress, albeit mainly to a relatively small, targeted audience of predominantly DELWP staff.

Participation in a range of conferences provided an important opportunity to highlight the VEFMAP approach and its findings to scientists from Australia and internationally. Efforts to attend and give presentations at conferences will likely increase in the next few years as journal articles and reports are released.

### *Documentation*

The annual unpublished client reports and fact sheets have been well received by key stakeholders. Some feedback has been received from CMA staff requesting more region-specific outputs, as well as outputs for more general audiences. The VEFMAP project team acknowledges this and will continue to reflect on the development of additional materials. The range of specific outputs and findings from Stage 6 will enable distinct stories and communication outputs to be developed.

### *Online*

Ensuring up-to-date VEFMAP content is available on ARI and DELWP websites represents a fundamental requirement and will continue. The inclusion of VEFMAP content in ARI enews, ARI Applied Aquatic Ecology Quarterly Update, and ARI Applied Aquatic Ecology Quarterly Update Influence will also continue and will likely increase as Stage 6 outcomes are finalised. These avenues are particularly valuable to share information across a broad range of target audiences.

Efforts to build and maintain strong relationships with VEWH and CMA staff will continue, to provide content and facilitate stories regarding VEFMAP findings. It would be worthwhile increasing efforts to provide content for other online sites and newsletters, including broadening connections with other target audiences, including recreational fishers, irrigation industry, indigenous audiences and conservation groups.

Videos are a simple way to engage audiences, and it would be valuable to prepare a DELWP video to summarise Stage 6 achievements. There may also be opportunities to work with CMAs and other collaborators on external videos.

### *Social media and networking*

Regular posting on the EWRO Yammer network proved a valuable avenue to share VEFMAP information and should continue.

Some VEFMAP content was produced for DELWP social media. Maintaining and enhancing relationships with CMA and other oganisations' communication staff will help ensure that VEFMAP results are being communicated to a wider audience via social media platforms.

### *Internal DELWP online networking*

Regular posting on DELWP’s Yammer required little effort and provided an avenue to promote VEFMAP to a broad DELWP audience including senior managers and communication staff. This can sometimes provide useful in garnering interest for further promotion and should continue. Similarly, development of VEFMAP content for Ada and the fortnightly internal newsletters (Spill and Yarn) is worthwhile.

The creation of internal DELWP content (Yammers, Ada stories) has assisted in sharing VEFMAP progress with senior managers. The Secretary, and relevant Executive Directors and Directors also receive ARI enews and Applied Aquatic Ecology Updates.

### *Other media*

The promotion of journal articles resulting from Stage 6 may increase opportunities for newspaper stories and radio and television appearances. Stronger connections with CMA communication staff can also enhance these opportunities, with VEFMAP staff following DELWP approval processes to participate.

### 4.3.2 Engagement outcomes

This section is an initial evaluation of engagement; a full report will be presented following the external end-of-program evaluation that is due for completion at the end of October 2020.

Evaluation of engagement outcomes has focused on whether the attitude and awareness of VEFMAP has changed with target audiences. Feedback has been received via a questionnaire (in March 2018), and less formal avenues such as the EWRO Yammer and direct contacts. This feedback has been encouraging, and indicates that views have improved, and there is a growing awareness of this program compared to the past. There has been a concerted effort by the project team to ask collaborating organisations to include reference to VEFMAP in their communications where relevant; and there is evidence that this has increased.

**Questionnaire**

The October 2015 questionnaire, conducted during Stage 5, identified clear issues regarding science, communication, program management and use for mangers. This questionnaire provided significant insights which guided the Stage 6 approach, and so another questionnaire was sent to key stakeholders in March 2018. This questionnaire included 18 detailed questions regarding stakeholder views on, and awareness of, the:

- science – the KEQs, sites, methods
- communication – the outputs developed (their usefulness, type and content) and the consultation by the project manager and team (quality, quantity, method)
- use for management – whether the program has helped planning and management of environmental flows.

The questionnaire also sought 'any other comments'.  While only 11 responses were received, valuable feedback and insights were provided. Figure 4.3.1 shows the responses to the overarching question of stakeholders' opinion of the science, engagement and use for management of VEFMAP Stage 6.

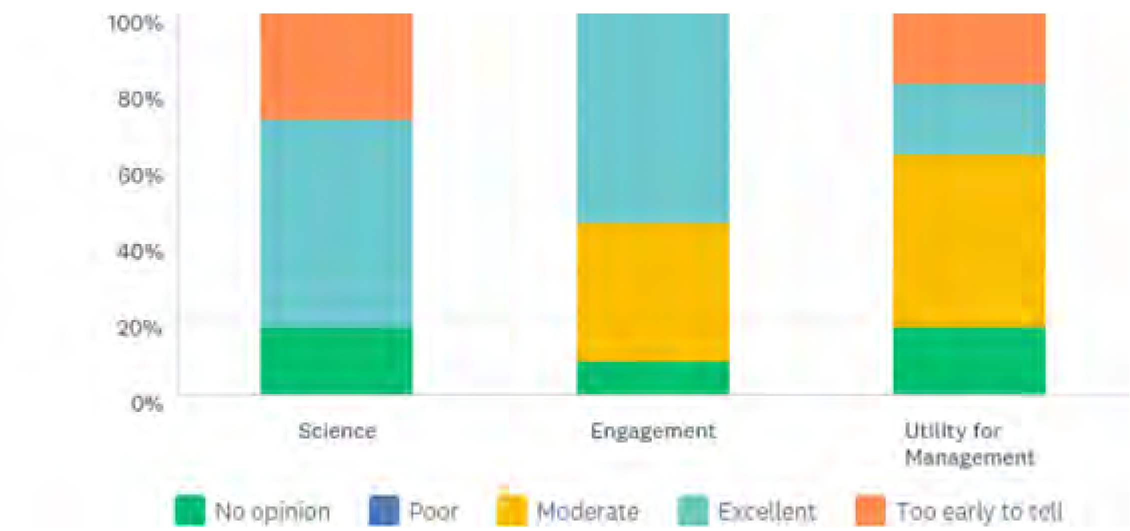



**Figure 4.3.1** Results for the question 'What is your opinion of the following components of VEFMAP Stage 6?'.

Overall, comments provided:

- positive feedback on all three core aspects of the program
- acknowledgement that it was too early in the program to provide definite views on the ecological findings and ability to inform management, although signs were encouraging
- valuable suggestions and views regarding sites, monitoring and what the stakeholders wanted
- indication of preference of communication methods, with the highest-ranking order of 'very valuable' given to regional visits (one on one), presentations at EWROs meetings, email updates, phone calls and meetings.
- indication of preference of communication outputs, with the highest-ranking order of 'very valuable' given to summary technical reports, annual reports, journals, case studies, Facebook, local TV, and newsletters.

- evidence of a desire for regionally focused content and good news stories.

Results from the March 2018 questionnaire provided guidance for Stage 6 communication and engagement for the remainder of the program.

**Stakeholder meetings and email feedback**

Feedback was also sought directly during and following stakeholder meetings (September 2016, October 2017, March 2019) and during email communication to stakeholders from the Program Manager and the Communication Lead. Most feedback has been informal and general in nature, while no specific concerns have been expressed by stakeholders.

Several CMAs indicated they would prefer fact sheets to be regionally focused. This desire is understandable and would make communication to local audiences easier. There are limitations, however, on how many fact sheets can be produced by the VEFMAP project team. Suggestions to include less detail and more photos and graphs in fact sheets have been acknowledged. The current approach to fact sheets was to provide a summary of information that would be of use for CMA communications teams to create their own regionally relevant material, as they are best place to do this. Stage 7 will investigate further, more regionally focused content.

**EWRO Yammer network**

The regular EWRO Yammer postings by the project team covered field trip highlights, program progress and sharing of fact sheets and reports. This provided an avenue for more informal feedback which was encouraging:

- ‘Great synthesis of a lot of data! Well done.’
- ‘Well done….[to] all the team at ARI! It's obvious that a lot of thought and effort has gone into this work. Well presented too!’
- ‘Looking forward to reading them!’
- ‘Great work everyone. Some really valuable findings’
- ‘Great work guys. Fantastic results!’
- ‘This is awesome – especially for people with slightly above average interest in the technical aspects of our work. Thanks ARI team!’

The participation of stakeholders in field trips also provided an opportunity for feedback via the EWRO Yammer. For example:

- ‘A BIG thanks to Frank and Gabriel for letting me tag along on Thursday to see what they get up to with the VEFMAP fish monitoring. ARI's offer to program partners to join them on their monitoring trips is a great initiative. Everything makes so much more sense when you can see it in the flesh! I saw at least half a dozen native species (which VEWH watering is trying to protect!), as well as the inevitable Carp. I did poorly with my ID skills (got the Carp one down pat) but did get to measure and weigh a few fish and rescue a turtle.’ – Alison Miller, VEWH (November 18).

**Community group feedback**

Encouraging feedback was recently received via a letter of support to DELWP senior managers, from the Campaspe Environmental Water Advisory Group (chairpersons Ted Gretgrix and Colin Smith). This letter included feedback regarding the Campaspe River Environmental Water Monitoring Program and the Environmental Flows Project, together with the linked Caring for Campaspe Project:

> ‘The last 4 years of funding has provided significant gains from the applied adaptive research program. The science and testing of theories is strong and robust, but even more importantly it is applied and adaptive science giving improved environmental outcomes enabling targeted environmental flows for both in-stream and bank vegetation improvements. This improved response is only able to be achieved as a result of the information from VEFMAP vegetation and fish ecology research.
>
> The key researchers from ARI involved in the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) – Dr Zeb Tonkin and Dr Chris Jones - have been able to provide innovative and complex science information and data in a very clear and easily understood manner. They regularly present this information to the CEWAG. All the partners in this project value the ability to interact with the scientists and to be involved in this project.’

### 4.3.3 Highlights

**Project team communication**

The VEFMAP project team included almost 20 staff from DELWP Water and Catchments and ARI, with varying levels of involvement. Through a clear governance and reporting structure, a strong team ethos was established at the start of Stage 6, which continued throughout its life. Monthly meetings were held to discuss progress and issues and identified actions. Minutes were taken, circulated and discussed at the following meeting. This regular, clear process ensured all members of the project team were kept up to date, lines of communication were open and effective, and comprehensive records were maintained. The preparation of Quarterly Progress Reports also contributed to maintaining open lines of communication across the team.

**Working with key stakeholders to share VEFMAP findings and stories**

Over time, the strength of the relationships and understanding between the VEFMAP project team and key stakeholders (including communication staff) has increased, enabling progress and achievements to be shared more effectively and efficiently. Where content has been developed by VEFMAP staff, they have sought to acknowledge the specific roles of all stakeholders involved, thereby building trust. Where stakeholders have developed content, VEFMAP staff have sought to emphasise the value of working with DELWP staff to finesse content to capture key messages that meet the needs of all relevant stakeholders, while also including appropriate acknowledgements. Stronger linkages with stakeholders help the VEFMAP project team to capture the multiple examples of the program's achievements being shared to build community awareness and support for environmental watering and scientific findings, which is one of the fundamental aims of VEFMAP communication.

The VEFMAP Communication Lead and ARI's Science Manager, Communication and Collaboration, are now members of the Victorian CMAs Communications Forum, which meets bimonthly and has helped build connections. Efforts by ARI to build more effective connections with DELWP Water and Catchments, Biodiversity, and Corporate Communications staff continue, which contributes to sharing VEFMAP achievements.

### 4.3.4 Recommendations for Stage 7

The Stage 6 end-of-program evaluation will provide additional valuable insights on what worked well for Stage 6, which will inform the approach to Stage 7. Now that strong connections have been established with many key stakeholders and the results of long-term monitoring are available, it will be timely to expand efforts to communicate and engage with a broader range of target audiences during Stage 7. This evaluation will include the circulation of another questionnaire to key stakeholders, following the release of the Synthesis Report and other final outputs of Stage 6 including fact sheets, journal articles and communication resources.

**Stage 7 Communication and Engagement Plan**

The preparation of a Stage 7 Communication and Engagement Plan is recommended, including reflection on the content of the plan for Stage 6. The following specific actions should be considered for inclusion in Stage 7 communication efforts:

- Continue to strengthen connections with VEWH and CMA communication and waterway management staff to support promotion of VEFMAP and its findings.
- Increase efforts to work with VFA, VRFish, the Victorian Fish Habitat and Flows Alliance to share VEFMAP findings and progress. This may include working with angler champions.
- Investigate opportunities to build stronger connections with Traditional Owner cultural flow officers, irrigation and agricultural industry contacts.
- Prepare fact sheets for the suite of journal articles and client reports prepared in Stage 6.
- Investigate other summary outputs, which are more suitable to the general public, including increased use of infographics and visually appealing approaches. This could include fact sheets with brief summary content with simple messages that would be of interest and understandable to local communities (e.g. comparing the number of fish over years), with simple graphs and photographs.
- Produce a video to summarise achievements and outcomes of Stage 6.
- Continue to explore opportunities to promote VEFMAP achievements via DELWP online and social media, while placing a focus on producing content for regional DELWP social media.
- Investigate opportunities to increase connections with a broader range of interest groups to ensure they are aware of VEFMAP and its progress, to encourage sharing of content via enewsletters and blogs.
- Work with CMA staff and other relevant organisations to identify appropriate regional forums and events to share the findings of Stage 6.

- Explore opportunities for VEFMAP project team members to attend and present at a broad range of appropriate Australian and international conferences
- Continue to explore opportunities for VEFMAP project team members to present at, and participate in State and Commonwealth agency forums and meetings regarding environmental flow programs.

## 4.4 An angler citizen science project – a case study

### 4.4.1 Background

There is increasing interest by both the public and government in volunteer participation in scientific research and monitoring programs. This is a result of the greater confidence in the scientific accuracy and validity of volunteer generated datasets largely driven by technological advances in recording tools, as well as the demonstration of how this data can be used to address both scientific and policy issues. There is also a growing understanding of what data sets are best suited to citizen science collection and how best they can be used. Projects can not only advance scientific understanding but also fill knowledge gaps and supplement existing government monitoring programs.

Citizen science projects can build community understanding and advocacy for natural resource management projects. There is growing recognition of the need to improve communication and interactions between recreational fishers and government agencies involved in water management, fisheries and habitat protection and rehabilitation. In the last 20 years in Victoria, significant progress has been made to build stronger connections between DELWP, VFA, VEWH, CMAs and recreational fishers, particularly in working together to restore habitats. This ties in with the increased recognition among fishers that improved instream and riparian habitats, together with suitable flows, are closely tied to improved fish populations. The Fish Habitat and Flows Alliance, initiated in 2018, demonstrates this collaborative spirit well, and represents a key tool to help facilitate effective collaborations and connections.

A VEWH-commissioned report on Victorians' knowledge of, and attitudes towards, environmental water also provides valuable insights to inform how government agencies can work effectively with recreational fishers and the broader community. This report indicated there was a limited community awareness and understanding of how water was managed, including for environmental benefits (ORIMA 2017). As a consequence, support for environmental flows was also limited, and negative perceptions were formed. Communication and engagement that helps build the understanding of environmental flows and their benefits will build trust in their management and is likely to contribute to increase support and advocacy for environmental flows. Citizen science projects involving anglers represents a potential avenue to contribute to these efforts.

Most citizen science projects are contributory, in that the public is asked by scientists to collect and contribute data or samples. There are many examples of volunteers participating in scientific studies on fish, and within commercial and recreational fisheries. Participation within commercial fisheries has largely involved fishers operating the boats and gear as part of surveys designed by scientists. In Australia the high participation rate in recreational fishing (e.g. 19.5% cited by Henry and Lyle 2003) highlights significant potential opportunities for involvement of recreational fishers in research, management and conservation programs. Most examples in recreational fisheries involve diary and volunteer tagging programs.

Citizen science is acknowledged within two key Victorian plans:

- *Water for Victoria* (DELWP 2016):
  - Action 3.4 – Provide long-term investment to improve waterway health, and
  - Action 3.8 – Support community partnerships and citizen science.
- *Protecting Victoria's Environment – Biodiversity 2037* (DELWP 2017c) via two goals (a) Victorians value nature and (b) Victoria's natural environment is healthy. The project was relevant to following priorities:
  - increase the collection of targeted data for evidence-based decision making
  - raise the awareness of all Victorians about the importance of the state's natural environment
  - increase opportunities for all Victorians to have daily connections with nature
  - increase opportunities for all Victorians to act to protect biodiversity
  - support and enable community groups, Traditional Owners, non-government organisations and sections of government to participate in biodiversity response planning.

This citizen science case study aimed to enhance both engagement and credible scientific data by engaging a group of recreational fishers in northern Victoria to collect otoliths (ear bones) from fish for assessing their age, natal origin and movement (as in Sections 2.4–2.6).

### 4.4.2 Anglers collecting ear bones

Victorian anglers had already participated in collecting ear bones in a seven-year monitoring program on the Murray River (2007–2014) which studied population responses of large-bodied native fish species after the reinstatement of instream woody habitat (Lyon et al. 2014). This study sought to:

- collect supplementary ear bones to those collected through existing monitoring
- compare angler catch per unit effort (CPUE) with conventional electrofishing CPUE in the rehabilitated reaches
- increase community awareness of river health.

This project trained recreational fishers in ear bone dissection, produced newsletters, participated in information nights, fishing events, and other communication activities such as newspaper and magazine articles, television and radio interviews. While conventional monitoring collected 414 ear bones, anglers collected 202, representing a significant additional sample size to establish age-based survival estimates and determine whether fish growth rates differed between study reaches.

- A Mulloway citizen science project funded by VFA (2014–2018) sought to engage with anglers to gain a better understanding of the stock structure and population status of this species. Over 150 fishers provided fish frames, from which the ear bones were extracted, and genetic samples taken and analysed. Further to this, a Mulloway tagging citizen science project also funded by VFA (2017–2020) is tracking broadscale movement of this species within Victoria and adjoining states. Over 500 fish have been tagged. This project has a Facebook page with a large following (over 1000 people) and prepares regular newsletters. These projects are run by the Nature Glenelg Trust.

### 4.4.3 A pilot project in VEFMAP Stage 6

VEFMAP Stage 6 used a range of methods to monitor fish in northern Victorian rivers, including the collection and analysis of ear bones. The analysis of ear bones can provide many insights into a fish's life including its age, growth rate, whether it bred naturally in the river or was stocked, and which rivers it has spent time in. Such information can provide insights into the links between flow events in rivers and fish movement, breeding and survival. While ear bones were collected for Golden Perch and Murray Cod as part of the routine VEFMAP monitoring, it was uncertain whether the target number of 50 per species would be achieved. The opportunity to increase the sample size by working collaboratively with anglers who were catching these species to keep and eat was recognised as worthwhile to pursue.

The multiple benefits of such a citizen science project included:

- Scientific
  - Supplementary data can be collected which is scientifically robust
  - This data collection can be cost effective.
- Social
  - There is increased engagement between management agencies and fishers, building shared understanding of each other's perspectives.
  - The relationships which can be built can facilitate trust, respect, cooperation and understanding within communities.
  - Participants can gain personal satisfaction and enjoyment in the activities and learn new skills.
  - Enhanced stewardship among fishers can result from participation in such activities.

### 4.4.4 Aims

This project included three key aims:

1. To obtain supplementary ear bone samples to those obtained through conventional monitoring, to provide a greater sample size for analysis.
2. To provide a successful, meaningful and satisfying citizen science program for anglers.
3. To increase angler and broader community awareness of the benefits of water for the environment, VEFMAP, and the information used to guide management of water for the environment.

### 4.4.5 Approach

This project has been a collaboration between DELWP, numerous angling clubs and other interested anglers, as well as the North Central CMA, the Goulburn Broken CMA, and the Victorian Fisheries Authority. During the initial planning stages, the approaches of the two recent Victorian projects involving angler citizen scientists collecting ear bones were considered. Given this was a small pilot project, with only a relatively low number of ear bones required from anglers, a targeted approach was used. Based on the evaluation of this pilot project, there will be potential to build on its efforts in Stage 7.

The project was promoted via:

- the ARI website content – Fishers fishing for fish ear bones (loaded Mar 2018).
- two project flyers were developed, one as a general overview, and one specifically targeted to recreational anglers.
- a video which provided background and outlined how to extract a fish ear bone (June 2018).
- internally within DELWP via an Ada story.
- DELWP Hume region Facebook.
- Yammers – EWRO and DELWP (Oct, Nov 2018).
- VEWH within 2018-19 Reflections and a news story.

In early 2018, 37 angling clubs across northern Victoria, as well as VRFish, NFA and VFA fisheries officers and managers were contacted via letters and emails to gauge their interest in taking part. Follow up emails and letters were sent, and individual contact made with angling clubs as much as feasible.

Meetings were held with both participating CMAs (Mar, April 2018), and discussions held with VFA managers and fisheries officers. All northern fisheries officers indicated they would support the project. The participating CMAs highlighted events where the project could be promoted. The Goulburn Broken CMA also visited the local tackle store in Shepparton and gave them project flyers.

Presentations were given at a range of events including:

- seven angling club meetings: Maldon, Baringhup, Numurkah, Nathalia, Goulburn/Nagambie, Rochester and Bendigo (total audience >110) (Figure 4.4.1).
- relevant regional events and seminars – Statewide Integrated Flora and Fauna Teams SWIFFT seminar (Feb 2018); EWRO meeting (Mar 2018); Lake Boga Fish Habitat Day (NCCMA) (Mar 2018) (Fern Hames); Koondrook event – World Fish Migration Day (NCCMA) (Apr 2018); Science on Country in Echuca (May 2018); Hume Regional Biodiversity Forum (June 2018) (Fern Hames).

**Figure 4.4.1 Pam Clunie meets with Rochester Angling Club to promote the project.**

In addition to the seven angling club presentations, the Undera, Castlemaine and Kyabram angling clubs also expressed interest in being involved. As people indicated their interest in the project, they were added to a group email list, which grew to 44 participants, including angling club group email addresses. Regular emails were sent to participants advising them of progress.

A total of 64 angler scientist kits were sent to participants; some angling clubs requested multiple kits (Figure 4.4.2 ). These kits provided background information, instructions and tools to extract and record the ear bone details. For those who did not wish to extract the ear bones themselves, there was an option to freeze the fish for collection. The project lead liaised with participants regularly via email.


**Figure 4.4.2** Angler scientist kits

A training day was held near Elmore in late 2018, with between 25 and 30 participants, including recreational angling club members, individual anglers and VFA staff. Presentations were given by Darren White from NCCMA and Pam Clunie and Zeb Tonkin from ARI. Zeb Tonkin demonstrated how to extract an ear bone, and then guided a number of participants who extracted ear bones themselves (Figure 4.4.3). Some participants who weren't confident in extracting the ear bones brought frozen fish to the field day for collection.

Participants were advised that the end of May 2019 was the cut-off date for ear bones, to allow sufficient time for processing and incorporation with the other samples for final analysis.

**Figure 4.4.3** Anglers and scientists field day at Elmore, Nov 2018 (clockwise from top left): Darren White NCCMA; Zeb Tonkin ARI; Zeb demonstrates how to extract an ear bone; an angler extracting an ear bone.

An initial questionnaire was prepared, and participants encouraged to complete it – either online (SurveyMonkey) or on hard copy (with a reply-paid envelope). Hard copies were provided at the training day. A final questionnaire will also be prepared and circulated to participants at the end of the project, once Stage 6 findings are shared with them.

The pre-project questionnaire asked about:

- The participant – gender, postcode, age group, whether a member of an angling club or other group interested in rivers
- Whether they had participated in other river, fish, nature or citizen science activities in the last year
- Their prior knowledge of Murray Cod and Golden Perch ecology, response to environmental water and threats
- How connected to rivers participants considered themselves
- Why participants got involved and how they heard about the project
- Participants' awareness of environmental water – this included four questions which aligned with those asked in the VEWH commissioned study (ORIMA 2017), to build on this previous work.
- How they wished to be kept informed.

A comparison of responses in the pre and post project questionnaires, particularly in answers for c), d) and f) will assist with evaluation.

### 4.4.6 Results

Eighty-four Golden Perch and 25 Murray Cod ear bones were collected from 12 rivers, creeks and lakes in northern Victoria, up until June 2019 (Table 4.4.1).

**Table 4.4.1. Ear bones collected by angler citizen scientists**

| | Golden Perch | Murray Cod |
|---|---|---|
| Rivers | 59 | 20 |
| Lakes | 25 | 5 |
| Broken catchment | 13 | 0 |
| Campaspe catchment | 35 | 7 |
| Goulburn catchment | 2 | 1 |
| Loddon catchment | 5 | 1 |
| Murray River | 29 | 12 |
| **TOTAL** | **84** | **25*** |

**Four Murray Cod were also provided by Victorian Fisheries Authority samples from Buffalo, Kiewa and Ovens rivers*

Once the samples were analysed, participants were provided with fish profiles (see example inFigure 4.4.4) for each of their fish which outlined the:

- fish's age
- where it was born
- where it was caught and by whom
- whether it had moved
- additional information and hyperlinks to the VEFMAP fish monitoring results so far, how water for the environment is managed in Victoria
- graphs of Golden Perch/or Murray Cod growth vs age (from a large dataset collected over the last 10 years across northern Victoria)

# My Profile

## Golden Perch

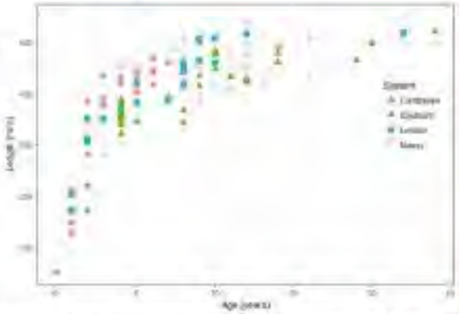
Golden Perch, *Macquaria ambigua*

Golden Perch otolith (earbone) – 11 years old

I am 11 years old.

I was born in the lower-Murray River, near the Darling River junction, during the spring of 2007. I travelled from this area before I was caught in the mid-Murray River area, at Chinamans Lagoon, on the 2nd of December 2018 by xx (ANGLER). That's over 1000km!

I have grown to be 43 cm long. If you're interested in how my growth compares with other Golden Perch, here's a graph which brings together information from fish from many surveys over the last 10 years.



Dispersal of fish throughout the river system is a critical process required for sustainable populations of species such as Golden and Silver Perch, and Murray Cod. This allows them to access areas which are most suited to each life stage, such as spawning, feeding and nursey habitats. Environmental flows are being used in Victorian rivers to enhance this process by providing cues for movement between river systems and through fishways. Environmental water (also called 'water for the environment') is being used to maintain suitable water quality, available habitat and food for native fish. Recent research has found that the population of Golden Perch in many northern tributaries has increased since 2012 (see a recent VEFMAP fact sheet). For more info on how water for the environment is managed in the northern Victorian tributaries check out: https://vewh.vic.gov.au/rivers-and-wetlands/northern-region

# What Do Golden Perch Like?

Golden Perch:

- live in many different habitats – from slow to fast flowing rivers and streams, to lakes and billabongs.
- love snags and deep water.
- eat a varied diet including shrimps, yabbies, small fish and insect larvae.
- are long-lived - up to 27 years.
- are fast growing, reaching up to 76cm in size. Our growth can vary a lot and depending on river conditions including how much food is around.
- start breeding at about three years old, and females can produce a lot of eggs – up to 500,000!! (but usually around 200,000).
- spawn when water temperatures reach 17°C in spring and early summer and water levels rise, so our eggs and larvae can drift downstream.
- eggs hatch after 1-2 days and larvae (which are only 4 mm long) can drift for 10-12 days, including along the main river channel and its edges.
- young fish often hang out in floodplains and in habitats along the edges of rivers.
- vary in how far they move. Some like to stay in just one area, while others can move hundreds – sometimes thousands - of kilometres along the Murray River and its tributaries.

  *A Golden Perch once swam 255km from South Australia to Victoria in 21 days. That's an average of 12km each day.*

  *One fish was recorded moving from South Australia to Queensland – that's about 4000km!*

- like to move/migrate in spring and summer, often during spawning, and when water levels rise and fall.

For more info on how Golden Perch respond to water for the environment, see the results of the VEFMAP (Victorian Environmental Flow Monitoring and Assessment Program): https://www.ari.vic.gov.au/research/rivers-and-estuaries/assessing-benefits-of-environmental-watering

Figure 4.4.4 Example of a fish profile prepared for each fish species.

Only 13 questionnaires where completed, despite consistent efforts to encourage participants to do so.

### 4.4.7 Key results and highlights

Ear bones collected from rivers have provided valuable additional information to help us assess the benefits of water for the environment. Highlights included:

- Three Golden Perch born in the lower Darling/Murray junction were caught near Cobram East (> 1000 kms away).
- Two Golden Perch born in the lower Darling/Murray junction region were caught near Piambie (> 400 kms away).
- A natural recruit of Murray Cod within the Campaspe River adding to recent data to show evidence of suitable conditions to support spawning and recruitment for the species in the system.
- Insights into the growth and survival of stocked Golden Perch in the Campaspe River.
- Strong engagement and knowledge transfer between scientists and anglers.

These large-scale movements of Golden Perch, which have been observed in other monitoring studies, emphasise the need to manage and coordinate river flows for this species at large spatial scales. The evidence of natural recruitment of Murray Cod and strong growth of stocked Golden Perch are encouraging signs in support of the flow management within the Campaspe River.

**Connections with participants**

Many participants expressed strong interest in finding out about their fish, including their growth rates and learning more about how fish respond to water for the environment. The field day and other presentations during the project provided valuable opportunities for scientists and anglers to connect and share information. Strong personal connections were made with some participants, which provided an avenue for participants to seek other information including about:

- Murray Cod growth vs age.
- Silver Perch and lesions.
- Catfish, their status and movement.

### 4.4.8 Evaluation

This pilot project did provide supplementary ear bones to the collection obtained through the conventional monitoring component of VEFMAP Stage 6. A full evaluation of participants’ views on the project and whether they increased their knowledge of environmental water management will be compiled after the second questionnaire.

Many valuable insights have been gained including:

- Contacting a broad range of angling clubs was an effective targeted approach for this pilot project. While interest across angling clubs was patchy, some groups were highly engaged. The reliance on one primary contact within each angling club could sometimes be problematic; where particular individuals failed to maintain contact, this limited the ability to connect with other angling club participants who were likely interested. In particular, the Goulburn Valley Association of Angling Clubs did not maintain contact, and very few samples were obtained from the Goulburn area. Some angling club members have however more recently expressed a strong interest in participating if the project continues.
- Participants varied in their confidence and ability to extract ear bones, and shared feedback on the sidecutters provided in the angler kits; some found other tools more effective Figure 4.4.4. While the video demonstrated the technique, and the training day provided an opportunity to practice, some participants still had difficulties with the process. One participant who was enthusiastic and highly engaged at the beginning of the project became disillusioned and then lost contact; further efforts to meet up with this angler would have been beneficial.
- Some participants indicated strong initial interest yet failed to stay engaged, either due to limited fishing opportunities or low catches. Some older participants who were very keen, regular and accomplished fishers provided a high number of samples.

- Given the time lag between the cut-off date for collection and the analysis of the earbones, more regular interactions with participants would have been worthwhile. In hindsight, it would have been valuable to produce a regular newsletter, along the lines of Croak, a component of the current WetMAP frog citizen science project.

**Figure 4.4.4** Tom Reid from the Rochester Angling Club extracting an ear bone.

### 4.4.9 Recommendations

Planning for VEFMAP Stage 7 will include an assessment of how this pilot project could continue, to obtain further ear bones for analysis, as well as to expand this collaboration and engagement with other recreational fishers. An approach that targets areas where there is a particular need for supplementary samples, and which identifies and engages with angler champions may be most useful.

# 5 Conclusions

*Monitoring and research*

VEFMAP Stage 6 has proved extremely successful. Results from the program provide clear evidence of benefits from environment watering for native fish and vegetation across a broad range of Victoria's regulated river systems.

For fish, the combined approach of event-based and long-term monitoring has enabled us to identify and quantify key pathways linking attributes of river flows to the processes governing native fish population dynamics across Victoria. Establishing and quantifying links between river flows and population processes within our KEQ framework has provided much-needed empirical evidence to support delivery of environmental water for enhancing native fish populations. Most notably, our assessments of fish movement in response to specific flow events generated overwhelming evidence and support for the use of environmental flows as an effective management tool to enhance migration, dispersal and subsequent populations of native fish species in coastal rivers such as the Glenelg and Moorabool (e.g. Section 2.3), and inland rivers such as the Campaspe, Loddon and Goulburn (e.g. Section 2.4). The addition of population modelling to this approach provided an important tool to help predict long-term population outcomes from a variety of managed flow scenarios, including existing flow recommendations and inter-valley transfers, and other interventions such as stocking (Section 2.7).

For vegetation, refined and varied sampling approaches, an expanded spatial distribution of monitoring, targeted and more frequent data collection, and focused experimental approaches all provided evidence that, for some species and some systems, environmental watering is clearly influencing key processes and populations of native vegetation. The incorporation of measurements related to other drivers of vegetation change (e.g. grazing, soil moisture, inundation tolerances) gave us a broader understanding of the interactive effects of management actions on vegetation in riparian systems, which has greatly improved our understanding of the links between flow regimes and ecological outcomes for vegetation (Section 3.11).

The use of this multi-faceted monitoring and research approach, particularly the event-based monitoring, has facilitated the provision of regular, directly relevant data to enable annual and intra-annual adaptive management by CMA waterway managers. Observations and results from VEFMAP Stage 6 monitoring have been used to support existing flow regimes, inform changes to the timing and magnitude of flow events, to enable the delivery of desired hydrographs to enhance key population processes for fish, and support instream, fringing and riparian vegetation in Victorian river systems.

For VEFMAP Stage 7, we recommend that the program continues using a combination of event-based intervention monitoring, condition monitoring, focused experiments and predictive modelling techniques to evaluate population outcomes and implications of current and future flow scenarios, and to test the transferability of knowledge gained to new species and other river systems. This mixed approach will enable an informed adaptive management approach, with researchers and managers continuously testing and refining plans for environmental water delivery. Evaluating the relative effects of drivers that are not related to flow, such as grazing, should also continue. Importantly, this should include expanding monitoring opportunities to sample interactions between fish, plants and other groups, so we can better understand more complex food webs and other ecosystem processes in Victorian rivers.

*Communication and engagement*

The multiple modes of communication and engagement used during VEFMAP Stage 6 fostered strong partnerships between the project team, CMAs and other water managers. This enabled regular communication regarding planning, progress and results, the establishment of genuine collaborations, and the provision of timely advice to influence environmental water management planning. The Stage 6 end-of-program evaluation will provide valuable insights on what worked well for Stage 6, to inform the approach to Stage 7. Now that strong connections have been established with many key stakeholders, it will be timely to expand efforts to communicate and engage with a broader range of target audiences during Stage 7. This may include an expanded focus on citizen science projects.

*Collaboration with other monitoring and research programs*

VEFMAP Stage 6 has been significantly improved by close collaborations with a broad range of scientists, research institutes, consultancies and government agencies. These partnerships have enabled the creation of multi-disciplinary teams to make use of diverse and targeted expertise, which has resulted in:

- enhanced understanding of the responses of fish populations over broad spatial scales

- improved knowledge of specific vegetation responses to the duration and timing of inundation
- increased capacity to explore the interaction of environmental flows with soil moisture, grazing and Carp
- improved knowledge of fish genetics and population composition in terms of natural spawning and recruitment versus stocking
- many benefits associated with the direct involvement of students in applied research projects.

We envisage an expansion of these collaborations for Stage 7 and look forward to working with scientists from a broad range of organisations, agencies and consultancies.

*Stage 6 End-of-Program evaluation*

Outcomes from the end-of-program evaluation will be used to inform our planning, approach, governance arrangements and program delivery of VEFMAP Stage 7, with the intent of building on and improving all aspects of the program throughout 2020–2024.

# 6 References


Amtstaetter, F., O'Connor, J., and Pickworth, A. (2016). Environmental flow releases trigger spawning migrations by australian grayling prototroctes maraena, a threatened, diadromous fish. *Aquatic Conservation* **26**: 35–43.

Amtstaetter, F., Koster, W., Tonkin, Z., O'Connor, J., Stuart, I., Hale, R. and Yen, J.D.L. (2020). Elevated river discharge promotes the immigration of juvenile diadromous fishes into rivers. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Amtstaetter, F., Tonkin, Z., O'Connor, J., Stuart, I. and Koster, W. (2020). Environmental flows stimulate the upstream movement of juvenile diadromous fishes. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Amtstaetter, F. and Koster, W. (2020). VEFMAP Stage 6: Long term fish community monitoring in the Thomson and Glenelg rivers. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Arthington, A.H. (2012). Environmental flows: saving rivers in the third millennium (Vol. 4). Univ of California Press.

Arthington, A.H., Bunn, S.E., Poff, N.L. and Naiman, R.J., (2006). The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications* **16(4):** 1311–1318.

Bennetts, K., Jolly, K. and Sim L. (2018). Gunbower Forest Carp Exclusion Study December 2017 – March 2018, unpublished report for the North Central Catchment Management Authority, Fire, Flood & Flora, Cape Woolamai, Victoria.

Biggs, B.J.F. (1996). Hydraulic habitat of plants in streams. *Regulated Rivers Research and Management* **12**:131–144.

Bornette G, and Puijalon, S. (2011). Response of aquatic plants to abiotic factors: A review. *Aquatic Science* **73**:1–14. doi: 10.1007/s00027-010-0162-7

Bringsøe, H. (2010). *NOBANIS – Invasive Alien Species Fact Sheet – Trachemys scripta*. Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS. http://www.nobanis.org (accessed 1 December 2015).

Brock, M.A. and Casanova, M.T. (1997). Plant life at the edges of wetlands; ecological responses to wetting and drying patterns. In: Frontiers in Ecology; Building the Links (Eds N. Klomp & I. Lunt), pp. 181– 192. Elsevier Science, Oxford.

Capon, S. J., Chambers, L. E., Mac Nally, R., Naiman, R. J., Davies, P., Marshall, N., et al. (2013). Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation? *Ecosystems,* **16(3)**, 359–381. http://doi.org/10.1007/s10021-013-9656-1.

Capon, S. J., and Pettit, N. E. (2018). Turquoise is the new green: Restoring and enhancing riparian function in the Anthropocene. *Ecological Management & Restoration*, **19(1-2):** 44–53. http://doi.org/10.1111/emr.12326

Casanova, M.T. (2011). Using water plant functional groups to investigate environmental water requirements. *Freshwater Biology* **56:** 2637–2652. doi: 10.1111/j.1365-2427.2011.02680.

Catford, J.A. and Jansson, R. (2014). Drowned, buried and carried away: Effects of plant traits on the distribution of native and alien species in riparian ecosystems. *New Phytol* 204:19–36. doi: 10.1111/nph.12951

Collazo, J.A., O'Harra, D.A. and Kelly, C.A. (2002). Accessible habitat for shorebirds: factors influencing its availability and conservation implications. *Waterbirds* **25 (Special Publ. 2):** 13–24.

Colwell, M.A. (2010). *Shorebird Ecology, Conservation, and Management*. University of California Press, Berkeley and Los Angeles, USA. (Include country if not Australia. If Australia, include state or territory: NSW, SA, WA, ACT, NT, but use 'Victoria', 'Tasmania', 'Queensland'.)

Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs. *Science* **199**:1302–1310.

Cottingham, P., Spruzen, F. and Wickson, S. (eds) (2014). Victorian environmental flows monitoring and assessment program: Stage 5 future directions workshop report. Report prepared for the Department of Environment, Land, Water and Planning by Peter Cottingham and Associates.

Crawford, R.M. (2004). Seasonal differences in plant responses to flooding and anoxia. *Canadian Journal of Botany* **81:**1224–1246. doi: 10.1139/b03-127.

Das, K.K., Panda, D., Sarkar R.K., et al (2009). Submergence tolerance in relation to variable floodwater conditions in rice. *Environmental and Experimental Botany* **66**:425–434. doi: 10.1016/j.envexpbot.2009.02.015

Davies, P. M., Naiman, R. J., Warfe, D. M., Pettit, N. E., Arthington, A. H., and Bunn, S. E. (2014). Flow–ecology relationships: closing the loop on effective environmental flows. *Marine and Freshwater Research* **65(2)**: 13–39. http://doi.org/10.1071/MF13110

Dawson, S. K., Kingsford, R. T., Berney, P., Catford, J. A., Keith, D. A., Stoklosa, J., and Hemmings, F. A. (2017). Contrasting influences of inundation and land use on the rate of floodplain restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems* **27(3)**: 663–674.

DELWP (2016). Water for Victoria - Water Plan. Department of Environment, Land, Water and Planning, Victoria.

DELWP (2016a). Managing grazing on riparian land: decision support tool and guidelines, 2nd edition. Department of Environment, Land, Water and Planning, Melbourne

DELWP (2017). *VEFMAP Stage 6 vegetation pilot study, Campaspe River.* A report by Arthur Rylah Institute for Environmental Research and Integrated Water and Catchments Division, Department of Environment, Land, Water and Planning, Victoria.

DELWP (2017a). VEFMAP Stage 6 Part A: Program context and rationale. A report prepared by Arthur Rylah Institute for Environmental Research, and Integrated Water and Catchments Division. Department of Environment, Land, Water and Planning Department of Environment, Land, Water and Planning.

DELWP (2017b). VEFMAP Stage 6 Part B: Program design and monitoring methods. A report prepared by Arthur Rylah Institute for Environmental Research, and Integrated Water and Catchments Division. Department of Environment, Land, Water and Planning Department of Environment, Land, Water and Planning.

DELWP (2017c). Protecting Victoria's Environment – Biodiversity 2037. Department of Environment, Land, Water and Planning 2017.

DELWP (2020). Bioregions and EVC benchmarks. https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks

DEPI (2013). The Victorian Waterway Management Strategy. Department of Environment and Primary Industries, Victoria.

DOC (2015). Field protocols for WaxTag®/Chew Card/Trap calibration, document version 1 – February 2015. Department of Conservation, Wellington, NZ.

Doody, T. M., Colloff, M. J., Davies, M., Koul, V., Benyon, R. G., & Nagler, P. L. (2015). Quantifying water requirements of riparian river red gum (*Eucalyptus camaldulensis*) in the Murray–Darling Basin, Australia–implications for the management of environmental flows. *Ecohydrology* **8(8)**: 1471 –1487.

DPI (2009). *Guidelines for assessing translocations of live aquatic organisms in Victoria, version 2*. Fisheries Management Report Series No. 65. Department of Primary Industries, Melbourne, Victoria.

Dufour, S., Rodríguez-González, P. M., and Laslier, M. (2019). Tracing the scientific trajectory of riparian vegetation studies: Main topics, approaches and needs in a globally changing world. *Science of the Total Environment* **653(C):** 1168–1185. http://doi.org/10.1016/j.scitotenv.2018.10.383

Evans, P.R. (1975). Exploratory investigation of feeding ecology and behaviour of shorebirds in Westernport Bay. In: Shapiro, M.A. (Ed.) *Westernport Bay Environmental Study, 1973–1974*, pp. 502–510. Ministry for Conservation, Melbourne, Victoria.

Greet, J., Webb, J.A. and Cousens, R.D. (2011). The importance of seasonal flow timing for riparian vegetation dynamics: a systematic review using causal criteria analysis. *Freshwater Biology* **56**:1231–1247. doi: 10.1111/j.1365-2427.2011.02564.x

Greet, J., Cousens, R. and Webb, J. A. (2012). Flow regulation affects temporal patterns of riverine plant seed dispersal: potential implications for plant recruitment. *Freshwater Biology* **57(12)**: 2568 –2579.

Greet, J. (2016). The potential of soil seed banks of a eucalypt wetland forest to aid restoration. *Wetlands Ecology and Management* **24**:565–577.

Hansen, B.D., Fraser, H.S. and Jones, C.S. (2019). Livestock grazing effects on riparian bird breeding behaviour in agricultural landscapes. *Agriculture Ecosystems and Environments* **270–271**:93–102. doi: 10.1016/j.agee.2018.10.016

Hao, F., Huang, D. and Lilburne, P. (2017). A preliminary investigation into the modelled impact of environmental flows on soil moisture content of stream banks in the Wimmera region, Victoria. The University of Melbourne, Masters research project thesis, Australia.

Harris, A., Tonkin, Z., Moloney, P., and Woodhead, J. (2020). Using Otolith Microchemistry to Assign Natal Origin to Juvenile Murray Cod. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Harris, J.H. (1984). Impoundment of coastal drainages of south-eastern Australia, and a review of its relevance to fish migrations. *Australian Zoologist* **21**: 235–250.

Harris, J.H., Bond, N., Closs, G.P., Gerhke, P.C., Nicol, S.J., and Ye, Q. (2013). Dynamics of Populations. In Ecology of Australian Freshwater Fishes. (Eds. H P. and K Walker) pp. 223–244. (CSIRO Publishing: Melbourne).

Heard, G., Scroggie, M. and Clemann, N. (2010). *Guidelines for managing the endangered Growling Grass Frog in urbanising landscapes*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 208. Department of Sustainability and Environment, Heidelberg, Victoria.

Henry, G. W. and Lyle, J. M. (2003). The National Recreational and Indigenous Fishing Survey July 2003. Australian Government Department of Agriculture, Fisheries and Forestry

Hu, K., Lin, A., and Liu, C. (2017). Soil analysis and modelling of soil moisture response to environmental flow in the riparian zone of the Campaspe River. The University of Melbourne, Masters research project thesis, Australia.

Jansen A, and Robertson, A.I. (2001). Relationship between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* **38**:63–75. doi: 10.1046/j.1365-2664.2001.00557.

Jones, C. and Vivian, L. (2019). VEFMAP Stage 6: Monitoring vegetation response to environmental flow delivery in Victoria 2018/19. Arthur Rylah Institute report to the Department of Environment, Land, Water and Planning, Melbourne.

Jones, C.S. and Vesk, P.A. (2016). Grazing. In: Capon S, James CS, Reid M (eds) Vegetation of Australian Riverine Landscapes: Biology, Ecology and Management. CSIRO Publishing.

Jones, C.S., Vivian, L., Mole, B., Thomas, F.M., Backstrom, A., Just, K., Gould, E., Caffrey, L., and Brooks, J. (2020). Evaluating the influence of environmental flows on vegetation in regulated rivers. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Jones, C.S., Vivian, L., Mole, B., Backstrom, A. (2020). Vegetation recruitment in river channels and the role of environmental flows on plant germination. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Jones, C.S., Unland, N., Hoxley, G., Lovell, D., White, D., and Fletcher, G. (2020) Understanding the links between environmental flows and soil moisture in waterways to improve vegetation condition. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Jones, M.J., O'Connor, J., Clunie, P., Lyon, J., Stuart, I., Saddlier, S., Hackett, G., Pickworth, A., Mahoney, J. Fairbrother, P., Moloney, P. and Tonkin, Z. (2020). Environmental flows cue fish movement and improve fishway functionality: case studies from a semi-arid river-floodplain system. Unpublished

Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Jonsson, B. (2006). Life-history effects of migratory costs in anadromous brown trout. Journal of Fish Biology. *Journal of Fish Biology* **69:** 860–869.

Kitanovic, V., Greet, J., McKendrick, S., Jones, C.S. (2020). Grasses in riparian zones display unexpected tolerance to cool-season inundation. In review.

Koehn, J. D. (2004). Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. *Freshwater Biology* **49 (7):** 882–894.

Koehn, J. (2005). Threats to Murray Cod. In: Lintermans, M. and Phillips, B. (Eds) *Management of Murray Cod in the Murray–Darling Basin: statement, recommendations and supporting papers.* Proceedings of a workshop held in Canberra ACT, 3–4 June 2004, pp. 30–37. Murray–Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Koehn, J.D., and Todd, C.R. (2012). Balancing conservation and recreational fishery objectives for a threatened species, the Murray Cod, *Maccullochella peelii*. *Fisheries Management and Ecology* **19:** 410–425.

Koster, W.M., Dawson, D.R., O'Mahony, D.J., Moloney, P.D. and Crook, D.A. (2014). Timing, frequency and environmental conditions associated with mainstem–tributary movement by a lowland river fish, Golden Perch (*Macquaria ambigua*). *PloS one* **9**, e96044.

Koster, W.M., Stuart, I.G., Tonkin, Z., Dawson, D., and Fanson, B. (2020). Environmental influences on migration patterns and pathways of a threatened Australian fish in a lowland river network. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Lunt, I.D., Jansen, A., Binns, D.L. and Kenny, S.A. (2007). Long-term effects of exclusion of grazing stock on degraded herbaceous plant communities in a riparian Eucalyptus camaldulensis forest in south-eastern Australia. *Austral Ecology* **32**:937–949. doi: 10.1111/j.1442-9993.2007.01782.

MacArthur, R.H. and Wilson, E.O. (1967). The theory of island biogeography. Princeton, NJ Princeton University Press.

Mackay, S.J., Arthington, A.H., Kennard, M.J. and Pusey, B.J. (2003). Spatial variation in the distribution and abundance of submersed macrophytes in an Australian subtropical river. *Aquatic Botany* **77**:169–186. doi: 10.1016/S0304-3770(03)00103-7

Mackay, S.J. and James, C.S. (2016). Aquatic vascular macrophytes of Australia's riverine systems. In: Capon SJ, James CS, Reid MA (eds) Vegetation of Australian Riverine Landscapes: Biology, Ecology and Management. CSIRO Publishing

Madsen, J.D. and Adams, M.S .(1989). The distribution of submerged aquatic macrophyte biomass in a eutrophic stream, Badfish Creek: the effect of environment. *Hydrobiologia* **171**:111–119. doi: 10.1007/BF00008171

Main, A. (2020) Effects of water temperature on the inundation tolerance of herbaceous riparian plants. A research thesis as part of the Masters of Environment at The University of Melbourne.

Marshall T (1947) Mechanical composition of soil in relation to field descriptions of texture. Council for Scientific and Industrial Research, Bulletin No. 224. Melbourne, Australia.

Miller, K,A,, Webb, J.A., De Little, S.C. and Stewardson, M.J. (2013). Environmental flows can reduce the encroachment of terrestrial vegetation into river channels: A systematic literature review. *Environmental Management* **52**:1202–1212. doi: 10.1007/s00267-013-0147-0

Miller, K.A., Webb, A., de Little, S., Stewardson, M. and Rutherfurd, I. (2014). How effective are environmental flows? Analyses of flow-ecology relationships in the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) from 2011-2014. Report prepared for the Department of Environment and Primary Industries.

Milner, N.J., Elliott, J.M., Armstrong, J.D., Gardiner, R., Welton, J.S., and Ladle, M. (2003) The natural control of salmon and trout populations in streams. *Fisheries Research* **62(2):** 111–125.

Mole, B., Vivian, L., Fletcher, G. and Tonkin, Z. (in prep). Environmental flows help structure fish and vegetation communities in a regulated semi-arid intermittent stream system.

Morris, K. (2019). Impacts of IVT delivery on the lower Goulburn River. Bank Vegetation. Unpublished Client Report for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Murdoch, F. (2005). Restoration ecology in the semi-arid woodlands of north-west Victoria. PhD thesis, University of Ballarat, Victoria.

O'Connor, J., Stuart, I. and Jones, M. (2017). Guidelines for the design, approval and construction of fishways. Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg,Victoria.

O'Connor, J., Jones, M. and Tonkin, Z. (2020). Water for the environment and its role in the upstream, downstream and dispersal movement of Golden Perch. Unpublished Client Report for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

O'Donnell, J., Fryirs, K. and Leishman, M.R. (2014). Digging deep for diversity: riparian seed bank abundance and species richness in relation to burial depth. Freshwater Biology **59:** pp.100–113.

O'Donnell, J., Fryirs, K. and Leishman, M.R., (2015). Can the regeneration of vegetation from riparian seed banks support biogeomorphic succession and the geomorphic recovery of degraded river channels? *River Research and Applications* **31(7)**: 834–846.

ORIMA (2017). A report on research to explore Victorians' knowledge of, and attitudes towards, environmental water to improve communication of the Victorian Environmental Watering Program. An unpubilshed report to the Victorian Environmental Water Holder. ORIMA Research, Melbourne.

Palmer, M., and Ruhi, A. (2019). Linkages between flow regime, biota, and ecosystem processes: Implications for river restoration. *Science 365* **(6459),** eaaw2087–15. http://doi.org/10.1126/science.aaw2087

Pavlova, A., Beheregaray, L.B., Coleman, R., Gilligan, D., Harrisson, K.A., Ingram, B.A., Kearns, J., Lamb, A.M., Lintermans, M., Lyon, J., Nguyen, T.T.T., Sasaki, M., Tonkin, Z., Yen, J.D.L., and Sunnucks, P. (2017). Severe consequences of habitat fragmentation on genetic diversity of an endangered Australian freshwater fish: A call for assisted gene flow. *Evolutionary Applications* **10(6):** 531–550

Pereira, M., Greet, J., Jones, C.S. (2020). Native riparian plant species dominate the soil seedbank of in-channel geomorphic features of a regulated river. In review.

Poff, N.L., Allan, J.D., Bain, M.B, et al (1997). The natural flow regime: a paradigm for river conservation and restoration. *Bioscience* **47:**769–784. doi: 10.2307/1313099

Poff, N. L., and Zimmerman, J. K. (2010). Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biology* **55(1)**: 194–205.

Price, A., Balcombe, S., Humphries, P., King, A. and Zampatti, B. (2019). Murray–Darling Basin Environmental Water Knowledge and Research Project — Fish Theme Research Report. Report prepared for the Department of the Environment and Energy, Commonwealth Environmental Water Office by La Trobe University, Centre for Freshwater, CFE Publication 223 June 2019 41p. [Appendices 203p.] 2019.

Raulings, E., Morris, K., Thompson, R., and Nally, R. M. (2011). Do birds of a feather disperse plants together? *Freshwater Biology* **56(7)**: 1390–1402.

Reid, M. and Capon, S. (2011). Role of the soil seed bank in vegetation responses to environmental flows on a drought-affected floodplain. *River Systems* **19(3):** 249–259

Reznick, D. (1983). The Structure of Guppy Life Histories: The Trade-off between growth and reproduction. *Ecology* **64(4):** 862–873.

Riis, T., Kelly-Quinn, M., Aguiar, F. C., Manolaki, P., Bruno, D., Bejarano, M. D., and Portela, A. P. (2020). Global overview of ecosystem services provided by riparian vegetation. *Bioscience*. doi.org/10.1093/biosci/biaa041

Riis, T. and Biggs, B.J.F. (2003). Hydrologic and hydraulic control of macrophyte establishment and performance in streams. *Limnology and Oceanography* **48**:1488–1497. doi: 10.4319/lo.2003.48.4.1488

Riis, T., Suren, A.M., Clausen, B., and Sand-Jensen, K. (2008). Vegetation and flow regime in lowland streams. *Freshwater Biology* **53**:1531–1543. doi: 10.1111/j.1365-2427.2008.01987.

Robertson, A.I. and Rowling, R.W. (2002). Effects of livestock on riparian zone vegetation in an Australian dryland river*. Regulated Rivers Restoration and Management* **16**:527–541. doi: 10.1002/1099-1646(200009/10)16:5<527::aid-rrr602>3.3.co;2-n

Robinson, D. A., Campbell, C. S., Hopmans, J. W., Hornbuckle, B. K., Jones, S. B., Knight, R.,Wendroth, O., et al. (2008). Soil moisture measurement for ecological and hydrological watershed-scale observatories: A review. *Vadose Zone Journal* **7(1)**: 358–389.

Rohr, J.R., Raffel, T.R., Halstead, N.T., McMahon, T.A., Johnson, S.A., Boughton, R.K. and Martin, L.B. (2013). Early-life exposure to a herbicide has enduring effects on pathogen-induced mortality. *Proceedings of the Royal Society of London: Biological Sciences* **280** doi:10.1098/rspb.2013.1502

Sanderson, J.S., Rowan, N., Wilding, T., et al (2012). Getting to scale with environmental flow assessment: the watershed flow evaluation tool. *River Research and Applications* **28:**1369–1377.

Schindelin, J., Arganda-Carreras, I., Frise, E., et al (2012). Fiji: an open-source platform for biological-image analysis. *Nature Methods* **9**:676–682. doi: 10.1038/nmeth.2019

Thiem, J. D., Wooden, I. J., Baumgartner, L. J., Butler, G. L., Forbes, J. P., and Conallin, J. (2017). Recovery from a fish kill in a semi-arid Australian river: Can stocking augment natural recruitment processes? *Austral Ecology* **42:** 218–226.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B, Marques, T.A. and Burnham, K.P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47:** 5–14.

Thompson, K. and Grime, J.P. (1979). Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. *Journal of Ecology*, pp.893–921.

Todd, C.R., and Koehn, J.D. (2008). Murray Cod modelling to address key management actions: Final report for project MD745. Arthur Rylah Institute for Environmental Research Progress Report to the Murray Darling Basin Commission. Department of Sustainability and Environment: Heidelberg.

Todd, C., Koehn, J., Yen, J., Koster, W. and Tonkin, Z. (2020). Predicting long-term population responses by Murray Cod and Silver Perch to flow management in the Goulburn and Campaspe rivers: a stochastic population modelling approach. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Tonkin, Z., Kitchingman, A., Ingram, B., Lieschke, J., Koster, W., Lyon, J., Lutz, M. and Pavlova, A. (2019). Smarter stocking: a synthesis of existing data to assess native fish stocking success in Victorian rivers. Unpublished Client Report for the Victorian Fisheries Authority. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Tonkin, Z., Yen, J., Lyon, J., Kitchingman, A., Koehn, J., Koster, W., Lieschke, J., Raymond, S., Sharley, J., Stuart, I., and Todd, C. (2020). Linking flow attributes to recruitment to inform water management for an Australian freshwater fish with an equilibrium life-history strategy. *Science of The Total Environment*, doi.org/10.1016/j.scitotenv.2020.141863.

Unland, N. P., Cartwright, I., Cendon, D. I., & Chisari, R. (2014). Residence times and mixing of water in river banks: implications for recharge and groundwater-surface water exchange. *Hydrology and Earth System Sciences*, **18** 5109 –5124. doi: http://dx.doi.org/10.5194/hess-18-5109-2014

van Eck, W.H.J.M., Lenssen, J.P.M., Rengelink, R.H.J., et al. (2005). Water temperature instead of acclimation stage and oxygen concentration determines responses to winter floods. *Aquatic Botany* **81**:253–264. doi: 10.1016/j.aquabot.2004.10.006

van Genuchten, M.T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, **44(5):** 892–898.

van Vliet, M.T.H., Franssen, W.H.P., Yearsley, J.R., et al (2013). Global river discharge and water temperature under climate change. *Global Environmental Change* **23**:450–464

Vivian, L., Greet, J., Jones, C.S. (2020) Responses of grasses to experimental submergence in summer: implications for the management of unseasonal flows in regulated rivers. Aquatic Ecology. https://doi.org/10.1007/s10452-020-09788-4

Vivian, L., Jones, C.S., Kitchingman, A. (in prep.). Drivers of the distribution and community composition of riparian vegetation in regulated rivers of Victoria.

VEWH (2020). Seasonal Watering Plan 2019-20. Victorian Environmental Water Holder.

Weber, M. J., and Brown, M. L. (2009). Effects of common carp on aquatic ecosystems 80 years after "carp as a dominant": ecological insights for fisheries management. *Reviews in Fisheries Science*, **17(4):** 524–537.

Wootton, R.J. (1998). 'Ecology of Teleost Fishes. 2nd edition edn. Kluwer Academic Publishers, Dordrecht.

Yen, J., Thomson, J., Lyon, J., Koster, W., Kitchingman, A., Raymond, S., Stamation, K., and Tonkin, Z. (2020). Flow attributes only partially explain long-term trends in fish populations. Unpublished Client Report for Water and Catchments, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Zampatti, B.P., Wilson, P.J., Baumgartner, L., Koster, W., Livore, J., Thiem, J., Tonkin, Z. and Ye, Q. (2015). Reproduction and recruitment of golden Perch (Macquaria ambigua) in the southern Murray-Darling Basin in 2013/14: an exploration of river-scale response, connectivity and population dynamics. Report to Murray-Darling Basin Authority.

# Appendix 1: List of plant species recorded during VEFMAP Stage 6

**Table A1** List of plant species recorded in VEFMAP Stage 6, including family, origin (native or exotic), lifeform (alga, climber, fern, forb, grass, sedge/rush, shrub or tree) and classification (aquatic, emergent, fringing high, fringing low, shrub, terrestrial, tree) (see Figure 3.1.3).

| Species | Family | Origin | Lifeform | Classification |
|---|---|---|---|---|
| *Acacia dealbata* | Fabaceae | native | shrub | shrub |
| *Acacia mearnsii* | Fabaceae | native | shrub | shrub |
| *Acacia melanoxylon* | Fabaceae | native | shrub | shrub |
| *Acacia paradoxa* | Fabaceae | native | shrub | shrub |
| *Acacia provincialis* | Fabaceae | native | shrub | shrub |
| *Acacia pycnantha* | Fabaceae | native | shrub | shrub |
| *Acacia salicina* | Fabaceae | native | shrub | shrub |
| *Acacia* spp. | Fabaceae | native | shrub | shrub |
| *Acacia verticillata* | Fabaceae | native | shrub | shrub |
| *Acaena echinata* | Rosaceae | native | forb | terrestrial |
| *Acaena novae-zelandiae* | Rosaceae | native | forb | terrestrial |
| *Acetosella vulgaris* | Polygonaceae | exotic | forb | terrestrial |
| *Adiantum aethiopicum* | Pteridaceae | native | fern | fringing high |
| *Agrostis capillaris* | Poaceae | exotic | grass | terrestrial |
| *Agrostis* spp. | Poaceae | exotic | grass | terrestrial |
| *Agrostis stolonifera* | Poaceae | exotic | grass | fringing low |
| *Aira elegantissima* | Poaceae | exotic | grass | terrestrial |
| *Alisma plantago-aquatica* | Alismataceae | native | forb | emergent |
| *Alisma* spp. | Alismataceae | unknown | forb | emergent |
| *Allium* spp. | Alismataceae | exotic | forb | fringing high |
| *Allium triquetrum* | Alismataceae | exotic | forb | fringing high |
| *Allocasuarina luehmannii* | Casuarinaceae | native | tree | shrub |
| *Alternanthera denticulata* | Amaranthaceae | native | forb | fringing low |
| *Alternanthera* sp. 1 (Plains) | Amaranthaceae | native | forb | fringing low |
| *Alternanthera* spp. | Amaranthaceae | native | forb | fringing low |
| *Althenia* spp. | Potamogetonaceae | native | forb | aquatic |
| *Amaranthus* spp. | Amaranthaceae | exotic | forb | terrestrial |
| *Amphibromus nervosus* | Poaceae | native | grass | emergent |
| *Anthemis cotula* | Asteraceae | exotic | forb | terrestrial |
| *Anthosachne scabra* | Poaceae | native | grass | terrestrial |
| *Anthoxanthum odoratum* | Poaceae | exotic | grass | terrestrial |
| *Anthoxanthum* spp. | Poaceae | exotic | grass | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Apiaceae* spp. | Apiaceae | unknown | forb | unknown |
| *Apium prostratum* | Apiaceae | native | forb | terrestrial |
| *Aponogeton distachyos* | Aponogetonaceae | exotic | forb | aquatic |
| *Araujia sericifera* | Apocynaceae | exotic | climber | terrestrial |
| *Arctotheca calendula* | Asteraceae | exotic | forb | terrestrial |
| *Arthropodium fimbriatum* | Asparagaceae | native | forb | terrestrial |
| *Arthropodium strictum* s.l. | Asparagaceae | native | forb | terrestrial |
| *Asparagus asparagoides* | Asparagaceae | exotic | climber | terrestrial |
| *Asperula conferta* | Rubiaceae | native | forb | terrestrial |
| *Asperula gemella* | Rubiaceae | native | forb | terrestrial |
| *Asperula* spp. | Rubiaceae | native | forb | terrestrial |
| *Aster subulatus* | Asteraceae | exotic | forb | fringing high |
| *Asteraceae* spp. | Asteraceae | unknown | forb | unknown |
| *Atriplex prostrata* | Chenopodiaceae | exotic | forb | fringing high |
| *Austrocynoglossum latifolium* | Boraginaceae | native | forb | terrestrial |
| *Austrostipa mollis* | Poaceae | native | grass | terrestrial |
| *Austrostipa scabra* | Poaceae | native | grass | terrestrial |
| *Austrostipa* spp. | Poaceae | native | grass | terrestrial |
| *Avena barbata* | Poaceae | exotic | grass | terrestrial |
| *Avena fatua* | Poaceae | exotic | grass | terrestrial |
| *Avena* spp. | Poaceae | exotic | grass | terrestrial |
| *Azolla* spp. | Salviniaceae | native | fern | aquatic |
| *Baloskion tetraphyllum* subsp. *tetraphyllum* | Restionaceae | native | sedge/rush | emergent |
| *Baumea arthrophylla* | Cyperaceae | native | sedge/rush | emergent |
| *Baumea articulata* | Cyperaceae | native | sedge/rush | emergent |
| *Baumea juncea* | Cyperaceae | native | sedge/rush | emergent |
| *Baumea* spp. | Cyperaceae | native | sedge/rush | emergent |
| *Blechnum nudum* | Blechnaceae | native | fern | fringing high |
| *Bolboschoenus fluviatilis* | Cyperaceae | native | sedge/rush | emergent |
| *Bolboschoenus medianus* | Cyperaceae | native | sedge/rush | emergent |
| *Bolboschoenus* spp. | Cyperaceae | native | sedge/rush | emergent |
| *Borago officinalis* | Boraginaceae | exotic | forb | terrestrial |
| *Bothriochloa macra* | Poaceae | native | grass | terrestrial |
| *Brachypodium distachyon* | Poaceae | exotic | grass | terrestrial |
| *Brassica* spp. | Brassicaceae | exotic | forb | terrestrial |
| *Brassica nigra* | Brassicaceae | exotic | forb | terrestrial |
| *Brassicaceae* spp. | Brassicaceae | unknown | forb | terrestrial |
| *Briza maxima* | Poaceae | exotic | grass | terrestrial |
| *Briza minor* | Poaceae | exotic | grass | terrestrial |
| *Bromus catharticus* | Poaceae | exotic | grass | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Bromus diandrus* | Poaceae | exotic | grass | terrestrial |
| *Bromus hordeaceus* subsp. *hordeaceus* | Poaceae | exotic | grass | terrestrial |
| *Bromus rubens* | Poaceae | exotic | grass | terrestrial |
| *Bromus* spp. | Poaceae | exotic | grass | terrestrial |
| *Bursaria spinosa* | Pittosporaceae | native | shrub | shrub |
| *Caesia* spp. | Asphodelaceae | native | forb | terrestrial |
| *Callistemon sieberi* | Myrtaceae | native | shrub | shrub |
| *Callistemon* spp. | Myrtaceae | native | shrub | shrub |
| *Callistemon wimmerensis* | Myrtaceae | native | shrub | shrub |
| *Callitriche brutia* var. *brutia* | Plantaginaceae | exotic | forb | aquatic |
| *Callitriche stagnalis* | Plantaginaceae | exotic | forb | aquatic |
| *Calocephalus citreus* | Asteraceae | native | forb | terrestrial |
| *Calotis scapigera* | Asteraceae | native | forb | fringing high |
| *Calystegia sepium* | Convolvulaceae | native | climber | terrestrial |
| *Calystegia* spp. | Convolvulaceae | exotic | climber | terrestrial |
| *Cardamine* spp. | Brassicaceae | native | forb | terrestrial |
| *Carex appressa* | Cyperaceae | native | sedge/rush | emergent |
| *Carex bichenoviana* | Cyperaceae | native | sedge/rush | emergent |
| *Carex breviculmis* | Cyperaceae | native | sedge/rush | fringing low |
| *Carex fascicularis* | Cyperaceae | native | sedge/rush | emergent |
| *Carex gaudichaudiana* | Cyperaceae | native | sedge/rush | emergent |
| *Carex inversa* | Cyperaceae | native | sedge/rush | fringing high |
| *Carex polyantha* | Cyperaceae | native | sedge/rush | emergent |
| *Carex* spp. | Cyperaceae | native | sedge/rush | emergent |
| *Carex tereticaulis* | Cyperaceae | native | sedge/rush | emergent |
| *Cassinia aculeata* subsp. *aculeata* | Asteraceae | native | shrub | shrub |
| *Cenchrus clandestinus* | Poaceae | exotic | grass | terrestrial |
| *Centaurium erythraea* | Gentianaceae | exotic | forb | terrestrial |
| *Centella cordifolia* | Apiaceae | native | forb | fringing high |
| *Centipeda cunninghamii* | Asteraceae | native | forb | fringing low |
| *Cerastium glomeratum* s.l. | Caryophyllaceae | exotic | forb | terrestrial |
| *Ceratophyllum demersum* | Ceratophyllaceae | native | forb | aquatic |
| Characeae spp. | Characeae | native | alga | aquatic |
| *Chenopodium album* | Chenopodiaceae | exotic | forb | terrestrial |
| *Chenopodium* spp. | Chenopodiaceae | unknown | forb | terrestrial |
| *Chloris truncata* | Poaceae | native | grass | terrestrial |
| *Chorizandra australis* | Cyperaceae | native | sedge/rush | emergent |
| *Chorizandra enodis* | Cyperaceae | native | sedge/rush | emergent |
| *Chrysocephalum apiculatum* s.l. | Asteraceae | native | forb | terrestrial |
| *Cirsium vulgare* | Asteraceae | exotic | forb | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Clematis aristata* | Ranunculaceae | native | climber | terrestrial |
| *Conium maculatum* | Apiaceae | exotic | forb | terrestrial |
| *Convolvulus arvensis* | Convolvulaceae | exotic | climber | terrestrial |
| *Coprosma quadrifida* | Rubiaceae | native | shrub | shrub |
| *Cotula australis* | Asteraceae | native | forb | terrestrial |
| *Cotula coronopifolia* | Asteraceae | exotic | forb | fringing high |
| *Cotula* spp. | Asteraceae | unknown | forb | terrestrial |
| *Crassula decumbens* var. *decumbens* | Crassulaceae | native | forb | terrestrial |
| *Crassula helmsii* | Crassulaceae | native | forb | fringing low |
| *Crataegus monogyna* | Rosaceae | exotic | shrub | shrub |
| *Crepis vesicaria* subsp. *taraxacifolia* | Asteraceae | exotic | forb | terrestrial |
| *Crocosmia* × *crocosmiiflora* | Iridaceae | exotic | forb | terrestrial |
| *Cycnogeton alcockiae* | Juncaginaceae | native | forb | aquatic |
| *Cycnogeton procerum* | Juncaginaceae | native | forb | aquatic |
| *Cynodon dactylon* var. *dactylon* | Poaceae | exotic | grass | terrestrial |
| *Austrocynoglossum latifolium* | Boraginaceae | native | forb | terrestrial |
| *Cynoglossum* spp. | Boraginaceae | native | forb | terrestrial |
| *Cynosurus echinatus* | Poaceae | exotic | grass | fringing high |
| *Cyperus eragrostis* | Cyperaceae | exotic | sedge/rush | emergent |
| *Cyperus exaltatus* | Cyperaceae | native | sedge/rush | emergent |
| *Cyperus gunnii* subsp. *gunnii* | Cyperaceae | native | sedge/rush | emergent |
| *Cyperus lucidus* | Cyperaceae | native | sedge/rush | emergent |
| *Cyperus* spp. | Cyperaceae | unknown | sedge/rush | emergent |
| *Dactylis glomerata* | Poaceae | exotic | grass | terrestrial |
| *Daucus carota* | Apiaceae | exotic | forb | terrestrial |
| *Daucus glochidiatus* | Apiaceae | native | forb | terrestrial |
| *Deyeuxia quadriseta* | Poaceae | native | grass | fringing high |
| *Dianella porracea* | Asphodelaceae | native | forb | fringing high |
| *Dianella tarda* | Asphodelaceae | native | forb | fringing high |
| *Dichanthium sericeum* subsp. *sericeum* | Poaceae | native | grass | terrestrial |
| *Dichelachne crinita* | Poaceae | native | grass | terrestrial |
| *Dichondra repens* | Convolvulaceae | native | forb | terrestrial |
| Dicot | unknown | unknown | unknown | unknown |
| *Dillwynia* spp. | Fabaceae | native | shrub | shrub |
| *Dipsacus fullonum* | Dipsacaceae | exotic | forb | terrestrial |
| *Distichlis distichophylla* | Poaceae | native | grass | fringing low |
| *Dittrichia graveolens* | Asteraceae | exotic | shrub | shrub |
| *Dodonaea viscosa* | Sapindaceae | native | shrub | shrub |
| *Drosera* spp. | Droseraceae | native | forb | terrestrial |
| *Dysphania pumilio* | Chenopodiaceae | native | forb | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Echinopogon ovatus* | Poaceae | native | grass | terrestrial |
| *Eclipta platyglossa* | Asteraceae | native | forb | fringing high |
| *Ehrharta calycina* | Poaceae | exotic | grass | terrestrial |
| *Ehrharta erecta* var. *erecta* | Poaceae | exotic | grass | terrestrial |
| *Ehrharta longiflora* | Poaceae | exotic | grass | terrestrial |
| *Ehrharta* spp. | Poaceae | exotic | grass | terrestrial |
| *Einadia nutans* subsp. *nutans* | Chenopodiaceae | native | forb | terrestrial |
| *Elatine gratioloides* | Elatinaceae | native | forb | fringing low |
| *Eleocharis acuta* | Cyperaceae | native | sedge/rush | emergent |
| *Eleocharis pusilla* | Cyperaceae | native | sedge/rush | emergent |
| *Eleocharis sphacelata* | Cyperaceae | native | sedge/rush | emergent |
| *Elodea canadensis* | Hydrocharitaceae | exotic | forb | aquatic |
| *Enteropogon acicularis* | Poaceae | native | grass | terrestrial |
| *Epilobium billardierianum* subsp. *billardierianum* | Onagraceae | native | forb | fringing low |
| *Epilobium hirtigerum* | Onagraceae | native | forb | fringing low |
| *Eragrostis brownii* | Poaceae | native | grass | terrestrial |
| *Eragrostis* spp. | Poaceae | native | grass | terrestrial |
| *Eragrostis infecunda* | Poaceae | native | grass | fringing low |
| *Erigeron bonariensis* | Asteraceae | exotic | forb | terrestrial |
| *Erodium moschatum* | Geraniaceae | exotic | forb | terrestrial |
| *Erodium* spp. | Geraniaceae | exotic | forb | terrestrial |
| *Eryngium ovinum* | Apiaceae | native | forb | terrestrial |
| *Eucalyptus camaldulensis* subsp. *camaldulensis* | Myrtaceae | native | tree | tree |
| *Eucalyptus leucoxylon* | Myrtaceae | native | tree | tree |
| *Eucalyptus polyanthemos* | Myrtaceae | native | tree | tree |
| *Eucalyptus* spp. | Myrtaceae | native | tree | tree |
| *Eucalyptus viminalis* | Myrtaceae | native | tree | tree |
| *Euchiton involucratus* s.l. | Asteraceae | native | forb | fringing low |
| *Euchiton sphaericus* | Asteraceae | native | forb | fringing low |
| *Euchiton* spp. | Asteraceae | native | forb | fringing low |
| *Euphorbia dallachyana* | Euphorbiaceae | native | forb | terrestrial |
| *Euphorbia lathyris* | Euphorbiaceae | exotic | forb | terrestrial |
| *Euphorbia* spp. | Euphorbiaceae | unknown | forb | terrestrial |
| *Exocarpos strictus* | Santalaceae | native | shrub | shrub |
| *Ficinia nodosa* | Cyperaceae | native | sedge/rush | emergent |
| *Fraxinus* spp. | Oleaceae | exotic | tree | tree |
| *Freesia* spp. | Iridaceae | exotic | forb | terrestrial |
| *Fumaria muralis* subsp. *muralis* | Papaveraceae | exotic | forb | terrestrial |
| *Fumaria* spp. | Papaveraceae | exotic | forb | terrestrial |
| *Gahnia sieberiana* | Cyperaceae | native | sedge/rush | fringing high |

| | | | | |
|---|---|---|---|---|
| *Galenia pubescens* | Aizoaceae | exotic | forb | terrestrial |
| *Galium aparine* | Rubiaceae | exotic | forb | terrestrial |
| *Geranium dissectum* | Geraniaceae | exotic | forb | terrestrial |
| *Geranium molle* | Geraniaceae | exotic | forb | terrestrial |
| *Geranium* spp. | Geraniaceae | unknown | forb | terrestrial |
| *Gladiolus* spp. | Iridaceae | exotic | forb | terrestrial |
| *Gladiolus undulatus* | Iridaceae | exotic | forb | terrestrial |
| *Glossostigma elatinoides* | Phrymaceae | native | forb | fringing low |
| *Glyceria australis* | Poaceae | native | grass | emergent |
| *Glyceria maxima* | Poaceae | exotic | grass | emergent |
| *Glyceria* spp. | Poaceae | unknown | grass | emergent |
| *Glycine* spp. | Fabaceae | native | forb | terrestrial |
| *Glycine tabacina* | Fabaceae | native | climber | terrestrial |
| *Gonocarpus tetragynus* | Haloragaceae | native | forb | terrestrial |
| *Goodenia elongata* | Goodeniaceae | native | forb | fringing low |
| *Goodenia humilis* | Goodeniaceae | native | forb | fringing low |
| *Goodenia ovata* | Goodeniaceae | native | shrub | shrub |
| *Gratiola peruviana* | Plantaginaceae | native | forb | aquatic |
| *Gratiola pumilo* | Plantaginaceae | native | forb | aquatic |
| *Gynatrix pulchella* s.l. | Malvaceae | native | tree | shrub |
| *Haloragis aspera* | Haloragaceae | native | forb | fringing high |
| *Haloragis heterophylla* | Haloragaceae | native | forb | fringing high |
| *Hedera helix* | Araliaceae | exotic | climber | terrestrial |
| *Heliotropium europaeum* | Boraginaceae | exotic | forb | terrestrial |
| *Helminthotheca echioides* | Asteraceae | exotic | forb | terrestrial |
| *Hemarthria uncinata* var. *uncinata* | Poaceae | native | grass | fringing low |
| *Holcus lanatus* | Poaceae | exotic | grass | terrestrial |
| *Holcus* spp. | Poaceae | exotic | grass | terrestrial |
| *Hordeum leporinum* | Poaceae | exotic | grass | terrestrial |
| *Hordeum marinum* | Poaceae | exotic | grass | terrestrial |
| *Hordeum* spp. | Poaceae | exotic | grass | terrestrial |
| *Hydrocotyle laxiflora* | Araliaceae | native | forb | terrestrial |
| *Hydrocotyle pterocarpa* | Araliaceae | native | forb | fringing low |
| *Hypericum androsaemum* | Hypericaceae | exotic | forb | terrestrial |
| *Hypericum gramineum* | Hypericaceae | native | forb | terrestrial |
| *Hypericum japonicum* | Hypericaceae | native | forb | terrestrial |
| *Hypericum perforatum* | Hypericaceae | exotic | forb | terrestrial |
| *Hypericum* spp. | Hypericaceae | unknown | forb | terrestrial |
| *Hypochaeris glabra* | Asteraceae | exotic | forb | terrestrial |
| *Hypochaeris radicata* | Asteraceae | exotic | forb | terrestrial |
| *Iris pseudacorus* | Iridaceae | exotic | forb | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Isachne globosa* | Poaceae | native | grass | emergent |
| *Isolepis cernua* | Cyperaceae | native | sedge/rush | fringing low |
| *Isolepis fluitans* | Cyperaceae | native | sedge/rush | aquatic |
| *Isolepis hystrix* | Cyperaceae | exotic | sedge/rush | fringing low |
| *Isolepis inundata* | Cyperaceae | native | sedge/rush | fringing low |
| *Isolepis marginata* | Cyperaceae | native | sedge/rush | terrestrial |
| *Isolepis* spp. | Cyperaceae | unknown | sedge/rush | emergent |
| *Juncus acutus* subsp. *acutus* | Juncaceae | exotic | sedge/rush | emergent |
| *Juncus amabilis* | Juncaceae | native | sedge/rush | emergent |
| *Juncus aridicola* | Juncaceae | native | sedge/rush | emergent |
| *Juncus aridicola* × *flavidus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus articulatus* subsp. *articulatus* | Juncaceae | exotic | sedge/rush | fringing low |
| *Juncus bufonius* | Juncaceae | native | sedge/rush | fringing low |
| *Juncus capitatus* | Juncaceae | exotic | sedge/rush | fringing low |
| *Juncus gregiflorus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus holoschoenus* | Juncaceae | native | sedge/rush | fringing low |
| *Juncus kraussii* subsp. *australiensis* | Juncaceae | native | sedge/rush | emergent |
| *Juncus pallidus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus pauciflorus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus planifolius* | Juncaceae | native | sedge/rush | emergent |
| *Juncus prismatocarpus* subsp. *prismatocarpus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus procerus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus* spp. | Juncaceae | native | sedge/rush | emergent |
| *Juncus subsecundus* | Juncaceae | native | sedge/rush | emergent |
| *Juncus usitatus* | Juncaceae | native | sedge/rush | emergent |
| *Kunzea ericoides* spp. agg. | Myrtaceae | native | shrub | shrub |
| *Kunzea* spp. | Myrtaceae | native | shrub | shrub |
| *Lachnagrostis filiformis* s.l. | Poaceae | native | grass | fringing low |
| *Lactuca serriola* | Asteraceae | exotic | forb | terrestrial |
| *Lactuca* spp. | Asteraceae | exotic | forb | terrestrial |
| *Lagurus ovatus* | Poaceae | exotic | grass | terrestrial |
| *Leersia oryzoides* | Poaceae | exotic | grass | emergent |
| *Lemna disperma* | Araceae | native | forb | aquatic |
| *Leontodon saxatilis* | Asteraceae | exotic | forb | terrestrial |
| *Lepidium africanum* | Brassicaceae | exotic | forb | terrestrial |
| *Lepidium pseudotasmanicum* | Brassicaceae | native | forb | terrestrial |
| *Lepidosperma elatius* | Cyperaceae | native | sedge/rush | fringing high |
| *Lepidosperma filiforme* | Cyperaceae | native | sedge/rush | fringing high |
| *Lepidosperma laterale* | Cyperaceae | native | sedge/rush | fringing high |
| *Lepidosperma longitudinale* | Cyperaceae | native | sedge/rush | fringing high |

| | | | | |
|---|---|---|---|---|
| *Lepidosperma* spp. | Cyperaceae | native | sedge/rush | fringing high |
| *Leptospermum continentale* | Myrtaceae | native | shrub | shrub |
| *Leptospermum lanigerum* | Myrtaceae | native | shrub | shrub |
| *Leptospermum obovatum* | Myrtaceae | native | shrub | shrub |
| *Leptospermum obvatum* | Myrtaceae | native | shrub | shrub |
| *Ligustrum* spp. | Oleaceae | exotic | tree | tree |
| *Lilaeopsis polyantha* | Apiaceae | native | forb | emergent |
| *Lobelia anceps* | Campanulaceae | native | forb | fringing low |
| *Lobelia beaugleholei* | Campanulaceae | native | forb | fringing high |
| *Lobelia pedunculata* s.l. | Campanulaceae | native | forb | fringing low |
| *Lobelia pratioides* | Campanulaceae | native | forb | fringing low |
| *Lolium perenne* | Poaceae | exotic | grass | terrestrial |
| *Lolium rigidum* | Poaceae | exotic | grass | terrestrial |
| *Lolium* spp. | Poaceae | exotic | grass | terrestrial |
| *Lomandra filiformis* subsp. *coriacea* | Asparagaceae | native | sedge/rush | terrestrial |
| *Lomandra longifolia* | Asparagaceae | native | sedge/rush | fringing high |
| *Lomatia fraseri* | Proteaceae | native | shrub | shrub |
| *Lomatia myricoides* | Proteaceae | native | shrub | shrub |
| *Lonicera japonica* | Caprifoliaceae | exotic | climber | terrestrial |
| *Lotus corniculatus* | Fabaceae | exotic | forb | terrestrial |
| *Lotus* spp. | Fabaceae | exotic | forb | terrestrial |
| *Ludwigia palustris* | Onagraceae | exotic | forb | emergent |
| *Ludwigia* spp. | Onagraceae | unknown | forb | emergent |
| *Lycopus australis* | Lamiaceae | native | forb | fringing high |
| *Lysimachia arvensis* | Primulaceae | exotic | forb | terrestrial |
| *Lythrum hyssopifolia* | Lythraceae | native | forb | fringing low |
| *Lythrum salicaria* | Lythraceae | native | forb | fringing low |
| *Malva* spp. | Malvaceae | unknown | forb | terrestrial |
| *Malva parviflora* | Malvaceae | exotic | forb | terrestrial |
| *Marrubium vulgare* | Lamiaceae | exotic | forb | terrestrial |
| *Medicago polymorpha* | Fabaceae | exotic | forb | terrestrial |
| *Medicago* spp. | Fabaceae | exotic | forb | terrestrial |
| *Melaleuca decussata* | Myrtaceae | native | shrub | shrub |
| *Melaleuca ericifolia* | Myrtaceae | native | shrub | shrub |
| *Melaleuca* spp. | Myrtaceae | native | shrub | shrub |
| *Melicytus dentatus* s.l. | Violaceae | native | shrub | shrub |
| *Mentha australis* | Lamiaceae | native | forb | fringing high |
| *Mentha pulegium* | Lamiaceae | exotic | forb | fringing high |
| *Mentha* spp. | Lamiaceae | unknown | forb | fringing high |
| *Microlaena stipoides* var. *stipoides* | Poaceae | native | grass | terrestrial |
| *Thyridia repens* | Phrymaceae | exotic | forb | fringing low |

| | | | | |
|---|---|---|---|---|
| *Modiola caroliniana* | Malvaceae | exotic | forb | terrestrial |
| *Modiola* spp. | Malvaceae | exotic | forb | terrestrial |
| *Moenchia erecta* | Caryophyllaceae | exotic | forb | terrestrial |
| Monocot | unknown | unknown | unknown | unknown |
| Monocot grass exotic | Poaceae | exotic | grass | terrestrial |
| Monocot grass | Poaceae | exotic | grass | terrestrial |
| Monocot sedge/rush | unknown | unknown | sedge/rush | unknown |
| *Montia australasica* | Montiaceae | native | forb | fringing low |
| *Montia* spp. | Montiaceae | native | forb | fringing low |
| *Moraea flaccida* | Iridaceae | exotic | forb | terrestrial |
| *Moraea lewisiae* | Iridaceae | exotic | forb | terrestrial |
| *Muehlenbeckia florulenta* | Polygonaceae | native | shrub | shrub |
| *Myoporum insulare* | Scrophulariaceae | native | shrub | shrub |
| *Myosotis arvensis* | Boraginaceae | exotic | forb | fringing low |
| *Myosotis laxa* | Boraginaceae | exotic | forb | fringing low |
| *Myosotis* spp. | Boraginaceae | exotic | forb | fringing low |
| *Myriophyllum amphibium* | Haloragaceae | native | forb | aquatic |
| *Myriophyllum simulans* | Haloragaceae | native | forb | aquatic |
| *Myriophyllum* spp. | Haloragaceae | native | forb | aquatic |
| *Myriophyllum variifolium* | Haloragaceae | native | forb | aquatic |
| *Nassella neesiana* | Poaceae | exotic | grass | terrestrial |
| *Nassella* spp. | Poaceae | exotic | grass | terrestrial |
| *Nitella* sp. | Characeae | native | alga | aquatic |
| *Olearia lirata* | Asteraceae | native | shrub | shrub |
| *Opercularia varia* | Rubiaceae | native | forb | terrestrial |
| *Ornduffia reniformis* | Menyanthaceae | native | forb | aquatic |
| *Ottelia ovalifolia* subsp. *ovalifolia* | Hydrocharitaceae | native | forb | aquatic |
| *Oxalis corniculata* | Oxalidaceae | exotic | forb | terrestrial |
| *Oxalis exilis* | Oxalidaceae | native | forb | terrestrial |
| *Oxalis incarnata* | Oxalidaceae | exotic | forb | terrestrial |
| *Oxalis perennans* | Oxalidaceae | native | forb | terrestrial |
| *Oxalis pes-caprae* | Oxalidaceae | exotic | forb | terrestrial |
| *Oxalis* spp. | Oxalidaceae | unknown | forb | terrestrial |
| *Ozothamnus ferrugineus* | Asteraceae | native | shrub | shrub |
| *Pandorea pandorana* | Bignoniaceae | native | climber | terrestrial |
| *Panicum coloratum* | Poaceae | exotic | grass | fringing low |
| *Panicum* spp. | Poaceae | native | grass | fringing low |
| *Paspalidium jubiflorum* | Poaceae | native | grass | fringing high |
| *Paspalidium* spp. | Poaceae | native | grass | fringing high |
| *Paspalum dilatatum* | Poaceae | exotic | grass | terrestrial |
| *Paspalum distichum* | Poaceae | exotic | grass | fringing low |

| | | | | |
|---|---|---|---|---|
| *Pelargonium australe* | Geraniaceae | native | forb | terrestrial |
| *Pentameris airoides* subsp. *airoides* | Poaceae | exotic | grass | terrestrial |
| *Persicaria decipiens* | Polygonaceae | native | forb | emergent |
| *Persicaria hydropiper* | Polygonaceae | native | forb | emergent |
| *Persicaria lapathifolia* | Polygonaceae | native | forb | emergent |
| *Persicaria praetermissa* | Polygonaceae | native | forb | fringing low |
| *Persicaria prostrata* | Polygonaceae | native | forb | fringing low |
| *Persicaria* spp. | Polygonaceae | native | forb | emergent |
| *Persicaria subsessilis* | Polygonaceae | native | forb | emergent |
| *Phalaris aquatica* | Poaceae | exotic | grass | fringing high |
| *Phalaris arundinacea* | Poaceae | exotic | grass | emergent |
| *Phalaris* spp. | Poaceae | exotic | grass | fringing high |
| *Phragmites australis* | Poaceae | native | grass | emergent |
| *Phyla canescens* | Verbenaceae | exotic | forb | fringing high |
| *Pittosporum undulatum* | Pittosporaceae | native | shrub | tree |
| *Plantago bellardii* | Plantaginaceae | exotic | forb | terrestrial |
| *Plantago coronopus* | Plantaginaceae | exotic | forb | terrestrial |
| *Plantago lanceolata* | Plantaginaceae | exotic | forb | terrestrial |
| *Plantago major* | Plantaginaceae | exotic | forb | terrestrial |
| *Plantago* spp. | Plantaginaceae | unknown | forb | terrestrial |
| *Platylobium parviflorum* | Fabaceae | native | shrub | shrub |
| *Platylobium* spp. | Fabaceae | native | shrub | shrub |
| *Poa annua* | Poaceae | exotic | grass | terrestrial |
| *Poa bulbosa* | Poaceae | exotic | grass | terrestrial |
| *Poa ensiformis* | Poaceae | native | grass | fringing high |
| *Poa fordeana* | Poaceae | native | grass | fringing high |
| *Poa labillardierei* var. *labillardierei* | Poaceae | native | grass | fringing high |
| *Poa sieberiana* | Poaceae | native | grass | fringing high |
| *Poa* spp. | Poaceae | native | grass | fringing high |
| *Polycarpon tetraphyllum* | Caryophyllaceae | exotic | forb | terrestrial |
| *Polygonum aviculare* | Polygonaceae | exotic | forb | terrestrial |
| *Polypogon monspeliensis* | Poaceae | exotic | grass | fringing low |
| *Polystichum proliferum* | Dryopteridaceae | native | fern | terrestrial |
| *Pomaderris aspera* | Rhamnaceae | native | shrub | shrub |
| *Portulaca oleracea* | Portulacaceae | native | forb | terrestrial |
| *Potamogeton cheesemanii* | Potamogetonaceae | native | forb | aquatic |
| *Potamogeton crispus* | Potamogetonaceae | native | forb | aquatic |
| *Potamogeton ochreatus* | Potamogetonaceae | native | forb | aquatic |
| *Potamogeton* spp. | Potamogetonaceae | native | forb | aquatic |
| *Potamogeton sulcatus* | Potamogetonaceae | native | forb | aquatic |
| *Potentilla indica* | Rosaceae | exotic | forb | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Prostanthera lasianthos* | Lamiaceae | native | shrub | shrub |
| *Prunella vulgaris* | Lamiaceae | exotic | forb | fringing low |
| *Prunus* spp. | Rosaceae | exotic | shrub | shrub |
| *Laphangium luteoalbum* | Asteraceae | native | forb | terrestrial |
| *Pteridium esculentum* | Dennstaedtiaceae | native | fern | terrestrial |
| *Pultenaea forsythiana* | Fabaceae | native | shrub | shrub |
| *Ranunculus amphitrichus* | Ranunculaceae | native | forb | aquatic |
| *Ranunculus pumilio* | Ranunculaceae | native | forb | fringing low |
| *Ranunculus repens* | Ranunculaceae | exotic | forb | fringing low |
| *Ranunculus sceleratus* subsp. *sceleratus* | Ranunculaceae | exotic | forb | fringing low |
| *Ranunculus sessiliflorus* | Ranunculaceae | native | forb | fringing high |
| *Ranunculus undosus* | Ranunculaceae | native | forb | emergent |
| *Myrsine howittiana* | Primulaceae | native | tree | tree |
| *Raphanus raphanistrum* | Brassicaceae | exotic | forb | fringing high |
| *Romulea rosea* | Iridaceae | exotic | forb | terrestrial |
| *Rorippa laciniata* | Brassicaceae | native | forb | fringing high |
| *Rorippa palustris* | Brassicaceae | exotic | forb | fringing low |
| *Rorippa* spp. | Brassicaceae | unknown | forb | fringing high |
| *Rosa rubiginosa* | Rosaceae | exotic | shrub | shrub |
| *Rubus anglocandicans* | Rosaceae | exotic | shrub | shrub |
| *Rubus parvifolius* | Rosaceae | native | shrub | shrub |
| *Rubus* spp. | Rosaceae | unknown | shrub | shrub |
| *Rumex bidens* | Polygonaceae | native | forb | fringing low |
| *Rumex brownii* | Polygonaceae | native | forb | fringing high |
| *Rumex conglomeratus* | Polygonaceae | exotic | forb | fringing high |
| *Rumex crispus* | Polygonaceae | exotic | forb | fringing high |
| *Rumex pulcher* | Polygonaceae | exotic | forb | fringing high |
| *Rumex* spp. | Polygonaceae | unknown | forb | fringing high |
| *Rumex tenax* | Polygonaceae | native | forb | fringing high |
| *Ruppia* spp. | Ruppiaceae | native | forb | aquatic |
| *Rytidosperma caespitosum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma duttonianum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma fulvum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma geniculatum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma penicillatum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma racemosum* var. *racemosum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma setaceum* | Poaceae | native | grass | terrestrial |
| *Rytidosperma* spp. | Poaceae | native | grass | terrestrial |
| *Salix cinerea* | Salicaceae | exotic | tree | tree |
| *Salix fragilis* | Salicaceae | exotic | tree | tree |

| | | | | |
|---|---|---|---|---|
| *Salix* spp. | Salicaceae | exotic | tree | tree |
| *Schoenoplectus* spp. | Cyperaceae | native | sedge/rush | emergent |
| *Schoenoplectus pungens* | Cyperaceae | native | sedge/rush | emergent |
| *Schoenoplectus tabernaemontani* | Cyperaceae | native | sedge/rush | emergent |
| *Schoenus apogon* | Cyperaceae | native | sedge/rush | fringing low |
| *Schoenus fluitans* | Cyperaceae | native | sedge/rush | aquatic |
| *Selliera radicans* | Goodeniaceae | native | forb | fringing low |
| *Senecio biserratus* | Asteraceae | native | forb | terrestrial |
| *Senecio campylocarpus* | Asteraceae | native | forb | terrestrial |
| *Senecio glomeratus* | Asteraceae | native | forb | terrestrial |
| *Senecio hispidulus* | Asteraceae | native | forb | terrestrial |
| *Senecio minimus* | Asteraceae | native | forb | terrestrial |
| *Senecio quadridentatus* | Asteraceae | native | forb | terrestrial |
| *Senecio runcinifolius* | Asteraceae | native | forb | terrestrial |
| *Senecio* spp. | Asteraceae | unknown | forb | terrestrial |
| *Setaria gracilis* var. *gracilis* | Poaceae | exotic | grass | terrestrial |
| *Setaria parviflora* | Poaceae | exotic | grass | terrestrial |
| *Setaria* spp. | Poaceae | exotic | grass | terrestrial |
| *Sisymbrium officinale* | Brassicaceae | exotic | forb | terrestrial |
| *Solanum lycopersicum* | Solanaceae | exotic | forb | terrestrial |
| *Solanum nigrum* | Solanaceae | exotic | forb | terrestrial |
| *Solanum pseudocapsicum* | Solanaceae | exotic | shrub | shrub |
| *Sonchus asper* s.l. | Asteraceae | exotic | forb | terrestrial |
| *Sonchus oleraceus* | Asteraceae | exotic | forb | terrestrial |
| *Sonchus* spp. | Asteraceae | exotic | forb | terrestrial |
| *Stellaria angustifolia* | Caryophyllaceae | native | forb | fringing low |
| *Stellaria media* | Caryophyllaceae | exotic | forb | terrestrial |
| *Symphyotrichum novi-belgii* | Asteraceae | exotic | forb | fringing high |
| *Symphyotrichum subulatum* | Asteraceae | exotic | forb | fringing high |
| *Taraxacum officinale* spp. agg. | Asteraceae | exotic | forb | terrestrial |
| *Taraxacum* spp. | Asteraceae | exotic | forb | terrestrial |
| *Templetonia stenophylla* | Fabaceae | native | shrub | shrub |
| *Tetrarrhena juncea* | Poaceae | native | grass | terrestrial |
| *Themeda triandra* | Poaceae | native | grass | terrestrial |
| *Thysanotus patersonii* | Asparagaceae | native | forb | terrestrial |
| *Tradescantia fluminensis* | Commelinaceae | exotic | forb | fringing high |
| *Tradescantia* spp. | Commelinaceae | exotic | forb | fringing high |
| *Tribolium obliterum* | Poaceae | exotic | grass | terrestrial |
| *Tricoryne elatior* | Asphodelaceae | native | forb | terrestrial |
| *Trifolium angustifolium* var. *angustifolium* | Fabaceae | exotic | forb | terrestrial |

| | | | | |
|---|---|---|---|---|
| *Trifolium arvense* var. *arvense* | Fabaceae | exotic | forb | terrestrial |
| *Trifolium dubium* | Fabaceae | exotic | forb | terrestrial |
| *Trifolium glomeratum* | Fabaceae | exotic | forb | terrestrial |
| *Trifolium repens* | Fabaceae | exotic | forb | terrestrial |
| *Trifolium repens* var. *repens* | Fabaceae | exotic | forb | terrestrial |
| *Trifolium subterraneum* | Fabaceae | exotic | forb | terrestrial |
| *Triglochin striata* | Juncaginaceae | native | forb | fringing low |
| *Typha domingensis* | Typhaceae | native | sedge/rush | emergent |
| *Typha latifolia* | Typhaceae | exotic | sedge/rush | emergent |
| *Typha orientalis* | Typhaceae | exotic | sedge/rush | emergent |
| *Typha* spp. | Typhaceae | native | sedge/rush | emergent |
| *Ulex europaeus* | Fabaceae | exotic | shrub | shrub |
| *Urtica incisa* | Urticaceae | native | forb | fringing high |
| *Vallisneria australis* | Hydrocharitaceae | native | forb | aquatic |
| *Vellereophyton dealbatum* | Asteraceae | exotic | forb | terrestrial |
| *Verbascum virgatum* | Scrophulariaceae | exotic | forb | terrestrial |
| *Verbena bonariensis* s.l. | Verbenaceae | exotic | forb | fringing high |
| *Verbena officinalis* s.l. | Verbenaceae | exotic | forb | fringing high |
| *Verbena* spp. | Verbenaceae | exotic | forb | fringing high |
| *Vicia* spp. | Fabaceae | exotic | forb | terrestrial |
| *Vinca major* | Apocynaceae | exotic | forb | terrestrial |
| *Vinca* spp. | Apocynaceae | exotic | forb | terrestrial |
| *Viola hederacea* | Violaceae | native | forb | fringing high |
| *Viola odorata* | Violaceae | exotic | forb | terrestrial |
| *Vittadinia* spp. | Asteraceae | native | forb | terrestrial |
| *Vulpia bromoides* | Poaceae | exotic | grass | terrestrial |
| *Vulpia* spp. | Poaceae | exotic | grass | terrestrial |
| *Wahlenbergia fluminalis* | Campanulaceae | native | forb | fringing high |
| *Wahlenbergia gracilis* | Campanulaceae | native | forb | terrestrial |
| *Wahlenbergia* spp. | Campanulaceae | native | forb | terrestrial |
| *Walwhalleya proluta* | Poaceae | native | grass | terrestrial |
| *Xanthium spinosum* | Asteraceae | exotic | forb | terrestrial |
| *Zantedeschia aethiopica* | Araceae | exotic | forb | terrestrial |

www.delwp.vic.gov.au

www.ari.vic.gov.au