Murray–Darling Basin Environmental Water Knowledge and Research Project

Multi-Year Research Plan

Prepared by: The Murray–Darling Freshwater Research Centre

December 2016

Final Report

MDFRC Publication 129

Murray–Darling Basin Environmental Water Knowledge and Research Project Multi-Year Research Plan 2016–2019

Final Report prepared for the Department of the Environment and Energy by The Murray–Darling Freshwater Research Centre.

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This report was prepared by The Murray–Darling Freshwater Research Centre (MDFRC). The aim of the MDFRC is to provide the scientific knowledge necessary for the management and sustained utilisation of the Murray–Darling Basin water resources. The MDFRC is a joint venture between La Trobe University and CSIRO. Additional investment is provided through the University of Canberra.

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Report Citation MDFRC (2016) Murray–Darling Basin Environmental Water Knowledge and Research Project: Multi-Year Research Plan 2016–2019. Report prepared for the Department of the Environment and Energy by The Murray–Darling Freshwater Research Centre, MDFRC Publication 129/2016, December 2016, 134 pp.

Cover Image: *Potamogeton* in Lake Lockie, Hattah-Kulkyne National Park

Photographer: Braeden Lampard

Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
Draft 1	27 May 2016	Jessica Davison	Ben Gawne	Initial Draft
Draft 2	17 Jun 2016	Jessica Davison	Ben Gawne	Revised Draft
Draft 3	18 Jun 2016	Jessica Davison	Ben Gawne	Review Draft
Draft 4	19 Jun 2016	Jessica Davison	Ben Gawne	Final Draft
Draft 5	23 Jun 2016	Jessica Davison	Ben Gawne	Internal Review
Draft 6	19 July 2016	Jessica Davison	Ben Gawne	Final Draft
Final 7	20 July 2016	Jessica Davison	Ben Gawne	Final Draft (pre-edit)
Final 8	10 Oct 2016	Jessica Davison	Ben Gawne	Final Draft (edited)
Final 9	13 Dec 2016	Jessica Davison	Ben Gawne	Final Draft (revised)
Final	13 Jan 2017	Jessica Davison	Ben Gawne	Final

Distribution of copies

Version	Quantity	Issued to
Draft 4	1 x Word	Anthony Moore and Nadia Kingham, Department of the Environment
Draft 6	1 x Word	Anthony Moore and Nadia Kingham, Department of the Environment
Draft 7	1 x Word	Anthony Moore and Nadia Kingham, Department of the Environment
Final 8	1 x PDF	Anthony Moore and Nadia Kingham, Department of the Environment
Final 9	1 x PDF	Anthony Moore and Nadia Kingham, Department of the Environment
Final	1xPDF	Anthony Moore and Nadia Kingham, Department of the Environment and Energy

Filename and path:	G:\SHE - Life Sciences\MDFRC\Projects\DSEWPC\465 MDB EWKR\PROJECT MANAGEMENT\PHASE 2 DELIVERABLES\2016_17 Milestones and Final Documents\16_17 Final Documents\Milestone 6 MYRP (Dec update_16)
Project Manager:	Jessica Davison
Client:	Department of the Environment and Energy
Project Title:	Murray–Darling Basin Environmental Water Knowledge and Research Project: Multi-Year Research Plan 2016–2019
Document Version:	Final
Project Number:	M/BUS/465
Contract Number:	N/A

Finalised December 2016

Acknowledgements:

The Murray–Darling Freshwater Research Centre offices are located on the land of the Latje Latje and Wiradjuri peoples. We undertake work throughout the Murray–Darling Basin and acknowledge the traditional owners of this land and water. We pay respect to Elders past, present and future.

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1 Introduction

The Murray–Darling Basin Environmental Water Knowledge and Research (MDB EWKR) project is a 5 year (to 2018–19), $10 million project to improve the science available to support environmental water management, and thereby contribute to achieving Basin Plan objectives. MDB EWKR will undertake research aimed at better understanding the:

- links between ecological responses to flow and medium and long-term changes in condition
- impacts of threats (hydrological, aquatic and terrestrial), which may reduce or prevent the ecological improvement expected through environmental flow regimes.

In turn, this improved understanding will:

- enhance environmental water management and complementary natural resources management to improve environmental outcomes (predominantly biotic outcomes)
- build capacity to report against Basin Plan objectives and targets. The ability to explain ecological improvement within the context of multiple threats will be important in building and maintaining public confidence in the Basin Plan.

The research will support the collaborative role of the Commonwealth Government in environmental watering in the Basin, in particular the:

- Murray–Darling Basin Authority's (MDBA's) role in implementing the Basin Plan
- Commonwealth Environmental Water Office's (CEWO's) role in managing Commonwealth Environmental Water
- Basin States' role in managing environmental water and aquatic assets.

The research will also promote collaboration among research institutions, which will be important in generating new knowledge about the complex responses of aquatic ecosystems to changes in flows across a range of spatial and temporal scales. The research will build on existing knowledge, data and information where possible, in order to minimise duplication and to maximise investment outcomes. The sharing of existing knowledge, data and information resources will facilitate constructive and efficient progression of priority research.

The project has collaborated with waterway managers, asset managers, water planners, scientists and relevant community groups to identify research priorities, and plans to build on these collaborative relationships to undertake research targeted at addressing those priorities. Phase 1, through to mid-2015, was a planning phase to identify research priorities, develop research project plans and agree to collaborative arrangements to undertake the work. Phase 2, delivery of the research, commenced in mid-2015. Feedback from the project's Science Advisory Group (SAG) led to the implementation of a conceptualisation process that will continue until September 2016, after which time research activities will commence and run through to the end of 2018–19.

This document describes the proposed research approach and activities over the life of the project. The approach and activities have been selected to address the priority research questions identified through Phase 1 consultation and endorsed by the Project Steering Committee (PSC). This Multi-Year Research Plan (MYRP) is accompanied by more detailed Annual Research Plans (ARPs), to be prepared in the lead up to each financial/water year of the project. The MYRP may also be updated each year, in response to outcomes of research activities, and in response to climatic conditions and watering events in the MDB.

2 Project background

2.1 Project objectives and outcomes

MDB EWKR will support the collaborative role of the Commonwealth in environmental watering in the Basin, and in particular the:

- MDBA's role in implementing the Basin Plan
- CEWO's role in managing Commonwealth environmental water
- Basin States' role in managing environmental water and aquatic assets.

The major body of research will focus on:

- improved identification, assessment and understanding of the links between ecological responses to watering regimes (e.g. natural and/or managed events) and incremental changes in ecological condition
- medium- and long-term changes in ecological condition, including the effects of threats (hydrological, aquatic and terrestrial) which may reduce or prevent the ecological improvement expected
- the Queensland floodplain vegetation watering requirements.

The research will also promote collaboration among research institutions, which will be important in generating new knowledge about the complex responses of aquatic ecosystems to changes in flows across a range of spatial and temporal scales.

2.1.1 Research objectives

The objectives of this research are to improve understanding of:

- how environmental flow management influences ecosystem function and thereby sustains biodiversity
- how the major drivers of system condition (e.g. flow, land use, invasive species) interact to affect biodiversity, ecosystem function, resilience and water quality
- how threats (hydrological, aquatic and terrestrial) may reduce or prevent the ecological improvement expected through the application of environmental water
- how the management or delivery of environmental flows influence environmental outcomes achieved over time
- the links between ecosystem responses to watering regimes (e.g. natural and/or managed events) and incremental changes in ecological condition
- how complementary water management and natural resource management enhance the outcomes of environmental water management.
- the links between ecosystem responses to management interventions (water management and natural resource management) and incremental changes in the ecological condition.

2.1.2 Project outcomes

MDB EWKR will assist with the generation, synthesis and communication of the knowledge required to inform the adaptive management of environmental water allocations to protect and restore healthy and productive aquatic ecosystems in the Murray–Darling Basin.

The research outcomes are expected to make a significant contribution to the ability to assess and understand incremental changes in ecological condition in the medium-to long-term within the context of multiple management interventions, stressors and pressures, and will support the following outcomes:

- improved capacity to predict outcomes of environmental flow allocations and their management over 1–5 years
- the development of predictive tools, conceptual models and frameworks to inform environmental watering regimes
- improved water management and complementary natural resource management
- building capacity to set realistic objectives and targets for water management and complimentary natural resource management as the climate changes
- improved environmental water effectiveness through the application of science to the development and operation of environmental works and measures
- improved monitoring, evaluation and reporting on progress toward the Basin Plan environmental objectives and targets
- building capacity to report against Basin Plan environmental objectives and targets.

2.1.3 Research priorities

MDB EWKR will undertake research that seeks to improve the understanding of the core processes that drive the achievement of biotic outcomes sought by the Basin Plan, including the impacts of pressures and stressors.

The report titled *Selection of Priority Research Questions and Research Sites* provides a description of selected research priorities and research sites, as well as the process by which they were determined. The selected research priorities provide the strategic direction for the project and the areas of focus in this research plan.

In summary, the following components are considered to be the main focus areas (note the research priorities are described in further detail in each of the theme chapters and in summary at Attachment A):

Vegetation

- drivers of diversity of understorey and wetland plant communities
- drivers of recruitment of River Red Gum (*Eucalyptus camaldulensis* Dehnh.), Black Box (*Eucalyptus largiflorens* F.Muell.), Coolibah (*Eucalyptus coolabah* Blakely & Jacobs) and Lignum (*Duma florulenta* Meissner) populations.

Fish

- drivers of recruitment of native fish populations
- drivers of reproduction of native fish populations — noting this will mostly focus on analysis of existing data, and so will be a relatively small component of work.

Waterbirds

- drivers of recruitment of waterbird populations.

Food Webs

- drivers of food webs that contribute to outcomes for native fish and waterbirds.

Mapping of EWKR research to Basin Plan objectives — 'line of sight'

To ensure that the EWKR research activities are, and remain, relevant to management and ultimately to the Basin Plan objectives, the MDB EWKR Theme Questions have been mapped up to

Basin Plan objectives (Figure 2-1) to demonstrate the 'line of sight'. Similarly, in the following chapters, the activities to be undertaken for each research theme have been mapped to the specific MDB EWKR Theme Questions (Figure 2-1).

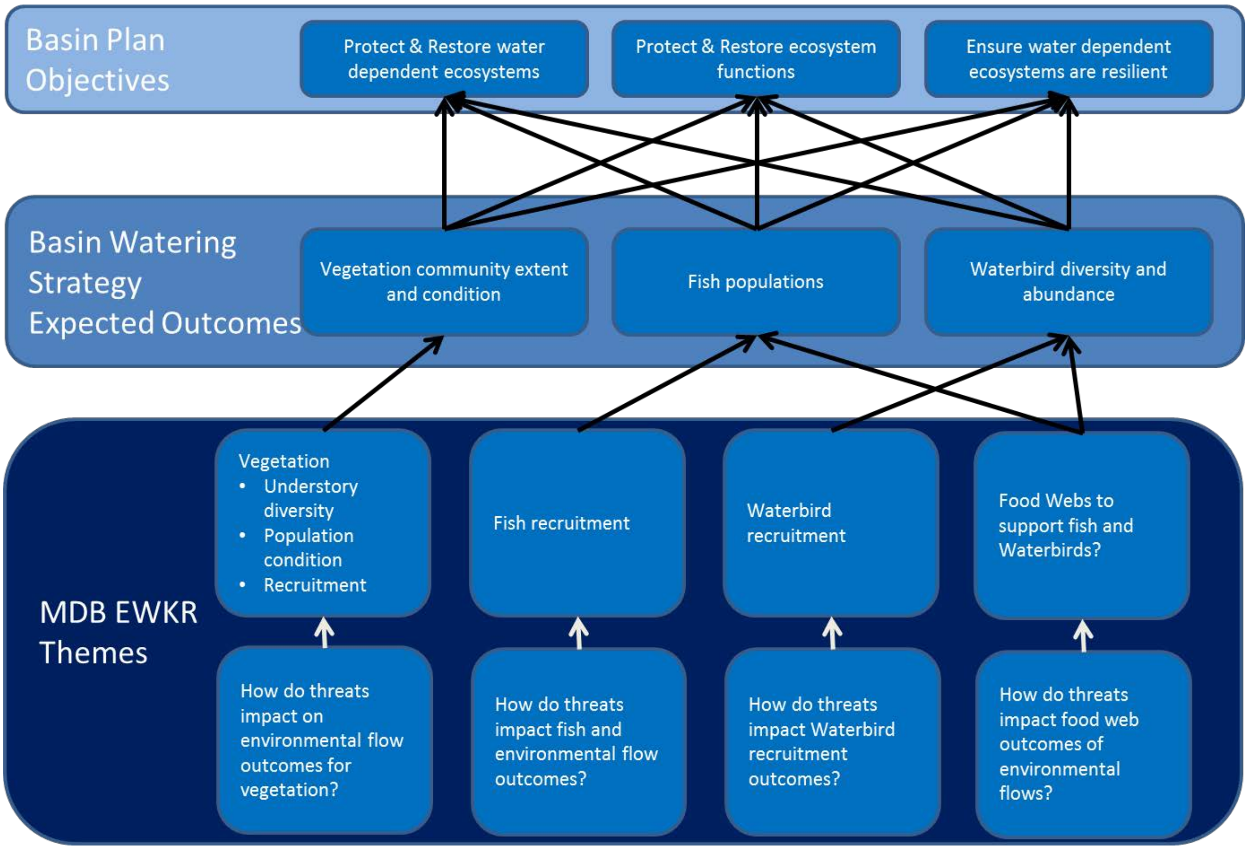

Figure 2-1. Relationship between the MDB EWKR research themes, Basin-Wide Watering Strategy - Expected Outcomes and Basin Plan objectives.

Table 2-1. MDB EWKR Priority Research Questions and alignment with Basin Plan objectives.

Basin Plan objectives	Basin-Wide Environmental Watering Strategy - Expected Environmental Outcomes	MDB EWKR Priority Research Questions
• To protect and restore water-dependent ecosystems of the Murray–Darling Basin • To protect and restore the ecosystem functions of water-dependent ecosystems • To ensure that water-dependent ecosystems are resilient	**Vegetation: Maintain the extent and improve condition** <u>Forests and woodlands</u> • To maintain the current extent of forest and woodland vegetation • No decline in the condition of River Red Gum, Black Box and Coolibah across the Basin • By 2024, improved condition of River Red Gum in the Lachlan, Murrumbidgee, Lower Darling, Murray, Goulburn–Broken and Wimmera–Avoca • By 2024, improved recruitment of trees within River Red Gum, Black Box and Coolibah communities — in the long term achieving a greater range of tree ages <u>Shrublands</u> • To maintain the current extent of extensive Lignum shrubland areas within the Basin • By 2024, improvement in the condition of Lignum shrublands <u>Non-woody vegetation</u> • To maintain the current extent of non-woody vegetation • By 2024, increased periods of growth for *selected* communities • A sustained and adequate population of *Ruppia tuberosa* in the south lagoon of the Coorong	<u>**Diversity** of understorey and wetland plant communities</u> 1. What **flow regimes** best support the **diversity** of understorey and wetland plant communities? o How significant are the individual drivers (habitat area, habitat heterogeneity, connectivity heterogeneity, and disturbance) for diversity? o How do key drivers interact to influence outcomes? o How should flows be managed to enhance drivers and thereby diversity? 2. How do threats impact on the drivers and diversity outcomes? <u>**Survival and condition** of long-lived floodplain vegetation (Red Gum, Black Box, Coolibah, Lignum)</u> 1. What **flow regimes** (particularly frequency, period between follow-up watering, event duration) best support the **survival and condition** of floodplain vegetation populations? o How do site characteristics (soil type, climate, and groundwater) influence these flow requirements? 2. How do **threats** (increased temperature, changes in rainfall seasonality) influence flow requirements? <u>**Recruitment** of long-lived floodplain vegetation (Red Gum, Black Box, Coolibah, Lignum)</u> 1. What **flow regimes** best support **recruitment** within populations of long-lived floodplain vegetation species? o How significant are the individual drivers (habitat availability, connectivity – dispersal) for recruitment? o How do key drivers interact to influence outcomes?

<table>
<tr><th>Basin Plan objectives</th><th>Basin-Wide Environmental Watering Strategy - Expected Environmental Outcomes</th><th>MDB EWKR Priority Research Questions</th></tr>
<tr><td></td><td></td><td>How should flows be managed to enhance drivers and thereby recruitment?
How do the characteristics of sites (soil type, climate etc.) influence these flow requirements?
2. How do threats impact on the drivers and recruitment outcomes?</td></tr>
<tr><td></td><td>Waterbirds: Maintain current species diversity, improve breeding success and numbers

From 2024:
The number and type of waterbird species present in the Basin will not fall below current observations
A significant improvement in waterbird populations in the order of 20–25% over the baseline scenario, with increases in all waterbird functional groups
Breeding events (the opportunities to breed rather than the magnitude of breeding per se) of colonial nesting waterbirds to increase by up to 50% compared to the baseline scenario
Breeding abundance (nests and broods) for all of the other functional groups to increase by 30–40% compared to the baseline scenario, especially in locations where the Basin Plan improves overbank flows</td><td>1. Which flow regimes best support recruitment of waterbirds?
Where and what are the critical foraging habitats during and after breeding events for recruitment? How might these be affected by environmental flows and threats such as habitat change?
What are critical nesting habitat characteristics we need to maintain and how do these affect recruitment? How might environmental flows, vegetation management and pressures and threats, such as predation, interact with nesting habitat characteristics to affect recruitment?
2. How do threats and pressures affect recruitment outcomes for waterbirds?</td></tr>
<tr><td></td><td>Fish: Maintain current species diversity, extend distributions, improve breeding success and numbers

By 2024:
No loss of native species currently present within the Basin</td><td>What flow regimes best support the reproduction/recruitment/condition and survival of native fish populations?
How significant are the individual drivers?</td></tr>
</table>

Basin Plan objectives	Basin-Wide Environmental Watering Strategy - Expected Environmental Outcomes	MDB EWKR Priority Research Questions
	• Improved population structure of key species through regular recruitment • Increased movement of key species • Expanded distribution of key species and populations in the northern and southern Basin For short-lived species: • Restored distribution and abundance to levels recorded pre-2007. This will require annual or biennial recruitment events depending on the species. For moderate to long-lived species: • Improved population structure in key sites. This will require annual recruitment events in at least eight out of 10 years at 80% of key sites, with at least four of these being 'strong'18 recruitment events • A 10–15% increase of mature fish for recreational target species (Murray cod and Golden perch) in key populations • Annual detection of species and life stages representative of the whole fish community through key fish passages; with an increase in passage of Murray cod, Trout cod, Golden perch, Silver perch, Hyrtl's tandan, Congolli, Short-headed lamprey and Pouched lamprey through key fish passages to be detected in 2019–2024; compared to passage rates detected in 2014–2019 For key species: • A doubling of the current distributions of key species in the northern Basin	o How do key drivers interact to influence outcomes? o How should flows be managed to enhance drivers and thereby the fish response? • How do threats impact on the drivers and reproduction/recruitment/condition and survival outcomes?

Basin Plan objectives	Basin-Wide Environmental Watering Strategy - Expected Environmental Outcomes	MDB EWKR Priority Research Questions
	• Significant increases in the distributions of key species in the southern Basin	
	Food Webs: Protection and restoration of ecosystem functions of water-dependent ecosystems To protect and restore ecological community structure, species interactions and food webs that sustain water-dependent ecosystems, including by protecting and restoring energy, carbon and nutrient dynamics, primary production and respiration	1. What flow regimes best support food webs that contribute to positive outcomes for native fish and waterbirds? 2. How do other stressors impact on food web processes and the achievement of native fish and waterbirds outcomes?

2.1.4 Research sites

The MDB EWKR project seeks to generate knowledge that is applicable across the Basin. To this end, research sites were identified that would enable information to be collected on how responses to flow regimes vary across the Basin. MDB EWKR identified four sites, noting that the project will also include laboratory experiments and data analysis activities that are not defined by the boundaries of the four sites. A paper outlining the approach to research at the four research sites can be found in Attachment B.

The selected sites are listed below. In all cases, the sites will include adjacent river, wetland and floodplain components, notwithstanding that floodplain and wetland system names are used to describe some sites. The exact boundaries of the research sites will be considered in further detail in planning the research projects to select the locations best able to support the research, and provide the most effective alignment with past and future monitoring and research activities (where relevant). These considerations may result in the scale of the sites reducing, or alternatively it may be desirable to extend the boundaries of the sites upstream or downstream to enhance research opportunities.

In some instances research may be undertaken at additional sites. This may occur for logistical reasons such as when waterbird breeding is not occurring at any of the 4 sites, but is occurring elsewhere. It may also occur for efficiency reasons, for example, collaborating with the Commonwealth Environmental Water Office (CEWO) Long-Term Intervention Monitoring (LTIM) project may enable more cost effective sampling from sites across the Basin.

MDB EWKR research sites

- Upper Murray — centred around Barmah–Millewa Forest and potentially including lower reaches of adjacent tributaries (Goulburn and Campaspe) and parts of the Edward–Wakool system
- Lower Murray — centred around the Chowilla–Lindsay–Wallpolla Floodplain and including the Riverland Ramsar site and adjacent floodplain systems and river reaches
- Macquarie Marshes
- Lower Balonne floodplain, including Narran Lakes

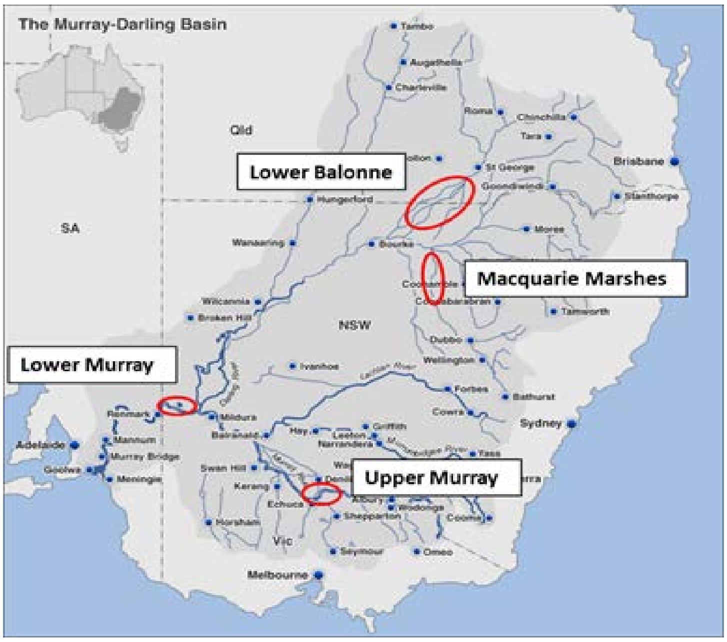

Figure 2-2. Location of selected research sites.

2.1.5 Flow types

Environmental flow managers allocate water to one of four flow types; base flows, freshes, bank-full and overbank (see Figure 2.3). In terms of the flow types that the project should focus on, three criteria have been considered:

1. the research questions derived from the prioritisation process
2. the value to management, i.e. the flow types that are the focus of management decisions
3. the flow types most important for sustaining the values of the systems.

As a result of applying these criteria, the MDB EWKR project will focus on the types of flows that will enable the priority questions to be addressed. In the case of the Vegetation and Waterbirds themes, this will be overbank flows. In the case of fish recruitment (Fish and Food Webs themes), the focus will be on in-channel habitats and the flow types will be determined by:

- the conceptualisation process
- the links back to available management levers
- opportunities to examine different flow types, including overbank flows.

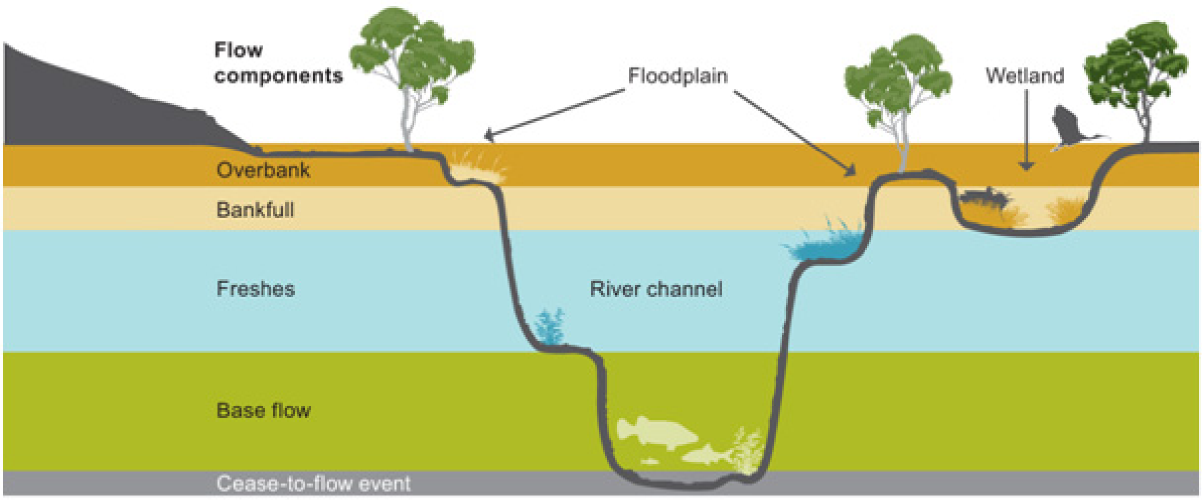

Figure 2-3. River cross section identifying five different flow types, four of which are flow types that environmental flow managers may allocate water toward, specifically base flows, freshes, bank-full and overbank.

A paper has been prepared to provide a rationale for the types of flow (in-channel versus overbank) on which the MDB EWKR theme research will focus (refer to Attachment C: In-channel versus overbank flow).

2.1.6 Research collaboration

Obtaining the best available science to address the research priorities requires a collaborative approach to research. Accordingly, the Murray–Darling Freshwater Research Centre (MDFRC) undertook an Expression of Interest process to select research collaborators to work with MDFRC on the planning and delivery of the project.

MDFRC has selected Theme Leadership Groups to work under the guidance of the Project Leader (Ben Gawne), Project Manager (Jessica Davison), and with the support of selected Theme

Coordinators (Table 2-2). The Theme Leadership Groups comprise senior researchers with the high-level expertise required to provide technical and process leadership to the development and implementation of research plans for the selected themes. The Theme Leadership Groups have contributed extensively to the theme components of this research plan.

Table 2-2. Theme Leadership Groups.

Vegetation	Fish	Waterbirds	Food Webs
Coordinator: Cherie Campbell (Murray–Darling Freshwater Research Centre) **Leadership Group:** • Sam Capon (Griffith University) • Cassandra James (James Cook University) • Kay Morris (Arthur Rylah Institute — ARI) • Jason Nicol (South Australian Research and Development Institute — SARDI) • Rachel Thomas (NSW Office of Environment and Heritage — NSW OEH) • Daryl Nielsen (MDFRC)	**Coordinator:** Amina Price (Murray–Darling Freshwater Research Centre) **Leadership Group:** • Paul Humphries (Charles Sturt University — CSU) • Stephen Balcombe (Griffith University) • Alison King (Charles Darwin University) • Brenton Zampatti (SARDI) • Rick Stoffels (MDFRC) • Lee Baumgartner (CSU)	**Coordinator:** Heather McGinness (CSIRO) **Leadership Group:** • Richard Kingsford and Kate Brandis (University of NSW — UNSW) • Ralph Mac Nally (University of Canberra — UC) • Veronica Doerr (CSIRO)	**Coordinator:** Darren Baldwin (2015-16). Paul McInerney (2017-) (Murray–Darling Freshwater Research Centre) **Leadership Group:** • Ross Thompson (UC) • Nick Bond (MDFRC) • Darren Ryder (University of New England — UNE) • Rebecca Lester (Deakin University) • Barbara Robson (CSIRO)

2.1.7 Planning

The project was designed to occur in two phases with a planning phase preceding an implementation phase. The planning phase was due to be completed in June 2015; however, upon advice from the Science Advisory Group, the planning phase was extended and a more thorough review of existing knowledge and conceptualisation process was undertaken. It was felt that this process was required in order to focus the research questions, provide a more robust logic and rationale for the proposed activities and clarify the outputs to be delivered. The conceptualisation process was completed in September 2016 and this version of the Multi-Year Research Plan has been developed on the basis of the outputs from that process.

3 Vegetation

Authors: Cherie Campbell (MDFRC), Sam Capon (Griffith University), Cassandra James (James Cook University), Kay Morris (Arthur Rylah Institute), Jason Nicol (SARDI), Daryl Nielsen (MDFRC), Rachael Thomas (NSW OEH)

3.1 Executive summary

3.1.1 Introduction

Wetland and floodplain plants provide refuge, breeding habitat and an important food source for a wide range of organisms, contribute to ecosystem services such as nutrient and carbon cycling, and water and sediment oxygenation, and have intrinsic biodiversity value. For managers to achieve vegetation outcomes from environmental water, there needs to be a clear understanding of the vegetation response objective, the effect of flow on vegetation response; and an understanding of how modifiers or non-flow drivers (e.g. climatic conditions) influence predicted vegetation responses from the use of environmental water.

Research undertaken on vegetation response will focus on defining and conceptually understanding the types of vegetation responses that occur across different vegetation traits (e.g. compositional, structural and process), different levels of ecological organisation (e.g. species, community, vegscape) and across different spatial and temporal scales. When considering responses to flows, these will also be considered across a variety of temporal scales, from long-term (decadal) to short-term (annual to one decade) regimes to a single event or flow pulse. Using this framework as a guide, research will focus on a number of key vegetation response types, and investigate these responses in relation to nested flow regimes. The key vegetation response types will include:

- compositional vegetation responses at different levels of ecological organisation
- structural vegetation responses at different spatial scales
- recruitment responses of long-lived woody vegetation.

3.1.2 Research focus

The research priorities described in 2.1.3 provided the framework for Leadership Groups to focus the proposed research for each of their themes. The overarching research aim of the Vegetation Theme is to address the following question:

What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?

Under this overarching aim, the conceptualisation process identified the following priority questions:

- *How do we define our vegetation response objectives to consider multiple trait responses, ecological levels of organisation and spatio-temporal scales?*
- *Once defined:*
    - *What flow regimes best support our targeted vegetation response?*
    - *What non-flow drivers influence our targeted vegetation response?*

These high-level aims will be applied to two priority research topics:

1. **Diversity** (understorey and wetland plants).
2. **Recruitment** of long-lived vegetation (River Red Gum (*Eucalyptus camaldulensis* Dehnh.), Black Box (*Eucalyptus largiflorens* F.Muell.), Coolibah (*Eucalyptus coolabah* Blakely & Jacobs) and Lignum (*Duma florulenta* Meissner)).

3.1.3 Summary approach and research components

The theme will undertake four research components supported by planning and coordination activities to address the research topics and aims. In line with the 'one-project' approach of MDB EWKR, the research components will complement each other with the theme planning, coordination and reporting bringing together outputs in a holistic way.

Component V1: Conceptualisation

Conceptualisation will organise existing knowledge and new ideas into a conceptual framework to provide a strong theoretical basis underpinning research planning. It is here that we develop our thinking around the 'what and why' of vegetation responses to flow and seek to provide a structured approach to defining targeted vegetation responses to assist in the planning, management and communication of watering decisions and actions. This framework provides the context from which to evaluate outcomes.

Component V2: Data integration and synthesis

Data integration and synthesis will provide an opportunity to combine and explore existing datasets for relationships between vegetation responses, flow and other non-flow drivers. This component will address understorey vegetation responses. Trait responses will depend on the datasets, but it is likely that the focus will be on composition.

Component V3: Field site assessments

This component will involve an assessment of flow and non-flow drivers on selected indicators at the four MDB EWKR research sites. Field site assessments will allow comparisons of the variability in the response of vegetation to be made between the four MDB EWKR research sites. The component will address (1) vegetation responses (across a range of strata), and (2) recruitment of long-lived woody vegetation. Trait responses will include composition, structure and recruitment processes.

Component V4: Mesocosm study

Mesocosm studies provide a powerful means of quantifying causal relationships in a controlled (or partially controlled) environment. This study will focus on the responses of seedlings to flow parameters such as duration, frequency and inter-flood dry period. It also considers the starting condition and development stage (early or late) of seedlings prior to inundation or drying. This component will address recruitment of long-lived vegetation.

Theme planning, coordination and reporting

Theme planning, coordination and reporting will enable integration across research components to address the overarching research aim in relation to the Vegetation Theme: *What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?*

The research outcomes will include recommendations to inform environmental water and natural resource management. The Vegetation Theme aims to provide:

- a framework to assist in the development of objectives, indicators and management of water for vegetation outcomes
- an enhanced understanding of how flows and contextual modifiers (e.g. climate variables) affect desired vegetation responses in terms of different trait responses (compositional, structural, process), different levels of ecological organisation (e.g. species, community, vegscape) and at different spatio-temporal scales.

3.3 Logic and rationale

3.3.1 Background

The Basin Plan objectives include that there be no loss, or degradation of the condition, diversity, extent and contiguousness of native water-dependent vegetation. This objective is reflected in the Basin-Wide Environmental Watering Strategy (BEWS) that has established expected outcomes around maintaining the current extent of vegetation communities and recruitment of trees. As a consequence, protecting or restoring vegetation will be the focus of environmental water management across the Murray–Darling Basin. Table 3-1 shows the relationship between the MDB EWKR priority research areas and questions, expected outcomes in the BEWS (MDBA 2014) and Basin Plan objectives.

Table 3-1. Relationship between MDB EWKR priority research areas and questions, expected outcomes in the Basin-Wide Environmental Watering Strategy (BEWS) and Basin Plan objectives.

Basin Plan objectives	BEWS expected outcomes	MDB EWKR priority research areas and questions
• To protect and restore water-dependent ecosystems of the Basin • To project and restore the ecosystem functions (e.g. recruitment, dispersal, habitat diversity) of water-dependent ecosystems • To ensure that water-dependent ecosystems are resilient to risks and threats	• Maintenance of the current extent of non-woody communities near or in wetlands, streams and on low-lying floodplains	• **Diversity** of understorey and wetland plant communities o What **flow regimes** best support the **diversity** of understorey and wetland plant communities? o How do **threats** impact on the drivers and **diversity** outcomes?
• To protect and restore water-dependent ecosystems of the Basin • To project and restore the ecosystem functions (e.g. habitat diversity) of water-dependent ecosystems • To ensure that water-dependent ecosystems are resilient to risks and threats	Maintenance of the current extent of forests and woodlands of: • ~360,000 ha of River Red Gum; • ~409,000 ha of Black Box; • ~310,000 ha of Coolibah; and • existing large communities of Lignum Maintained condition of lowland floodplain forests and woodlands of: • River Red Gum • Black Box • Coolibah Improved condition of: • Southern River Red Gum	• **Survival and condition** of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum) o What **flow regimes** (particularly frequency, inter-flood dry period, event duration) best support the **survival and condition** of floodplain vegetation populations? o How do **threats** (increased temperature, changes in rainfall seasonality) influence flow requirements?
• To protect and restore water-dependent ecosystems of the Basin • To project and restore the ecosystem functions (e.g. recruitment) of water-dependent ecosystems	Improved recruitment, achieving a greater range of tree ages in communities of: • River Red Gum • Black Box • Coolibah	• **Recruitment** of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum) o What **flow regimes** best support **recruitment** within populations of long-lived

Basin Plan objectives	BEWS expected outcomes	MDB EWKR priority research areas and questions
• To ensure that water-dependent ecosystems are resilient to risks and threats		floodplain vegetation species? o How do **threats** impact on the drivers and **recruitment** outcomes?

Research priorities

The research priorities provided the framework for the Leadership Groups to focus the proposed research for each of their themes.

The overarching research aim of the Vegetation Theme is to address the following question:

What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?

This high-level aim is broken down into three priority research areas:

3. **Diversity** of understorey and wetland plant communities.
    1. Population **survival and condition** of long-lived floodplain vegetation species (River Red Gum, Black Box, Coolibah and Lignum).
    2. Population **recruitment** of long-lived vegetation species (River Red Gum, Black Box, Coolibah and Lignum).

The relationship between the priority questions and Basin Plan objectives are summarised in Table 3-1 and illustrated in Figure 3-1. Priority questions for each research area are:

Diversity of understorey and wetland plant communities

1. What **flow regimes** best support the **diversity** of understorey and wetland plant communities?
    - o How significant are the individual drivers (habitat area, habitat heterogeneity, connectivity heterogeneity, and disturbance) for diversity?
    - o How do key drivers interact to influence outcomes?
    - o How should flows be managed to enhance drivers and thereby diversity?
2. How do **threats** impact on the drivers and **diversity** outcomes?

Survival and condition of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum)

1. What **flow regimes** (particularly frequency, period between follow-up watering, event duration) best support the **survival and condition** of floodplain vegetation populations?
    - o How do site characteristics (soil type, climate, and groundwater) influence these flow requirements?
2. How do **threats** (increased temperature, changes in rainfall seasonality) influence flow requirements?

Recruitment of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum)

1. What **flow regimes** best support **recruitment** within populations of long-lived floodplain vegetation species?
    - o How significant are the individual drivers (habitat availability, connectivity – dispersal) for recruitment?
    - o How do key drivers interact to influence outcomes?

   - How should flows be managed to enhance drivers and thereby recruitment?
   - How do the characteristics of sites (soil type, climate etc.) influence these flow requirements?
2. How do **threats** impact on the drivers and **recruitment** outcomes?

Refinement of research priorities

The overarching aim and priority research topics are very broad and do not easily lend themselves to a research portfolio that is achievable within the budget and timeframes of MDB EWKR. In order to focus the research direction while still being applicable to a range of locations and watering situations, we needed to focus and refine the research priorities.

We started by unpacking what is meant by water-dependent vegetation outcomes, particularly around diversity responses of understorey and wetland vegetation. As mentioned above, maintaining or improving vegetation condition or diversity are objectives of environmental water management common to wetlands across the Murray–Darling Basin. Targets associated with vegetation objectives tend to emphasise diversity and/or stability as desirable characteristics, despite recognition that many highly valued wetlands may support virtual monocultures or highly dynamic vegetation communities. As mentioned, managers require a clear understanding of the vegetation response objective, the effect of flow on vegetation response, and an understanding of how modifiers or non-flow drivers (e.g. climatic conditions) influence predicted vegetation responses.

Research undertaken on vegetation responses will focus on defining and conceptually understanding the types of vegetation responses that occur across different vegetation traits (e.g. compositional, structural and process), levels of ecological organisation (e.g. species, community, vegscape), and spatial and temporal scales. Given the range of vegetation responses that could be assessed and the importance of assessing outcomes against clearly defined objectives, we wanted to develop a vegetation response framework to assist in the articulation of vegetation response objectives.

Along with developing a vegetation response framework, research within MDB EWKR will focus on (1) understorey vegetation responses, and (2) recruitment of long-lived woody vegetation for the following reasons:

- *Management relevance:* Basin Plan objectives and the BEWS seeks to (1) maintain the current extent of non-woody communities, and (2) improve the recruitment of long-lived vegetation. There are also objectives to maintain the extent and improve the condition of long-lived vegetation. Other programs (such as The Living Murray, MDBA Basin-scale monitoring, and the QLD floodplain component of MDB EWKR) address these objectives and, as such, the survival and condition of long-lived vegetation was viewed as a lower priority.
- *Key knowledge gaps:* Identified through consultation with managers and researchers.
- *Potential to improve predictive capacity:* A key aspect of predictive capacity is defining what response managers want to predict. A part of this decision making process involves understanding and predicting the trade-offs between different management strategies. In order to do this, there needs to be clearly defined objectives around management strategies and communication of the justification and value of the decision. Therefore, part of our research focus is on developing a vegetation response framework that provides a strategic approach to defining objectives, indicators and management actions for vegetation outcomes. This approach acknowledges the breadth of potential vegetation response objectives and attempts to provide a strategic way of capturing explicit links between the value of the outcome (e.g. functions and services), the objective (considering multiple trait responses, ecological levels of organisation and spatio-temporal scales), flow and non-flow drivers. In addition, the predictive capacity of understorey vegetation responses and recruitment responses can be improved through the collection of additional, as well as the collation of existing, information.

Under the overarching question '*What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?'* we refined the following high-level questions:

- *How do we define our vegetation response objectives to consider multiple trait responses, ecological levels of organisation and spatio-temporal scales?*
- Once defined:
    - *What flow regimes best support our vegetation response objective?*
    - *What non-flow drivers influence, positively and/or negatively, our vegetation response objective?*
- In relation to both flow and non-flow drivers and their influence on vegetation response objectives:
    - How significant are individual drivers?
    - How do key drivers interact to influence outcomes?
    - How should flows be managed to enhance outcomes?
    - How do site characteristics influence outcomes?

These high-level aims and questions will be applied to two priority research topics:

1. **Diversity** (understorey and wetland plants)
2. **Recruitment** of long-lived vegetation (River Red Gum, Black Box, Coolibah and Lignum).

As our research program involves a number of components, there are specific research questions within components that fall under these high-level aims and questions.

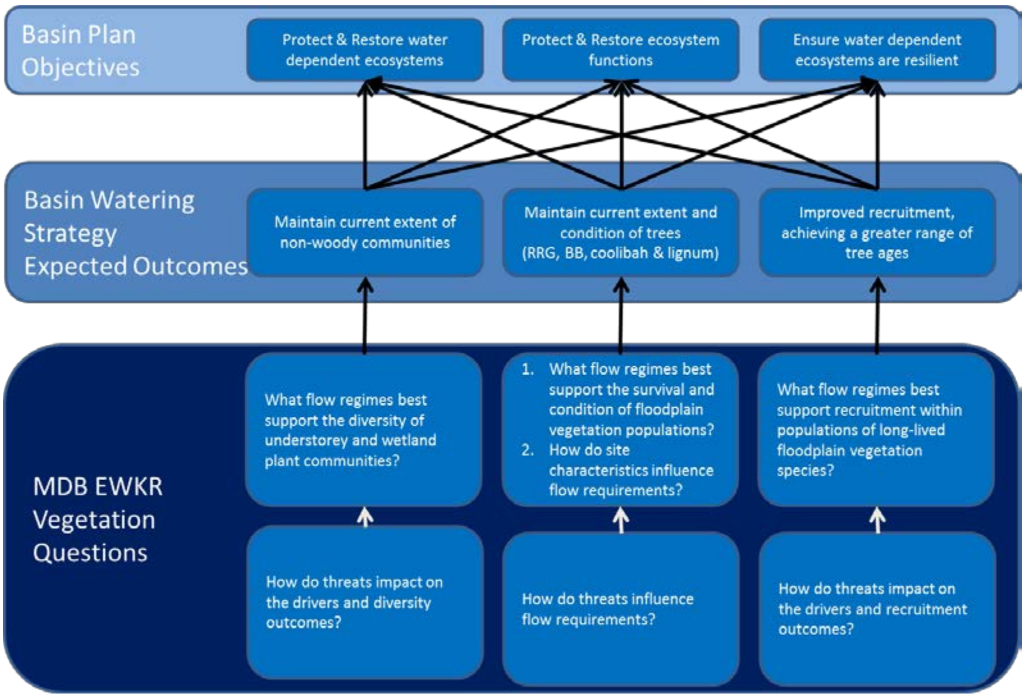

Figure 3-1. Illustration of the relationship between Vegetation Theme questions, Basin-Wide Watering Strategy Expected Outcomes and Basin Plan Objectives.

3.3.2 Conceptual understanding

Vegetation responses — what are we watering for and why?

Wetland and floodplain plants are critical components of both aquatic and terrestrial ecosystems. They have intrinsic value, but also provide ecosystem functions that support economic, social and environmental values. Ecosystem functions include the supply of energy to support food webs, provision of habitat and dispersal corridors for fauna, (Bornette & Puijalon 2011; Boulton & Brock 1999), and contribute to other ecosystem services such as nutrient and carbon cycling, and water and sediment oxygenation (Aldridge & Ganf 2003; Baldwin *et al.* 2013; Boulton & Brock 1999; Brookes *et al.* 2005). Additionally, they have aesthetic, cultural and recreational values.

The diversity of species recorded in wetland and floodplain habitats across the Murray–Darling Basin is in excess of 800 species (Campbell and Nielsen 2014). These species take a range of structural forms, from floating ferns to 600-year-old trees, and provide a range of functions at different locations and different times. Given this complexity, it is critical that the following processes are considered in guiding management decisions: (i) vegetation management objectives need to be clearly expressed; (ii) relationships between management objectives and management interventions need to be represented in conceptual models along with the variables that modify these relationships; and (iii) the uncertainties around these relationships need to be expressed. This process underpins the development of sensitive and appropriate indicators, and reveals key knowledge gaps that can be addressed through monitoring and research.

Vegetation outcomes from environmental flow management may seek to achieve objectives that are focused on compositional, structural or process responses. The situation is further complicated because objectives may be scale dependent, with objectives for a landscape providing context for smaller-scale objectives that will vary from location to location (e.g. improve condition of adult trees in some areas, or recruitment of juvenile trees, or control seedling recruitment in other areas). Once specific management objectives are defined, conceptual models can be developed that represent the relationships between the objective and the flow regime. These inform management actions and the expected outcomes. The clarification of objectives and development of conceptual models aid in both determining specific water requirements and the development of monitoring and research programs. Objectives and conceptual models are also useful tools in communicating the rationale of decisions and outcomes to stakeholders.

Vegetation response framework

Here we present a framework that aims to assist in the development of more specific vegetation objectives that support the function and services provided by vegetation. Delivering environmental water to achieve objectives requires conceptual models that summarise understanding of the relationships between a particular objective and environmental water delivery. We propose that in building these conceptual models, the influence of flow across temporal scales needs to be considered. In addition, we wanted this framework to consider the context in which environmental watering decisions are made, in terms of water availability, constraints to the delivery of flows and the influence of complementary management.

Response traits and levels of ecological organisation

When considering vegetation responses, there are three broad categories of responses that may be included in managers’ objectives, specifically composition, structure and process. These responses may occur at different levels of ecological organisation, ranging from landscape to individual plant responses. These perspectives have been synthesised in the conceptual model adapted from Noss (1990) (Figure 3-2).

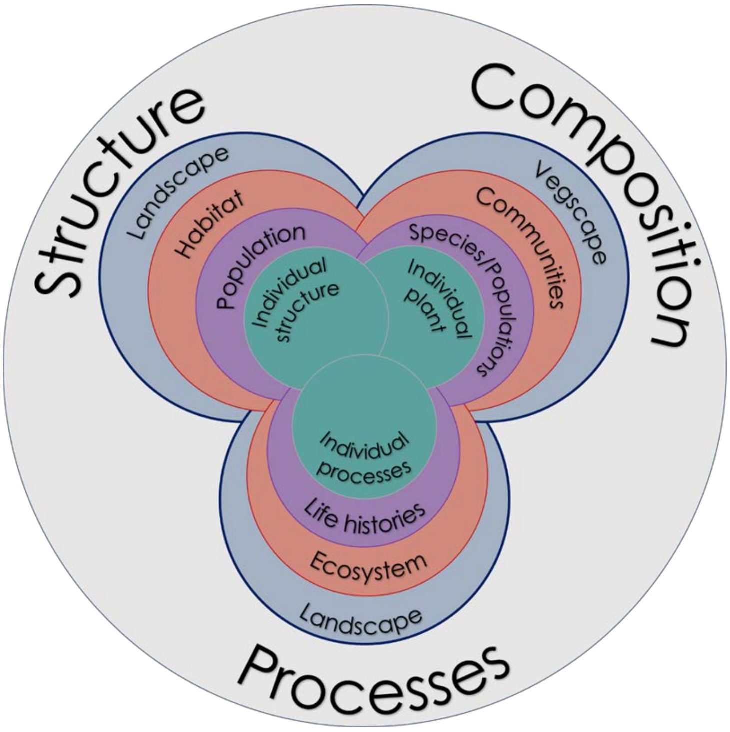

Figure 3-2. Vegetation attributes and levels of ecological organisation.

For example, objectives may be focused on:

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

Functions and services

When considering the functions and services provided by vegetation, these can be grouped into four different types: habitat, regulating, production and information (Figure 3-3) (adapted from de Groot *et al.* 2002 and Capon *et al.* 2013). Examples of the kinds of functions and services provided under each group are given in Figure 3-3. For example, vegetation can provide habitat in terms of nursery habitat for fish, corridor habitat for the movement of birds, or structural habitat for frogs. When setting objectives, this model allows scope to incorporate both ecological functions and services (largely included under habitat and regulating functions), as well as economic and social functions and services, such as food sources (e.g. honey production from River Red Gums), recreational values (e.g. improving the submerged habitat at important fishing locations) and cultural values (e.g. health of scar trees or the maintenance of totem species).

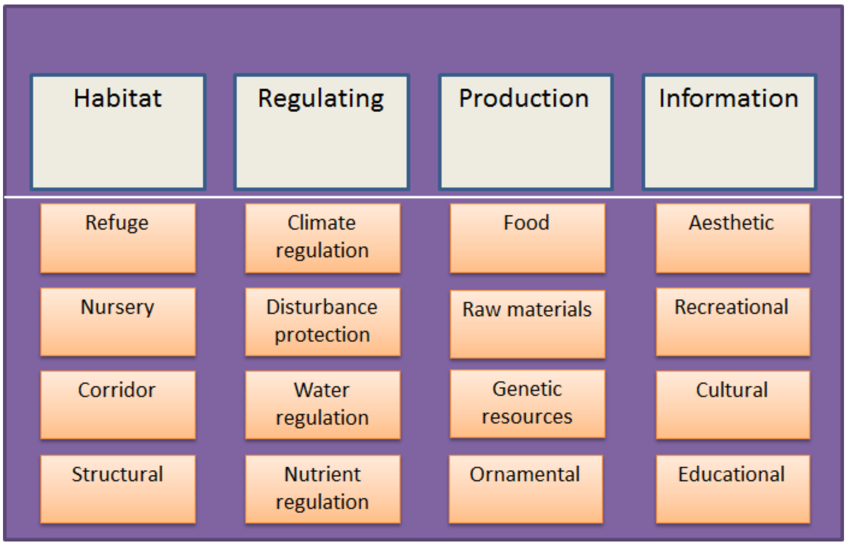

Figure 3-3. Structural grouping of potential functions and services provided by vegetation.

Nested flow regimes

Responses of vegetation to flows will be influenced by flow history. We propose that three temporal scales collectively shape vegetation communities including (i) flow pulses, representing inundation events lasting days to months, (ii) short-term flow regimes that characterise flow history over 1–10 years, and (iii) long-term flow regimes that characterise flow history over decadal time spans (Figure 3-4).

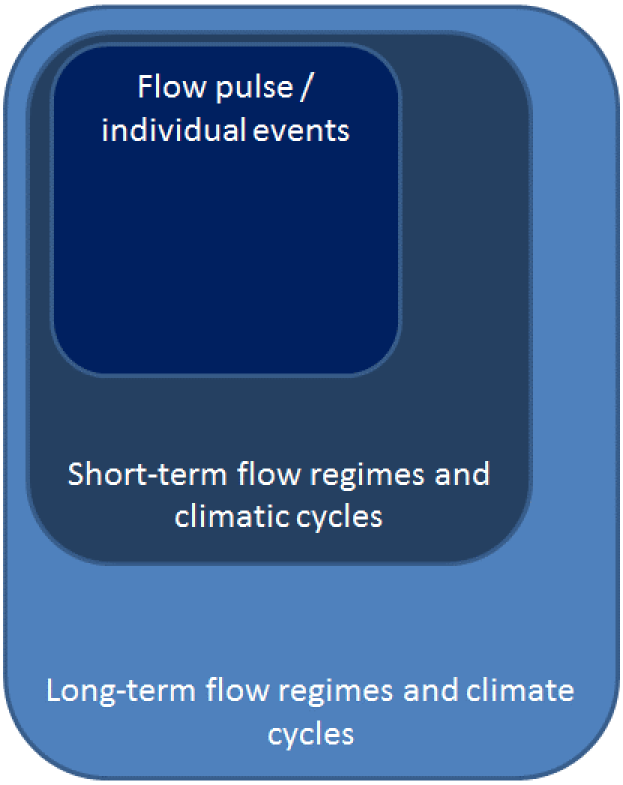

Figure 3-4. Model of nested flow regimes that can influence vegetation.

1. **Long-term** (decadal) cycles of wet and dry periods. At this scale, flow influences landscape patterns of vegetation, such as the types, distributions and relative

abundance of different vegetation communities. The key flow characteristics that are expected to be important at this temporal scale are described below:

- average inundation frequency and patterns of frequency
    - an important determinate of community distribution on decadal time scales
- average and maximum period without inundation
    - an important disturbance for communities such as forests, marshes and reed beds
    - an important determinant of community distribution on decadal time scales
- wet sequence duration (number of sequential years in which inundation occurs)
    - an important opportunity for forests, woodlands and shrublands to expand their distribution
    - an important disturbance for some ecosystems
- average and maximum inundation depth and duration
    - a disturbance for some ecosystems
    - an important determinant of community distribution on decadal time scales
- magnitude and connectivity of inundation
    - an important determinant in species dispersal patterns and transport of nutrients and sediment
- patterns of inundation seasonality
    - an important determinant of species distribution on decadal time scales.

These flow regime characteristics interact with landform and key climate variables including average, maximum and minimum rainfall and temperatures to determine landscape vegetation composition, structure and processes.

2. **Short-term** (1–10 years) flow regimes. At this scale, flow influences the composition of ecosystems and the condition of populations within those systems. The important flow characteristics at this scale are similar to those that are important for long-term flow regimes; however, the vegetation responses are finer scale (in terms of the magnitude of the response) in recognition of the longer time frames over which landscape vegetation patterns change. The key flow characteristics that are important at this scale are:

- inundation frequency and the sequencing of inundation
    - for trees and long-lived shrubs, frequency is important in meeting water requirements for persistence and recruitment opportunities
    - flow frequency influences seedbank and rhizome viability
- maximum period without inundation
    - both prolonged inundation or prolonged drought may cause a decline in the health and persistence of trees and woody understorey species
    - both prolonged inundation or prolonged drought may reduce seedbank and rhizome viability

- time-since-last inundation
    - an important determinant of vegetation condition and seedbank and rhizome viability
- wet sequence duration (number of sequential years in which inundation occurs)
    - an important opportunity for trees and long-lived shrubs to expand their distribution
    - an important disturbance for species intolerant of inundation, which will influence seed availability over time
    - influences condition and recovery trajectories
- average and maximum inundation depth and duration
    - most species have limits to the depth or duration of inundation that they can tolerate and so this can act as a filter or disturbance
- magnitude and frequency of hydrological connectivity
    - an important determinate in species dispersal patterns and transport of nutrients and sediment
- seasonal patterns of inundation
    - species cued to germinate and/or grow in different seasons will be influenced by seasonality in their extant distributions and abundance of propagules

These flow regime characteristics interact with landform and key climate variables including average, maximum and minimum rainfall and temperatures to determine vegetation composition, structure and processes. There is also an important interaction with long-term flow regime characteristics, in that the establishment of long-lived vegetation will have an influence on the understory that develops at the site. The processes are not well understood, but it is likely to be due to a variety of factors including the changes in the microclimate under the canopy (e.g. light, temperature), changes in soil properties, competition for nutrients and water and allellopathic interactions.

3. **Flow pulses/individual events**. At this scale, key flow characteristics influence individual plant responses, which may include growth, reproduction, germination, dispersal, quiescence or death. The important flow characteristics include:

- depth
    - individual plants have limits to the depth of inundation that they can tolerate. Their tolerance will be influenced by species characteristics, but also the condition they are in when inundated. For individuals whose tolerance is exceeded, inundation will act as a disturbance leading to declines in condition or death.
    - for some species, depth is an important habitat characteristic providing resources and an opportunity to successfully compete for those resources
- duration
    - individual plants have limits to the duration of inundation that they can tolerate. Their tolerance will be influenced by species characteristics, but also the condition they are in when inundated. For individuals whose tolerance is

exceeded, inundation will act as a disturbance leading to declines in condition or death.
    - duration is also important for species that require inundation to complete either their entire life-cycle or a particular stage. It is important that the duration is equivalent to the time required for the species to complete development, or there will be long term implications for the population.

- rate of recession
    - most aquatic plants have the capacity to tolerate a range of habitat conditions associated with cycles of wetting and drying. The capacity of plants to deal with the changes associated with drying is limited, and if the rate of drawdown is too rapid this will act as a disturbance for the plant, essentially shortening the duration of the inundation.

- season of inundation
    - timing is important as day length and temperature act as cues for germination and reproduction
    - seasonal timing is also important as temperature and light influence the plant's productivity or the productivity of competing species that may influence the plant's capacity to capitalise on the opportunity
    - timing may also influence external processes such as sediment microbial processes which may influence nutrient or oxygen availability within the sediments

- magnitude of hydrological connectivity
    - an important determinate in species dispersal patterns and transport of nutrients and sediment

- flow velocity
    - velocity exerts a physical stress on individuals that can lead to either scouring or sedimentation which may subsequently lead to death or reduced production
    - velocity may also influence the availability of nutrients and carbon dioxide in the water column, which may affect productivity

- turbidity/euphotic depth
    - turbidity affects the light available to submerged plants, which will affect their productivity
    - turbidity, combined with increased water depth, can reduce the light reaching submerged plants below the level required for plant growth
    - higher turbidity may result in the deposition of sediment on leaves and limit productivity.

Combining the components into a framework

Consideration of response traits and levels of ecological organisation, and functions and services and flow regimes on different temporal scales helps to shape objectives for targeted vegetation responses (Figure 3-5). The relationship between objectives and the proposed flow regime to meet the objectives is shown as a cyclic process to acknowledge that the flow design needs to incorporate/consider flow conditions (e.g. water availability), non-flow drivers, and any complementary actions, and that objectives may need to be revised/revisited if a suitably designed flow cannot be achieved because of constraints such as water availability.

With monitoring, the actual vegetation response can be compared to the predicted vegetation response and improve predictive capacity for future flows.

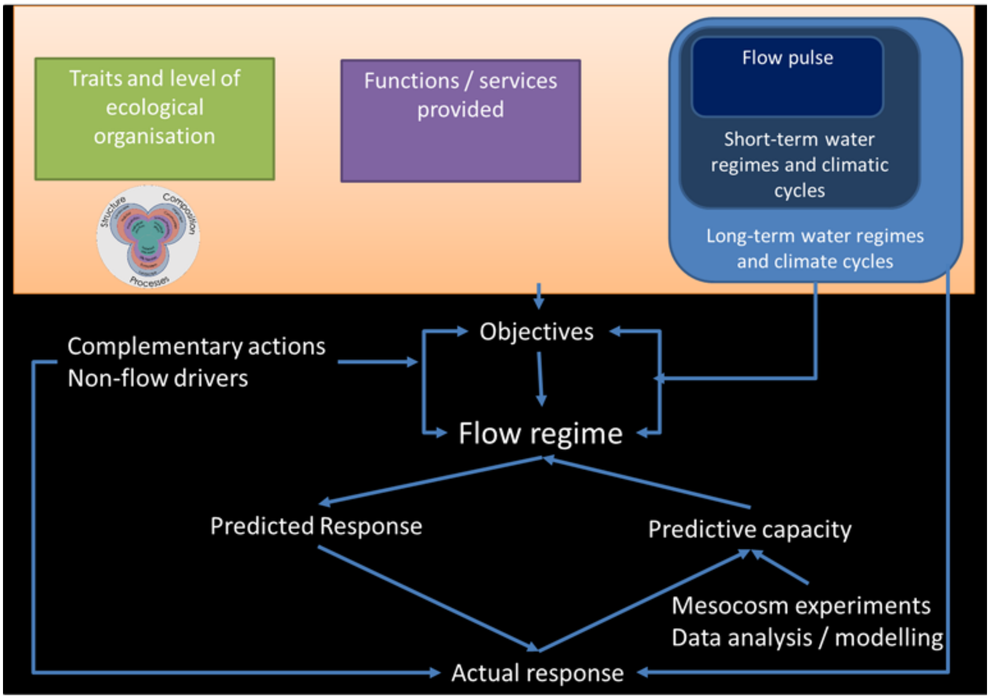

Figure 3-5. Framework incorporating different vegetation response traits, levels of ecological organisation, functions and services, and temporal scales of flow regime into an adaptive management framework.

Applicability to the MDB EWKR Vegetation Theme

The wide range of management objectives for vegetation can be interpreted broadly in terms of three types of response outcomes, specifically:

- **composition** outcomes, which can include species, community or landscape responses. Composition outcomes may be sought to protect biodiversity, threatened species and communities
- **structural** outcomes that are sought because vegetation provides critical habitat structure for a range of other biota, and structure is an important determinant of habitat quality
- **process** objectives that may include recruitment, productivity, nutrient cycling, soil formation or climate modification.

The Vegetation Theme aims to enhance our understanding of the effects of flow on:

- the composition of water-dependent vegetation
- structural outcomes
- process outcomes
- how non-flow drivers influence predicted outcomes from the use of environmental water.

While we have some understanding of vegetation responses to individual water actions, many of the critical changes are driven by longer-term responses to flow regimes. As a consequence, the MDB EWKR Vegetation Theme will improve our understanding of:

- compositional changes to individual flows and short-term (1–10 year) flow regimes through an analysis of existing environmental flow monitoring data. Where possible compositional responses will also be considered within the long-term context of the flow regime
- compositional, structural and process changes through field surveys that will examine vegetation responses to flow regimes. Where possible the field surveys will document responses to inundation and place these within the long-term context of the flow regime. This will be done by sampling sites with similar inundation frequencies (a key flow regime characteristic) and vegetation communities (an indicator of long-term flow history)
- process (recruitment) responses through experiments on the water requirements of long-lived seedlings.

3.4 Research Approach

The theme aims to improve the capacity to predict vegetation outcomes in response to the delivery of environmental water through an enhanced understanding of how flows and non-flow variables influence vegetation responses. Research will assess vegetation responses to environmental water in terms of different vegetation traits (e.g. compositional, structural, process), different levels of ecological organisation (e.g. species, community, vegscape), and across different spatial and temporal scales. Vegetation responses will predominantly include understorey vegetation responses and recruitment of long-lived woody vegetation. Incorporated into the research will be how vegetation responses to environmental flows are modified by non-flow variables that operate at local and landscape scales.

The proposed research will utilise existing literature, knowledge and data, investigate causal relationships in controlled environments, and will incorporate the flow conditions experienced over the life of MDB EWKR. The risk of unpredictable flow conditions will be managed by adopting this mixed portfolio approach of conceptualisation, data analysis, field assessments and mesocosm experiments.

The proposed approach includes five main research components with associated activities:

- V1. Conceptualisation
    - V1.1 Conceptualisation workshop
    - V1.2 Preliminary reporting to inform research components
    - V1.3 Reporting
- V2. Data integration and synthesis
    - V2.1 Planning and data workshop
    - V2.2 Data collation
    - V2.3 Data analysis
    - V2.4 Reporting
- V3. Field site assessment
    - V3.1 Fieldwork planning
    - V3.2 Field surveys
    - V3.3 Field reporting
- V4. Mesocosm studies

- V4.1 Mesocosm planning
- V4.2 Mesocosm studies
- V4.3 Mesocosm reporting

- V5. Theme planning, coordination and reporting
    - V5.1 Theme coordination
    - V5.2 Budget, workplan and contracts
    - V5.3 Annual Research Plan
    - V5.4 Multi-Year Research Plan
    - V5.5 Mid-Year and Annual Progress reports
    - V5.6 Annual EWKR coordination workshops
    - V5.7 Scientific Advisory Group (SAG) workshops
    - V5.8 Jurisdictional Reference Group (JRG) workshops
    - V5.9 Regional stakeholder workshops
    - V5.10 End-of-project reporting

In line with the 'one-project' approach of MDB EWKR, the research components will complement each other with the theme planning, coordination and reporting component proposed to bring together the findings and learnings in a holistic way (Figure 3-6). This will provide summary reporting for the Vegetation Theme as a whole and allow easier integration across all research themes.

Proposed research within the Vegetation Theme will be cognisant of the aims and objectives of the other MDB EWKR themes as well as, where possible, other research and monitoring programs occurring within the Basin. Such programs include the MDB EWKR Queensland vegetation project, LTIM, The Living Murray (TLM) monitoring, as well as monitoring and research undertaken as part of the Northern Basin Review, MDBA Basin-wide monitoring and state-based monitoring programs.

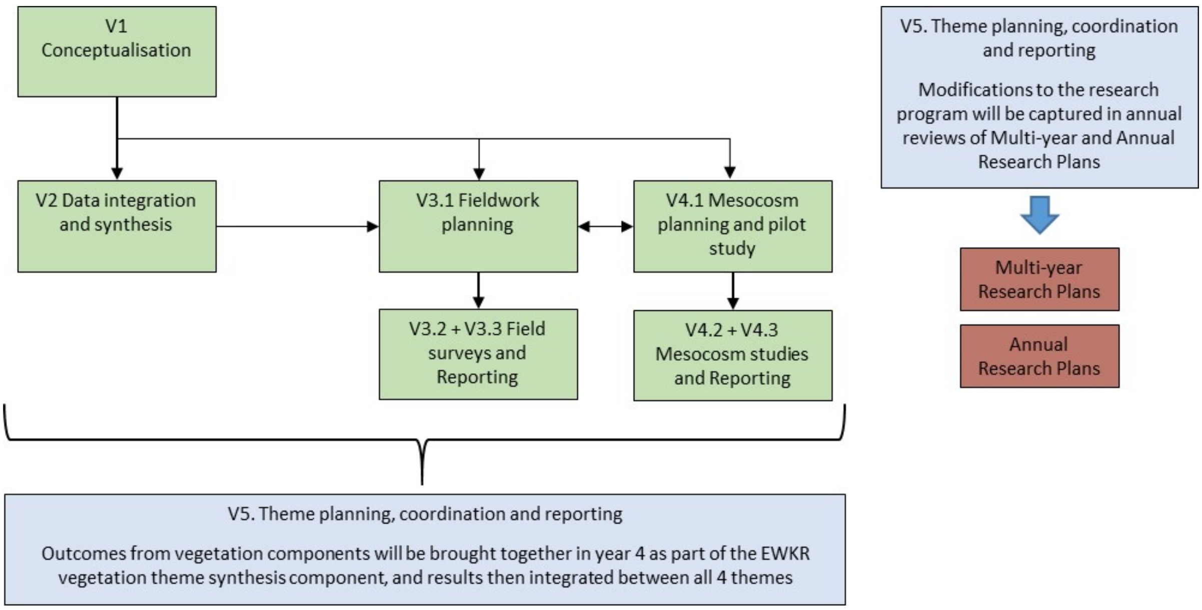

Figure 3-6. Flow diagram depicting the relationship between key research components.

3.5 Description of work components

This section gives an overview of the proposed work components and activities over the life of MDB EWKR (to 2018–19). The Annual Research Plan provides further details of when components and activities are scheduled.

3.5.1 Component V1 — Conceptualisation

Description and objectives

This activity will organise existing knowledge and new ideas into a conceptual framework to provide a strong theoretical basis underpinning the research planning. The need for this component arose, in part, from early discussions around defining what was meant by 'vegetation response'. In order for managers to achieve vegetation outcomes from environmental water, there needs to be a clear understanding of the targeted or desirable vegetation response, the effect of flow on vegetation response; and an understanding of how non-flow drivers (e.g. climatic conditions) influence predicted vegetation responses from the use of environmental water. In addition, there also needs to be consideration of water availability scenarios, constraints within the systems and the communication of decisions and outcomes to the broader community.

In order to focus the research direction of MDB EWKR while still being applicable to a range of locations and watering situations, we needed to conceptualise the types of vegetation responses that can occur (e.g. different trait responses and different levels of ecological organisation), their value in the broader context (e.g. functions and services) and the effects of flow and non-flow drivers.

The response of certain wetland and floodplain vegetation species, particularly long-lived woody vegetation, has been extensively, and recently, reviewed[1]. Consequently, it is not the intent of the Vegetation Theme to undertake another review of species-specific responses to flow. Rather, the focus will be on compositional, structural and process traits, from individuals to landscapes; the function represented by these traits; and the way in which interacting drivers may constrain the expression of traits. Where relevant, reference to existing information and conceptual models will be made to avoid duplication of effort.

Specifically, this component will:

- focus on the need to consider responses across multiple scales of organisation (i.e. individual plants, populations, communities, landscapes/vegscapes) and multiple types of vegetation traits (e.g. compositional, structural and process)
- build on our understanding of the contribution of vegetation to wetland function
- provide recommendations for adaptive management of environmental water delivery for vegetation outcomes, including implications for water planning, setting objectives and targets, indicator selection and monitoring.

1

Capon SJ, James CS, Mackay SJ, Bunn SE (2009) Literature review and identification of research priorities to address retaining floodwater on floodplains and flow enhancement hypotheses relevant to understorey and aquatic vegetation. Report to the Murray–Darling Basin Authority (project MD1252). 149pp.

Johns C, Reid CJ, Roberts J, *et al.* (2009) Literature review and identification of research priorities to address retaining floodwater on floodplains and flow enhancement hypotheses relevant to native tree species. . Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre. 70pp.

Mac Nally R, Cunningham SC, Baker PJ, Horner GJ, Thomson JR (2011) Dynamics of Murray-Darling floodplain forests under multiple stressors: The past, present, and future of an Australian icon. *Water Resources Research* **47**

Roberts J, Marston F (2011) Water regime for wetland and floodplain plants: A source book for the Murray–Darling Basin. National Water Commission, Canberra.

Rogers, K and Ralph, TJ (2011) Floodplain wetland biota in the Murray–Darling Basin: Water and habitat requirements. CSIRO Publishing, Collingwood.

Casanova MT (2015) Review of water requirements for key floodplain vegetation for the northern Basin: Literature and expert knowledge review. Murray–Darling Basin Authority, Canberra

Output

The primary output of this component will be to develop a vegetation framework. This framework will guide the refinement of objectives and the selection of indicators, aid in the consideration of functions and services provided by particular vegetation responses, and support communication of the rationale behind watering decisions and the value of anticipated responses. This conceptualisation will also result in the production of a scientific paper, and plain-English fact sheets. The primary audience will be the waterway managers, the EWKR project team and the scientific community.

How will the output be used?

This conceptualisation will be used to set the direction of MDB EWKR research questions for the Vegetation Theme by providing a structured approach to defining targeted vegetation responses, selecting indicators, and considering the influence of flow regimes across multiple temporal scales.

This component will inform all subsequent components within the MDB EWKR Vegetation Theme.

Outputs will also inform the broader scientific and water management community in relation to water planning and management. Our conceptualisation will be presented to managers at adoption workshops and feedback sought on how to incorporate it into management processes. This may potentially lead to some modification and the development of some examples in collaboration with managers.

Activities V1.1 — Workshop, V1.2 Preliminary reporting to inform research components, V1.3 Reporting

The activities for the conceptualisation component have been considered here together and are reported above.

- **V1.1 Workshop:** A workshop was held with the Vegetation Theme Leadership Group to develop our conceptual understanding and framework.
- **V1.2 Preliminary reporting to inform research components:** Outcomes from this component were presented to the Scientific Advisory Group and at the 2016 Australian Society of Limnology conference. Outcomes have also been incorporated into this document (see section 3.3.2 in particular).
- **V1.3 Reporting:** See information above.

3.5.2 Component V2 — Data integration and synthesis

Across the Basin, there are numerous datasets that span multiple years and multiple sites. The data integration and synthesis component (DISC) will provide an opportunity to combine and explore existing datasets for relationships between vegetation responses, flow and non-flow drivers such as rainfall. A data integration and synthesis approach is not limited to the four MDB EWKR research sites, nor is it limited to the inclusion of data collected only during the timeframe of the MDB EWKR project.

Developing a better understanding of the information within these existing datasets will inform other components of the research program so that the research that is undertaken builds on existing datasets where appropriate and avoids duplication of effort. Early outputs from data integration and synthesis will be used to inform the field and mesocosm components.

The DISC is also an excellent opportunity to foster collaboration with external stakeholders and to acknowledge and utilise data collected from numerous monitoring efforts that have occurred, in some cases, over decades.

Activity V2.1 — Planning and Data workshop

Objective

- To prepare for a workshop and scope the availability of datasets
- To hold a DISC workshop with vegetation ecologists, water managers, statisticians and modellers to discuss the potential for analysing large, combined vegetation datasets

Description

- Engagement with stakeholders
- Collation of preliminary information regarding potential datasets
- Hold workshop

Outputs

- Circulation of workshop notes to participants, including:
    - the workshop summary
    - the workshop notes
    - the guiding principles developed at the workshop by Dr Michael Reid
    - the additional recruitment notes developed from small group discussions
    - the workshop participation list
    - the summary metadata spreadsheet
    - copies of nine presentations given at the workshop.

How will the output(s) be used?

Outputs will inform the direction of the data analysis component and will form the foundations for collaboration with participants willing to share data.

Outputs from the DISC Workshop, along with outcomes from *V1 Conceptualisation*, will be used to refine research and analysis questions to be tested by the DISC.

Activity V2.2 — Data collation

Objective

- To collate datasets from willing collaborators
- To establish data-share agreements

Description

- Engagement with stakeholders (emails, phone calls, meetings)
- Collation of datasets

Outputs

- Collated dataset for analysis
- Data-share agreements with collaborators as required

How will the output(s) be used?

Outputs from the initial collation and summary of data will be used to refine research and analysis questions to be tested by the DISC.

Final datasets will be used for analysis.

Activity V2.3 — Data analysis

Objective

- To analyse vegetation responses to flow regimes and other non-flow drivers to better understand the effects of flow sequencing and spatial and temporal variability in response to flows
- Specifically, to address the following question:
  - How do legacy effects modify responses to flow in complex floodplain-wetlands?

Vegetation response in this context refers primarily to understorey vegetation composition and, where comparable, cover/abundance. Where sufficient data is available, responses will also include tree recruitment.

Additional specific questions may be addressed as more datasets become available.

Description

First phase of analysis

The primary aim of the first phase of analysis is to use a subset of data (Hattah Lakes floodplain data) to prepare the data format (including sorting out formatting issues and collating potential predictors) and investigate potential methods for analysis. For further details of the trialled approaches and preliminary results see the attached progress report (James 2016).

The second phase of analysis is to apply the successful approach(es) to a larger, collated dataset. This second phase is contingent on data being available and suitable.

This component will include ongoing consultation with quantitative ecologists to ensure that the best available analytical approaches are used to address the main questions and make the best use of the available data.

Outputs

- Progress update (September 2016)
- Dataset
- Analysis outputs, e.g.
  - Boosted GAMs (general additive models)
  - Random forest regression

How will the output(s) be used?

Outputs from the DISC analyses will provide information that will be used to refine existing conceptual models. It is anticipated that outcomes from this component will inform water managers and the scientific community with regards to the flow regimes that support particular understorey plant responses as well as the recruitment of long-lived floodplain vegetation. This component will provide information on how responses vary between locations and across different scales. It will also provide information on the influence of flow and non-flow drivers (such as rainfall and temperature) on vegetation responses.

Information from this component, along with the other research components, will inform end-of-project reporting for the Vegetation Theme.

Activity V2.4 — Reporting

Objective

- To report the results of research undertaken in the DISC

Description

- A peer-reviewed scientific publication(s) describing the results of the analysis — aimed at a scientific audience
- A brief summary report or fact sheets (or alternative format) describing the results of the analysis — aimed at a management and community audience

Output(s)

Results from the DISC will be developed into a publication(s) in a peer-reviewed scientific journal, and a summary report or fact sheets for dissemination to water resource managers.

How will the output(s) be used?

The outputs will document outcomes from the DISC. Outputs will be used by the scientific community and water managers. It is anticipated that outcomes from this component will inform water managers and the scientific community in terms of what flow regimes best support understorey plant communities. This component will provide information on how responses vary between locations and across different scales. It will also provide information on the influence of particular flow parameters (e.g. frequency) and non-flow drivers (e.g. rainfall) on vegetation responses.

3.5.3 Component V3 — Field site assessment

The fieldwork component will involve a program of work across the life of MDB EWKR, with fieldwork planning undertaken in 2015–16, and data collection, analysis and reporting in subsequent years.

Field site assessments are proposed to be undertaken at four locations across the Basin. It is predicted there will be variation in the vegetation responses among different regions of the Basin, such as between the north and south, potentially driven by differences in climate. Field site assessments at different locations will allow comparisons of the variability in responses of vegetation communities to advance the understanding of how flow and non-flow drivers influence vegetation responses. The field-site assessments will also create opportunities to develop links with the other MDB EWKR research themes, for example by potentially assessing the response and condition of vegetation communities that are important waterbird or fish habitat.

Activity V3.1 — Fieldwork planning

In order to ensure MDB EWKR addresses key knowledge gaps, fosters collaboration with key stakeholders such as water and land managers, and builds on, rather than duplicates, work undertaken by existing programs, a series of fieldwork planning activities commenced in 2015–16.

Field research questions were reviewed and refined at the Vegetation Theme research workshop in late May 2015. These will adaptively be reviewed and refined as further outputs from *V1 Conceptualisation* and *V2 Data integration and synthesis* become available, ensuring field-based research questions are targeted towards key knowledge gaps.

Site selection criteria and a preliminary methodology were also developed at this workshop to help guide the selection of sites. The final selection of sites will be an iterative process that occurs in parallel with the finalisation of the experimental design. Visits to local managers will be made to prioritise site selection (based on common site selection criteria), and to finalise methodology and timing. The final experimental design will be reviewed by local managers and researchers involved in implementing the field assessments.

It is anticipated that field work will commence in autumn 2017. Field sampling will involve a stratified design that incorporates different (broad) vegetation classes (e.g. non-woody wetland communities, floodplain shrublands, floodplain woodlands/forests) and different watering regimes (e.g. annual inundation, 1 in 3, 1 in 5, 1 in 10).

This activity will address the following questions:

- How does the extant understorey response differ between structural class, flooding regime and location?
- How do seedbanks (the potential for vegetation response) vary in relation to structural class, flooding regime and location?

Objective

- To design the fieldwork program to be undertaken in 2016–17 and 2017–18

Description

- Question revision and preliminary design workshop
- Desktop site selection and refinement with site managers
- Final field methodology document and data sheets

Output(s)

Information from this activity will be documented in a Field Assessment Experimental Design report. The audience for this report will be the MDB EWKR project team, including: DoEE, the Vegetation Theme Leadership Group and any additional personnel involved in the on-ground field assessments. The primary aim of the report will be to document the location of sites and the methodology for site assessments. This document will form the basis of consistent implementation of field assessments across the four sites and multiple years.

How will the output(s) be used?

The Field Assessment Experiment Design report will be used to direct the field assessments in future years.

Activity V3.2 — Field surveys

Description and objective(s)

To undertake field surveys as detailed in the Field Assessment Experiment Design report (Campbell *et al*. 2016).

Output(s)

The outputs from this component will be a collection of data.

How will the output(s) be used?

Outputs will be used to inform component and theme reporting.

Activity V3.3 — Reporting

Objective

- To report the results of research undertaken in the field site assessment component

Description

- A peer-reviewed scientific publication(s) describing the results of the field studies — aimed at a scientific audience
- A brief summary report or fact sheets (or alternative format) describing the results of the field studies — aimed at a management and community audience

Output(s)

Results from the field site assessment component will be developed into a publication(s) in a peer-reviewed scientific journal and a summary report or fact sheets for dissemination to water resource managers.

How will the output(s) be used?

Outputs will be used to better understand compositional, structural and process (tree recruitment and biomass) responses to flow regimes within both a short-term and longer-term context.

3.5.4 Component V4 — Mesocosm studies

The focus of the mesocosm studies will be seedling recruitment. Seedling recruitment was identified as being a priority for water managers and recent literature reviews identified successful recruitment as a knowledge gap. It was felt that datasets looking specifically at recruitment responses were likely to be limited, and that focusing mesocosm studies on seedling responses was an appropriate way to ensure that this priority research question was addressed.

The mesocosm experiment will focus on addressing the following question:

> *'What is the relationship between flow parameters such as duration, frequency and interflood-dry period (sequential, cumulative events) and seedling establishment?'*

With secondary questions:

1. How important are patterns of root development to overall growth and survival in changing conditions?
2. How do sequential flooding and drying events affect seedling growth?
3. How does the initial condition of seedlings affect their response to a flooding/drying treatment?

Activity V4.1 — Mesocosm planning

Description and objective(s)

A seedling-specific literature review will be undertaken to assess and collate the existing information available about the recruitment of seedlings of the four key species (River Red Gum, Black Box, Coolibah and Lignum). This brief review acknowledges the recent work of others and draws heavily on this information to not duplicate effort[2]. This review will also include an assessment of experimental techniques that have been used to assess seedling responses to ensure techniques applied build on the knowledge of previous work.

Output(s)

Outputs from this component will include the:

2

Johns C, Reid CJ, Roberts J, *et al.* (2009) Literature review and identification of research priorities to address retaining floodwater on floodplains and flow enhancement hypotheses relevant to native tree species. Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre. 70pp.

Roberts J, Marston F (2011) Water regime for wetland and floodplain plants: a source book for the Murray–Darling Basin. National Water Commission, Canberra.

Rogers, K and Ralph, TJ (2011) Floodplain wetland biota in the Murray–Darling Basin: Water and habitat requirements. CSIRO Publishing, Collingwood.

Casanova MT (2015) Review of water requirements for key floodplain vegetation for the northern Basin: Literature and expert knowledge review. Murray–Darling Basin Authority, Canberra.

- Literature review report summarising the current knowledge of seedling recruitment
- Experimental design report.

How will the output(s) be used?

The Experimental design report will be used by research staff to implement the mesocosm studies in 2016–17 and 2017–18.

Activity V4.2 — Mesocosm studies

Description and objective(s)

To undertake seedling mesocosm experiments as detailed in the Experimental design report (Durant *et al*. 2016).

Output(s)

The outputs from this component will include a collection of data

How will the output(s) be used?

Outputs will be used to inform component and theme reporting.

Activity V4.3 — Reporting

Objective

- To report the results of research undertaken in the seedling mesocosm component

Description

- A peer-reviewed scientific publication(s) describing the results of the experiment — aimed at a scientific audience
- A brief summary report or fact sheets (or alternative format) describing the results of the experiment — aimed at a management and community audience

Output(s)

Results from the mesocosm component will be developed into a publication(s) in a peer-reviewed scientific journal and a summary report or fact sheets for dissemination to water resource managers.

How will the output(s) be used?

Outputs will be used to inform water regimes targeting the successful establishment of tree and Lignum seedlings. Specifically, outputs will inform components of the flow regime such as frequency and duration. Additionally outputs will highlight the influence of the initial condition of seedlings to their response to wetting or drying and the potential importance of early intervention. For example, how do seedlings respond to either wetting or drying given exposure to either wet or dry conditions in their early development?

3.5.5 Component V5 — Theme planning, coordination and reporting

This component includes:

- theme research coordination, to ensure that research activities are administered effectively and delivered in a coordinated manner to deliver MDB EWKR objectives, including participation in Annual MDB EWKR coordination workshops

- theme research planning, including contributions to budgets, workplans and contracts
- development and refinement of Annual and Multi-Year research plans
- project reporting, including contributions to:
    - mid-year and annual progress reporting
    - Scientific Advisory Group Workshops
    - Jurisdictional Reference Group Workshops
    - Regional Stakeholder Workshops
- theme level reporting, including the Final Research Report for the Vegetation Theme, and contributions to the Final Research Report for each site and the Overall MDB EWKR Synthesis Report (noting that these reports will build on the specific reports associated with individual research components and activities).

The Annual Research Plan will be revised each year to reflect proposed activities for the forthcoming year. The Multi-Year Research Plan will be updated each year if any significant changes are required.

Workplan

The following workplan (Table 3-2) and anticipated timelines are proposed for the delivery of research components and activities within the Vegetation Theme. This workplan will be revised each year if any significant changes are required.

Table 3-2. MDB EWKR Vegetation Theme workplan timelines and activities.

Component	Activity	Status	Due/End	Responsible agencies
V1. Conceptualisation	V1.1 Workshop	✓	Completed (May 2016)	Leadership Group
	V1.2 Preliminary reporting to inform research components		End October 2016	Leadership Group
	V1.3 Reporting: Scientific paper/fact sheets		End December 2016	Leadership Group, led by Sam Capon
V2. Data integration and synthesis	V2.1 Planning and Data workshop	✓	Completed (Nov 2015)	Leadership Group
	V2.2 Data collation		End December 2016	Leadership Group, led by Cherie Campbell
	V2.3 Data analysis		End October 2017	Leadership Group, led by Cassie James
	V2.4 Reporting: Scientific paper(s)/fact sheets		End May 2018	Leadership Group, led by Cassie James
V3. Field site assessments	V3.1 Field work planning	✓	Completed (May 2016)	Leadership Group

Component	Activity	Status	Due/End	Responsible agencies
	• Question revision and preliminary design workshop			
	V3.1 Field work planning • Desktop site selection and refinement with site managers		End November 2016	Leadership Group, led by Cherie Campbell (southern sites) and Rachael Thomas (northern sites)
	V3.1Field work planning • Field methodology document and data sheets		End January 2017	Leadership Group, led by Cherie Campbell
	V3.2 Field surveys		2016–17 and 2017–18, end of spring 2018	Leadership Group, led by different agencies at different sites
	V3.3 Reporting: Scientific paper(s)/fact sheets		End January 2019	Leadership Group, coordinated by MDFRC (individual papers may be led by other organisations)
V4. Mesocosm study	V4.1 Mesocosm planning • Experimental design	✓	Completed (September 2016)	Leadership Group, led by MDFRC
	V4.1 Mesocosm planning • Literature review		End October 2016	Leadership Group, led by MDFRC
	V4.2 Seedling experiments		End June 2017	Leadership Group, led by MDFRC
	V4.3 Reporting: Scientific paper(s)/fact sheets		End May 2018	Leadership Group, led by MDFRC
V5. Theme coordination, leadership and reporting	V5.1 Theme coordination		Ongoing	Leadership Group, led by MDFRC
	V5.2 Budget and work plan review		September 2016 (+May 2017, 2018)	Leadership Group, led by MDFRC

Component	Activity	Status	Due/End	Responsible agencies
	V5.2 Renew/extend contracts	●	September 2016	MDFRC
	V5.3 Annual Research Plan 2016–17 (additional September revision)	●	September 2016	Leadership Group, led by MDFRC
	V5.4 Multi-Year Research Plan (additional September revision)	●	September 2016	Leadership Group, led by MDFRC
	V5.3 Annual Research Plan (annual revision)		May 2017 (+2018)	Leadership Group, led by MDFRC
	V5.4 Multi-Year Research Plan (annual revision)		May 2017 (+2018)	Leadership Group, led by MDFRC
	V5.5 Mid-year Progress Report		February 2017 (+ 2018, 2019)	Leadership Group, led by MDFRC
	V5.5 Annual Progress Report		August 2017 (+2018)	Leadership Group, led by MDFRC
	V5.6 EWKR coordination workshop		February 2017 (+2018, 2019)	Leadership Group, led by MDFRC
	V5.7 Scientific Advisory Group Workshop — presentation		May 2017 (+2018, 2019)	Leadership Group, led by MDFRC
	V5.8 Jurisdictional Reference Group — presentation		May 2017 (+2018, 2019)	Leadership Group, led by MDFRC
	V5.9 Regional Stakeholder Workshops — presentations		TBC	Leadership Group, led by MDFRC
	V5.10 End of project reporting • scientific papers • fact sheets • Theme summary • synthesis/project summary		April 2019–June 2019	Leadership Group, led by MDFRC (individual papers may be led by other organisations)

Key:

✓	Completed
(green circle)	Underway. On track for completion by planned date.
(amber circle)	Underway but some difficulties. May be completed slightly after the planned date, or scope or approach modified.
(red circle)	Underway but major difficulties. Unlikely to be completed by planned date. Likely to impact project delivery.
(blue circle)	Yet to proceed. Awaiting completion of prior tasks and milestones.

3.6 References

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4 Native fish

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4.1 Executive summary

4.1.1 Introduction

The distribution and abundance of native species within the MDB have declined significantly in the last 50–100 years (MDBC 2004) and as such, are a key target for improvement under a number of basin-wide programs including The Basin Plan and The Living Murray. The Basin-Wide Environmental Watering Strategy lists improvements in distribution, abundances, population structure and movement as expected outcomes for fish (MDBA 2014). In order to appropriately design environmental watering programs to benefit native fish, it is vital that the links between key watering parameters and potential fish responses are clearly understood. This requires an understanding of the biotic processes that maintain fish populations, the key drivers of these processes and the interaction with flows. This will be the focus of the Fish Theme, with research addressing the relative importance of key recruitment drivers and their interaction with flow and other variables at multiple spatial scales. Research outcomes will assist managers in gaining significantly improved predictive and explanatory capacity across a range of species.

4.1.2 Research focus

MDB EWKR research priorities and research sites, and the process by which they were determined, are described in the report titled *Selection of Priority Research Questions and Research Sites*. The selected research priorities provided the strategic framework for the Theme Leadership Groups to focus the proposed research for each of their themes.

The overarching question in relation to the MDB EWKR Fish Theme is: *What are the drivers of sustainable populations and diverse communities of native fish?* This is the key question that underpins the Fish Theme and it seeks to explore the key functional processes that drive outcomes for native fish populations and communities, as well as the situations under which each of these processes become limiting.

This high-level question is broken down into three priority areas:

1. recruitment of native fish populations (highest priority)
survival and condition of native fish populations (medium priority)
reproduction of native fish populations (lowest priority)

Priority questions for each priority area are:

- What flow regimes best support the reproduction/recruitment/condition and survival of native fish populations?
    - How significant are the individual drivers?
    - How do key drivers interact to influence outcomes?
    - How should flows be managed to enhance drivers and thereby the fish response?
- How do threats impact on the drivers and reproduction/recruitment/condition and survival outcomes?

The three identified priority areas encompass the entire life-cycle of fish and therefore all potential processes and drivers. The Leadership Group decided that attempting to undertake targeted work for all priority areas would result in resources being spread too thinly to address any priority area in a meaningful way. Consequently, the Leadership Group decided that the focus of the theme would be recruitment and that the remaining two priority areas would only be addressed where reproduction and/or survival conditions questions could easily be incorporated into recruitment-focussed activities. The relationship between the priority questions and Basin Plan objectives are illustrated in Figure 4-1.

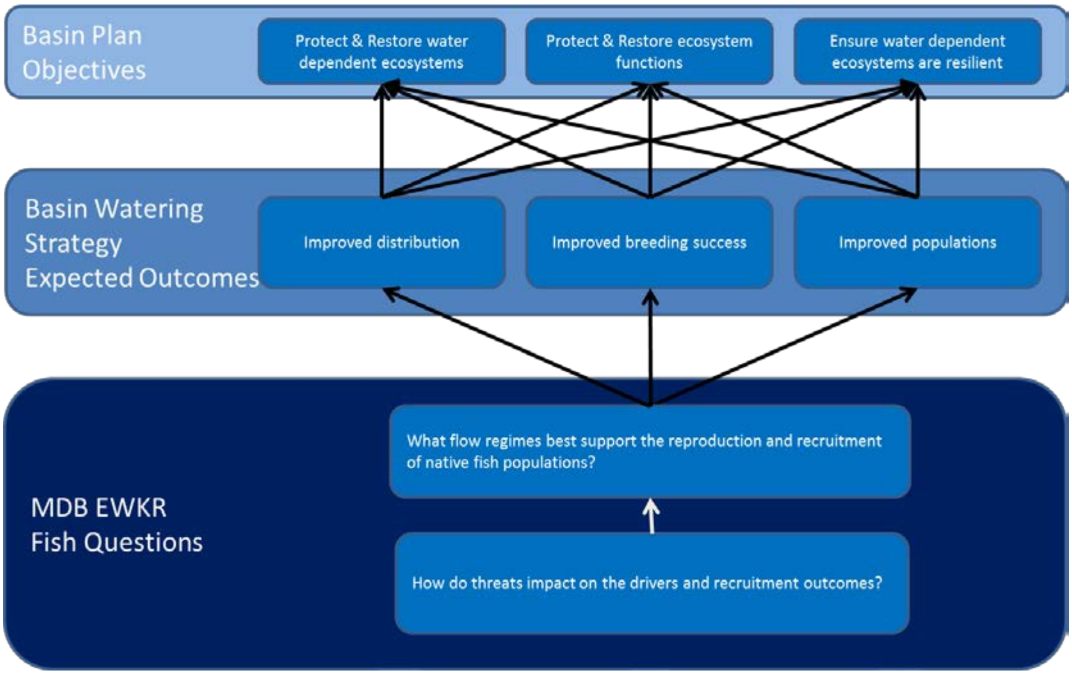

Figure 4-1. Illustration of the relationship between Fish Theme questions, Basin-Wide Watering Strategy Expected Outcomes and Basin Plan objectives.

4.1.3 Summary approach and research components

We propose to approach the theme in two stages. In the first stage, we will undertake synthesis and conceptualisation activities which will:

- be used to inform the identification of priority focus areas
- generate hypotheses upon which the research undertaken by the theme will be based
- provide a framework for the development of a predictive model
- generate stand-alone, high level scientific and management outputs.

These foundational activities will primarily be undertaken during 2015–16 and underpin the activities that will be undertaken in the second stage of the project (2016–19). Second stage activities will include laboratory and field studies in key knowledge gap areas and will result in an improved understanding of the direct and indirect relationships between fish recruitment drivers and flow, and how these are mediated by non-flow related factors.

4.2 Logic and rationale

4.2.1 Background

The distribution and abundance of native species within the MDB have declined significantly in the last 50–100 years (MDBC 2004). Whilst no native species are believed to have become extinct, over half of the species are currently listed as threatened or of conservation concern (Lintermans 2007).

In addition, the fish fauna of the Basin is now characterised by a high proportion of alien species, which comprise approximately 80–90% of fish biomass in many rivers (Lintermans 2007). Native fish are a key target for improvement under a number of basin-wide programs including The Basin Plan, The Living Murray and the Long-Term Intervention Monitoring Program. The Basin-Wide Environmental Watering Strategy lists improvements in distribution, abundances, population structure and movement as expected outcomes for fish (MDBA 2014).

In freshwater systems, fish declines have been attributed to a variety of factors, including habitat destruction, altered flow regimes, over-exploitation and the introduction of alien species (MDBC 2004). Alterations to natural flow regimes have resulted in major changes to riverine ecosystems, including to the timing, frequency and magnitude of flows, food and habitat quality and availability, and water quality (Bunn & Arthington 2002; Poff *et al.* 1997). Many of the critical life-history processes for fish (e.g. pre-spawning condition and maturation, spawning cues and movements, larval and juvenile dispersal, growth and survival) are intrinsically linked, either directly or indirectly, to the flow regime (Humphries *et al.* 1999; Lytle & Poff 2004; Welcomme 1985). In order to appropriately design environmental watering programs to benefit native fish, it is vital that the links between key watering parameters and possible fish responses are clearly understood. This requires an understanding of the biotic processes that maintain fish populations (e.g. spawning and recruitment), the key drivers of these processes and the interaction with flows.

The overarching question in relation to the MDB EWKR Fish Theme is: *What are the drivers of sustainable populations and diverse communities of native fish?* This is the key question that underpins the Fish Theme and it seeks to explore the key functional processes that drive outcomes for native fish populations and communities, as well as the situations under which each of these processes become limiting.

This high-level question is broken down into three priority areas:

1. recruitment of native fish populations (highest priority)
2. survival and condition of native fish populations (medium priority)
3. reproduction of native fish populations (lowest priority).

Priority questions for each priority area are:

- What flow regimes best support the reproduction/recruitment/condition and survival of native fish populations?
    - How significant are the individual drivers?
    - How do key drivers interact to influence outcomes?
    - Under what conditions do these individual drivers influence outcomes?
    - How should flows be managed to enhance drivers and thereby the fish response?
- How do threats impact on the drivers and reproduction outcomes?

The identified three priority areas encompass the entire life-cycle for fish and therefore all potential processes and drivers. The Fish Theme Leadership Group decided that attempting to undertake targeted work for all priority areas would result in resources being spread too thinly to address any priority area in a meaningful way. Consequently, the Leadership Group decided that the focus of the theme would be recruitment and that the remaining two priority areas would only be addressed where reproduction and/or survival conditions questions could easily be incorporated into recruitment-focussed activities. There are a number of ways in which fish recruitment can be defined (see King *et al.* 2013). For the purposes of the MDB EWKR project, the Fish Theme Leadership Group considers recruitment to encompass survival to sexual maturity in relation to both the abundance of survivors and the processes that govern survival. However, for the purposes of the MDB EWKR project, the primary focus will be on survival to the end of the first year of life. This decision is based on work undertaken during the foundational stage, which showed that year-class strength is thought to be determined prior to the juvenile stage (Fuiman 2002).

4.2.2 Conceptual understanding

Recruitment in fish populations is dependent on spawning magnitude and mortality rates of early life-stages (King *et al.* 2013). Mortality rates for teleost fish are typically high (>95% for most species), especially in early-life stages and changes in mortality rates during the embryonic and larval stages can lead to changes in juvenile abundances and subsequent recruitment levels (Houde 1987). Mortality can be caused by both intrinsic (morphological or physiological faults) and extrinsic factors (King *et al.* 2013). Extrinsic mortality is most commonly linked to starvation, predation, disease and environmental stress (King *et al.* 2013). Habitat availability, dispersal and density-dependent processes interact to influence these parameters and ultimately the growth and survival of offspring (Fuiman 2002; Houde 2002).

The risk of both predation and starvation generally decline with increased size; consequently, rapid growth is vital to reduce the risk of mortality during the early life-stages (Jones 2002; Trippel *et al.* 1997; Werner 2002). In combination with food availability, temperature is a key determinant of growth rates (Jones 2002; Morrongiello *et al.* 2011; Tonkin *et al.* 2011). Consequently, survival will be maximised when there is suitable habitat that provides plentiful food, low predation risk and appropriate temperatures for optimal growth and when appropriate dispersal and settlement processes occur to enable eggs, larvae and juveniles to access these habitats. All of these factors may be influenced, either directly or indirectly by flow (Figure 4-2).

Much of our current empirical knowledge has been generated from small-scale correlative studies that have attempted to link aspects of flow directly with fish responses. Whilst some relationships have been observed between the recruitment of particular species and flow attributes such as flow magnitude (high and low), aspects of floodplain connections and antecedent conditions (Balcombe *et al.* 2014; Beesley *et al.* 2014; Tonkin *et al.* 2008; Wedderburn *et al.* 2013), for the majority of species evidence is limited and in some cases conflicting. In addition, some studies suggest that there may be significant spatio-temporal variability in relation to flow responses and relationships, even at relatively small spatial scales (for example, see Balcombe *et al.* 2014). This indicates that whilst some flow-related effects may be direct (e.g. desiccation of eggs due to drops in water level, washout of larvae from nursery habitats during high flow events), many flow-related effects are indirect, with elements of the flow regime affecting other drivers of fish recruitment (Humphries *et al.* 2013). However, the underlying drivers and processes are rarely investigated (Humphries *et al.* 2013). This results in limited capacity to explain individual results or variability between studies and to predictively manage flow for fish recruitment. Furthermore, a clear understanding of the non-flow related drivers, which may influence recruitment either independently or in combination with flow, is critical in order to both generate realistic expectations regarding the capacity of managers to improve fish recruitment using environmental flows alone and to provide information regarding the types of complementary actions that may be required to generate desired fish recruitment outcomes.

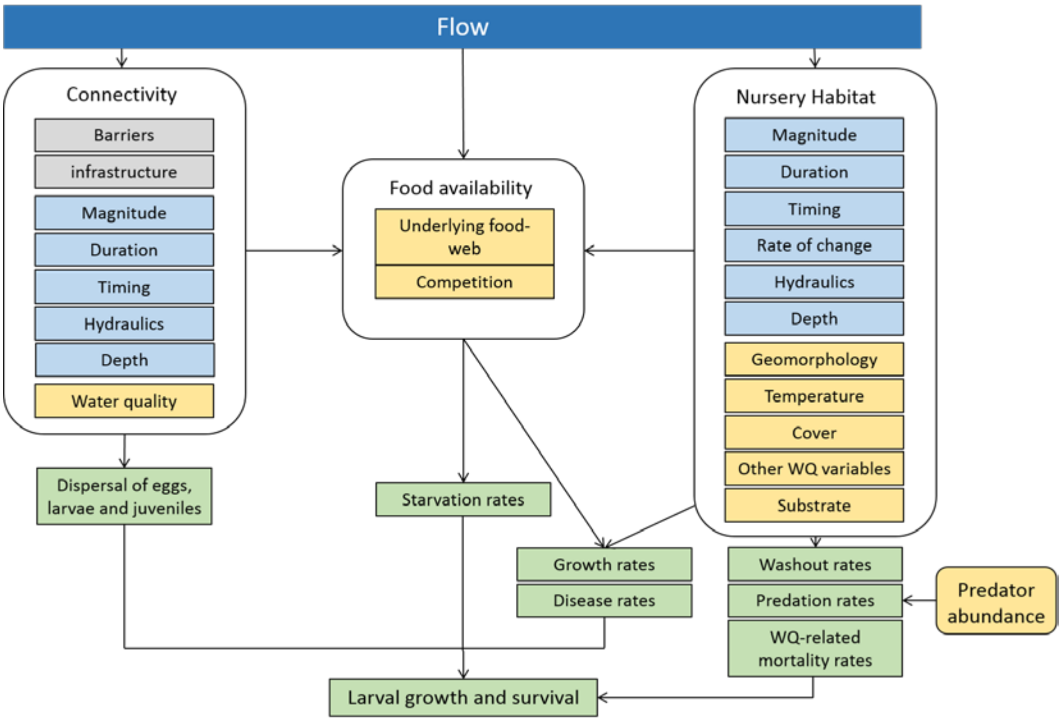

Figure 4-2 Conceptual model depicting the influence of flow on the growth and survival of larval riverine fish. Blue boxes represent flow-related drivers, yellow boxes represent other drivers and green boxes represent fish responses. WQ = Water Quality

In addition, it is possible that important processes or drivers may be operating at much larger spatial and temporal scales than existing work has considered. Recent research suggests that key drivers of population dynamics for several long-lived native fish species, in particular growth, spawning and recruitment, may be operating at a whole-of-river scale and/or over extended time periods. For example, significant recruitment events for Golden perch (*Macquaria ambigua ambigua* Richardson) in the lower Murray River may occur as infrequently as every nine years, and are often driven by spawning in the Darling River (Zampatti and Leigh 2013; Zampatti *et al.* 2015).

There is a good broad-scale conceptual understanding of the key drivers as well as the stressors and threats that are likely to impact on fish recruitment. However, our ability to assess the relative importance of individual drivers and threats and the interactions between them, and to predictively manage environmental flows for fish is limited by a number of factors. These include:

- an inadequate conceptual understanding of the more complex interactions among and between fish response, flow, other key drivers and stressors
- the species- and life-stage-specific nature of flow-relationships
- significant knowledge gaps in relation to particular processes and drivers
- the correlative nature of many studies
- the relatively small spatial and temporal scales over which most studies are carried out.

Until these are addressed, our ability to predictively manage flow for multiple species across space and time will be limited.

4.3 Research Approach

The Fish Theme will enhance understanding of the key drivers and functional processes of sustainable populations and diverse communities of native fish, as well as the situations under which key processes become limiting. Ultimately, the theme aims to provide improved capacity to predict fish recruitment outcomes in response to different environmental flow conditions. This will be achieved through synthesis of existing knowledge, analysis of existing datasets and experimental and field studies in key knowledge gap areas in order to better understand the direct and indirect relationships between fish recruitment and flow, and how these are mediated by non-flow related factors. The theme as a whole will be underpinned by foundational activities that will provide the basis for identifying key knowledge gaps and generating specific testable hypotheses that will inform both the work that will be undertaken and the predictive outputs that will be generated from this work.

4.4 Description of work components

The Fish Theme is divided into five components. Component F1 (Foundational activities) is proposed for 2015–16 and the first quarter of 2016–17, and is described in some detail. The outputs from this component will inform the activities undertaken in Component F2 (Research Activities) to be undertaken in 2016–18. A summary of key outcomes and priority knowledge gaps is provided for each foundational activity as this provides the context and rationale for Component F2. Component F3 is comprised of student projects which are complementary and will add value to the Fish Theme. Component F4 involves the synthesis and model development for the theme as well as the development of management recommendations. Component F5 is concerned with theme planning, coordination and reporting.

4.4.1 Component F1 — Foundational activities

The MDB EWKR project seeks to improve our knowledge of the relationship between flow and fish populations based on both existing knowledge and data and, where this is lacking, the generation of new knowledge. Consequently, the MDB EWKR project provides the opportunity to:

1. improve our conceptual understanding of the relationship between flow and fish populations

test key relationships, particularly those of management relevance in the MDB, identified in the conceptual model by analysing existing datasets and undertaking research to generate new information.

As recommended by the Scientific Advisory Group and endorsed by the Department of the Environment and Energy, work undertaken within the Fish Theme will begin with synthesis and conceptualisation activities, which will:

- be used to inform the identification of priority focus areas
- generate hypotheses upon which the research undertaken by the theme will be based
- provide a framework for the development of a predictive model
- generate stand-alone, high level scientific and management outputs.

Activity F1.1 — Fish recruitment conceptualisation

There is a good conceptual understanding of the high level drivers of fish responses. Despite this, effective management and restoration has proved difficult due to the complexity of, and the associated uncertainty around the relationship between flow modification and fish. The situation is further complicated because flow modification is believed to interact with a number of other stressors including invasive species, habitat alteration (geomorphology, vegetation, wood) and fragmentation (regulators, levies). The MDB EWKR project seeks to improve our understanding of the relationship between flow and fish populations; however, it is increasingly clear that our current general, broad scale conceptual understanding does not provide the detail required to support effective management of environmental flows to support native fish. Therefore, improvements in the conceptual understanding of the relationship between fish and flow will be of direct benefit to managers.

The refinement of our conceptual understanding is a critical component of the research plan, because it will:

1. improve our conceptual understanding of the relationship between flow and fish populations in such a way that greater and more appropriate levels of detail and complexity can be understood and communicated
2. underpin the design of the other activities undertaken by the Fish Theme
3. represent a significant project output of direct and immediate value to both water managers and researchers
4. become an input to the development of the MDB EWKR project's decision support tools.

The development of a more refined conceptual model of the relationship between flow and fish populations is of significant value to both the MDB EWKR project and managers. The development of such a conceptual model is not, however, a trivial activity. The relationship between fish and flow is complex and influenced by a number of non-flow drivers. There has also been considerable investment in both improving our understanding of, and restoring fish communities both around the world and in the MDB. As a consequence, there is a large and dispersed pool of existing information available to inform the development of the conceptual model. While not all available information will be of equal value, it will all need to be evaluated to determine whether it can contribute to the conceptualisation process. The Leadership Group believe that the investment in this process should be commensurate with both the amount of work to be undertaken and its value to the project and management.

The Leadership Group believe that the conceptualisation process will be most effective if it is divided into four components: theoretical (global), management (MDB), non-flow related stressors and threats and an integration of all of these to provide a management-focussed, MDB-specific conceptualisation of fish recruitment based on the best available science and most up-to-date management information (see Figure 4-3).

The rationale for this decision is that (i) the magnitude and complexity of the task requires that the work be divided into components, (ii) devolving responsibility for components will more fully engage the Leadership Group and their associated expertise in the process, and (iii) having different teams responsible for the three components ensures that all three areas (theory, management and other stressors) are given equal consideration.

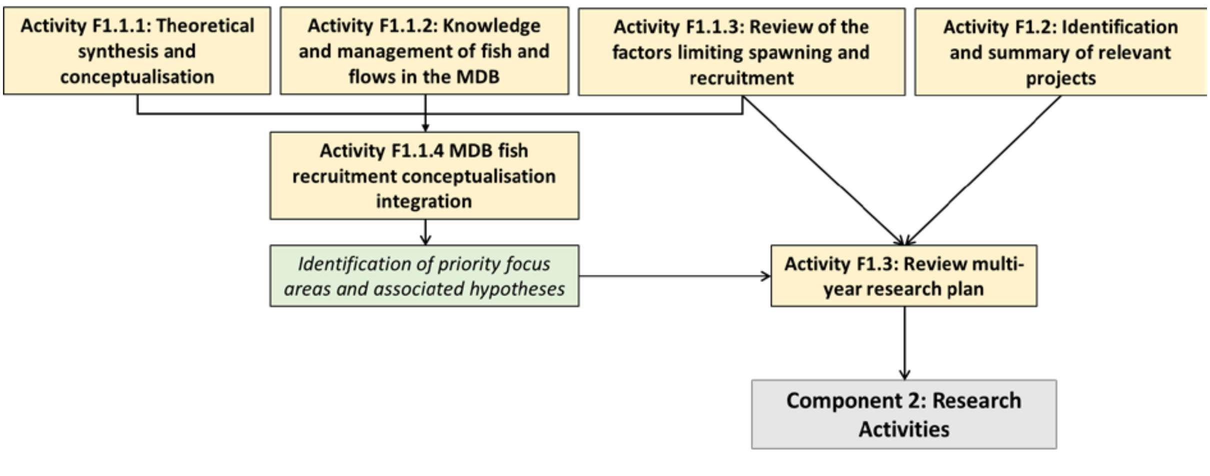

Figure 4-3. Flow diagram depicting the proposed foundational activities and how these relate to the later work components.

Activity F1.1.1 — Theoretical synthesis and conceptualisation

Description and objective(s)

This activity will integrate life-history theory, behaviour and physiology, river ecosystem concepts and fish recruitment hypotheses to establish current understanding, determine knowledge gaps and develop testable hypotheses relating to flow/fish recruitment relationships. A unifying model that integrates these disparate conceptual areas will enable greatly enhanced predictions about how particular flow regimes influence the recruitment of fish and other aquatic ecosystems in the Murray–Darling Basin. It will also allow the formulation of hypotheses about the mechanisms driving recruitment, which can be tested experimentally in the future in the field and laboratory.

Specifically, this activity will:

1. investigate if and how physiological, behavioural and life-history traits are correlated how these three components interact with the key features of river ecosystems — and flow in particular — to contribute to fish recruitment
2. explore the relevance of river ecosystem concepts for explaining patterns and processes in fish recruitment and population dynamics
3. relate current ideas and hypotheses about fish recruitment from all aquatic environments to rivers and riverine fishes
4. identify knowledge gaps, and generate hypotheses and guidelines for future research to better inform future management.

This is a desktop literature review/conceptualisation activity. Part of this work has started in the form of collaborative discussions, related publications in-progress, and agreement on the need for this synthesis. This will be led by Paul Humphries and will be written with input from key members of the fish Leadership Group.

Output(s)

The key output from this activity will be a conceptual framework that will be used to form the basis of the fish recruitment conceptualisation. In addition, this work will result in a scientific publication.

How will the output(s) be used?

This activity will inform both the fish conceptualisation and also the constraints synthesis by providing a strong theoretical underpinning based on the best available science. The identification and prioritisation of causal fish-flow relationships will allow for an assessment to be made of the likely importance of different flow components and threats to the different species within the MDB, based on their life-history, physiology and behaviour.

Summary of key outcomes and priority knowledge gaps

Recruitment success is influenced by a range of factors, but is most commonly linked to food availability, predation rates and dispersal processes that interact to influence the growth and survival of offspring (Houde 1987; Trippel and Chambers 1997; Trippel *et al.* 1997; Fuiman, 2002; Houde 2002). As the risk of both predation and starvation generally decline with increased size, rapid growth is vital to reduce the risk of mortality during the early life-stages (Trippel *et al.* 1997; Jones 2002; Werner 2002). Growth rates are influenced by a variety of biotic and abiotic factors, including environmental conditions, genetics and maternal contribution (Jones, 2002). Of the abiotic factors, food availability and temperature are thought to be the main determinants of growth (Houde 1997; Jones 2002). Temperature affects growth rates directly by influencing metabolic rates, the duration of developmental stages, and feeding and digestion rates, as well as indirectly by influencing the timing of the production and availability of prey (Houde 2002; Jones 2002; Werner 2002). A number of marine studies have examined the relationship between temperature and the growth of larvae (e.g. Mooji *et al.* 1994; Mann 1997; Johnston 1999; Otterlei *et al.* 1999), and correlations have been found between water temperature and recruitment success (Mills and Mann 1985; Grenouillet *et al.* 2001).

The majority of recruitment hypotheses that have been developed are based on food availability, growth-mediated predator avoidance, or dispersal and retention (Hjort 1914; Cushing 1990; Humphries *et al.* 1999; Schiemer *et al.* 2001; Humphries *et al.* 2013). Dispersal and retention are seen as critical as these processes determine the capacity of eggs and larvae to arrive at, and be retained in appropriate nursery habitats (Houde 2002). Most recruitment hypotheses and concepts are centred around either the temporal or the spatial coincidence of larvae with appropriate conditions. However, successful recruitment is most likely to occur when there is both spatial and temporal coincidence of larvae with optimal conditions (Bakun 2010; Hoagstrom and Turner 2015). For fish larvae, optimal conditions can be defined as areas with high densities of suitable prey, low predation rates and optimal temperature regimes (Humphries *et al.* in prep).

For most MDB fish species, we have limited understanding of the dietary requirements and thermal tolerances of early-life stages and how these interact to influence growth and survival. Similarly, there are significant knowledge gaps with respect to our understanding of the dispersal and retention patterns, requirements and capabilities of the early-life stages of most species.

Likewise, our understanding of the processes and drivers underpinning food production and how these might influence the spatial and distribution patterns of prey are poorly understood. However, the Fundamental Triad model (Bakun 1996, 1998, 2010), which is notable in that it considers both spatial and temporal aspects, suggests that nutrient enrichment and concentration at relatively small spatial scales (patch-reach), combined with propagule retention in favourable habitats is a key driver of recruitment. Whilst this model was developed for marine systems, the principles of enrichment (e.g. via decomposition of terrestrial material during floods or upwelling groundwater), concentration (e.g. in high retention zones such as slackwaters and floodplain wetlands) and propagule retention (e.g. in low velocity habitats) are readily applicable to rivers and floodplains. In these systems, flow, nutrient and carbon inputs, hydraulic habitat and structural complexity may interact to drive spatial and temporal patterns in food availability. Similarly, flow, geomorphology and structural complexity as we all as the swimming capabilities of larvae will interact to drive the dispersal and retention of patterns of larvae, and ultimately determine whether they are retained in appropriate habitat for growth and survival.

The drivers of temperature are relatively well known; however, our understanding of the spatial dynamics of temperature regimes is poor. Overseas studies have shown that complex landscapes, such as floodplains, can represent spatially heterogeneous thermal mosaics, which can impact on the chemical, biological and ecological processes (Tonolla *et al.* 2010). Although there is limited capacity to influence temperature regimes using flow management levers, temperature is, nonetheless, a critical driver of fish recruitment. Thus, gaining an understanding of not only the temperature requirements that enable good recruitment, but also the variability in temperature among different habitats, will enable managers to make informed decisions around the need for complementary actions (e.g. riparian revegetation).

Activity F1.1.2 — Knowledge and management of flows and fish recruitment in the MDB

Description and objective(s)

This activity will provide an up-to-date synthesis of fish and flows information (knowledge and management) for the MDB. Links will be provided to other existing relevant programs. The management needs of key fish-flows managers will be determined through a short workshop, and the current ecological thinking regarding MDB fishes will be documented. Knowledge gaps will be identified. This activity will address issues such as:

- how flows are managed for fish in the MDB, including spatial and temporal variations

- the future direction of flows management in the MDB
- geographic (locality)-specific flow and ecological considerations within the MDB
- current evidence for the importance of the different flow components for all species and all life-stages
- current knowledge and thinking regarding the ecology on MDB fishes and their populations in relation to flows in the MDB
- a summary of MDB species traits (life-history, movement, physiological and behavioural)
- the identification of key knowledge gaps and management needs.

This activity will largely involve collating, reviewing and synthesising existing literature and seeking out expert opinion (knowledge and management). The work will be led by John Koehn (ARI) and will be written with input from key members of the fish Leadership Group and other staff.

Output(s)

The key output from this activity will be a management-focussed publication. This will then be converted to a refereed scientific journal article.

How will the output(s) be used?

The outputs from this activity will be used to provide contextual relevance to the theoretical framework, ensuring that the conceptualisation is firmly based within the context of the species and flow-specific considerations of the MDB. The outputs from this activity will also be used to highlight the key knowledge components needed by fish-flows managers and inform which of these can be addressed by the EWKR research portfolio.

Summary of key outcomes and priority knowledge gaps

This activity is comprised of two key approaches: reviewing literature and gaining an understanding of management needs and priorities based on surveys and a workshop.

The literature review examined contemporary knowledge and emerging trends in flow-related fish ecology relevant to the MDB and found that current flow ecology knowledge is limited to a restricted number of species and life stages, with the major knowledge being for spawning and recruitment for Murray cod (*Maccullochella peelii peelii* Mitchell) and Golden perch, then to a lesser extent for Silver perch (*Bidyanus bidyanus* Mitchell) and Macquarie perch (*Macquaria australasica* Cuvier). There is limited knowledge for Freshwater catfish (*Tandanus tandanus* Mitchell) and much of this knowledge is from coastal streams. Our understanding around flow requirements for promoting recruitment of the small-bodied priority species is even more limited than the larger-bodied species.

As with the general knowledge of life stages for the MDB priority fish species, most of our understanding of key recruitment drivers are for the larger-bodied species, particularly Murray cod, Trout cod (*Maccullochella macquariensis* Cuvier)and Golden perch. There is limited knowledge for understanding the influence of flow as a driver and its influence on other drivers for the successful recruitment of small-bodied species and Freshwater catfish. There are clear knowledge gaps for all species in relation to biotic recruitment drivers, such as competition and predation and disease.

In general, our knowledge of the influence of flow and other drivers on fish recruitment is lacking, and consequently the review identified a number of *key knowledge gaps*:

- scale — temporal and spatial scales
- rates — growth, survival
- understanding of factors that grow populations
- outcomes of watering for a target species (on associated species)
- links between flow and habitat hydrodynamics leading to fish outcomes

- location relevance — how transferrable are the results?
- northern Basin species and processes
- threatened species — often targeting last gasp efforts rather than longer-term understanding of population needs.

Based on managers' responses to surveys and in the workshop setting, the *management objectives* relating to fish were to:

1. ultimately have more native fish in their rivers. Managers want successful life-cycle completion from spawning and recruitment right through to a larger adult population size.
2. achieve measurable benefits from flow management (e.g. increased distributions, abundance) — this may include interim measures (e.g. quantifiable improvements in all life stages).

*Key management priorities and knowledge gap*s included:

- the scale at which populations operate. Population dynamics and recruitment, demographic processes, connectivity etc. Scales include: sites, regional and, landscape
- movement, dispersal and connectivity
- mechanisms, drivers and causal links underpinning recruitment and population dynamics
- food webs, primary productivity, food resources
- flow-related thresholds, less than optimum duration, partial events, etc.
- refuge habitats, intermittent rivers, northern Basin
- trade-off processes
- species and life-stage specific responses to flows
- recovery time (drought/blackwater) — recolonization, barriers.

Priority species for managers were generally large-bodied native fishes and this tended to be based on public interest. Nevertheless, there is also consideration of the whole of fish community, umbrella or keystone species and particularly the need to address the requirements of threatened species. Estuarine and diadromous species are also priorities in South Australia. The large-bodied species were: Murray cod, Golden perch, Trout cod, Silver perch, Macquarie perch, Freshwater catfish. The small-bodied species (in order of priority) were: Southern pygmy perch (*Nannoperca australis* Günther), Southern purple spotted gudgeon (*Mogurnda adspersa* Castelnau), Olive perchlet (*Ambassis agassizii* Steindachner), Murray hardyhead (*Craterocephalus fluviatilis* McCulloch), Yarra pygmy perch (*Nannoperca obscura* Klunzinger. Carp (*Cyprinus carpio* Linnaeus) were also of significant management concern.

Managers strongly expressed the view that *adoption and engagement* could be facilitated through the use of hydrographs. Hydrographs are a useful tool for flow managers and are now widely used; there is much interest in refining these. Providing causal relationships of fish response to flow components is a key request from fish-flow managers. Managers are looking for more guidance/interaction with fish ecologists and the provision of definitive, easily applicable information.

Activity F1.1.3 — Review and synthesis of the factors limiting spawning and recruitment and how these are influenced by flow and other stressors

Description and objective(s)

The capacity for fish to respond positively to flow management activities is dependent on a variety of factors, some of which may not be directly related to flow. The key factors which can limit fish responses to management activities are reasonably well known and include:

- food quality and quantity
- hydraulic, geomorphic and structural habitat occurrence, diversity and abundance

- connectivity (lateral and longitudinal)
- population size/condition and population structure of spawning stock
- presence of spawning and movement cues
- water quality
- competition
- predation
- lag times of responses.

However, requirements in relation to these factors vary among species and life-stages and the relative importance of different factors is spatially and temporally variable. In addition, whilst flow regulation is recognised as one of the stressors that can significantly impact on these factors, there are a number of other stressors that can also have significant negative impacts. These include stressors that are associated with flow regulation, for example floodplain disconnection, irrigation extraction, barriers to movement and thermal regimes, as well as others that may not be flow-related such as habitat destruction/degradation, over-exploitation and the introduction of alien species (MDBC 2004). These, in combination with changes to the flow regime, can significantly impact on the key drivers and processes that underpin fish responses.

In order to achieve desired responses to flow management activities, it is critical that managers consider which limiting factors should be prioritised at different times, how flow might be expected to influence these factors, and also how other stressors that may be operating in the system can impact on these factors. This component will synthesise existing knowledge to describe the key limitations on potential fish responses (focussing on spawning and recruitment), how these vary spatially and temporally and the influence of flow and other stressors. The specific questions that will be addressed are:

- What are the factors limiting fish spawning and recruitment?
- What is the relationship between these factors, flow and other stressors?
- Do these factors vary in space and time?
- Are there any factors which are data poor?
- Are complementary actions needed where factors cannot be influenced with flow?

This component will largely involve collating, reviewing and synthesising existing literature and seeking out expert opinion where required. The component will be led by Amina Price (MDFRC) and will be written with input from members of the Leadership Group.

Output(s)

The key output from this activity will be to inform the position paper outlined in section F1.1.4.

How will the output(s) be used?

This activity will both inform, and be informed by the fish recruitment conceptualisation and will be a key input into the identification of priority knowledge areas and hypotheses.

Summary of key outcomes and priority knowledge gaps

This activity identified a number of limiting factors for fish recruitment which were then used to define the key recruitment drivers (Table 4-1). These drivers were classified as either direct (i.e. those that had a direct effect on growth and/or survival), or indirect mediating drivers. Mediating drivers were those that influenced the direct recruitment drivers.

Table 4-1. Direct and indirect (mediating) fish recruitment drivers.

Direct recruitment drivers	Mediating (indirect) recruitment drivers
Quality and quantity of foods ingested	Nutrient and carbon inputs
Temperature	Connectivity
Predation	Hydraulic habitat
Disease and parasites	Macrophyte cover
Desiccation	Snag cover
Water quality	Water quality
Pollutants	Community composition (competition and predation)
Other sources of mortality (infrastructure)	Species traits
Movement and retention	Spawning success (adult populations; spawning cues; spawning habitat)

Non-flow related threats, associated impacts and ecological effects were identified, as were the recruitment drivers that had the potential to be affected (Table 4-2).

Table 4-2. The key non-flow related threats and processes that might impact on the recruitment drivers.

Key threat	Key impacts (stressors)	Ecological effects	Affected recruitment drivers
Altered land use	Erosion, channelization, altered patterns of runoff and overland flow, sedimentation, geomorphological change; riparian alteration and degradation; altered substrates; altered nutrient regimes, pollutants; raised groundwater levels; de-snagging	Smothering, infilling or scouring of aquatic habitat (substrates and hydraulic habitat); loss of shading; loss of instream structural habitat; changes to food webs; changes to water quality; changes to community composition; changes to adult population, size and condition; changes to organic matter inputs (amount, timing type)	Temperature; predation rates; food quality and quantity; turbidity and sedimentation; salinity; eutrophication; dissolved oxygen; acidification
Barriers	Loss of lateral (floodplain) connectivity, loss of longitudinal connectivity; cold water pollution; raised groundwater levels; stranding in impoundments and weir pools; pumping into inappropriate habitat	Altered nutrient regimes; changes to organic matter inputs (amount, timing type); altered sediment regimes; channelization and scouring; geomorphological change; alteration to hydraulic habitat; changes to community composition; changes to adult population size, structure and condition; reduced up- and downstream dispersal of juveniles; reduced downstream dispersal of eggs and larvae; reduced growth or mortality resulting from stranding in sub-optimal habitats; physical damage and mortality resulting from passing though pumps, weirs and dams.	Temperature food quantity and quality; dissolved oxygen; turbidity and sedimentation; salinity; eutrophication; acidification; infrastructure-related mortality

Key threat	Key impacts (stressors)	Ecological effects	Affected recruitment drivers
Climate change	Increased water temperatures; changes to precipitation patterns; changes to evaporation rates	Changes to species distribution patterns; changes to aquatic vegetation; changes to riparian and floodplain condition; altered nutrient regimes; changes to organic matter inputs (amount, timing type); altered sediment regimes	Temperature; predation rates; food quantity and quality; dissolved oxygen; turbidity and sedimentation; salinity; eutrophication; acidification
Alien species	Disturbance of substratum	Changes to species distribution patterns and community composition; changes to aquatic vegetation; competition rates	Predation rates; food quality and quantity; turbidity and sedimentation
Harvesting		Changes to community composition; changes to adult population size, structure and condition	Predation rates; food quality and quantity

Based on this, a series of conceptual models depicting the relationships (and hypothesised strength of these relationships) between threats, impacts and mediating drivers were developed for each direct recruitment driver. Spatio-temporal variability was considered and where the strength of relationships was thought to differ based on spatial or temporal variability, separate models were developed. These models included 'flow alteration' as a key threat as this provided an indication of the relative influence of flow versus non-flow related factors on each recruitment driver under different spatio-temporal scenarios.

The key outcomes from this work can be summarised as follows:

- There is limited information regarding the water quality tolerances of early-life stages of MDB fish species.
- There is strong evidence for increased mortality rates associated with barriers and infrastructure; particularly, mortality of drifting eggs and larvae is high. Recruitment rates may also be affected by decreased capacity for movement and stranding on floodplains. However, the flow-on effects to recruitment rates have not been quantified.
- Food quantity and quality are likely to be key drivers of recruitment; however, we understand little of the relationship between prey type and density and rates of growth and survival of larvae and juveniles. The processes and drivers underlying food production are not clearly understood, but are likely to be strongly impacted by flow, land use change, altered connectivity, habitat degradation and changes in water quality.
- The effect of predation on recruitment rates is unknown. However, it is likely that predation rates may be significantly affected by habitat degradation and alien species.
- Most recruitment drivers are more strongly influenced by non-flow related factor such as land use impacts (e.g. sedimentation, riparian alteration) and barriers than they are by flow. Consequently, our capacity to improve fish recruitment outcomes by focussing on flow management alone is probably low.
- Of all of the recruitment drivers considered, food quality and quantity and movement and retention were the drivers most likely to be directly affected by flow.

Activity F1.1.4 — MDB Fish recruitment foundational integration

Description and objective(s)

This activity will integrate the outcomes from the previous three activities to develop a clear synthesis of our current conceptual and empirical understanding of MDB fish recruitment drivers and associated flow relationships based on the best available science and most up-to-date management information. For different MDB fish species, this activity will:

- prioritise recruitment drivers and relationships between flow and recruitment in terms of:
    - their influence on outcomes
    - our current level of understanding
    - the capacity to be influenced by existing management levers
- identify and prioritise knowledge gaps
- develop testable hypotheses that are applicable to flow management scenarios and MDB fishes.

Outputs

A management-focussed position paper describing:

- flow management for fish targets in the MDB context
- the drivers and limiting processes for fish spawning and recruitment
- how strongly and directly these drivers are influenced by flow and non-flow related factors
- in light of the point above (#3), what fish outcomes can managers realistically expect to achieve using flow as their only management lever versus using complementary actions as well.

This publication will also represent the output for Activity F1.1.3.

Summary of key outcomes and priority knowledge gaps

Priority knowledge gaps and focus areas for the Fish Theme were identified at a Leadership Group workshop following the conceptualisation activities. Recruitment drivers were prioritised with respect to:

1. ecological relevance
2. the capacity to manage the driver using flow
3. the capacity to manage the driver using complementary actions.

Based on this process, four recruitment drivers, food quantity, movement and retention and infrastructure-related mortality, were rated as high priority drivers for EWKR work to focus on. It was also noted that the presence of viable adult populations is a critical pre-cursor for successful spawning and subsequent recruitment.

Knowledge gaps were identified for each of the four highest priority drivers and these were then prioritised based on:

1. ecological relevance
2. management relevance (managers' priority questions and target species and scope for improving predictive capacity)
3. Basin-wide relevance and applicability
4. capacity for integration across themes
5. feasibility (time, budget).

The highest priority knowledge gaps centred around:

- the relative importance of key recruitment drivers (food, temperature and movement and retention) across multiple spatial scales and interaction with flow.
    - How does flow influence food production (nutrients, energy, basal resources, direct food sources) at local (reach) and landscape (segment to basin) scales? How is this influenced by geomorphic and structural complexity and diversity to drive spatial and temporal variability in the landscape?
    - What are the large-scale spawning and recruitment patterns of periodic and equilibrium species? How do these relate to spatial and temporal variability in temperature, food production and the distribution of adult populations in the landscape? What role does movement and connectivity play for large-scale population processes?
    - How do hydrodynamics (flow, geomorphology and structural habitat) influence larval movement and retention? What are the consequences of inappropriate hydrodynamic conditions? What are the movement and settlement cues (e.g. magnitude of in-channel flows and/or hydraulic conditions for larvae and to what extent do larvae control their settlement?
    - Dietary requirements of early-life stages: spatio-temporal variability, influence of food source and quality on growth and survival, capacity and propensity to be selective, bioenergetic costs of varying prey densities; relationship between diet, temperature and growth.
- water quality thresholds and optima for growth and survival.

To attempt to ensure that wherever possible, research findings would be applicable to a range of different species, The Fish Theme Leadership Group grouped MDB fish species based on work undertaken as part of Activity F1.1.1. Investigating if and how physiological, behavioural and life-history traits are correlated. Based on the outcomes of this work, the Fish Theme Leadership Group decided to categorise MDB fish species on the basis of Winemiller and Rose's life-history model, whereby species are considered to be opportunistic, periodic or equilibrium (Winemiller and Rose, 1992). As per the definitions in King *et al.* (2013), opportunistic species are small, short-lived species that mature early and make a large reproductive effort, but with low fecundity per batch and a small investment of energy per offspring; periodic species are those which are relatively long-lived, mature late and make moderate reproductive effort, with high fecundity per batch and a small energetic investment per offspring; equilibrium species are of variable size, mature at medium to late stages, with low fecundity per batch and large energetic investment per offspring.

This model does not, however, consider movement patterns and these do not always correlate well the life-history model. Because of the importance of movement and retention for recruitment, it was decided that movement patterns would be incorporated in the life-history model, and based on the species that were identified as being of management priority this produced five species groups:

1. Periodic species (e.g. Golden perch, Silver perch, Macquarie perch, Bony herring (*Nematalosa erebi* Günther).
2. Equilibrium species with a juvenile dispersal phase (e.g. Murray cod, Trout cod)
3. Equilibrium species with no juvenile dispersal phase (Freshwater catfish)
4. Opportunistic species with no juvenile dispersal phase (e.g. Southern pygmy perch, Olive perchlet, Murray hardyhead, Purple-spotted gudgeon).
5. Opportunistic species with a juvenile dispersal phase (e.g. Flat-headed gudgeon (Philypnodon grandiceps Krefft , Australian smelt (Retropinna semoni Weber).

It was agreed that as much as possible, research activities would focus on one representative species from each group, with the focus group(s) selected being based on the specific research questions, the species collected and the number of species it would be feasible to include.

Activity F1.2 — Identification and summary of relevant projects

Description and objective(s)

The SAG noted that the work undertaken within EWKR needs to build on work undertaken by other large projects (e.g. the Flagship Cluster), and to be explicit in relation to linkages with other programs (in particular LTIM). In response to this, the Leadership Group agreed that an additional activity, involving cataloguing and summarising relevant projects (national and international) that the work within the Fish Theme should either build on or link with, should be undertaken at the same time as conceptualisation is being developed. This work will be undertaken by MDFRC staff with input from the Leadership Group.

Output(s)

A document listing all relevant past and current projects and summarising the information such as the project aims and objectives, study sites, methods and, in the case of completed projects, the key findings.

How will the output(s) be used?

The project summary document will be used by the Leadership Group to assist in planning the next stages of work for the theme to ensure that there is no duplication, potential linkages are maximised and that outcomes from other major projects are built on.

Activity F1.3 — Review Multi-Year Research Plan

Description and objective(s)

The existing Multi-Year Research Plan will be reviewed and updated based on the outcomes of activities F1.1.4 and F1.1.5, with the review to provide further definition of Components F2 and F3. This activity will be led by Amina Price, with input from the Theme Leadership Group.

Output(s)

The output of this project will be an updated Multi-Year Research Plan, including detailed methodological approaches. The users of this output will be the broader project team.

4.4.2 Component F2 — Research activities

This component will focus on addressing key knowledge gaps identified through the conceptualisation process relating to the relative importance of key recruitment drivers and their relationship with flow and other variables. The work is comprised of a number of sub-components (Figure 4-2) addressing the:

- diet of larval fishes
- relationship between growth and survival and food density and temperature
- spatial variability in the thermal and nutritional riverscape at multiple spatial scales (patch, riverscape, reach, river segment)
- relationship between flow, geomorphic and structural habitat and three key drivers of recruitment: food, temperature and larval dispersal and retention.

Although we acknowledge the role of predation in driving recruitment success, this will not be the main focus of the work undertaken in this component. This decision is based on budget and on the fact that of the three most important recruitment drivers, predation is the one that managers have the least capacity to address.

Whilst the Fish Theme proposes to limit its scope to examining the quantity of direct food sources, the questions are strongly linked with those of the Food Webs Theme such that the underpinning processes and relationships (nutrient and carbon inputs, basal resources and primary production and their relationship with flow and habitat structure) will be addressed by the Food Webs Theme. This will allow for the development of an integrated model of the influence of flow on food production and the subsequent influences on fish recruitment.

Activity F2.1 — Understanding the feeding requirements of larval fish in the northern Murray–Darling Basin (Griffith University and Department of Science, Information Technology and Innovation)

Description and objective(s)

Knowledge of the larval diets for MDB fish species is extremely limited, with only one known study undertaken on the ontogenetic changes in diets of the larval fish community in the Broken River (King 2005). Two other known MDB larval diet studies have been single-species focussed — for Flat-headed gudgeon (Gehrke 1992) and Murray cod (Kaminskas & Humphries 2009). To date, there has been no such analysis of the dietary patterns of any larval fish species in the northern MDB (NMDB). This lack of knowledge on the feeding ecology of one of the most vulnerable life stages for all species represents a significant and fundamental knowledge gap for managing MDB fish populations.

This activity aims to examine the relationships between prey abundance and diversity and size structure with the diet of larval fish species in the Narran and Culgoa Rivers (Lower Balonne system). Work will also focus on larval condition (using both body condition indices and RNA:DNA ratios) and how this relates to the nutritional quality of prey. Owing to the clear knowledge gaps in relation to larval distribution and abundance in the NMDB, this study provides an opportunity to provide some new learnings that will enhance our current understanding around the feeding requirements and feeding ecology of early life stage fish.

The project will be undertaken in collaboration with the Department of Science, Information Technology and Innovation, whose in-kind contributions will cover field work and some of the laboratory analyses. It is proposed that sampling will be undertaken monthly in three locations (upstream middle downstream) within two waterholes (Narran and Culgoa) over a 12-month period. Sampling will target both fish larvae (using larval tows, and box traps and potentially larval light traps) and potential prey (zooplankton — plankton net). The project is planned to commence in July 2017 so as to coincide with winter moving into the start of spring to capture increasing water temperatures and target any early spawning. Larvae will be identified and counted, with a subsample retained for diet analysis and one for body condition. Zooplankton will be enumerated and identified and assessed for size structure. Larval diets will be assessed for both volume and prey size to examine both ontogenetic variability and variation through the sampling season. We will undertake the diet analysis on two to four species with contrasting reproductive traits in relation to flow triggers (those that spawn with flow as a trigger such as Spangled perch (*Leiopotherapon unicolor* Günther) or Hyrtl's tandan (*Neosilurus hyrtlii* Steindachne); those that spawn independently of flow such as Bony herring and Australian smelt; those that spawn in both the absence or presence of flow such as Golden perch. Final species selection will be based on numbers of larvae collected, integration with the species that are being examined in other work components, and species for which our dietary knowledge is poorest. We aim to analyse between 500–1000 individual larvae (which will cover both temporal ontogenetic and larval species differences). The exact nature of the dietary analysis will be determined based on prey abundance and larval diversity following the first four sampling periods (to ensure we have sufficient individuals/species to run a complete ontogenetic analysis).

The outcomes of this study will be to identify peaks of larval abundance and spawning windows. It will also aim to identify links between larval abundance and survival with prey availability and diversity. These outcomes will provide new knowledge into early life-history of NMDB fish and be presented in relation to the application of this knowledge for flow management in the NMDB.

Outputs

An improved understanding of the dietary and nutritional requirements of the fish larvae of a number of contrasting MDB species.

How will the output(s) be used?

The outputs will be integrated with, and provide supporting data for other components and sub-components that are proposed to be undertaken by the Fish Theme. In particular, the assessment of a larval condition measure (validated by RNA:DNA ratios) may enable an assessment of the condition of larvae that are collected in the sub-components described below. The outputs from this sub-component will also provide insight into the composition and nutritional value of different size-classes of prey. This information will add important value to the size-class biomass data that will be collected as part of Activity F2.3 (described below). The outputs will also link very strongly with the work proposed by the Food Webs Theme and will be used to inform the predictive model that will be developed at the end of the project.

Activity F2.2 — Examination of the relationship between food density, temperature and early-life stage growth and survival (MDFRC)

Objective and description

Rapid growth is believed to be a key factor in the survival of larvae (Trippel *et al.* 1997; Jones 2002; Werner 2002). Growth rates are influenced by a variety of biotic and abiotic factors, including environmental conditions, genetics and maternal contribution (Jones 2002). Of the abiotic factors, food availability and temperature are thought to be the main determinants of growth (Houde 1997; Jones 2002). Temperature affects growth rates directly, influencing metabolic rates, the duration of developmental stages, feeding and digestion rates, and indirectly by influencing the timing of production and availability of prey (Houde 2002; Jones 2002; Werner 2002). A number of studies in marine environments have examined the relationship between temperature and the growth of larvae (e.g. Mooji *et al.* 1994; Mann 1997; Johnston 1999; Otterlei *et al.* 1999) and correlations have been found between water temperature and recruitment success (Mills and Mann 1985; Grenouillet *et al.* 2001). For freshwater species, information regarding growth rate in relation to food availability and temperature is sparser and, for MDB fish species, there has only been one study, assessing growth rates that we are aware of that has examined larval growth with respect to food and temperature (Tonkin *et al.* 2008). This study examined growth rates of Australian smelt at two temperatures and three food densities.

We propose to use laboratory experiments to investigate the relationship between food density and temperature on the growth and survival of the early life-stages of up to four species, which will cover a range of life-history/trait-based groups including:

- periodic species e.g. Golden perch
- equilibrium species e.g. Murray cod
- opportunistic species (good dispersers) e.g. carp gudgeons (*Hypseleotris* species'), Australian smelt
- opportunistic species (poor dispersers) e.g. Southern pygmy perch.

We propose to obtain larvae and juveniles from a range of sources. We will source large-bodied species from the Narrandera hatcheries program, opportunistic species (good dispersers) from local rivers and opportunistic species (poor dispersers) from captive breeding programs if available.

Growth and survival will be measured at fourteen food densities and five temperatures. The ranges of prey densities that will be used will be determined based on existing literature of natural prey densities across the MDB. The range of temperatures that will be used will be based on both the current knowledge of the lethal minimum and maximum temperatures for the fish species that will be used, and the natural temperature ranges experienced across the MDB during the breeding season. This work will commence in 2017–18.

Outputs

Quantitative models describing growth and survival as a function of food density and temperature.

How will the output(s) be used?

This information will provide significant insights into whether food density is likely to be a limiting factor for fish larvae. Outputs will be linked to the thermal and nutritional mapping of the riverscape (see sub-component F2.3) to identify those habitats in which optimal growth and survival of the larvae of different species can be expected to occur.

Activity F2.3 — Multi-scale assessment of the spatial heterogeneity in the thermal and nutritional landscape (MDFRC and CSU)

This activity aims to describe the spatial heterogeneity in the thermal and nutritional landscape at multiple spatial scales to determine at what scale and to what extent thermal and nutritional habitat quality for early life-stages varies.

The work will be broken into three activities:

2.3.1: Detailed assessment of thermal and nutritional patch-level variability among main channel and floodplain habitat patches at one river-floodplain area (Ovens River). The work will be undertaken during spring, summer and autumn and will be undertaken over two years (2016–17 and 2017–18). It is hoped that this will allow us to gain insights into how patterns vary seasonally and with respect to flow and the degree of floodplain connectivity.
2.3.2: Examination of larger-scale variability in food density and larval abundance at the river segment, reach and riverscape scales. The work will be undertaken during spring, summer in 2017–18.
2.3.3: Preliminary investigation into variability in larval food availability in relation to different structural habitat types using existing data. This will be undertaken in 2016–17. Activity is focused on temperature and food density and does not include associated fish sampling. The rationale for this is that the distribution and abundance patterns of larvae are relatively well-understood, and that it is the mechanisms underpinning these distribution patterns about which we lack a clear understanding.

The Fish Theme is seeking to gain an understanding of how and why different hydraulic and structural patches support fish recruitment. It was originally intended that this work be undertaken at Barmah; however, a number of risks associated with this site have subsequently identified by the Fish Leadership Group, specifically:

- some of the patch types may not be present and those that are may have been affected by changes to geomorphology, flow, vegetation or the installation of river management infrastructure (e.g. regulators).
- any changes in the hydraulic patches will affect data collected with unknown consequences for interpretation of the factors influencing recruitment.
- the mid-Murray is modified in ways that are specific to the area and there would be challenges in applying knowledge derived from this area to other areas in the Basin without a better understanding of how fish recruitment may have been affected by the specific geomorphological, flow or vegetation changes.

Within this context, undertaking the work in a more natural system will provide more reliable insight into the processes required to support fish recruitment within key hydraulic and structural patches. This knowledge could then be applied to other sites by considering how to best create the appropriate patch types (e.g. within anabranches or creeks as well as wetlands on the floodplain) in modified systems.

The Fish Leadership Group, therefore, decided to undertake the field sampling in the Ovens River because there is the appropriate hydraulic and structural habitat diversity, an abundance of naturally connected floodplain habitats and a more natural flow and thermal regime. Improved understanding of the habitats and processes required to support fish recruitment could then be used as a benchmark against which modified systems could be evaluated and rehabilitation opportunities identified. It is unlikely this could be undertaken if the knowledge were generated in a modified system.

Activity F2.3.1 — Comparison of the thermal and nutritional regimes among main channel and floodplain habitat patches

Objective and description

Work previously undertaken in the mid-Murray has clearly shown that prey densities and temperatures differ markedly between the main channel and permanent floodplain wetlands (Beasley *et al.* 2011). Prey densities were found to be significantly and markedly higher in floodplain wetlands throughout the breeding season and water temperatures were higher on average, but far more variable than in the main channel. This work has indicated that, provided there is appropriate access, floodplain habitats may represent areas with far greater opportunities for rapid growth and survival than the main channel. This may be of importance for species such as Golden perch and Silver perch, whose larvae are small and have limited swimming capacity and, therefore, require conditions conducive to rapid growth, or for floodplain species. However, this study was not habitat-specific in its sampling within the main channel; main channel habitats such as slackwaters, which are thought to be most important for recruitment of many species, were not sampled or contrasted with other main channel habitat types. On the floodplain, only relatively small permanent oxbow wetlands in close proximity to the main channel were sampled and potential heterogeneity among different floodplain habitats types was not addressed.

Floodplains are comprised of a range of different habitat types, ranging from intermittently or permanently flowing creeks and anabranches to permanent and ephemeral wetlands. Variability in food production among floodplain habitats may occur in relation to both the degree of retention and the level of permanence of the particular habitat. Studies have shown that inundation of intermittent or ephemeral systems results in increased productivity immediately following inundation (Baranyani *et al.* 2002; Winemiller, 2005; Schemel *et al.* 2004). Therefore, ephemeral systems may provide greater food production benefits for fish than permanent ones. In addition, a permanently flowing creek or anabranch may be less productive due to relatively low retention times, and may in fact be more similar to the main channel than to intermittent or ephemeral habitats.

For this activity, we propose to compare temperature and prey density across a range of sites in the main channel and up to four different floodplain habitats: permanent wetlands, ephemeral wetlands, permanent creeks/anabranches, and ephemeral creeks/anabranches in the Lower Ovens.

We will deploy temperature loggers to assess thermal differences and will collect planktonic and epibenthic microinvertebrate samples in each patch to determine the biomass of different size fractions. Samples will also be preserved for analysis of prey quality if the budget permits. Sampling will occur during the peak breeding season (December–February) in 2016–17 and will be repeated in a non-flood year (ideally 2017–18).

Outputs

The results from this sub-component, coupled with results from component F2.2, will inform us as to the potential role of the floodplain versus the main channel for growth and fish recruitment for different species.

How will the output(s) be used?

The combined outputs from this work and from component F2.2 will provide managers with information regarding the importance of providing floodplain connections during the breeding season for recruitment outcomes for a variety of species. In addition, the temperature and prey density data collected will also serve as inputs to models predicting growth as a function of temperature and food. The outputs will be used to inform the final synthesis and model that will be developed at the end of the project.

Activity F2.3.2 — Examination of variability in food density and larval abundance at the river segment, reach and riverscape scales

Objective and description

To date, the majority of work that has been undertaken in the MDB on fish generally, and fish spawning and recruitment specifically, has focussed on a single spatial scale. For example, studies have examined patterns in larval distribution at the patch scale (e.g. Price 2007) and at the reach scale (e.g. Humphries *et al.* 2002; King 2004; King *et al.* 2009; 2010; Humphries *et al.* 2013). Whilst these studies have provided important information regarding scale-specific patterns and processes, and insights into management actions (e.g. environmental water delivery) that can be undertaken to trigger spawning or maintain populations or processes at particular scales, they do not provide managers with information regarding the relative importance of management actions at different scales. For example, what is the benefit of locally managing for instream habitat patches versus managing flow to allow for settlement or retention of larvae in optimal reaches? Alternatively, the greatest variability in recruitment may occur at much larger spatial scales and, therefore, flow and other management actions may need to be focussed on the maintenance of large stretches of river.

This sub-component aims to describe the spatial heterogeneity in the thermal and nutritional landscape at multiple spatial scales to determine at what scale and to what extent thermal and nutritional habitat quality for early life-stages varies.

At the larger spatial scale, we propose to select a 50 km section of river (Barmah–Millewa) and to undertake sampling based on a nested design, whereby river-floodplain pairs (riverscape), within reaches, within river segments will be sampled for microinvertebrates and temperature.

Relative prey density will be determined by sampling the planktonic and epibenthic microinvertebrates in floodplain wetlands and main channel slackwaters to determine the biomass of different size fractions. Samples will also be preserved for analysis of prey quality if the budget permits. Thermal regime will be assessed by deploying temperature loggers.

This project will be undertaken during the peak breeding season (December–February) in 2017–18. This sampling regime will allow temporal variability throughout the breeding season.

Output(s)

The results from this sub-component will provide information regarding spatial scale(s) at which food production and larval abundances differ and how this may vary over time.

How will the output(s) be used?

This information will provide guidance as to the scale at which sub-component F2.4, Examining larval retention and settlement with respect to flow, should focus. The outputs will be important in guiding managers as to the scale at which management actions should occur.

Activity F2.3.3 — Preliminary assessment of the influence of structural habitat on prey composition and density

A key hypothesis that has arisen from the conceptualisation process is that structural habitats, such as snags and macrophytes, act as important retention zones for nutrients and carbon, and that these therefore are likely to represent areas of high productivity. This capacity for retention may be of particular significance during high flow periods when nutrients and carbon are imported from upstream and/or the floodplain. It is hypothesised, therefore, that if habitat structure is lacking, the potential in-channel benefits of nutrient and carbon inputs may be lost as these will not be retained and instead will be transported downstream. These hypotheses have not, however, been tested.

As part of the NWC funded 'Watering Wetlands in The Murray–Darling Basin for Native Fish' project, which was completed in 2011, a number of samples were collected as a pilot study with the aim of examining differences in zooplankton community composition and abundance among different habitat types within floodplain wetlands and the main channel. Samples were collected in woody habitat, pelagic zones and the benthos in spring and summer. These samples were processed; however, the data was not analysed or written up. We propose to undertake a preliminary investigation into whether habitat structure (as opposed to hydraulic habitat characteristics such as retention time) is likely to influence the composition and abundance of zooplankton communities using this data. This work will be undertaken in 2016–17.

Outputs

The results from this sub-component will provide preliminary information regarding the variability in zooplankton abundances and community composition in relation to habitat structure.

How will the output(s) be used?

The outputs from this work will enable us to make an initial assessment of the role of habitat structure, such as snags, in driving differences in food production for larvae.

Activity F2.4 — Investigating the relationship between flow, structural habitat, hydrodynamics and patterns larval settlement and retention (CSU and MDFRC)

Objective and description

This work aims to generate information regarding the capacity of larvae to be retained and settled within appropriate habitats (as determined by all of the previous sub-components). The project will quantify relationships among flow (discharge) and the retention and settlement of larvae in rivers by using field-based experimental releases of Murray cod and Golden perch larvae and passive particles. The influence of flow will be assessed by measuring how discharge drives changes in the dispersal and settlement patterns of larval fish in reaches of river in which flow can be manipulated. Up to 10 000 neutrally-buoyant passive particles and larvae of each species will be released at dusk, and transport, retention and settlement of larvae and passive particles will be determined. This process will be repeated at three different discharges (on three different days): base flow, elevated base flow and enhanced regulated flow.

The scale at which this work will be undertaken is dependent on the outcome from Activity F2.3.1 (Examination of variability in food density and larval abundance at the river segment, reach and riverscape scales). The specific approach that will be undertaken will depend on the scale that the work is being done at. This flow manipulation experiment will also provide the opportunity to test flow-related hypotheses that have arisen from the previous work. For example, if the outputs from Activity F2.3.3 (Preliminary assessment of the influence of structural habitat on prey composition and density) indicate that examination of the interaction between flow, structural complexity and larval food production is warranted then this could be explored as part of this flow manipulation experiment. This work will be undertaken in 2017–18 at Barmah-Millewa.

Outputs

Models will be developed to explain how different flow management scenarios influence the retention of native species with different life-history strategies.

How will the output(s) be used?

The outputs from this work will be able to be fed into hydrodynamic models to predict settlement and retention patterns on larvae in different river sections or reaches. The outputs developed by this work will be also used to inform the predictive model that will be developed at the end of the project.

Activity F2.5 — Basin-scale population dynamics of Golden perch and Murray cod: relating flow to provenance, movement and recruitment in the Murray–Darling Basin (SARDI)

Objective and description

Fragmentation and flow regulation imperil riverine fishes. Accordingly, reinstating connectivity and ecologically relevant aspects of natural flow regimes are considered fundamental to rehabilitating fish populations. To be effective, however, this requires an understanding of relationships between flow and the key life-history processes that influence population dynamics (e.g. spawning, recruitment and movement), and the spatio-temporal scales of these processes.

In large and complex river systems, specific regions may act as sources and sinks of particular life stages, and connectivity between these are important determinants of population dynamics. Understanding 'sources' of early life stages and subsequent recruitment and dispersal is fundamental to effective management. In riverine ecosystems, where flow is the primary determinant of physical and biological processes, fish recruitment, dispersal and population dynamics may be intrinsically linked to hydrologic processes.

An overarching objective of the Basin Plan is to protect and restore native fish populations. Fish population growth is implicit in restoring populations, and environmental water allocations are considered a key mechanism for achieving this. In the MDB, environmental water is generally managed in a regional manner, at a reach or site scale (10s km), and for fish, has been used to facilitate spawning and movement. Nevertheless, despite many years of water delivery and monitoring, it is still unknown at what spatial scale the processes that govern population growth operate, or if they are associated with flow. These are the questions that will form the basis of our study.

Recent research in the MDB indicates that key drivers of fish population dynamics, in particular spawning, recruitment and movement, for at least one long-lived native fish species, may be operating at a whole-of-river or multiple catchment scales and/or over extended time periods. For example, significant recruitment events for Golden perch in the lower and mid-Murray River may occur as infrequently as every 9 years, and may be driven by flow-mediated spawning and recruitment (to 0+) in the Darling River (Zampatti, unpub. data). Subsequent dispersal of juveniles and adults, and recruitment into regional populations may also be flow mediated.

Golden perch and Murray cod are the largest and longest-lived native freshwater fishes in the MDB. They are culturally important for Indigenous and non-indigenous Australians, historically formed the primary target species for substantial commercial fisheries, and continue to be popular recreational angling species. Populations of both species have declined in abundance and range, due to altered flow regimes, fragmentation and overharvesting, amongst other factors. To various extents, the reproduction, recruitment and movement of both species has been linked (rightly or wrongly) to flow (see Humphries *et al.* 1999, Zampatti and Leigh 2013, Koster *et al.* in press), and these key life-history processes form objectives for environmental water allocations in rivers throughout the Basin.

Murray cod and Golden perch have distinct life-history strategies that correspond, respectively, with the equilibrium and periodic categorisations developed by Winemiller and Rose (1992). This divergence in life-history strategies may result in distinct population responses to environmental perturbation, including flow. In the MDB, environmental water is often delivered to achieve outcomes (e.g. recruitment and movement) for Golden perch and Murray cod. To be effective, this requires the life-history processes of Murray cod (equilibrium) and Golden perch (periodic) to operate at spatial scales relevant to contemporary environmental flow management. For example, a key question is whether flow be manipulated at the river reach scale (1–10s km) to promote Murray cod recruitment and subsequent population growth? Also, will the same approach work for Golden perch, or do factors outside of the reach also need to be considered?

Through integrating biological, chemical and hydrological data, this project aims to: (1) elucidate spatio-temporal relationships between flow and key population processes for Golden perch and Murray cod, (2) contrast responses between the distinct life-history strategies of Golden perch and Murray cod, and (3) improve large scale flow management to improve population outcomes for species whose populations operate at larger spatial scales. Our ultimate aim is to inform flow management to promote the growth of Golden perch and Murray cod populations in the MDB.

Our specific objectives are to:

1. investigate spatial and temporal variability in the water $^{87}Sr/^{86}Sr$ isoscape (and potentially secondary isotopes and trace elements) of the southern and northern MDB. (This is fundamental to developing a template to elucidate the spatial origin of fish).
2. determine regional age structures, and use otolith chemistry to retrospectively determine the spatio-temporal provenance (birth year and place) and movement history of Golden perch and Murray cod from each region, and relate these to environmental conditions (particularly flow and water temperature) at appropriate scales.
3. integrate these data to develop a river-scale understanding of Golden perch and Murray cod life-history, movement and population dynamics, and response to flow.
4. use this understanding to inform the spatial scale of environmental water management.

We hypothesise that the spatial scale of life-history processes that influence population dynamics will vary between Golden perch and Murray cod, as will the influence of flow on recruitment to young-of-year (life stage) and of fish to regional populations (adult/juvenile movement to specific regions). Specifically, we predict that Golden perch population dynamics in the MDB are influenced by flow-related recruitment (to YOY) and movement (into juvenile/adult regional populations) at large, inter-regional spatial scales (100–1000s km). In contrast, regional Murray cod population dynamics are influenced by localised spawning and recruitment (to YOY) that may be related to flow, and flow-mediated inter-regional movement is not a major contributor to regional population structure. Hence, we expect Murray cod population dynamics to operate over scales of 10–100 km.

Study sites and methods

Recent investigations of the demographics, natal origin and movement of Golden perch in the southern MDB have demonstrated that larval, juvenile and adult Golden perch move passively and actively over 100–1000s km, including between the lower Darling and lower and mid-Murray rivers (larvae, juveniles and adults), and potentially the mid- and upper Murray and Goulburn rivers (juveniles and adults). In this project, we intend to expand on these investigations by using otolith microstructure and chemistry to further explore the regional spawning, movement and demographics of Golden perch and Murray cod, and then integrate biological (age structure, natal origin and movement history) and hydrological data from sites/regions across the southern and northern MDB.

It is proposed to sample from a number of sites/regions across the southern and northern MDB and not necessarily from the four MDB EWKR sites. There are two reasons for this. First, the research will require samples from more than 4 sites to identify the spatial scale over which recruitment is taking place. Second, collaborating with the CEWO LTIM and other monitoring projects represents an efficient and cost effective means of collecting samples while minimising the number of fish that need to be sampled. This collaborative approach is also in line with the MDB EWKR objectives. At this stage, the sites being considered include the lower Murray and Darling Rivers, mid-Murray, Campaspe and Goulburn rivers, upper Murray, Edward–Wakool, Murrumbidgee in the southern MDB and the upper Darling and its tributaries in the northern Basin (Figure 4-4). Through integrating biological and hydrological data, we aim to elucidate relationships between flow and key population processes for Golden perch and Murray cod. Due to variability in Murray cod abundance in rivers across the Basin, it is likely that we will sample Murray cod from a subset of sites, but still encompassing the southern and northern MDB.

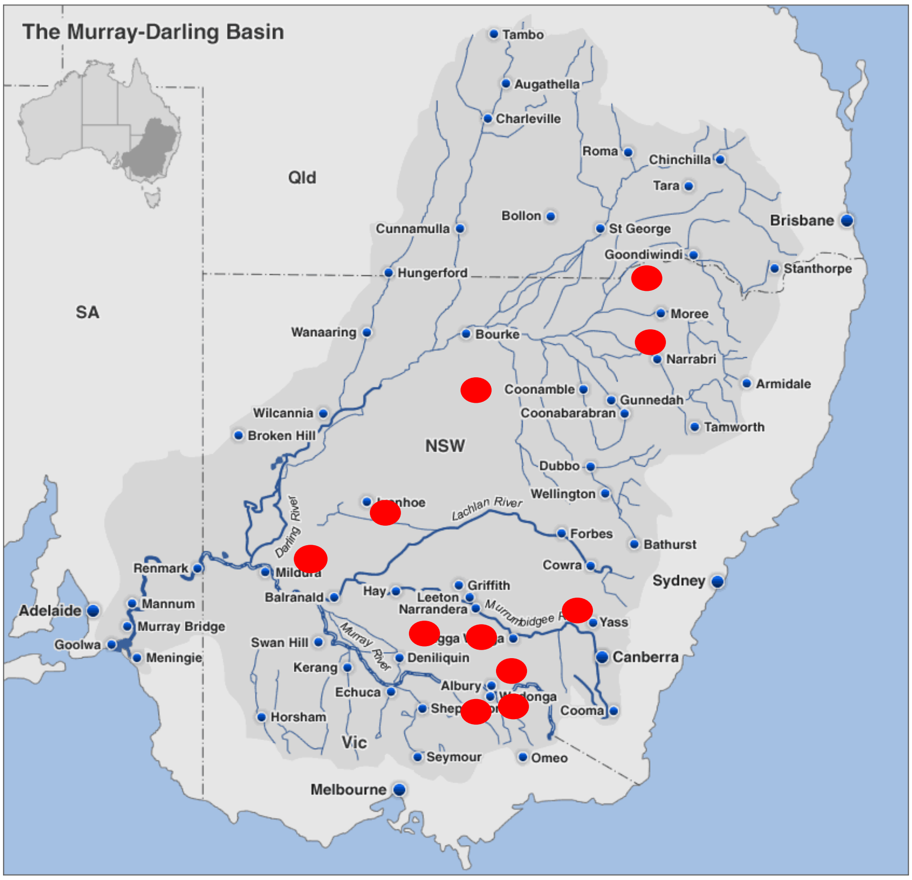

Table 4-4. Potential regions (red symbol) in the Murray–Darling Basin where Golden perch and Murray cod demographics and recruitment will be investigated.

Otolith chemistry provides a tool for investigating the environmental histories of fishes, and when combined with data on age, can be used to interpret life-history in a spatio-temporal context. In this project, we will use otolith microstructure (to determine age) and chemistry (e.g. Sr isotope ratios, and potentially other isotopes and elements, to determine location) to retrospectively investigate the environmental factors (particularly hydrology) that are associated with the spawning, recruitment and dispersal of Golden perch and Murray cod in the MDB. We will also investigate spatio-temporal variation in these parameters and whether dispersal between regions influences population dynamics.

We propose a three-year investigation (2016–19) that is undertaken by a team comprising Brenton Zampatti and Chris Bice (SARDI), Jason Thiem and Gavin Butler (NSW Fisheries), Zeb Tonkin, Wayne Koster, Jarod Lyon and Katherine Harrison (ARI), Lee Baumgartner (CSU), Stephen Balcombe (Griffith University), and David Crook and Alison King (Charles Darwin University). Water and otolith chemistry analysis will be undertaken by Melbourne University or Adelaide University. The specific methods for analysis of $^{87}Sr/^{86}Sr$ in water and otoliths, and annual ageing of Golden perch are outlined in detail in Zampatti *et al.* 2015, and similar methods will be used for Murray cod. Otolith chemical analysis for complementary isotopes and analysis will be explored where $^{87}Sr/^{86}Sr$ may not provide adequate resolution between regions. There is also the potential to align this investigation with a project being undertaken by La Trobe University/Arthur Rylah Institute that is using contemporary genetic techniques to explore provenance, movement and connectivity of native fish populations in the MDB.

In 2016–17, we propose to initially investigate the availability of data/samples from other fish monitoring programs in the MDB that could be used to collect samples for this study. This will determine the specific additional fish sampling requirements for this project. Monthly water samples from select regions in the northern MDB will be collected to ascertain whether water $^{87}Sr/^{86}Sr$ in the upper Darling River is distinct from tributary rivers and the River Murray system. Furthermore, we will integrate data from an ongoing program (CEWO LTIM) that is investigating the temporal stability of water $^{87}Sr/^{86}Sr$ at multiple sites across the southern MDB (including the River Murray, Goulburn, Murrumbidgee and Edward–Wakool systems). If there is a lack of water $^{87}Sr/^{86}Sr$ resolution between particular regions, we may explore the use of complementary/secondary isotopes (e.g. $\delta^{18}O$) and/or trace elements (in water and otoliths).

In 2017–18, we will collect (through existing monitoring programs or targeted surveys) representative samples (50–100 fish) of the size/age structure of Golden perch and Murray cod from each of the designated regions and investigate age-structures using otolith micro-structure, and natal origin of fish using otolith chemistry (e.g. $^{87}Sr/^{86}Sr$). We will also retrospectively investigate movement of a subset of individuals using otolith $^{87}Sr/^{86}Sr$ transect analysis.

Outputs

Information regarding the:

- environmental factors (particularly hydrology) that are associated with the spawning, recruitment and dispersal of Golden perch and Murray cod in the MDB
- patterns of spatio-temporal variation in these parameters and whether dispersal between regions influences population dynamics.

How will the output(s) be used?

The outputs from this activity will inform the restoration of flow regimes (volumes, spatial scales, etc.) for Golden perch and Murray cod objectives, and provide a basis for the design of monitoring programs that are undertaken at appropriate spatio-temporal scales, and using suitable indicators, to rigorously measure fish population responses to flow restoration, including environmental water allocations.

4.4.3 Component F3 — Swimming capacity, settlement cues and environmental tolerances of the early life stages of Murray–Darling Basin fishes (student projects)

Activity F3.1 — Investigating swimming capacity and environmental tolerances of the early life stages of Murray–Darling Basin fishes (2016–2018)

Objective and description

This student project will investigate the swimming capacity and the effects of the physico-chemical environment (e.g. temperature, dissolved oxygen and turbidity) on the survival and growth of the early life stages of Murray–Darling Basin fishes.

Swimming capacity is an important influence on larvae's capacity to disperse and maintain themselves within desirable habitats. Improved understanding of swimming capacity will enable greater understanding of how flow velocity influences swimming ability. Laboratory swimming experiments will be conducted on the larvae of selected native freshwater fish species. This will determine how temperature, current speed, ontogeny and body size interact to shape swimming capability and duration. Experiments will be conducted using larvae with different life-history modes to determine behaviour during dispersal, how they use refuges, and how and when settlement decisions are made.

Swimming capability experiments will be undertaken in a swimming chamber, which has raceways in which water flow can be modified. Sustained swimming experiments will use the same swimming chamber. Fish will be swum at two sub-critical speeds, representing low flow and moderate flow conditions typical of lowland rivers during spring and summer. They will be swum with no food and no rest, until they can no longer hold position. The duration of swimming will be recorded and the distance swum, calculated. All trials will be replicated.

A range of physical and chemical attributes (e.g. temperature, dissolved oxygen and turbidity) on larval fish growth and survival will be evaluated in replicated tank trials to assess the optimal and limiting factors.

This project will be undertaken by an existing PhD student, Dale Campbell who is being supervised by Paul Humphries at CSU.

Outputs

- A report and fact sheet regarding the optimal, sub-lethal and lethal ranges of water quality parameters for early-life stages of a number of native fish species.
- Models describing the swimming capability of a number of native fish species through the larval period under a range of environmental conditions

How will the output(s) be used?

The project will provide information that can immediately be disseminated and used by managers to identify potential non-flow related threats and complementary actions, which may be required to improve the capacity to improve recruitment responses of native fish. The swimming capability models will link directly with the outcomes of sub-component F2.4, and will be used to inform the predictive model that will be developed at the end of the project.

Activity F3.2 — Water infrastructure and challenges for fish conservation: larval trait-based analysis to foresee fish recruitment in regulated rivers (2016–2018)

Objective and description

This student project will investigate and model the influence of several key mediating recruitment drivers, such as water velocity, flow and habitat availability on the settlement ability of fish larvae with differing reproductive strategies. The study will take a trait-based approach by first undertaking an analysis of the different reproductive, ecological and morphological traits that may affect key survival parameters, such as swimming ability and feeding success. Based on this analysis, a number of species representing a range of traits will be selected. The ability of larvae to actively select nursery habitats under different hydraulic scenarios will be experimentally tested in a flow laboratory in which water velocity can be precisely controlled. In addition, through addition of physical structures and substrates into the tank, the interactions between hydraulic conditions and physical habitat will be assessed, as well as the effect of structure on larval swimming behaviour. This data will be used to develop a model, which can predict the likelihood of larval settlement under different hydraulic and structural habitat scenarios. The model will be validated in the field as part of activity F2.4.2.

This project will be undertaken by an existing PhD student, Lorena Noguiera, who is being supervised by Amina Price (MDFRC), Lee Baumgartner (CSU) and Paul Humphries (CSU).

Outputs

The key output from this work will be the predictive model for larval settlement based on flow, hydraulics and habitat structure for a number of species with differing traits.

How will the output(s) be used?

The outputs from this work will provide managers with critical information regarding flow delivery to enable larval settlement. The work will also inform a critical knowledge gap regarding the fate of larvae that encounter lentic habitats associated with impoundments and weirs.

In addition, this work links strongly with other work being undertaken by the Fish Theme, most notably sub-component F2.4, which is examining larval transport and retention in the field at different discharges with a focus on hydraulic and structural habitat.

4.4.4 Component F4 — Synthesis and model development and management

This component will draw together all of the outputs from the conceptualisation and research activities to produce a conceptual model for MDB fish that will describe:

1. which recruitment drivers are most important for water managers to consider when managing for recruitment of different:
    - species
    - seasons
    - systems
    - flow scenarios.
2. how can water managers best manage delivery of environmental water to target the most appropriate recruitment drivers for the species and system of interest?
3. what non-flow related factors are likely to impact on the key recruitment drivers and how? What complementary actions can be used to improve recruitment outcomes.

4.4.5 Component F5 — Theme planning, coordination and reporting

This component includes:

- theme research planning, including contributions to Annual and Multi-Year research plans
- theme research coordination, ensuring the research activities are administered effectively and delivered in a coordinated manner to deliver MDB EWKR objectives
- theme level reporting, including the Final Research Report for the Fish Theme, and contributions to the Final Research Report and the Overall MDB EWKR Synthesis Report (noting that these reports will build on the specific reports associated with individual research components and activities)
- project reporting, including contributions to mid-year and annual progress reporting.

In October 2016, the Theme Leadership Group will finalise the Annual Research Plan for 2016–17 and Multi-Year Research Plan for the life of MDB EWKR, guided by the outcomes of Component F1. The Annual Research Plan will be revised each year to reflect proposed activities for the forthcoming year, and the Multi-Year Research Plan will be updated every year, if any significant changes are required.

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5 Waterbirds

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5.1 Executive summary

5.1.1 Introduction

Environmental watering events in the MDB are frequently targeted at supporting waterbird breeding. Whilst knowledge exists regarding key breeding locations in the Basin and the flows required to trigger and complete nesting events, there is limited knowledge about recruitment rates and drivers — particularly in terms of the relative influence of flow variables, habitat variables, pressures and threats. Research outcomes of this theme will assist managers to identify, maintain or restore key habitats, as well as better understand the scales at which key habitats and environmental flows are required to support recruitment.

5.1.2 Research focus

MDB EWKR research priorities and sites are described in the report titled *Selection of Priority Research Questions and Research Sites.* The research priorities provided the strategic framework for the Theme Leadership Groups to focus the proposed research for each theme. The research questions to be addressed by the Waterbirds Theme relate specifically to recruitment, and include:

1. Which flow regimes best support recruitment of waterbirds?
2. How do threats and pressures affect recruitment outcomes for waterbirds?

Colonially-breeding waterbird species (e.g. ibis, egrets, spoonbills) are proposed as the primary targets for recruitment data collection, because they are important targets for water management, easily surveyed, and have known breeding locations. Consequently the project is more likely to be able to improve the knowledge base for management within the EWKR budget and timeframe.

5.1.3 Summary approach and research components

Two sets of research activities are proposed that address critical knowledge gaps relating to the above questions, which were identified through consultation with environmental water managers and scientists, and review of existing literature:

Critical Knowledge Gap 1: Where and what are the critical foraging habitats during and after breeding events for recruitment? How might these be affected by environmental flows and threats such as habitat change?

Flow regimes, water management and threats such as habitat change and habitat loss affect the availability (quantity and distribution) and quality of foraging sites at multiple scales. These in turn will affect the survival of young birds and consequently recruitment. However, data describing waterbird foraging preferences, locations and movements (and how these affect survival) are scarce, limiting our ability to predict the effects of changes in water management and threats to habitat.

Critical Knowledge Gap 2: What are critical nesting habitat characteristics we need to maintain and how do these affect recruitment? How might environmental flows, vegetation management and pressures and threats, such as predation, interact with nesting habitat characteristics to affect recruitment?

This research aims to produce information that will allow managers to better target water, vegetation and feral animal management actions to ensure 'event readiness' at nesting sites between flooding events, and to maximise recruitment during flooding events. Maximising recruitment of young colonial waterbirds into the adult population necessarily depends on maximising the number of birds that fledge from each nesting colony. Management for protection and maintenance of nesting habitat both between and during flood events is critical. However, recent declines and losses of colonies have raised questions concerning the influence of nesting habitat management, type, condition, and configuration on species site choice, predation impacts, nest success and eventual recruitment.

5.2 Logic and rationale

5.2.1 Background

Environmental watering events in the MDB are frequently targeted at supporting waterbird breeding. Whilst knowledge exists regarding key breeding locations in the Basin and the flows required to trigger and complete nesting events, there is limited knowledge about recruitment rates and drivers — particularly in terms of the relative influence of flow variables, habitat variables, pressures and threats. Research outcomes of this theme will assist managers to identify, maintain or restore key habitats, as well as better understand the scales at which key habitats and environmental flows are required to support recruitment.

MDB EWKR focuses on waterbird recruitment (see Table 5-1 for definitions) for the following reasons:

- *Management relevance:* The Basin-Wide Environmental Watering Strategy seeks to increase abundance and increase breeding success; both of these depend on recruitment.
- *Key knowledge gap:* Consultation with managers and researchers together with review of the literature has identified that aspects of recruitment are a key knowledge gap.
- *Potential to improve predictive capacity:* Recruitment is an area in which there are significant opportunities to improve predictive capacity within the time and budget constraints of MDB EWKR.

The broad research questions to be addressed by the Waterbirds Theme are:

1. **Which flow regimes best support recruitment of waterbirds?**
2. **How do threats and pressures affect recruitment outcomes for waterbirds?**

Maximising recruitment of young waterbirds into the adult population necessarily depends on maximising the number of birds that fledge from the nesting colony. Maintenance of appropriate nesting habitat both between and during flood events is critical. However, recent declines and losses of colonies have raised questions concerning the influence of nesting habitat management, type, condition, and configuration on species site choice and on nest success and eventual recruitment. In addition, potential interactions between flows, vegetation, and threats and pressures influencing recruitment, such as predation and habitat loss, are poorly understood. This research aims to produce information that will allow managers to better target environmental flows, vegetation and fauna management actions to ensure 'event readiness' at nesting sites between flooding events and to maximise recruitment during flooding events.

Survival of young birds is also believed to be affected by foraging habitat and food availability at local, landscape and basin scales, both before and after fledging. Flow, water management and threats and pressures, such as habitat change and loss, will affect the availability (amount and distribution) and quality of foraging, refuge or roosting sites. Habitat distribution and functional connectivity at local, regional, and basin scales will also influence waterbirds' access to available habitat. However, data are lacking regarding colonial waterbird habitat use and movements. These data are important for understanding population responses to management and for decision-making on the spatio-temporal allocation of water. This research links tracked movements of waterbirds and breeding success with foraging habitat characteristics at multiple scales. It includes the largest colonial waterbird satellite-tracking project ever conducted in Australia.

Colonially-breeding waterbird species are proposed as the primary targets for recruitment data collection, because:

- they are the main waterbird targets for environmental flows management and policy
- recruitment response variables are more easily measured for these than for other species, because breeding events and nests for these species are easier to locate and survey. Locations of major colonies are known, as are some of the breeding thresholds related to flows and inundation. Consequently the project is more likely to be able to improve the knowledge base for management within a reasonable budget and timeframe
- surveys of recruitment for these species are likely to cover a greater proportion of each population than for other species (e.g. ducks) where breeding is widely distributed, making interpretation more reliable
- the effects of predation and other threats on these species are likely to be more easily measured because their nests, eggs and fledglings are more visible
- there is good evidence that this group of waterbirds provides a reasonable model for understanding relationships between environmental flows and waterbird recruitment.

5.2.2 Conceptual understanding

Overall, the factors potentially influencing successful recruitment are generally known, but their relative importance and interactions are not well understood, and will be the focus of research in MDB EWKR. Below, we outline potential factors and variables that may affect recruitment directly and indirectly as part of an overarching draft conceptual model (Figure 5-1). Not all of these factors and variables will be included in the planned research activities. Instead, critical factors and variables have been selected from this overarching conceptual model to address key knowledge gaps identified through consultation with managers, scientists and review of the literature — these are represented in Figures 2 and 3.

Flow-related variables that affect waterbird recruitment include (see Figure 1):

- **flow regime — local to basin scales**
    - **location, frequency, volume, duration, timing**
    - **separation of environmental flow component from natural and regulated flows**
- **flood regime — local to basin scales**
    - **location, frequency, extent, duration, timing, depth, rate of change in depth, interflood period (dry duration)**
- **local and catchment rainfall, evaporation and temperature.**

These interact with pressures such as:

- **habitat loss, fragmentation and degradation**
- **predation (native, introduced)**
- **competition**
- **disease and parasites**
- **pollution**
- **human disturbance and hunting**
- **climate change.**

At different spatial and temporal scales, these interactions affect the following critical cues/factors:

- **food abundance or availability**
- **habitat availability, distribution and quality (breeding (courtship, nesting), foraging, roosting and refuge)**
- **connectivity between habitats/sites and within the population**
- **condition of critical individual sites (nesting, foraging, roosting and refuge)**
- **catchment condition.**

These variables affect waterbird abundance, through their influence on bird condition, breeding initiation (courtship, nesting and egg-laying), and recruitment of juveniles into the adult population. Some of these can be measured by the number of pairs/nests, the number of eggs laid, egg survival, hatchling survival, fledgling survival, juvenile survival, adult survival, individual and population movements, population size and age structure, and hence waterbird diversity.

For **short-term recruitment** from individual flow events at local scale, the critical waterbird response variables are:

- numbers of nests and breeding pairs per species
- fledging rates (taking into account repeat-nesting — i.e. nest success) (*see Figure 3 for a draft conceptual model of the mechanisms determining the number of fledglings produced*)
- juvenile survival.

For **long-term recruitment** and population maintenance/growth at Basin to continental scales, the **frequency of breeding initiation** is also important (Figure 1).

Given that managers are interested in sustaining waterbird diversity, consideration also needs to be given to how flow-related variables may influence the diversity of waterbirds that recruit.

The following definitions apply to this research plan.

Table 5-1. Definition of terms.

Term	Definition in this document
Waterbird	Birds that primarily live in and are dependent on freshwater habitats (foraging in them and breeding in or near them). Excluding species that are predominantly marine-associated or spend most of their lives in terrestrial habitats.
Colonial-nesting waterbird	Species that nest communally. E.g. Straw-necked Ibis, Glossy Ibis, Australian White Ibis, Great Egret, Intermediate Egret, Little Egret, Royal Spoonbill, Yellow-billed Spoonbill, Pacific Heron, Nankeen Night Heron, Great Cormorant, Pied Cormorant, Little Black Cormorant, Australian Pelican
Recruitment	Number of birds that survive to fledging and become juveniles from a particular breeding event, expressed as a proportion of the adult breeding population associated with that breeding event (e.g. breeding resulted in 17% more birds recruited into the adult population)
Nestling	A young chick that is confined to the nest. E.g. for ibis, Brandis *et al.* 2011 used the following categories: *'downy chick' (recently hatched, downy feathered, 21–25 days old); 'squirter' (larger chicks with some feather development, that remained in nests, 26–30 days old).*
Fledging	The moment of fledging is when young first leave the nest and cease to occupy it 100% of the time.
Fledgling	Young that have ceased to occupy the nest 100% of the time, but are still dependent on their parent(s) for some resources. Note that the nest may still be used by fledglings for

Term	Definition in this document
	rest and shelter, but it is not exclusively used. Associated with a measurement of age for each species, and may be split into categories. E.g. for ibis, Brandis *et al.* 2011 used the following categories: *'runner' (mixture of developed and down feathers, ability to leave the nest on foot, 31–35 days old); 'flapper' (could not fly, flapped while moving between nests, 36–40 days old); and 'flyer', (young juvenile that could fly, 41–45 days old).*
Juvenile	A juvenile has left the nest *and* is able to fly and forage for itself, but is not mature or part of the breeding population (e.g. a chick that has fledged and left the nesting site but is under 1 year old).
Adult	A bird that is independent of its parents and reproductively mature.

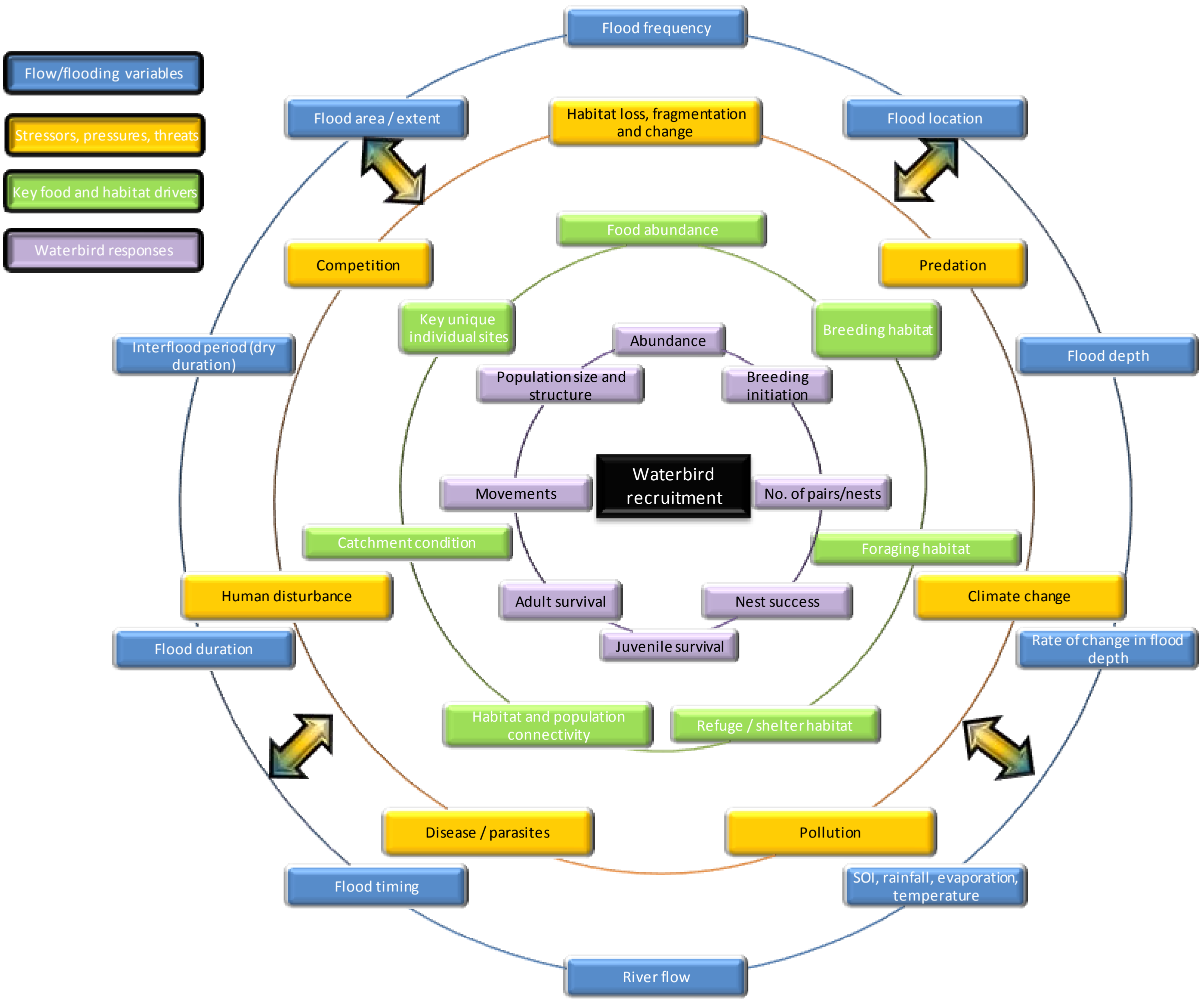
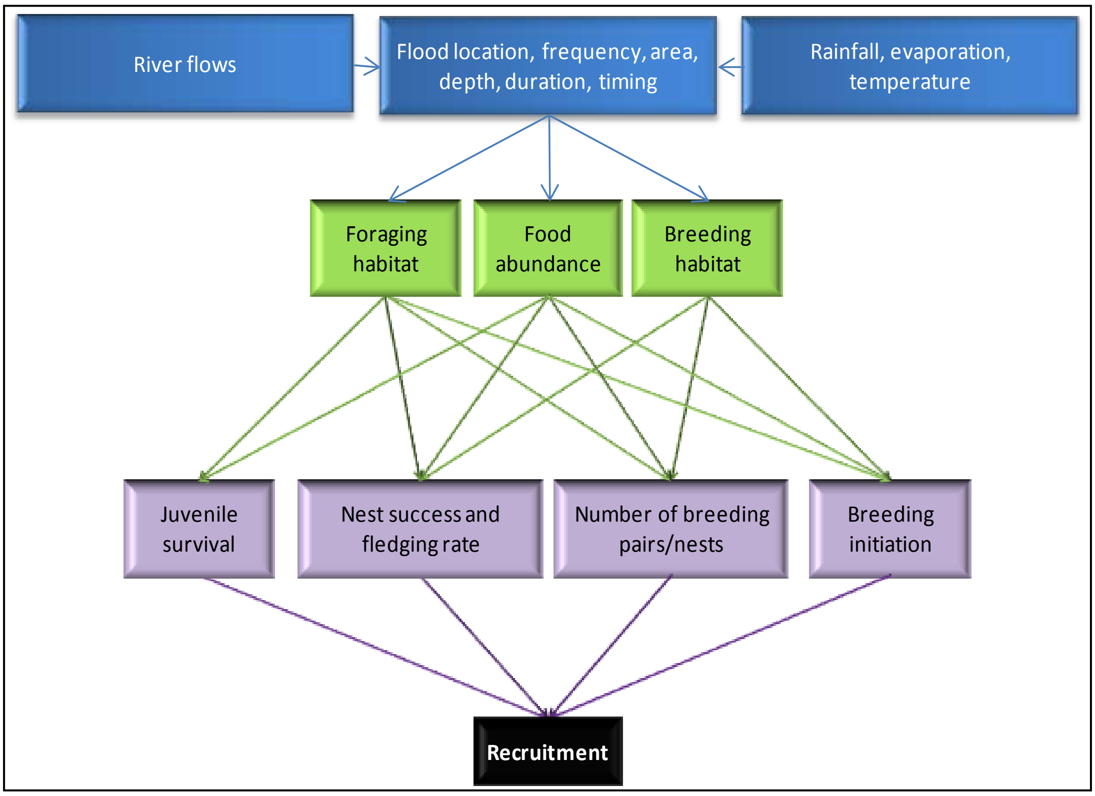
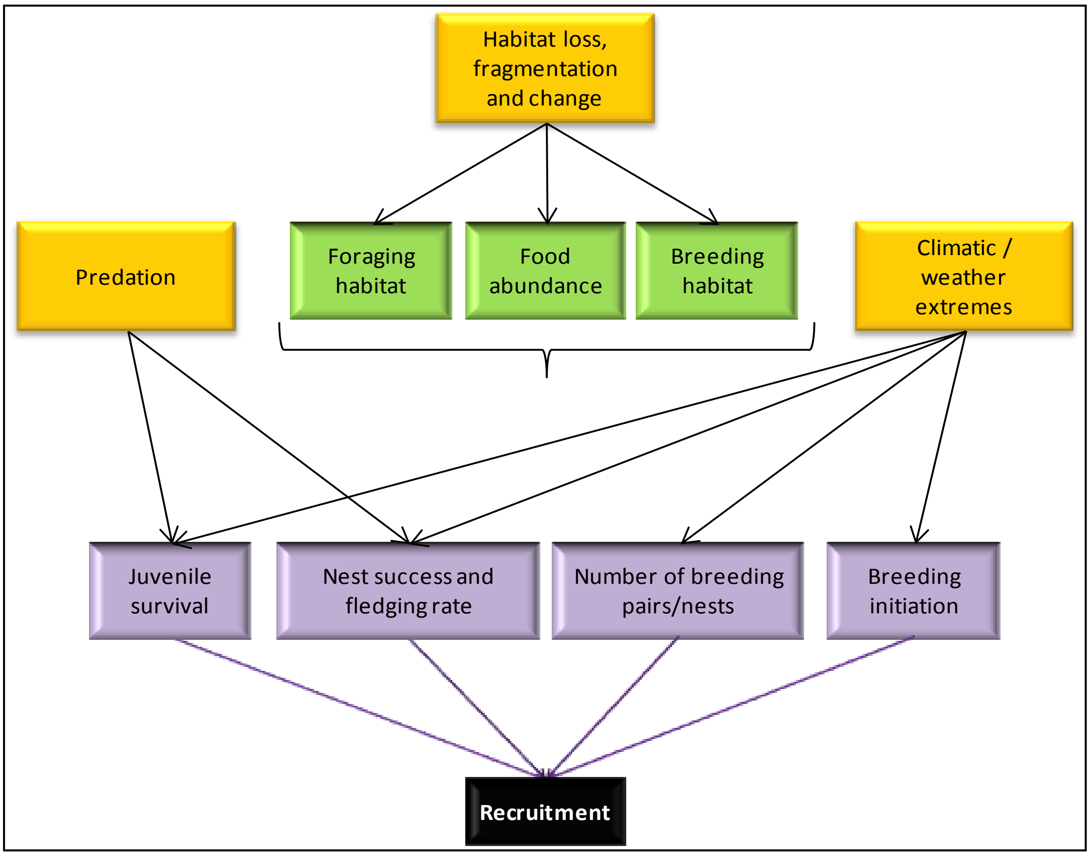


Figure 5-1. Overarching conceptual model of factors that may directly or indirectly affect waterbird recruitment and ultimately species persistence and diversity, including flow/flooding variables, stressors/pressures/threats, key food and habitat drivers, and waterbird responses.


River flows
Flood location, frequency, area, depth, duration, timing
Rainfall, evaporation, temperature
Foraging habitat
Food abundance
Breeding habitat
Juvenile survival
Nest success and fledging rate
Number of breeding pairs/nests
Breeding initiation
Recruitment

a)


Habitat loss, fragmentation and change
Predation
Foraging habitat
Food abundance
Breeding habitat
Climatic / weather extremes
Juvenile survival
Nest success and fledging rate
Number of breeding pairs/nests
Breeding initiation
Recruitment

b)

Figure 5-2. Primary drivers of recruitment (a) and primary threats to recruitment (b) identified through consultation with managers, scientists and a review of the literature.

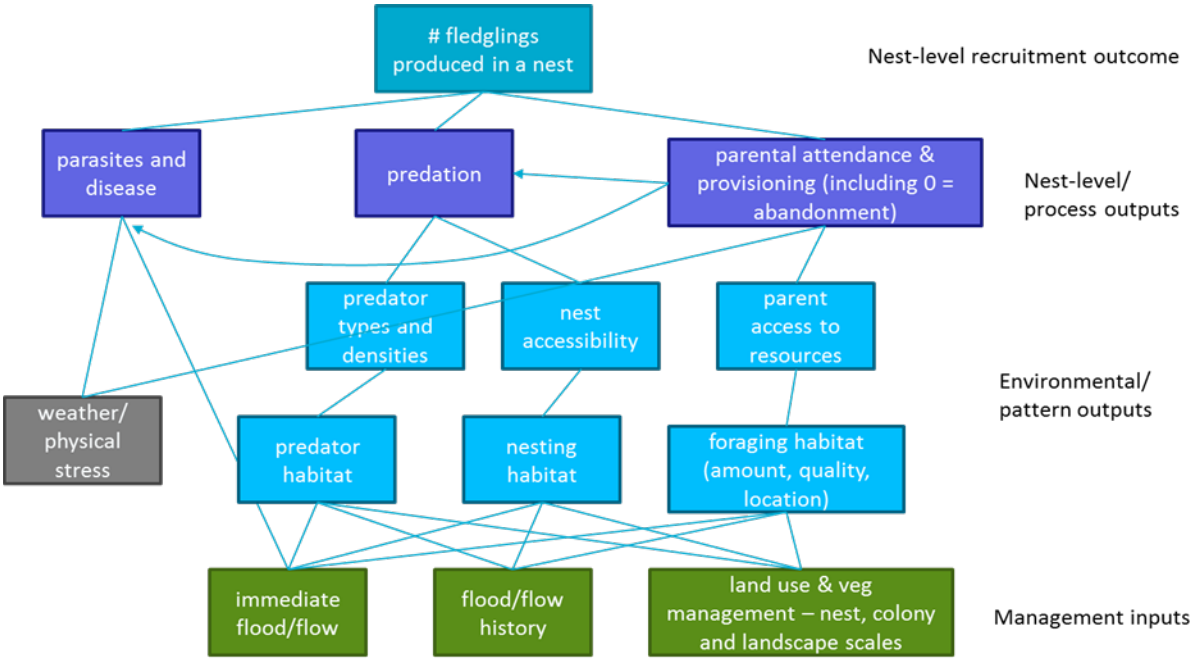


Figure 5-3. Draft conceptual model of the mechanisms determining the number of fledglings produced at colonial waterbird nests.

5.3 Research approach

The research approach and activities proposed are planned in the context of the occurrence, location, and extent of flooding and waterbird breeding events. Those aspects dependent on the occurrence of flooding and breeding will have the effort allocated to them adjusted or scaled to correspond with the size of the breeding event being surveyed. For example, small managed flow events with associated small numbers of breeding birds are expected to occur at Barmah–Millewa Forest and/or the Macquarie Marshes regardless of climatic trends (e.g. El Nino) in most years, while large breeding events with thousands of birds are unlikely to occur every year or at every site, especially during dry years. The same basic parameters will be measured during breeding regardless of the size of the event.

For all field research activities, surveyed sites will be dictated by where flooding occurs, where waterbirds choose to breed, and funding limitations. MDB EWKR research sites will be prioritised (Barmah, Narran, Macquarie); however, data collection may occur elsewhere if breeding does not occur at MDB EWKR sites (e.g. Lachlan, Lowbidgee, Gwydir, Yantabulla, Paroo). Similarly, the species for which detailed data are collected will be partly dictated by which species are breeding. Estimates of precision and variability will be obtained wherever possible.

Knowledge Gap 1: Where and what are the critical foraging habitats during and after breeding events for recruitment? How might these be affected by environmental flows and threats such as habitat change?

Survival of young birds is believed to be affected by foraging habitat and food availability at local, landscape and basin scales, both before and after fledging. Flow, water management and habitat change will affect the availability (amount and distribution) and quality of foraging, refuge or roosting sites. Habitat distribution and functional connectivity at local, regional, and basin scales will also influence waterbirds access to available habitat. However, data are lacking regarding colonial waterbird habitat use and movements. These data are important for understanding population responses to management and for decision-making on the spatio-temporal allocation of water — but are difficult and expensive to collect. This research links tracked movements of waterbirds and breeding success with foraging habitat characteristics at multiple scales. It includes the largest colonial waterbird satellite-tracking project ever conducted in Australia; however, the latter is just a start, and additional funding for more extensive data collection and analysis for this critical life-history stage would be required for better understanding and eventual population modelling.

The questions of relevance for management that this research will address are:

1. Where do juveniles and adults forage *after* a breeding event?

   a. How long do they forage around the nesting area? When do they leave? Are there differences between juveniles and adults?
   b. Where do they go? Are there differences between juveniles and adults?
   c. What are the characteristics of foraging habitats for juveniles versus adults — e.g. vegetation type, distance from colony?

Where do adults forage *during* nesting (where are they getting the food for the chicks)?

   a. What are the characteristics of adult foraging habitats — e.g. vegetation type, distance from colony?
   b. What are birds eating and does diet change over time?
   c. Are the above related to higher or lower feeding rates at the nest, or chick survival?

How can environmental flows be managed to better support foraging habitats?

Field research approach

- Detailed movement and habitat use studies of at least 40 individuals of a focal species over the duration of the EWKR project using tracking devices (satellite/GPS), Australian Bird and Bat Banding Scheme (ABBBS) leg banding and possibly radio-tracking. Trackers will be deployed in two phases: tracking of adults captured at the beginning of the breeding event, and tracking of juveniles captured at fledging.
- Surveys of foraging habitats surrounding nesting sites (species counts, foraging strike rates, water depth, vegetation type, distance from colony) at different points during the nesting cycle
- Quantification of feeding rates, chick condition and survival using analysis of images from remote motion-sensing and time-lapse cameras focused on 50 nests. The latter will be linked where possible to tagged birds being tracked.
- Colony mapping, nest counts, monitoring of eggs and chicks, and collection of scat, regurgitate and shed feather samples at a subset of tagged nests (where these data are not already collected by other programs). The latter will be linked where possible to tagged birds being tracked.
- Integrative data analysis and interpretation
- Reporting and scientific manuscript preparation
- Engagement with stakeholders and other communications

Tracking of bird movements will focus on a single species. Detailed data collection within colonies will focus on colonial nesting species that represent a range of diets, nesting habitat requirements and foraging habitat requirements: e.g. *Ibis* (Australian White and/or Straw-necked) and *Spoonbills* (Royal and/or Yellow-billed). The final species tracked and monitored will depend on which species nest and where. This research will also attempt to compare data collection methods for accuracy and precision.

Desktop research approach

Contingency research — only undertaken if field research is cancelled, i.e. in severe drought years

If field research is cancelled, the question of relevance for management that this desktop study will address is:

Does foraging habitat availability influence breeding event location, size or recruitment outcomes?

- Development of a conceptual model of foraging habitat requirements for colonial nesting species that represent a range of diets, nesting habitat requirements and foraging habitat requirements: *Ibis* (Australian White and Straw-necked); *Spoonbills* (Royal and Yellow-billed); and *Egrets* (Great, Intermediate, and Little).
- Desktop analysis of existing Murray–Darling Basin datasets to explore whether the availability and distribution of foraging habitats influences the location and size of breeding events (and if possible, fledging rates). This will:

a) quantify foraging habitat availability in and around key nesting sites on, before, and after the dates when breeding events were recorded. This step will be informed by the conceptual model of foraging habitat requirements and by historical inundation and vegetation imagery, mapping, and modelling
b) collate nesting and fledging data from wherever available and add to the existing waterbird breeding event database (Brandis *et al*.)
c) model any relationships between foraging habitat availability and type and the location, size, and success of breeding events for key species.

- Integrative data analysis and interpretation
- Reporting and scientific manuscript preparation
- Engagement with stakeholders and other communications

In the event that field research occurs in all years, alternative funding will be sought for this component.

Links with other research themes

This research is intended to link with the Food Webs Theme through a bioenergetics study examining how much food (energy) is required to raise a chick to fledging. The Waterbirds Theme team may collect waterbird samples such as regurgitates or feathers for analysis by the Food Webs Theme. This research will also link with the Vegetation Theme in terms of foraging habitat (vegetation) type, distribution and condition mapping.

Critical resources

Satellite transmitter tracking equipment; field staff with A-Class bird capture and banding licences, equipment and tracking expertise; staff with mapping, bird movement/behaviour, modelling, spatial analysis, and data analysis expertise; landholder and manager cooperation and support; remote time-lapse/motion-sensing cameras; staff/student/volunteer time for data extraction from photographs.

Table 5-2. Knowledge Gap 1 response variables and associated measurement methods.

Response variables	Methods
Movement origin	GPS/satellite tracking; ABBBS leg-banding
Movement timing	As above
Movement distance	As above
Movement direction	As above
Movement destination	As above
Movement route	As above
Flight times	As above
Residence times (foraging, roosting etc.)	As above
Site fidelity — did the bird return to its natal/nesting site?	As above
Breeding event location	Data from other monitoring programs; Brandis *et al.* and other literature
Numbers of nests per species	On-ground surveys supported by counts or aerial photography/video from manned or unmanned aircraft; data from other monitoring programs; Brandis *et al.* and other literature
Numbers of breeding pairs per species	As above
Number of eggs laid per nest (including repeat-nesting)	As above; monitoring by automatic nest cameras (time-lapse); Brandis *et al.* and other literature
Chick feeding/provisioning rate	Monitoring by automatic nest cameras (motion-sensing)
Fledging rates (number of fledglings produced per nest)	On-ground surveys; monitoring by automatic nest cameras (time-lapse); Brandis *et al.* and other literature
Bird regurgitate components and biomass; general diet information	On-ground sampling; existing literature (e.g. HANZAB and references therein)

Table 5-3. Knowledge Gap 1 drivers and associated measurement methods.

Drivers	Primary method
Local foraging location habitat type and state	Tracking data; aerial photography/satellite/mapping data and inundation mapping/modelling; ground-truthing surveys; monitoring by other programs/EWKR Vegetation Theme
Local roosting location habitat type and state	As above
Foraging habitat area in the month prior to nesting (within set radii from colony site)	Aerial photography, satellite imagery, mapping data and inundation modelling; monitoring by other programs/EWKR Vegetation Theme
Foraging habitat area at egg-laying (within set radii from colony site)	As above
Foraging habitat area at hatching (within set radii from colony site)	As above

Drivers	Primary method
Foraging habitat area at fledging (within set radii from colony site)	As above
Foraging habitat area one month post-fledging	As above
Foraging area quality	As above
Regional and basin scale foraging habitat availability	Satellite/mapping data and inundation mapping/modelling; monitoring by other programs/EWKR Vegetation Theme
Regional and basin scale connectivity (vegetative and hydrological)	As above
Food quantity available in landscape	Monitoring by other programs/EWKR Themes?
Food quality (type)	Analysis of scats and boluses by Food Webs Theme
Rate of change in water depth — colony site	On-ground surveys and monitoring camera images
Rate of change in water depth — foraging area	Remote sensing and/or aerial photography mapping

Knowledge Gap 2: What are critical nesting habitat characteristics we need to maintain and how do these affect recruitment? How might environmental flows, vegetation management and pressures and threats, such as predation, interact with nesting habitat characteristics to affect recruitment?

Maximising recruitment of young colonial waterbirds into the adult population necessarily depends on maximising the number of birds that fledge from the nesting colony. Maintenance of nesting habitat both between and during flood events is critical. However, recent declines and losses of colonies have raised questions concerning the influence of nesting habitat management, type, condition, and configuration on species site choice and on nest success and eventual recruitment. This research aims to produce information that will allow managers to better target both flooding and vegetation management actions to ensure 'event readiness' at nesting sites between flooding events and to maximise recruitment during flooding events.

The questions of relevance for management that this research will address are:

- Do nesting habitat characteristics affect accessibility to predators (e.g. vegetation type, nest position, water level), and therefore the number of fledglings produced?
- Do nesting habitat characteristics influence exposure of chicks to extremes in temperature or weather, and therefore the number of fledglings produced?
- How can environmental flows be managed to better support nesting habitats?

Field research approach

- Surveys of nesting habitat characteristics (e.g. species, nest position, nest materials, water depth, vegetation type and distribution/density, nest density, location within colony, exposure)
- Monitoring of predation (species, impacts, timing, location) using analysis of images from remote motion-sensing and time-lapse cameras focused on nests
- Analysis and modelling of relationships between flows (water-related variables), nesting habitat characteristics, predation, temperature and weather variables and nest success variables
- Reporting and scientific manuscript preparation
- Engagement with stakeholders and other communications

Desktop research approach

Contingency research — only undertaken if field research is cancelled, i.e. in severe drought years

If field research is cancelled, the question of relevance for management that this desktop study will address is:

How do nesting habitat preferences vary among species, sites and events, and do these preferences affect nest success?

- Development of a conceptual model describing relationships between nesting habitat characteristics and recruitment outcomes
- Collation of datasets describing aspects of nest success, timing of breeding initiation and other site and event-specific parameters (e.g. species present, predators/predation, disease, disturbances, changes in water depth/extent, food availability etc.) during individual breeding events, e.g.:

    a. Narran Lakes 2008–209 breeding event
    b. Lower Murrumbidgee 2010–2011 breeding event
    c. Macquarie Marshes 1998–2000 breeding events
    d. Barmah–Millewa Forest (unconfirmed)

- Extraction of vegetation configuration, type and condition variables from aerial photography, satellite imagery, LIDAR and/or vegetation data for these events or locations at three scales: nest, colony and floodplain. At each scale, vegetation data will be extracted both for locations at which birds chose to nest, and for locations at which they chose not to nest.
- Modelling of relationships between vegetation and breeding/nest success parameters from the above datasets at each scale, and if possible, assessment of relationships between breeding/nest success and other parameters (e.g. species interactions, predators, disease etc.)
- If relationships exist and time and funding allow, modelling of how the identified key drivers have changed over time at selected sites (e.g. in response to changes in flood regime and/or land and vegetation management), and the implications for waterbird recruitment
- Integrative data analysis and interpretation
- Reporting and scientific manuscript preparation
- Engagement with stakeholders and other communications

Links with other research themes

This research should link with the Vegetation Theme in terms of habitat (vegetation) type, distribution and condition mapping, especially if key colony nesting sites are surveyed by the Vegetation Theme.

Critical resources

Staff with skills in analysis of aerial photography, satellite imagery, and/or LIDAR data, or existing data derived from these sources; staff with experimental design and data analysis expertise; collaborator and stakeholder cooperation and support.

Table 5-4. Knowledge Gap 2 response variables and associated measurement methods.

Response variables	Methods
Numbers of nests per species	On-ground surveys supported by counts or aerial photography/video from manned or unmanned aircraft; existing data/mapping from other monitoring programs
Numbers of breeding pairs per species	As above
Number of eggs laid per nest (including repeat-nesting)	As above and monitoring by automatic nest cameras
Fledging rates (number of fledglings produced per nest)	As above and monitoring by automatic nest cameras
Temperature	Bureau of Meteorology records and nest cameras
Wind speeds	Bureau of Meteorology records
Rainfall (local, regional and Basin)	Bureau of Meteorology records
Nest defence	Monitoring by automatic nest cameras (motion-sensing)
Nest abandonment	As above; on-ground surveys and nest camera data supported by counts or aerial photography/video from manned or unmanned aircraft; existing data/mapping from other monitoring programs
Nest height above water or ground	On-ground surveys and nest camera data; existing data/mapping from other monitoring programs
Nest position (vegetation type/species and condition)	On-ground surveys supported by nest camera data and aerial photography/video from manned or unmanned aircraft; existing data/mapping from other monitoring programs/EWKR Vegetation Theme
Nest concealment	As above
Predation impacts (by species, predator and prey)	Monitoring by automatic nest cameras (motion-sensing)
Predator species presence	As above
Predator species activity level (abundance)	As above

Table 5-5. Knowledge Gap 2 drivers and associated measurement methods.

Driving variables	Methods
Flood depth and extent	Remote sensing and/or aerial photography mapping; or existing data/mapping from other monitoring programs
Vegetation community	On-ground surveys or existing data/mapping from other monitoring programs/EWKR Vegetation Theme
Vegetation species	On-ground surveys or existing data/mapping from other monitoring programs/EWKR Vegetation Theme
Vegetation structural type (e.g. tree, shrub, reed/rush).	As above
Vegetation density	As above
Vegetation height	As above

Vegetation configuration/distribution (patchiness, gaps, fractals?)	As above
Vegetation condition	As above possibly supported by satellite imagery (e.g. normalised difference vegetation index (NDVI))

5.4 Description of work components

Our intent is for all research activities to be conducted as collaborations among the personnel involved in the Leadership Group and the organisations/staff selected for the Implementation Team. To ensure clear roles and responsibilities, each field and desktop activity will be assigned an activity leader. Clear plans will then be developed for each activity that specify staff, timelines, deliverables, budgets, specific links to other activities and themes etc. after the Implementation Team is finalised. These will be overseen by the Leadership Group.

The core staff for each research activity will be drawn from UNSW and CSIRO, with additional staff invited to collaborate as necessary.

This section gives an overview of the proposed work components and activities over the life of MDB EWKR (to 2018–19). Component B1 (Knowledge review and conceptualisation) and Activity B2.1 (2015–16 Field research) were completed in 2015–16, and are described in some detail. Work components and activities in later years are included in summary and will be further defined in the MYRP and future ARPs based on the outcomes of 2015–16 activities (including cross theme integration).

5.4.1 Component B1 — Knowledge review and conceptualisation

In scoping research activities for the MDB EWKR Waterbirds Theme, a literature review was undertaken to consolidate existing knowledge on waterbird responses to flooding, stressors and threats (McGinness 2015). Component B1 involved the revision, peer review and approval of the literature review to ensure that it is fit-for-purpose in providing a solid foundation for research proposed in MDB EWKR.

Objective

To provide a solid foundation for MDB EWKR research, by reviewing past studies, providing conceptualisations of the drivers of waterbird recruitment, and identifying key knowledge gaps and research questions

Description

The existing literature review (McGinness 2015) was revised to summarise key messages and knowledge gaps in a new front section and to provide more detail around conceptual models. While the existing document was peer-reviewed within CSIRO and MDFRC, the revised version was also subject to MDB EWKR Science Advisory Group review, and submitted to the Department for approval.

Outputs

- Draft literature review for SAG review
- Final literature review for Department approval

How will the output(s) be used?

This literature review has provided direction to MDB EWKR research activities by providing a strong conceptual basis, identifying knowledge gaps and describing critical research questions that should be addressed.

5.4.2 Component B2 — Field research

Field research activities are proposed in 2015–16, 2016–17 and 2017–18, in the event that waterbird breeding events occurs at one-or-more MDB EWKR research sites. Colony monitoring activities trialled during a pilot study in 2015–16 will be expanded in subsequent years to include satellite tracking of juvenile and adult birds. The field research component is an integrated set of activities, with interim reports to be provided at the end of each year (e.g. Activity B2.1.4), and overarching data analysis and reporting at the end of the project (Component B4).

Field research pilot study activities were conducted during 2015–16 in parallel with completion of the Knowledge review and conceptualisation (Component B1) for two reasons. Firstly, waterbird breeding events are infrequent and missing opportunities to collect data has implications for the development of predictive capacity in MDB EWKR. Secondly, the suite of methods proposed required testing and refinement and the information generated from pilot research during this first year was used to inform adaptation of the research plan and research activities in later years of the project.

Activity B2.1 — 2015–16 Pilot field research

Activity B2.1.1 — Preparation and equipment purchase

Objectives

- To prepare for field data collection activities

Description

- Engagement with stakeholders (e.g. travel, phone meetings)
- Animal ethics applications, meetings and reporting (CSIRO, UNSW)
- Scientific licence applications, meetings and reporting (CSIRO, UNSW)
- Volunteer/student/staff engagement and management (CSIRO, UNSW)
- Preliminary equipment purchase and setup (CSIRO, UNSW)
- Testing and training in bird capture and satellite device attachment methods including bird harnesses (CSIRO, UNSW)

Outputs

- Equipment ready for use in field data collection
- Fieldwork planned and ready to implement

How will the output(s) be used?

Outputs will prepare the theme staff for conducting field data collection (B2.1.2) and other research activities.

Activity B2.1.2 — Field data collection

Objectives

- To collect field data describing waterbird recruitment and its drivers
- To test data collection methodologies

Description

Three main field data collection trips during the summer of 2015–2016 in Barmah–Millewa Forest (CSIRO and UNSW).

1. At breeding initiation (egg-laying)

- Fieldwork preparation and packing
- Nest and egg counts and nest tagging
- Surveys of nesting habitat characteristics
- Motion-sensing/time-lapse camera installation
- Data collation/entry

During breeding

- Fieldwork planning, preparation and packing
- Nest, egg and chick counts
- Surveys of nesting habitat characteristics
- Motion-sensing/time-lapse camera maintenance and downloads
- Data collation/entry

At the end of the breeding event

- Fieldwork planning, preparation and packing
- Nest, egg and chick counts
- Surveys of nesting habitat characteristics
- Motion-sensing/time-lapse camera collection and downloads
- Foraging habitat surveys
- Data collation/entry
- Communications

Other minor fieldtrips, depending on: (i) which species breed, where, and when; (ii) if circumstances change in terms of breeding event timing, size, location, and success; and (iii) if time-lapse and motion-sensing cameras require maintenance more frequently than anticipated (e.g. changing batteries and memory cards).

Outputs

- Data collection methodologies refined and staff trained in new methods
- Datasets describing colony size, location, nest, egg and chick counts, and fledging rates
- Datasets describing nesting habitat characteristics
- Samples for Food Webs Theme analyses
- Motion-sensing/time-lapse photographs documenting egg, chick, and fledgling survival and mortality, predation, nest defence and feeding rates by parents for selected species

How will the output(s) be used?

Outputs will be used in subsequent theme activities to refine methodologies and generate integrated datasets suitable for analysis and modelling.

Activity B2.1.3 — Data processing and analysis

Objective

The objective of this activity is to analyse data collected in Activity B2.1.2.

Description

Data to be processed and analysed include:

- motion-sensing and time-lapse camera image data extraction (CSIRO with assistance from UNSW)
- data analysis: predation, nest defence, nest attendance (CSIRO)
- data analysis: tagged nest success (UNSW)
- data analysis: measurement and analysis of colony size (UNSW and CSIRO)
- collation of inundation, wetland area, cropping area/type, vegetation type, vegetation condition, and weather datasets (spatial and temporal — ARCGIS and G-EARTH) (CSIRO and UNSW)
- Integrative data analyses and interpretation (CSIRO and UNSW)

As this is the first year of research, data analysis will be preliminary, with further analysis of data to be undertaken in subsequent years as further breeding events are studied.

Output

Data analysis outputs to support Activity B2.1.4.

How will the output(s) be used?

Analysis results will be used to inform reporting as part of the subsequent activity and methodologies in subsequent years.

Activity B2.1.4 — Reporting

Objective

To report the results of research and method development conducted during the foundational year.

Description

The process and outcomes of activities B1.3 to B1.5 will be documented in a progress report. The report will be subject to internal peer review, with the outcomes of that review to inform activities in subsequent years. As an interim report it is not anticipated that the report will be published or subject to formal external review.

Output(s)

A report (to be co-authored by CSIRO & UNSW) describing the results of:

- theme planning and preparation for field data collection
- field data collection
- preliminary data processing and analysis.

The draft report will be circulated and finalised following an internal review process.

How will the output(s) be used?

This report will document outcomes from 2015–16 field research and inform research activities to be undertaken in following years.

Activity B2.2 — 2016–17 field research

In order to build on dataset quality and size, Activity B2.2 will involve essentially the same activities as those conducted during 2015–16, with greater coverage, replication and adjustments (where required) based on learnings from 2015–16. It will also include the following additional activities:

- purchase and deployment of satellite GPS transmitter devices to track movements of both juvenile and adult birds — short-term and long-term, during breeding events and between breeding events
- bird movement tracking data mapping and analyses.

Activity B2.2.1 — Preparation and equipment purchase

Objective

To prepare for field data collection activities.

Description

- Engagement with stakeholders (e.g. travel, phone meetings)
- Animal ethics applications, meetings and reporting (CSIRO, UNSW)
- Scientific licence applications, meetings and reporting (CSIRO, UNSW)
- Volunteer/student/staff engagement and management (CSIRO, UNSW)
- Equipment purchase and setup (CSIRO, UNSW)
- Testing and training in bird capture and satellite device attachment methods including bird harnesses (CSIRO, UNSW)

Outputs

- Equipment ready for use in field data collection
- Fieldwork planned and ready to implement

How will the output(s) be used?

Outputs will prepare the theme staff for conducting field data collection (B2.2.2) and other research activities.

Activity B2.2.2 — Field data collection

Objectives

- To collect field data describing waterbird recruitment and its drivers
- To test data collection methodologies

Description

A minimum of three main field data collection trips are planned for the summer of 2016–17, most likely in either Barmah–Millewa Forest or the Macquarie Marshes (CSIRO and UNSW). If bird breeding occurs at both sites, satellite tagging and banding of waterbirds may be conducted at both sites. Site selection for other activities, such as camera deployment, will be based on the nature of the flooding and breeding events in each location (e.g. species, event size, accessibility and other logistical issues) and the comparative quality of the data obtainable.

1. At breeding initiation (egg-laying)

- Fieldwork preparation and packing
- Capture, satellite tagging and banding of <u>adult</u> waterbirds
- Colony mapping
- Nest tagging and egg counts
- Surveys of nesting habitat characteristics
- Sample collection for diet/bioenergetics research
- Motion-sensing/time-lapse camera installation
- Foraging habitat surveys
- Data collation/entry

During breeding (chicks)

- Fieldwork planning, preparation and packing
- Colony mapping
- Nest tagging and egg and chick counts
- Surveys of nesting habitat characteristics
- Sample collection for diet/bioenergetics research
- Motion-sensing/time-lapse camera maintenance and downloads
- Foraging habitat surveys
- Data collation/entry

At the end of the breeding event

- Fieldwork planning, preparation and packing
- Capture, satellite tagging and banding of juvenile waterbirds
- Colony mapping
- Nest tagging and egg and chick counts
- Surveys of nesting habitat characteristics
- Sample collection for diet/bioenergetics research
- Motion-sensing/time-lapse camera collection and downloads
- Foraging habitat surveys
- Data collation/entry
- Communications

Other minor fieldtrips may also be required, depending on: (i) which species breed, where, and when; (ii) if circumstances change in terms of breeding event timing, size, location, and success; and (iii) if time-lapse and motion-sensing cameras require maintenance more frequently than anticipated (e.g. changing batteries and memory cards).

Outputs

- Datasets describing colony size, location, nest, egg and chick counts, and fledging rates
- Datasets describing nesting habitat characteristics
- Samples for diet/bioenergetics research
- Motion-sensing/time-lapse photographs documenting egg, chick, and fledgling survival and mortality, predation, nest defence and feeding rates by parents over time for selected species
- Datasets describing foraging habitat characteristics
- Data describing foraging movements of nesting adult waterbirds, and movements of immature and adult waterbirds post-fledging

How will the output(s) be used?

Outputs will be used in subsequent theme activities to generate integrated datasets suitable for analysis and modelling.

Activity B2.2.3 — Data processing and analysis

Objective

The objective of this activity is to analyse data collected in Activity B2.2.2.

Description

Data to be processed and analysed include:

- motion-sensing and time-lapse camera image data extraction (CSIRO with assistance from UNSW)
- data analysis: predation, nest defence, nest attendance, nest success (CSIRO)
- data analysis: tagged nest success, nesting habitat characteristics, colony mapping (UNSW)
- data analysis: movement and/or foraging (CSIRO and UNSW)
- data analysis: diet/bioenergetics (UNSW, CSIRO, EWKR Food Webs Theme)
- collation of inundation, wetland area, cropping area/type, vegetation type, vegetation condition, and weather datasets (spatial and temporal — ARCGIS and G-EARTH) (EWKR Vegetation Theme, CSIRO and UNSW)
- integrative data analyses and interpretation (CSIRO and UNSW).

The data analysis will address the following questions:

- Where do adults forage during nesting (where are they getting the food for the chicks?)
- What are the characteristics of foraging habitats — e.g. vegetation type, distance from colony?
- What are birds eating, is it good quality, does diet change over time, and what are the primary sources?
- How do nesting habitat characteristics influence the numbers of fledglings produced?
- How much does physical accessibility to predators (nest position, water level) affect fledging rates?
- How much does nesting habitat influence exposure of chicks to extremes in temperature or weather?
- How much predation takes place on eggs and chicks and which species are responsible?
- What are the relationships between nesting habitat characteristics, predation, temperature and weather variables and fledging rates?

Further analysis of data will be undertaken in subsequent years as further breeding events are studied.

Output

Data analysis outputs to support Activity B2.2.4.

How will the output(s) be used?

Analysis results will be used to inform reporting as part of the subsequent activity.

Activity B2.2.4 — Reporting

Objective

To report the results of research conducted during the 2016–17 year.

Description

The process and outcomes of activities undertaken during the 2016–17 year will be documented in a progress report. The report will be subject to internal peer review, with the outcomes of that review to inform activities in subsequent years. As an interim report, it is not anticipated that the report will be published or subject to formal external review.

Output(s)

A report (to be co-authored by CSIRO and UNSW) describing the results of:

- theme planning and preparation for field data collection
- field data collection

- preliminary data processing and analysis.

The draft report will be circulated and finalised following an internal review process.

How will the output(s) be used?

This report will document outcomes from 2016–17 field research and inform research activities to be undertaken in following years.

Activity B2.3 — 2017–18 field research

Activity B2.3 will involve essentially the same activities as those conducted during the previous year.

Activity B2.4 — 2018–19 field research analyses

Activity B2.4 will involve final data collation, processing, analysis and reporting for the field research component.

5.4.3 Component B3 — Theme planning, coordination and reporting

This component includes:

- theme research planning, including contributions to Annual and Multi-Year research plans
- theme research coordination, ensuring the research activities are administered effectively and delivered in a coordinated manner to meet MDB EWKR objectives
- theme level reporting, including the Final Research Report for the Waterbirds Theme , and contributions to the Final Research Report for each site and the Overall MDB EWKR Synthesis Report (noting that these reports will build on the specific reports associated with individual research components and activities)
- project reporting, including contributions to mid-year and annual progress reporting
- integration activities across EWKR with other themes, and with external stakeholders, including participation in workshops and other meetings
- stakeholder consultation, including emails, phone calls, workshops and meetings to ensure that project activities are fit-for-purpose and fill useful knowledge gaps.

In late 2016–17, the Theme Leadership Group will develop an Annual Research Plan for 2017–18, guided by the outcomes of Component B1 and Activity's B2.1 and B2.2. The Annual Research Plan will be revised each year to reflect proposed activities for the forthcoming year, and the Multi-Year Research Plan will be updated every year, if any significant changes are required.

5.5 Outcomes

The research outcomes for the Waterbirds Theme will inform recommendations for environmental water planning, prioritisation and management and other natural resource management actions at local to basin scales. Specifically, this research will provide improved understanding for land and water managers of the following:

Field research

- Locations and characteristics of critical foraging habitats for adult and juvenile colonial-nesting waterbirds both *during* and *between* breeding events
- Required extent and duration of inundation of foraging habitats around nesting sites to support recruitment
- Where juveniles and adults go after fledging/breeding, and if juveniles return to their natal site
- Waterbird diet composition, quality, and changes over time (with the Food Webs Theme)

- How nesting habitat characteristics influence the numbers of fledglings produced, including whether physical accessibility to predators (nest position, water level) affects fledging rates, and how much nesting habitat influences exposure of chicks to extremes in temperature or weather
- How water and vegetation management and threats, such as habitat loss and predation, interact to affect recruitment

Desktop research

Contingency research — only undertaken if field research is cancelled, i.e. in severe drought years

- The influence of foraging habitat availability on breeding event location, size and recruitment outcomes
- How nesting habitat preferences vary among species, sites and events.

5.6 Outputs

Field research

- Recruitment data for breeding events at EWKR sites within the life of the project
    - Conclusions on the relative importance of the underlying mechanisms determining the numbers of fledglings produced and implications for management
    - Evaluation of data collection methods for ongoing use in the future
- Movement (tracking) data for birds breeding/bred at (at least one) EWKR site
    - Novel data describing where juvenile (and adult) birds forage and roost and their movements in the short- and long-term, including evaluation of evidence for site fidelity
    - Identification of links between critical microhabitats that promote survival and coarse broad-scale habitat variables
    - Implications for collaborative management of waterbird habitat at local to continental scales
- Targeted dissemination information
    - Real-time feedback to local managers from staff on-site
    - Clear management and policy implications from local to Basin scales
- Scientific papers (estimate: six)
- Overarching Theme Research Report
- Contributions to Site Research Report and MDB EWKR Synthesis Report

Desktop research

Contingency research — only undertaken if field research is cancelled, i.e. in severe drought years

- Novel data describing the availability and distribution of foraging habitats associated with breeding events at key nesting sites
    - Evaluation of the influence of the availability and distribution of foraging habitats on the location and size of breeding events (and if possible, fledging rates)
- Identification of whether individual waterbird species show preferences for nesting sites with vegetation of particular configuration, type, or condition

  - Assessment of the influence of vegetation characteristics on recruitment
  - Implications for targeting both flooding and vegetation management actions, and prioritisation of areas that must be maintained between breeding events

- A complete dataset of all known colonial waterbird nesting and fledging data for the MDB with associated habitat characteristics
- Integration of data into relevant models (e.g. Bayesian) describing the primary drivers of colonial nesting waterbird recruitment

5.7 Available datasets or models to support research

Dataset	Sources
Breeding of colonial waterbirds, past datasets	UNSW, NSW OEH, Broken catchment, CSIRO Ecological Outcomes of Flow Regimes project data, published reports and papers
Locations and abundances of breeding colonial waterbirds, project years	UNSW aerial surveys
Water depth	Measured on-site during surveys and/or estimated from flood extent mapping
Flow	Different gauges, also modelled data; UNSW, NSW OEH, NSW Office of Water
Flood extent mapping	NSW OEH, UNSW, CSIRO
Flood duration	NSW OEH, UNSW, CSIRO
Vegetation type and condition mapping	NSW OEH, UNSW
Rainfall (local and catchment)	Bureau of Meteorology
Temperature	Bureau of Meteorology
Evapotranspiration	Bureau of Meteorology
Wind speed	Bureau of Meteorology
Fish abundance (by size or species)	UNSW, other themes, LTIM
Invertebrate abundance (by functional group?)	UNSW, other themes, LTIM
Frog/tadpole abundance	NSW OEH, UNSW, CSU

5.8 Other programs that link to the questions

There are no current projects other than MDB EWKR surveying waterbird recruitment response variables in the Murray–Darling Basin. However, if breeding occurs at Lachlan, Lower Murrumbidgee, and/or Gwydir sites, the UNSW will be monitoring breeding parameters related to the MDB EWKR Waterbirds Theme at these sites for the Commonwealth Environment Water Holder

(CEWH) LTIM. In this case, MDB EWKR may fund additional activities at these sites if breeding is not occurring at MDB EWKR sites (Barmah–Millewa, Narran Lakes, or Macquarie Marshes). This process will be outlined in the risk/contingency plan. UNSW also does annual aerial surveys in October/November of major breeding sites and estimates breeding colony sizes. NSW and Victorian conservation agencies collect some data on species nesting and size of colonies, possibly most detailed for Barmah– Millewa Forest.

Table 5-6. Summary of major programs within the MDB collecting waterbird data. VEWH – Victorian Environmental Waterholder**.**

Agencies	Program/ project	Locations	Frequency/ timing	Parameters	Recruitment?
CEWH/ CEWO, UNSW	Long-Term Intervention Monitoring	Lachlan, Lowbidgee, Gwydir	Large breeding events (none so far)	Species, colony size and stage	Possibly, if a large event occurs
MDBA, UNSW	Aerial waterbird survey in eastern Australia (AWSEA)	Basin-wide — all rivers, waterbodies and other wetlands (>1 ha) surveyed within seven 30 km wide survey bands that extended across about 13.5% of the land surface of the Murray–Darling Basin	Annual: 1983-current	Species, colony size and stage	No
MDBA The Living Murray, UNSW	Aerial waterbird surveys of The Living Murray Icon Sites and Hydrological Indicator Sites	39 wetland sites (for example Barmah–Millewa; Gunbower–Koondrook–Pericoota; Hattah Lakes, Chowilla–Lindsay–Wallpolla; Lower Lakes–Coorong–Murray Mouth; River Murray Channel) in spring to coincide with the annual Eastern Australian Waterbird Survey	Annual 2007–2012 (MI) and 2010–2012 (Hydrological Indicator Sites) — combined in 2013- current (targeted wetland sites)	Species, colony size and stage	No
MDBA	Intervention monitoring	As required	As required	Species, colony size and stage, number of eggs/chicks	No
NSW State agencies e.g. NSW OEH	Most monitoring in collaboration with CEWH and MDBA	As required	As required	Species, colony size and stage	No
VIC State agencies e.g. VEWH	Most monitoring in collaboration with CEWH and MDBA	As required	As required	Species, colony size and stage	No

5.9 Quality assurance and risk assessment

5.9.1 Quality assurance

The Waterbirds Theme involves research activities that are defined based on key questions and outcomes, rather than by sites or personnel. Thus, the same personnel may work across multiple sites for any given activity and will use the same project methodology. The exact methods to be used at all (relevant) sites will be confirmed in future planning stages following approval of animal ethics and scientific licence applications and pilot studies. If adaptations need to be made to the methodology over the course of MDB EWKR, the Leadership Group will be consulted and kept informed, with updates made to annual research plans to ensure consistency. Data analysis will be undertaken following standard methods agreed upon during planning. While input into the design and analysis of the project will be a collaborative process involving a number of people it is anticipated that the actual analysis will be undertaken by a limited number of team members, minimising the risk of different approaches being taken. Decisions on issues such as taxonomy or functional group allocations will be agreed using consensus decisions within the Leadership Group, with definitions and terminology made explicit and consistent. If consensus cannot be reached, the Leadership Group will consult with the EWKR leadership for guidance. It is anticipated that the Leadership Group and activity leaders will conduct phone meetings approximately monthly with the Theme Coordinator, and more often during detailed method development, data collection and data analysis periods. Scientific papers and reports will be produced collaboratively, potentially involving managers where appropriate, and will be peer-reviewed and checked by relevant managers before publication.

5.9.2 Risk assessment

Risk assessment will adopt standard MDFRC processes, based on the Australian Standard for Risk Management (AS/NZS ISO 31000:2009), as provided in Project Plan. The inclusions below will be updated accordingly.

Risk	Consequence	Control measures
No flood events occur at MDB EWKR research sites	Colonial-nesting waterbird breeding is not triggered at EWKR sites	Surveyed sites will be dictated by: where flooding occurs; where waterbirds choose to breed; and funding limitations. MDB EWKR sites will be prioritised (Barmah, Narran, Macquarie); however, data collection may need to occur elsewhere if breeding does not occur at EWKR sites (e.g. Lachlan, Lowbidgee, Gwydir, Yantabulla, Paroo). Across all major breeding sites, it is highly unlikely that no flooding will occur, or that no environmental watering events will be delivered. Sites selected are known to be priority sites for the delivery of environmental water (for CEWH, MDBA and State agencies). Establishment and monitoring of field sites will be undertaken in consultation with relevant land/water managers for the selected sites. It is anticipated that the likelihood of this risk occurring is low. However, in the event that it does occur, desktop studies will be implemented as described in the previous sections, with priority desktop research activities to be agreed following consultation with the JRG and endorsement by the Department and Steering Committee.
Dependency on external data	Project is unable to source sufficient datasets	Members of the Leadership Group are custodians of a number of the identified datasets and/or have links to organisations that are. Meetings will identify and seek appropriate permissions for the use of datasets. It is anticipated that the likelihood of this risk occurring is low.

Risk	Consequence	Control measures
Quality of sourced data is poor	Restricts the type of analysis that can be undertaken Restricts the number of datasets that can be included in the analysis	Modify analysis approach to reflect the quality of the data (e.g. presence/absence data); exclude sites/datasets if necessary. Members of the Leadership Group have experience compiling and analysing fauna response and environmental datasets and/or have access to colleagues with statistical/modelling experience in that area. It is anticipated that the ability to find a solution to this risk is high and that the consequence of the risk affecting reportable outcomes is low.
Incompatible field methods	Project is unable to undertake Basin-wide comparisons between research sites	Members of the Leadership Group will be involved with the coordination and/or on-ground collection of field data and recognise the importance of consistency within methodology. Multi-Year and/or Annual research plans will contain detailed methodology to be followed. It is anticipated that the likelihood of this risk occurring is low.
Variability within and between research sites	High variability within and between sites limits the strength of predictions/ outcomes	The outcome of significant variability within and between sites is a response of interest in itself.
Loss of staff	Disruption to methods or deliverables	The UNSW, CSIRO, and UC personnel involved in the Waterbirds Theme have skills and expertise that match and are also complementary. Therefore, the loss of individual staff is not expected to significantly hamper the project, provided staffing adjustments are possible, including potentially bringing in staff outside of these institutions.

6 Food Webs

Authors: Darren Baldwin (2015-16) (MDFRC), Paul McInerney (2017-) (MDFRC), Nick Bond (MDFRC), Rebecca Lester (Deakin University), Barbara Robson (CSIRO), Darren Ryder (University of New England), Ross Thompson (University of Canberra) and Ben Gawne (University of Canberra)

6.1 Executive Summary

6.1.1 Introduction

Food webs are one of a number of critical ecosystem functions believed to be important in sustaining patterns of diversity. It is anticipated that improved understanding of the influence of flow on food webs will complement our understanding of the influence of flow on habitat and connectivity and that in combination, this knowledge will enable better management of environmental flows within the Basin.

A food web describes the pathways that energy and essential nutrients are routed through an ecosystem, from basal resources such as organic matter, through consumers, to apex predators such as fish and waterbirds. While most major conceptual models of river ecosystems propose food webs as a critical ecosystem function, our knowledge of the influence of flow on food webs is not robust enough to make specific predictions about how flow’s effects on food webs influence outcomes. Addressing these knowledge gaps will be the focus for research in the Food Webs Theme.

6.1.2 Research Focus

The broad research questions to be addressed by the Food Webs Theme are:

1. *What flow regimes best support food webs that contribute to positive outcomes for native fish and waterbirds?*
2. *How do other stressors impact on food web processes and the achievement of native fish and waterbirds outcomes?*

The focus of activities will be the development of predictive capacity through the application of bioenergetics modelling which is an approach that has been successfully applied in a range of fisheries and ecosystem studies. The Food web Theme will undertake a range of field sampling and experimental activities that will generate data in support of either the improvement of an existing model or development of a new food web model that will enable evaluation of a range of flow scenarios.

The Food web Theme will focus on the food resources required to support the recruitment of native fish and waterbirds in collaboration with the Fish and Waterbird Themes. This focus will ensure that the information generated by the Food web Theme can be used by managers to support achieving outcomes for fish and waterbirds and will add value to the outcomes of the project through integration between the outputs of the 3 other research themes.

6.1.3 Summary approach and research components

The proposed research will be undertaken in four components. The first component, will undertake a review to consolidate our knowledge in order to underpin planning the next three components. The remaining three components will focus on data generation and model development, calibration and validation.

Component W1 — Review and Conceptualisation. Due to the uncertainty and knowledge gaps surrounding the influence of flow on food webs, the first step is to systematically review and synthesise available knowledge, so as to inform decisions around key sub-questions and appropriate method selection. This component has four Activities.

3. *Food web conceptualisation*
4. *Model scoping*
5. *Method review and testing*
6. *Integrating outcomes into the MYRP*

Component W2 — Understanding food web dynamics: a structured program of field sampling will be undertaken to generate information needed to inform model development.

Component W3 — Identifying important sites of production. This information will be used to identify characteristics (including flow) of habitats that make a disproportionate contribution to basal resource productivity or food availability.

Component W4 — Model development and validation: The modelling strategy identified in Component W1 will be implemented using data gathered in Component W2. The model will then be used to evaluate a range of flow scenarios.

6.2 Logic and rationale

6.2.1 Background

The Basin Plan seeks to protect and restore biodiversity in the Basin's aquatic ecosystems. Food webs are one of a number of critical ecosystem functions believed to be important in sustaining patterns of diversity along with connectivity and nutrient cycling. It is anticipated that improved understanding of the influence of flow on food webs will complement our understanding of the influence of flow on habitat and connectivity and that in combination, this knowledge will enable better management of environmental flows within the Basin.

A food web describes the pathways that energy and essential nutrients are routed through an ecosystem, from basal resources such as organic matter, through various trophic levels, to apex predators such as fish and waterbirds. Processes represented by food webs are critical ecosystem functions that underpin the environmental outcomes often sought by environmental water management, such as enhanced native fish and waterbird populations. Understanding food web structure and function and how they are influenced by flow is important in maximising the outcomes of environmental watering.

There is a generic conceptual understanding of the nature and function of aquatic food webs in the MDB, and in some cases we know the important food resources for some native fish and waterbird species. However, our knowledge of food web structure and dynamics, including the strength and importance of key trophic linkages to target species (often fish and birds), is not robust enough to make specific predictions about how flow, or other drivers, influence outcomes. Addressing these knowledge gaps will be the focus for research in the Food Webs Theme. Research outcomes will assist in managing flow regimes to best support food web processes, and thereby maximise outcomes for fish and waterbirds.

Research priorities

MDB EWKR research priorities and research sites, and the process by which they were determined, are described in the report titled *Selection of Priority Research Questions and Research Sites*. The selected research priorities provided the strategic framework for the Theme Leadership Groups to focus the proposed research for each of their themes. The broad research questions to be addressed by the Food Webs Theme are:

1. *What flow regimes best support food webs that contribute to positive outcomes for native fish and waterbirds?*
2. *How do other stressors impact on food web processes and the achievement of native fish and waterbirds outcomes?*

The consensus view is that the best way to address this question is to develop predictive capacity linking flow regimes to food web dynamics in lowland river ecosystems so as to be able to inform management decisions. It is highly unlikely that over the course of this project the range of environmental flows delivered in the MDB will be sufficiently variable to allow development of robust predictive capacity based on empirical observations alone. Therefore, we propose to either develop or adapt one or more numerical, process-based computer models linking flow regimes to food web dynamics.

However, before we can implement an appropriate model, we need to have an understanding of the structure of lowland food webs. One of the reasons why it is difficult to describe the architecture of riverine food webs in the Murray–Darling Basin is that most trophic studies in the Basin have relied on a limited number of approaches to understanding trophic dynamics — techniques that are not necessarily suited to lowland rivers and/or offer poor resolution of trophic structures. The relationship between the Food Webs Theme and Basin Plan objectives is illustrated in Figure 6-1.

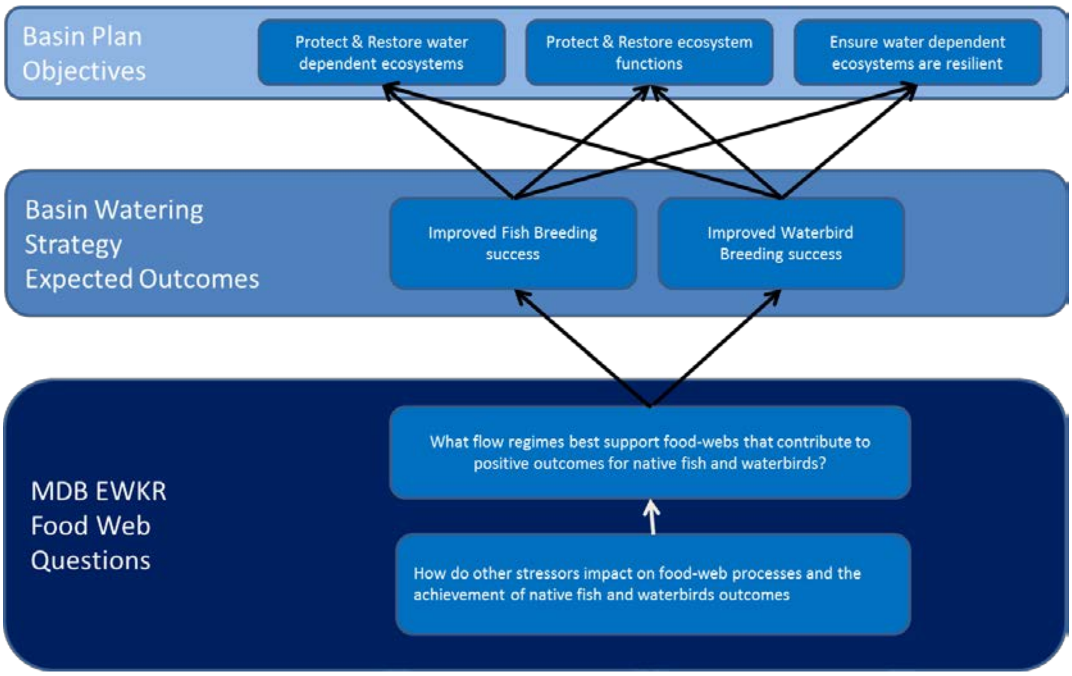


Figure 6-1. Illustration of the relationship between Food Webs Theme questions, Basin-Wide Watering Strategy Expected Outcomes and Basin Plan objectives.

Refinement of research priorities

The overarching aim and priority research topics are very broad and do not easily lend themselves to a research portfolio that is achievable within the budget and timeframes of MDB EWKR. In order to focus the research direction while still being applicable to a range of locations and watering situations, we needed to focus and refine the research priorities.

Having considered a range of possible options, and having consulted with the other MDB EWKR themes, the Food Webs Theme has identified the following key questions:

1. **What flow regimes best support food webs that transfer energy to support recruitment of native fish and waterbirds?**
2. **How do other stressors (e.g. land use change, invasive species) impact on food web processes and the achievement of native fish and waterbirds outcomes?**

Environmental flows directly impact on energy flow via a number of mechanisms (e.g. Davies *et al.* 2014). These include affecting the productivity and distribution of different types of basal resources (e.g. aquatic plants, algae, phytoplankton). Increased flows can wet substrates that allow algal, fungal and bacterial growth, and cause resuspension of organic matter from upstream, off in-channel benches or the floodplain. Flow can also 'wash out' phytoplankton, and concentrate resources into particular microhabitats, for example backwater eddies. There are likely to be spaces in the landscape that are disproportionally important in space and time for primary and/or secondary production with their location and productivity being influenced by flow.

Numerous studies of large systems around the world and in Australia have shown that the movements of energy associated with flow are a critical factor influencing fish and waterbird recruitment. The use of a bioenergetics framework for studying the effects of environmental flows has two additional advantages. Firstly, it is highly amenable to acting as an integrating element across all of the MDB EWKR themes (6-4). Second it allows development of simple models through the aggregation of species into functional groups.

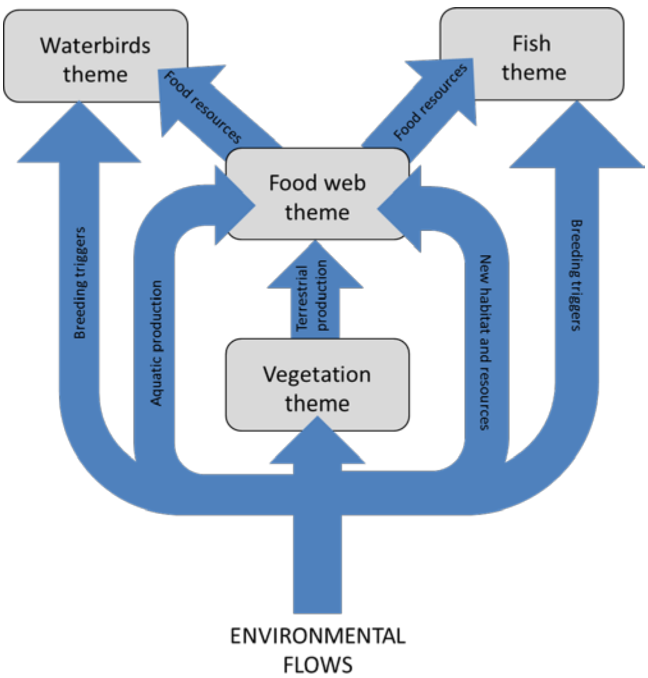


Figure 6-2. Conceptual diagram illustrating the effects of environmental flows on the movement of energy and resources across and between the four themes of MDB EWKR.

The Food Webs Theme represents a critical link between the work being carried out across other themes. The proposed research plan is therefore structured in such a way that there is clear line of sight to the information needs and data that will emerge from the Fish and Waterbirds themes.

Within each of the main questions, a set of subsidiary questions have been generated based on existing knowledge of likely sources of variation in energy flow.

1. **What flow regimes best support food webs that transfer energy to support recruitment of native fish and waterbirds?**

   1A What are the main energy sources contributing to larval fish biomass and waterbird recruitment in the field?

   1B Are there clear spatial patterns in the importance of different energy sources?

   1C Are there clear temporal patterns in the importance of different energy sources?

   1D Is there evidence of 'energy bottlenecks' preventing passage of energy to higher trophic levels?

   1E How does provision of flow affect any patterns detected in 1.1A–D?

2. **How do other stressors (e.g. land use change, invasive species) impact on food web processes and the achievement of native fish and waterbirds outcomes?**

   2A Is there evidence for energy being diverted away from native fish and waterbirds (e.g. by carp)?

   2B Is there evidence that productivity in the channel is limited by other factors (e.g. water turbidity, availability of productive substrates)?

6.2.2 Conceptual understanding

Flow has three major functions in riverine systems; **disturbance** acting to influence community composition and dynamics, providing **cues** for major life-history events, and as an influence on **energetics** through transferring materials longitudinally along the river, laterally between the river and its margins, and vertically between the sediment and the water column (Poff and Zimmerman 2010).

In the Murray–Darling Basin, the role of flow in disturbance dynamics and as a trigger of life-history events (such as breeding or dispersal) is reasonably well known (e.g. Humphries *et al.* 1999; Gre*et al.* 2011). Over several decades, we have gained an understanding that low flow can reduce the biomass and change the composition of ecological communities (e.g. Mac Nally *et al.* 2011; Thomson *et al.* 2012; Wedderburn *et al.* 2012). Flooding in the years following the Millennium Drought has allowed a greater understanding of the role of high flow disturbance (Mac Nally *et al.* 2014). Similarly, work on a range of species including native fish, floodplain vegetation, woodland birds, small mammals and amphibians has shown that flow events are important triggers for life-history events such as flowering, seed set and breeding (e.g. Capon 2003; Kingsford and Auld 2005; King *et al.* 2009).

What is much less clear is the role of flow in generating the resources that are needed for key life-history events, which result in recruitment of plants and animals into breeding populations (Shenton *et al.* 2012). There have now been numerous instances where bird breeding, for example, has been triggered by a flow event, but where the birds have either aggregated and then not nested, or nested and failed to raise chicks to independence. Once breeding has been initiated, then the key currency in determining success is based on energetics; the condition of the animals at the time of breeding, the size of the eggs and offspring, and availability of the correct resources that allow all of the life-stages to be completed. Similarly, even where fish breeding is initiated by a flow event, we have limited evidence that the resulting fish larvae have access to the resources needed to allow them to grow to sexual maturity.

The Food Webs Theme has identified the relationship between environmental flows and the provision of resources across life stages of plants and animals to be a critical knowledge gap in the Murray–Darling Basin.

The emphasis on resource availability has led us to take a **bioenergetic approach** to investigating the effect of environmental flows. Bioenergetics describes ecological systems as a series of 'stocks' of energy (the biomass of plants or animals) and 'fluxes' between those stocks. A food web is the most complete representation of bioenergetics, and at its most complex describes the biomass of all species and the amount of energy moving between them. However, full food web analysis is extremely labour intensive and highly complex (see Figure 6-2 A below). Combining species into 'functional units' based on size, similar feeding techniques or close taxonomic relationships can simplify these systems into the main flow paths for energy (Figure 6-2 B).

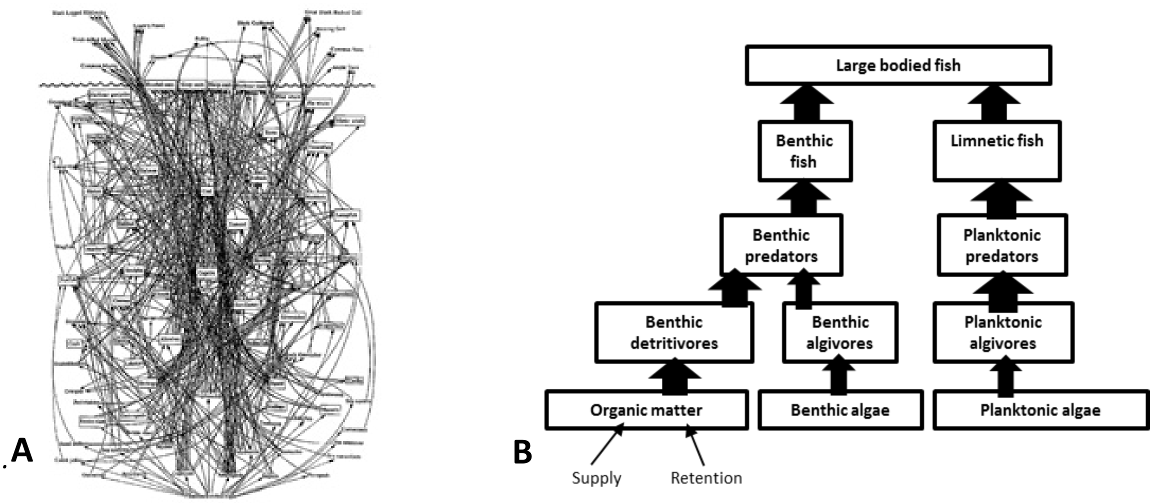


Figure 6-3. Examples of describing food webs A) using species and links and B) using a simpler bioenergetic representation.

The purpose of the Food Webs Theme is to determine the effects of environmental flows on primary productivity and the passage of that productivity through the food web to vertebrate consumers (fish and birds). Based on that core question, it was identified the modelling approach should be:

1. able to determine pathways of energy through the food web to the species of interest
2. relatively simple to implement and have been subjected to peer-review
3. amenable to running simulations or scenarios relevant to management.

Based on those requirements, we identified mass-balance models as being the most appropriate modelling framework. There are a number of bioenergetics modelling approaches that could be used to undertake this work including the approach taken in modelling fish stocks in the Murray River (Australian Centre for Ecological Analysis and Synthesis (ACEAS) 2013) and the commercially available Ecopath with Ecosim (EwE) (Pauly *et al.* 2000). The ACEAS model is a bioenergetic model that predicts the biomass of fish that can be supported under different flow scenarios.

One of the benefits of this type of modelling is that rather than describing all elements of the food web to a high level of taxonomic resolution, most often 'compartments' or groups of taxa are modelled based on type of biomass production (producer/consumer), habitat (water column/sediment), body size (micro-, meso- and macro-), type of food (herbivorous, carnivorous, detritivorous, omnivorous) and way of feeding (filter feeders, mixed feeders, predators). This makes modelling of large, complex ecosystems tractable.

A simple model of this type is shown below (Figure 6-3), based on the lake fisheries of Great Bear Lake (Janjua *et al.* 2015). Species are grouped together functionally, with the size of the circles in the figure indicating biomass and the colours of the lines fluxes of energy through the food web to the top consumers.

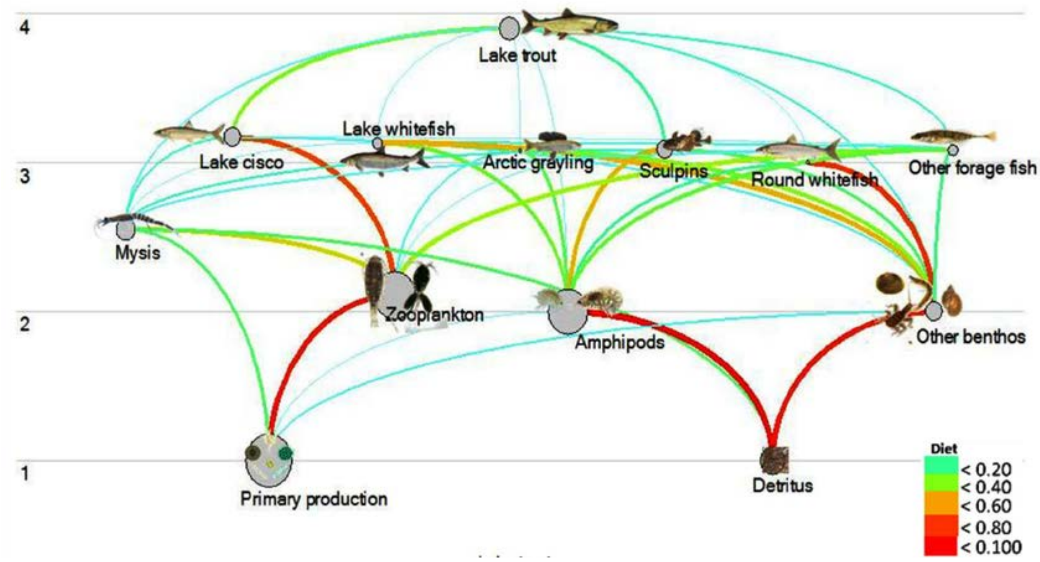


Figure 6-4. A simple bioenergetics model based on the lake fisheries of Great Bear Lake with different coloured connectors illustrating the proportion of the diet comprised of the food resource.

A major strength of taking an approach that includes mapping energy flows is that it conceptualises ecological systems in a way that allows:

- a visual assessment of the likely flow-on effects of changes that affect particular groups
- identification of groups that are critical to energy flow along particular food chains
- quantified modelling of scenarios and management interventions.

There are numerous examples of where this approach has led to the development of useful models and decision support tools for managers.

Fisheries stock models and management interventions; e.g. Hansen *et al.* (1993) 'Applications of bioenergetics models to fish ecology and management' *Transactions of the American Fisheries Society* **122(5)**, 1019–1030.

Impacts of climate change; e.g. Ainsworth *et al.* (2011) 'Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries.' *ICES Journal of Marine Science*: fsr043.

Environmental flow management outcomes; e.g. Cross *et al.* (2011) 'Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon.' *Ecological Applications* **21(6)**, 2016–2033.

6.3 Research approach

The proposed research will be undertaken in four components. The first component, will undertake a review to consolidate our knowledge in order to underpin planning the next three components. The remaining three components will focus on data generation and model development, calibration and validation.

Component W1 — Review and Conceptualisation. Due to the uncertainty and knowledge gaps surrounding the influence of flow on food webs, the first step is to systematically review and synthesise available knowledge, so as to inform decisions around key sub-questions and appropriate method selection. This component has four Activities.

1. *Food web conceptualisation*: This will involve a rigorous and structured literature review to identify key components and linkages/processes in aquatic food webs in lowland rivers, and a prioritisation of knowledge gaps in terms of the importance of each component to fish/bird outcomes, and level of current knowledge. The key output of this sub-component will be a conceptualisation to inform subsequent project activities. To add rigour, the conceptualisation will explicitly refer to models of riverine productivity.
2. *Model scoping: This activity will review the available scientific literature to define worlds-best-practice for modelling food web dynamics in the context of environmental flows and establish a proposed approach to food web modelling in MDB EWKR.*
3. *Method review and testing: This activity will review the best approaches for studying trophic dynamics in lowland river ecosystems; with the feasibility of the most promising techniques being examined using pilot studies with real-world samples.*
4. *Review MYRP: The forth activity will take the results from each of the three activity, in consultation with mangers to prioritise key sub-questions that can be addressed within the time frame and resources of the project, and identify the best approaches to take in Components W2 and W3.*

Component W2 — Understanding food web dynamics: a structured program of field sampling will be undertaken to generate information needed to inform model development. The particular aspects of food webs to be assessed through this work will be informed by Component W1, but will likely comprise aspects of the following:

- the influence of flow on the basal resources supporting fish and waterbird recruitment
- the influence of flow on energy transfer efficiency between trophic levels
- spatial variation in basal resource use across the Basin

Fieldwork will respond to climatic conditions experienced in the timeframe of MDB EWKR, focussing on in-channel responses to freshes during dry years, and responses to overbank and return flows in wet years (or alternatively where environmental flows result in substantial overbank events).

Component W3 — Identifying important sites of production.

This component will build on the data generated within Component W2 examining patterns of variation in productivity among habitats. This information will be used to identify characteristics (including flow) of habitats that make a disproportionate contribution to basal resource productivity or food availability. These patterns will be used to generate hypotheses that will be used to inform further field sampling. The resultant data will contribute to the model's capacity to be spatially explicit.

Component W4 — Model development and validation: The modelling strategy set out in Component W1 will be implemented using data gathered in Component W2. The model will be validated using data collected in MDB EWKR, as well as other programs such as LTIM. A range of scenarios will be explored using the validated model to provide recommendations to environmental water managers about how to best manage environmental flows to maximise food web outcomes for fish and waterbirds.

6.4 Description of work components

6.4.1 Component W1 — Review and conceptualisation

While it is conceptually possible to link flows with food web dynamics, substantial knowledge gaps exist in our empirical understanding of food web dynamics in lowland rivers in the Murray–Darling Basin, and how they are influenced by flow. The knowledge gaps exist in part because the relationship between flows and food web dynamics is often assumed, but is rarely explored. Furthermore, many of the techniques used elsewhere to look at food web dynamics are not as reliable in lowland river ecosystems (in-channel or floodplain). As a consequence of the uncertainty and knowledge gaps surrounding the topic, some foundational activities are required to ensure that the theme delivers improved predictive capacity.

Component W1 will undertake a detailed literature review of the existing knowledge on large river food webs, approaches to modelling them, and potential interactions between environmental flows and energy flows. A particular emphasis was placed on identifying the potential role of basal resources and their interaction with flow (Stage 2), spatial distribution of resources and the potential for flow to increase availability of those resources (Stage 3), and identifying existing models relevant to the project (Stage 4). Other themes were consulted in order to identify the particular 'taxa of interest' that will be the focus of the analysis of the relationship between environmental flows and energy flow.

The review process will comprise three activities:

Activity 1.1 — The influence of flow on lowland river food webs

The review will inform development of a conceptual model, identify critical knowledge gaps, and provide the logic and rationale for the research activities proposed in the theme's research plan.

This activity will build on the review undertaken as part of the Knowledge Status and Needs Report and includes the following steps:

1. a review of published studies and the availability of data on key relationships relevant to the effects of flow on food webs
2. development of conceptual models. The model will build on the conceptualisation included in the Knowledge Status and Needs Report and will:
    a. describe the effects of flow and stressors on food webs
    b. identify the relative importance and certainty in key components and interactions, including under different flow conditions
3. development of a matrix of 'current best knowledge' for the effects of different flow regimes on food web components, with an emphasis on energy passage to high order vertebrate consumers, using the typology of environmental flows outlined in Table 6-1.
4. use of the matrix and conceptual models to identify priority components and/or interactions, which will be further assessed in subsequent activities.
5. development of a summary table for consultation with managers and policy makers, which describes the degree of certainty around flow-food web relationships for the MDB, and which would be revised and refined throughout the project as knowledge is generated.

This activity will be carried out by senior research fellow/s with relevant experience, in consultation with the Leadership Group, and include at least one face-to-face workshop with managers, and an additional writing workshop with the leadership team.

Table 6-1. Flow topologies to be used in constructing 'a current best knowledge' table linking flows with food webs.

Source	Characteristics	Delivery	Extent	Return flows
Upstream dam	Velocity	Flow rules	Base flow	No return water
In-channel flow	Temperature	Natural channels	Freshes	Partial return
Upstream flood water	Water quality	Infrastructure	Floodplain water bodies	Full return
		Pumps	Shedding floodplain	

Activity 1.2 — Incorporating food web indicators into monitoring and evaluation of environmental flows

Ecosystem function, including food webs is included among the Basin Plan objectives and managers believe that one of the major pathways by which flow influences fish and waterbird populations is through its influence on food resources. Managers are currently limited in their capacity to manage flows to promote food web outcomes, in part because they do not have access to a suite of appropriate indicators that would enable them to measure responses and then incorporate the outcomes through their adaptive management framework.

This review will examine the ways in which flow may influence food webs and then, for each possible outcome, consider potential indicators that could be monitored. The review will evaluate each of the potential indicators against established criteria for selecting indicators. The output will be a manuscript that will help managers identify indicators appropriate to their objectives and particular situation, acknowledging the diversity of outcomes and challenges faced by managers.

The review seeks to address a management need to evaluate ecosystem function outcomes of environmental flows. This activity will be undertaken by Darren Baldwin and a UC-appointed post-doc (Rob Rolls). This review will identify appropriate indicators and assessment methods for monitoring food web responses to environmental flows.

Activity 1.3 — A review of approaches to modelling predictive capacity

This review will inform the development of the theme's research plan by identifying the most appropriate approaches to modelling food web responses to environmental flows.

Predictive modelling will be used as a tool to focus and integrate other components of the food web project and to translate the findings into meaningful predictions concerning the outcomes of flow management. There are a wide variety of food web models and modelling approaches in the literature (e.g. Ecopath, Bayesian belief networks, dynamical systems modelling, network structure modelling), each with strengths and weaknesses, and each with different data requirements and predictive capabilities. To ensure that MDB EWKR develops a robust and defensible food web model that is well suited to the type of data that we can collect and appropriate for the type of management scenario to which it will be applied, we will begin by conducting a review of the current state of the art in food web modelling.

The review will identify current approaches in food web and ecosystem modelling in the literature, assessing each approach in terms of capabilities, limitations, rigour and data requirements, and also considering best-practice guidelines in this field. This will lead to a well-considered and appropriate modelling approach that will deliver to management needs for the MDB. The approach will be peer-reviewed as a quality assurance process to ensure that the selection of modelling approach is fit for purpose. Concurrent development of modelling and measurement strategies will ensure that the sampling and analysis program is designed to efficiently support prediction of food web responses to variations in flow.

The reviews were commenced in April 2016. It is expected that the reviews will be well enough advanced to inform the development of the research plans in October, and that the manuscripts will then be finalised and submitted for publication by February 2017.

6.4.2 Component W2 — Identifying critical basal resources

Activity 2.1 — Fish field program

Objective

To identify the basal resources supporting fish recruitment in lowland rivers.

Description

This program will be undertaken in collaboration with the Fish Theme.

The Fish Theme is seeking to test the Fundamental Triad concept of fish recruitment, which proposes that fish recruitment is associated with habitat patches in which food resources are enriched and concentrated and where both food and larvae are retained. This year the Fish Theme will undertake complementary field sampling and laboratory experiments. The field sampling seeks to describe the nutritional and thermal landscape within riverine and floodplain habitats. To do this, the Fish Theme will sample zooplankton from various riverine habitats at nested scales ranging from tens of metres to 100 km, and will correlate observed densities with physical attributes, particularly flow velocity and temperature. These measurements will be used to inform the design of the laboratory experiments that will quantify the effects of the observed variation in food and temperature on larval growth and survival. While fish food is important, food resources are believed to depend on the productivity of basal resources. Understanding the basal resources on which larval fish depend will help identify the extent to which the enrichment and concentration processes are acting on the basal resources or on the fish food. The Food Webs Theme therefore proposes to take complementary zooplankton and basal resource samples. The data will then be integrated with our understanding of the influence of flow on patterns of productivity to identify relationships between basal resources, fish food and larval fish.

Approach

We propose to participate in joint field sampling trips with the Fish Theme. The Food Webs Theme will augment the Fish Theme sampling program by exploring the nutritional landscape at the same nested scales. Zooplankton and basal resources will be analysed for bulk stable isotope content and fatty acid and amino acid composition. In 2016–17, sampling will be undertaken in the Ovens River to align with the fish sampling. In subsequent years field sampling will be undertaken at additional sites across the Basin. A description of these proposed activities is included in the description of Activity 2.4, and will be undertaken in conjunction with the Basin-scale recruitment activity in the Fish Theme and LTIM sampling.

Sampling will be undertaken in December 2016 by MDFRC staff. In 2016, basal resource sampling will follow the methods used by Hladyz *et al.* 2012, while zooplankton sampling will use the same methods employed by the Fish Theme. Initial sample processing to prepare samples for analysis will be undertaken through January and February prior to samples being sent to appropriate providers for analysis of stable isotopes, fatty acid and amino acid composition. Once samples have been analysed, the data will be analysed in May or June 2017.

Outputs

Empirical data that expresses relative magnitudes of energy pathways to taxa of interest
A short report targeted at water managers, which provides an indication of the likely basal resources supporting larval and juvenile fish in the Ovens River and, based on our conceptualisation study, implications for flow management. The work in the first year will be applicable to the forested floodplains in the southern-connected Basin, but work in subsequent years and described in the MYRP in Activity 2.4 will inform the process for extrapolating to the Basin scale.

How will the outputs be used?

The data will be used to:

- inform both refinement of the ACEAS model and development of new models
- inform the development of conceptual models within the Fish Theme
- develop adoption outputs describing the management implications of the findings.

Timelines

The timeline for this Activity consists of:

Table 6-2. Schedule of tasks for Activity 2.1.

Year	Month	Activity	Responsible
2016–17	November	Liaise with Fish Theme regarding design and permits	MDFRC
	December	Undertake sampling in Ovens River	MDFRC
	February–July	Sample analysis (Stable Isotope Analysis, Fatty Acids, Amino Acids, calorific values)	MDFRC
2017–18	August	Data analysis and presentations to riverine managers	MDFRC
	October	Field trip planning in collaboration with Fish Theme	MDFRC
	November	Field sampling	MDFRC
	January	Field sampling preparation	MDFRC
	February	Field sampling	MDFRC
	February–July	Analysis of October/November and February samples	MDFRC
	February–August	Sample analysis (SIA, FA, AA, calorific values)	
2018–19	September	Data analysis and presentations to riverine managers	MDFRC
	October	Field trip planning in collaboration with Fish Theme	MDFRC
	October–November	Field sampling	MDFRC
	December–March	Sample analysis (SIA, FA, AA, calorific values)	
	April–June	Data analysis and preparation of manuscripts and final report	MDFRC

Communication

We will work closely with the MDB EWKR project Leadership Group to identify appropriate communication strategies for this activity. At a minimum, we intend to give regular (at least annual) updates to key stakeholder groups including the Murray Valley Environmental Watering Advisory Group and the Southern Connected Basin Environmental Watering Committee.

Activity 2.2 — Waterbird field program

Objective

To quantify the food resources chicks require to recruit.

Description

The Waterbirds Theme have summarised existing information on diets of waterbirds, including some gut content data, and most waterbirds have been allocated to a feeding guild (e.g. piscivorous, herbivorous). While useful, this data does not currently identify the basal resources on which the waterbirds rely or changes in prey type that may be associated with changes in available habitat. An improved understanding of these issues will help identify ways in which managers can better target environmental flows to those habitats critical to the provision of food for waterbird chicks. The Food Webs Theme will work with the Waterbirds Theme to collect samples that will enable identification of prey and use imagery from nest cameras to quantify feeding behaviour, which will provide estimates of the amount of material required to successfully fledge chicks. The Waterbirds Theme does not have the resources to analyse the imagery to quantify feeding frequency and so this activity will be undertaken by the Food Webs Theme.

Approach

In 2016–17, the Waterbirds Theme intend to collect regurgitate from about 40 individuals and visually identify the prey items in the regurgitate at Barmah Forest. Regurgitate, larval fish, zooplankton and basal resources collected by the Food Webs Theme (see above) will be analysed for bulk stable isotope content and fatty acid and amino acid composition. Calorific and nutritional (fatty acid and amino acid) value of prey will be determined. This analysis will be able to provide information on the amount of energy required to fledge a chick, when integrated with data from the motion-sensitive cameras collected by the Waterbirds Theme. We will appoint a summer cadet to determine water bird feeding frequency using motion-sensor camera photographs. Sampling is focussed on 2016 because of the opportunity to sample during a natural flooding event.

Outputs

1. Empirical data that expresses relative magnitudes of energy pathways supporting waterbird recruitment
2. A manuscript for submission to a scientific journal for 2016–17. Further outputs for subsequent years will depend on the outcomes from the activities in 2016–17.

How will the output be used?

The data will be used to inform both refinement of the ACEAS model and development of new models. The data and model outputs will also inform managers how to use environmental water at their sites to maximise energy production for bird breeding success.

Timeline

The timeline for Activity 2.2 consists of:

Table 6-3. Schedule of tasks for Activity 2.2.

Year	Month	Activity	Responsible
2016–17	November	Appoint summer cadet to undertake bird feed frequency analysis on images supplied by the Waterbirds Theme	MDFRC
	December–March	2016 Straw-necked Ibis chick feeding frequency analysis	MDFRC

	January	Receive regurgitate samples from Waterbirds Theme	UNSW
	January–April	Analysis of regurgitate samples from Waterbirds Theme	MDFRC
	June	Manuscript preparation	MDFRC
2017–18	July	Hold point	MDFRC

Hold point. The hold point has been included at the end of 2016–17 to evaluate the outcomes of this activity and to review investment in 2017–18 and 2018–19.

Description

This program includes activities that will be undertaken in collaboration with the Waterbirds Theme.

Communication

The results of this activity will be communicated to the science community through publication of the manuscript. We will use the network and tools developed by the Waterbirds Theme to disseminate these results to water and site managers responsible for waterbird breeding success.

Activity 2.3 — Basal resource transfer efficiency to first order consumers (mesocosm experiments)

Objective

To determine energy production and rates of transfer into the food web.

Description

Understanding the way that basal resources are assimilated into the food web and the efficiency with which this material is transferred through the food web will improve our ability to predict the outcomes of environmental flows. The review of our understanding of the influence of flow on food webs identified that:

- changes in the number of trophic steps will affect the amount of food available to support animal populations
- variations in food quality may influence an animal's capacity to grow or reproduce.

Examining these relationships in natural systems is not practical due to high levels of variation in response to a range of drivers, and technical challenges in terms of both manipulating the system and collecting appropriately quantitative samples. Mesocosms provide a means of controlling the environment and collecting representative samples.

Approach

Experiments will be undertaken in replicate 75 L tanks, which will be stocked with natural communities of zooplankton from the Murray River. To evaluate the utilisation and transfer efficiency of different basal resources, a range of substrates (leaf litter, woody debris, macrophytes, wood blocks with biofilms) will be added to the tanks, which will enable identification of the critical basal resources supporting zooplankton productivity in lowland rivers and the relative efficiency with which this is converted to zooplankton biomass.

The experiments will complement experiments undertaken by the Fish Theme. The Fish Theme experiments seek to quantify the influence of food and temperature on larval fish growth and mortality. The Food Web experiments will seek to quantify the influence of basal resources on the zooplankton community. Integrating the outcomes of the two series of experiments will enable identification of the influence of flow on the food chain that links basal resources to larval fish.

Quantitative subsamples for zooplankton community, Chlorophyll *a* and DOC analysis will be taken periodically. At the end of the experiment, the Microcrustacea will be harvested from the tanks, identified, dried and weighed and analysed for stable isotope analysis.

Stable isotope analysis will be undertaken to identify the mix of basal resources that zooplankton have been assimilating. Differences in DOC concentrations at the beginning and end of the experiment and differences in zooplankton biomass will be used to estimate transfer efficiency. Transfer efficiency for individual microcrustacean groups can be estimated from zooplankton counts and published weights for individual zooplankton (Nielsen et al, 2016). The nutritional value of DOC (calorific value, fatty acid composition and amino acid composition) from the different sources will be determined from freeze-dried litter extract.

These mesocosm experiments will be carried out in year 1 and 2 in order to make funds available for the broad research program associated with flooding in 2016.

Timelines

Table 6-4. Schedule of tasks for Activity 2.3.

Year	Month	Activity	Responsible
2017	January–February	Prepare for mesocosm experiment	Post-doc
	March	Conduct mesocosm experiment	Post-doc
	April–July	Sample analysis	Post-doc
2017–18	July–November	Data analysis and preparation of manuscript (output)	Post-doc
	December	Hold point	Post-doc

Hold point. The hold point will provide an opportunity to review whether additional mesocosm experiments will be undertaken in 2018.

Outputs

Empirical data that expresses relative magnitudes of energy pathways to taxa of interest

How will these outputs be used?

The output from this activity will inform future model development (Activity 4). The manuscript will provide the basis for presentations to managers and development of summary material to be made available through the web page or Collaboration Space.

Communication

The results of this activity will be communicated to the science community through publication of the manuscript.

Activity 2.4 — Basin-scale resource use by fish larvae

Objective

To determine the extent to which the patterns observed in field sampling in the southern Basin can be applied across the Basin.

Description

The field measurements collected in the Ovens River and the laboratory experiments will provide useful information about the basal resources supporting fish recruitment. The extent to which these results can usefully be applied to other sites will remain uncertain without field sampling at a range of sites across the Basin. This activity seeks to capitalise on the monitoring of fish larvae being undertaken by the CEWO LTIM project, and the Basin scale recruitment project to be undertaken by the Fish Theme.

The LTIM project is sampling fish larvae at four sites across the Basin (Murrumbidgee, Edward–Wakool, Lachlan and Goulburn), while microinvertebrate samples are being collected at three sites (Murrumbidgee, Warrego–Darling confluence and Gwydir). It may be possible to have the various field teams collect complementary basal resource samples to enable analysis of variations in basal resource use across the Basin. In addition, within the Fish Theme, SARDI is proposing to collect otoliths from fish sampled by the LTIM project and to undertake isotope analysis of otoliths, which will provide insight into the natal origin of the fish and the scales over which recruitment processes occur. A coordinated approach between the LTIM, SARDI and EWKR Food Web teams may enable quantification of basal resource use by larval fish from a variety of sites across the Basin in a cost-effective manner.

Approach

Achieving coordinated sampling of fish and basal resource samples across the Fish Theme and LTIM will take place thorough planning and negotiation with the various researchers involved in the projects. The first step will be to establish a working group comprised of Fish and Food Web leadership team members to develop a coordinated sampling and engagement strategy.

In terms of the sampling, the working group will use the field work undertaken in 2016 to identify the most cost effective means of collecting basal resource samples. The lessons learned will be used to develop a standard method for the collection of these samples. It is hoped that the LTIM field teams will be able to collect these, but it may be that we will need to support these sampling activities through the provision of field staff.

In terms of collaborating with the LTIM service providers, the working group will develop a plan including clear roles and responsibilities, and this plan will inform approaches to the various service providers. For those sites where personnel are involved in both LTIM and MDB EWKR (Lower Murray, Gwydir, Warrego-Darling, Edward–Wakool), it is hoped that development of an appropriate strategy will be easy to achieve. For those sites where there is no overlap (Lachlan, Murrumbidgee and Goulburn), there are existing relationships that should help facilitate a cooperative and integrated approach to the work.

Once arrangements are in place and samples have been collected, the samples will be analysed for stable isotopes, fatty acids and amino acids using the same methods used to analyse samples from the field and mesocosm activities.

Timelines

Table 6-5. Schedule of tasks for Activity 2.4.

Year	Month	Activity	Responsible
2016–17	March	Working group meeting	MDFRC
	April	Standard method development	MDFRC
	April	Engagement with LTIM service providers	MDFRC
	May	Input into 2017–18 Annual Research Plan	MDFRC
2017–18	October–November	LTIM sampling	Various

Year	Month	Activity	Responsible
	December	Sample analysis (SIA, FA, AA)	Collaborators
	March	Data analysis	Collaborators
2018–19	October–November	LTIM sampling	Collaborators
	December	Sample analysis (SIA, FA, AA)	Collaborators
	March	Data analysis	Collaborators
	April–June	Preparation of manuscripts and final report	All

Outputs

Empirical data that expresses relative magnitudes of energy pathways to taxa of interest.

How will these outputs be used?

1. The output from this activity will inform future model development (Activity 4).
2. The manuscript will provide the basis for presentations to managers and development of summary material to be made available through the web.

6.4.3 Component W3 — Identifying important sites of production

Objective and description

The objective of Component W3 is to identify areas that are disproportionally more important in delivering and/or transforming basal resources.

To achieve the objective, this component will test the idea suggested by hierarchical patch dynamic models (Thorp *et al*. 2006) that there are likely to be spaces in the landscape that are disproportionally important in space and time for primary and/or secondary production. Some of these will be sensitive to the addition of water, and, importantly, a subset of these will be accessible to fish and birds. Accessibility will be influenced by habitat characteristics (e.g. depth) and patterns of connectivity.

The Fundamental Triad model of fish recruitment (Bakun, 2010), suggests that successful fish recruitment requires patches that are enriched, accumulate resources and retain larval fish. The implication being that patches where these processes coincide are disproportionately important in terms of both food availability and providing suitable habitat for larval fish.

It appears likely that similar principles apply to waterbird foraging habitat. As noted earlier, models of lowland river functioning are not well suited to identifying these critical spatial and temporal nodes. However, a model for predicting spatial and temporal nodes has been developed for biogeochemical cycles in riverine systems, which has the potential to be adapted to the study of trophic interactions in lowland rivers. McClain *et al.* (2003) propose a model, which posits that some patches are disproportionally more important in the biogeochemical cycling of nutrients (like carbon and nitrogen) under specific conditions. These patches occur where 'hydrological flowpaths converge with substrates [chemical reactants] or other flowpaths containing complementary or missing reactants. The period over which the patch is productive is often short and occurs when episodic hydrological flow paths reactivate and/or mobilise accumulated reactants' (McClain *et al.* 2003). It is possible to identify places and times that contribute disproportionally to the flow of energy through food webs.

Based on this premise, there are a number of additional questions that can be answered:

a. Do these spaces exist within the landscape?

b. Which and when are the most critical patches for birds and fish?

Are there temporal or spatial discontinuities in what is a productive space for basal resources and the consumers of interest?

This component will seek to identify areas that are disproportionally more important in delivering and/or transforming basal resources. In terms of recruitment for both fish and waterbirds, it is believed that inundation is associated with the creation of a shifting spatio-temporal mosaic of foraging habitats (Reid *et al.* 2009, Brandis *et al.* 2011). An improved understanding of this mosaic and the critical habitats and associated resources they provide will improve managers' ability to target environmental flows at those habitats that provide the best outcomes for these taxa.

In terms of fish recruitment, the influence of flow on microinvertebrates is critical. There has been considerable work on the effects of changes in flow on microinvertebrates that has shown that higher current speeds favour rotifers while slow current speeds favour crustaceans. Given these preferences, slackwater habitats are associated with a higher diversity and abundance of microinvertebrates (Ning *et al.* 2010). The Fundamental Triad hypothesis suggests that the critical habitats will be those that provide the right physical conditions to support concentration and retention of zooplankton and their food resources.

Using the information gained from identifying the critical basal resources and existing knowledge of the zooplankton habitat requirements, the leadership team should be well placed to predict the areas and flow conditions likely to promote areas of high zooplankton abundance and productivity. With these hypotheses in place, it will be possible to design a further field sampling program to test the hypotheses. This activity will be undertaken in collaboration with the Fish Theme.

Approach

Component W3 focusses on spatial variability in the data from Component W2**.** Once the key basal resources have been identified for microinvertebrates, it will then be possible to assess whether there are areas that contribute disproportionately to the provision of food to larval fish. These areas could arise from either areas of high:

- primary production or decomposition
- concentration or retention of zooplankton.

Once the key basal resources have been identified for waterbird chicks, the information will be integrated with data from the Waterbirds Theme on the locations of important foraging habitats to design a sampling program to evaluate the key characteristics of these areas. There are several possibilities, including that they are sites:

1. of high productivity for the identified basal resource
2. that are typically productive for the basal resource, with preferred hydraulic characteristics
3. of above average rates of transformation of the identified basal resource (e.g. preferred habitat for prey)
4. that support typical rates of production of the basal resource, with preferred hydraulic characteristics (prey are easily found or caught).

Outputs

1. Empirical data that assesses potential spatial and temporal variability in determining productivity (Q1B, Q1C, Q1E)
2. Generalised identification of types and spatial extent of productive areas that may be enhanced by the provision of environmental flows (Q2B)

The cost of this analysis has been included in the work program outlined above (2.1).

Timelines

Detailed timelines for this activity will be developed for the 2017–18 Annual Research Plan.

6.4.4 Component W4 — Modelling bioenergetics within production sites

This activity will take the outcomes of the other work and existing knowledge to improve our capacity to predict the outcomes of environmental flows in terms of their influence on food webs.

Approach

The overall outputs for this activity at project end will be:

1. models that express relative magnitudes of energetic responses to flow
2. models that assess potential spatial and temporal variability in determining productivity
3. an assessment of the potential role of covariates (invasive species, water chemistry, turbidity, substrate availability) in determining productivity of different habitats in relation to flow.

In the conceptualisation stage of the project, a review of modelling approaches was completed. Based on this, the Leadership Group have agreed to focus on spatially explicit bioenergetics modelling that will support flow scenario modelling.

The first steps in the modelling will be to update the code for Murray River fish (ACEAS) model and then facilitate its publication. The ACEAS model is a bioenergetic model that predicts the biomass of fish that can be supported under different flow scenarios. Publication and refinement of the model will enable the project team to test hypotheses about the outcomes of environmental flows, as well as to incorporate the model's key ecological relationship into the models that will be developed by the Food Webs Theme. The outputs from the ACEAS model and subsequent Food Webs Theme models will be used to evaluate the outcomes of various flow management options, which can then be communicated to managers and help inform their flow management decisions.

This model, which specifically links flow with native fish outcomes, was identified during the modelling review process as a potentially very useful tool for river managers. Although at this stage, it is still a research tool that integrates information on hydrology and floodplain inundation, together with information about rates of primary production in the channel and on the floodplain, and couples that with food web information, to produce predictions about the capacity of the system to support higher consumers such as fish. These questions are fundamental to the Food Webs Theme, but require a quantitative framework such as the ACEAS model in order to integrate these different data sources.

The model was developed by a number of people associated with MDB EWKR, with the lead author being Nick Bond. However, in its current form the model requires experience using the 'R' programming language. Part of the update will help to ensure that a broader range of end users can use the model without the need to understand R.

With very limited funding, the model can be updated and made available for immediate use by water managers. By funding the completion of the model through the MDB EWKR project, it will be possible to very quickly have a tool available to water managers linking flows with food web outcomes; especially as other modelling products from the theme will take time to develop and refine. The output will be a joint ACEAS-MDB EWKR product.

The main reason for the update is to provide the necessary documentation and quality assurance (via publication of the model and its application) to other scientists as much as to water managers. Since 2013, the interest in the types of questions this model can help answer has increased dramatically, both among scientists and water managers. The model was developed with input from the Murray–Darling Basin Authority, Arthur Rylah Institute and NSW Fisheries, and completing the model has been supported by organisations including Mallee Catchment Management Authority and NSW Office of Environment and Heritage.

Once completed, we will host a workshop to evaluate the remaining modelling options within the context of the anticipated outputs from the other three research themes and the finalised ACEAS model. This will include drafting alternate model structures, in order to evaluate both the suitability of the different approaches and identify those knowledge gaps that will be filled within the MDB EWKR program.

Timelines

Table 6-6. Schedule of tasks for Component W4.

Year	Month	Activity	Responsible
2016–17	November	Finalise contracts for ACEAS work	CSU
	December–March	ACEAS model manuscript	CSU
	December–March	Refine ACEAS model code	University of Melbourne (UoM)
	March	Complete manuscript describing ACEAS model	CSU
	March	Make refined ACEAS model code available	UoM
	April	Food web modelling workshop	Deakin
	May	Outcomes of review used to inform development of 2017–18 Annual Research Plan	Deakin/MDFRC
2017–18	July	Hold point	

Hold point. A hold point has been included at this point because, while the theme sees modelling as a key pathway to adoption of the research and a way to integrate all of the information generated in Activities 1-4, the exact nature of the models (and therefore the approach and resources needed to complete the models) is still not confirmed. Depending on the outcomes of the review, ACEAS model development and workshop, a decision will be made about activities to be included in the 2017–18 workplan and whether MDB EWKR will continue to invest in model development.

Outputs

The output from this activity in 2016–17 will be a manuscript for submission to a scientific journal, a complete set of code for predicting native fish outcomes based on area of floodplain inundated, and a blue-print for modelling activities in 2017–18 and 2018–19.

How will these outputs be used?

The completed ACEAS model can be used by water planners to inform their environmental watering decisions. The output from the workshop will inform future model development (Activity 4).

Communication

The results of this activity will be communicated to the science community through publication of the manuscript. In addition, the theme will present the results of the pilot study to the Murray Valley Environmental Watering Advisory Group and the Southern Connected Basin Environmental Watering Committee.

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7 Attachments

Attachment A — Research priorities

MDB EWKR will undertake research that seeks to improve the understanding of the core processes that drive the achievement of biotic outcomes sought by the Basin Plan, including the impacts of pressures and stressors.

The Basin Plan seeks to achieve a healthy working Murray–Darling Basin, predominantly through the recovery of water for the environment. Environmental works and measures (including sustainable diversion limit (SDL) adjustment 'supply measures') and constraints management activities will also contribute to achieving a healthy working Basin. These 'water management levers' influence the hydrology of the Basin's rivers, wetlands and floodplains, which in turn influences physical and functional process, and which subsequently drive the biotic outcomes (Figure 5). Pressures and stressors can affect the biotic outcomes, either directly through impacts such as predation or grazing, or indirectly through impacts on the physical conditions (e.g. water quality impacts) or functional processes (e.g. restricting movement and dispersal).

The proposed priority research areas for MDB EWKR were identified by applying a framework that breaks down the biotic outcomes shown in Figure 5 into relevant component parts (e.g. life-history stages) and supporting processes. The objectives for MDB EWKR were then expressed as prioritisation principles to guide the selection of priorities at each step in the framework. The prioritisation process was strongly guided by the environmental objectives of the Basin Plan (as expressed in the environmental outcomes framework developed under the Commonwealth Environmental Water Office's Long Term Intervention Monitoring (LTIM) project) and the environmental outcomes described in the MDBA's Basin-Wide Environmental Watering Strategy (BEWS).

The principles guiding the selection of research priorities were that research:

4. must be of management relevance now and into the future (alignment with the Basin Plan objectives, and particularly the BEWS outcomes will support this)
5. will focus on the links between ecological responses to individual flow events, and medium-to-long term environmental outcomes from environmental watering
6. will focus on key knowledge gaps where further knowledge has the capacity to significantly enhance environmental watering
7. will focus on questions where it is feasible to develop or significantly improve predictive capacity in a five year timeframe.

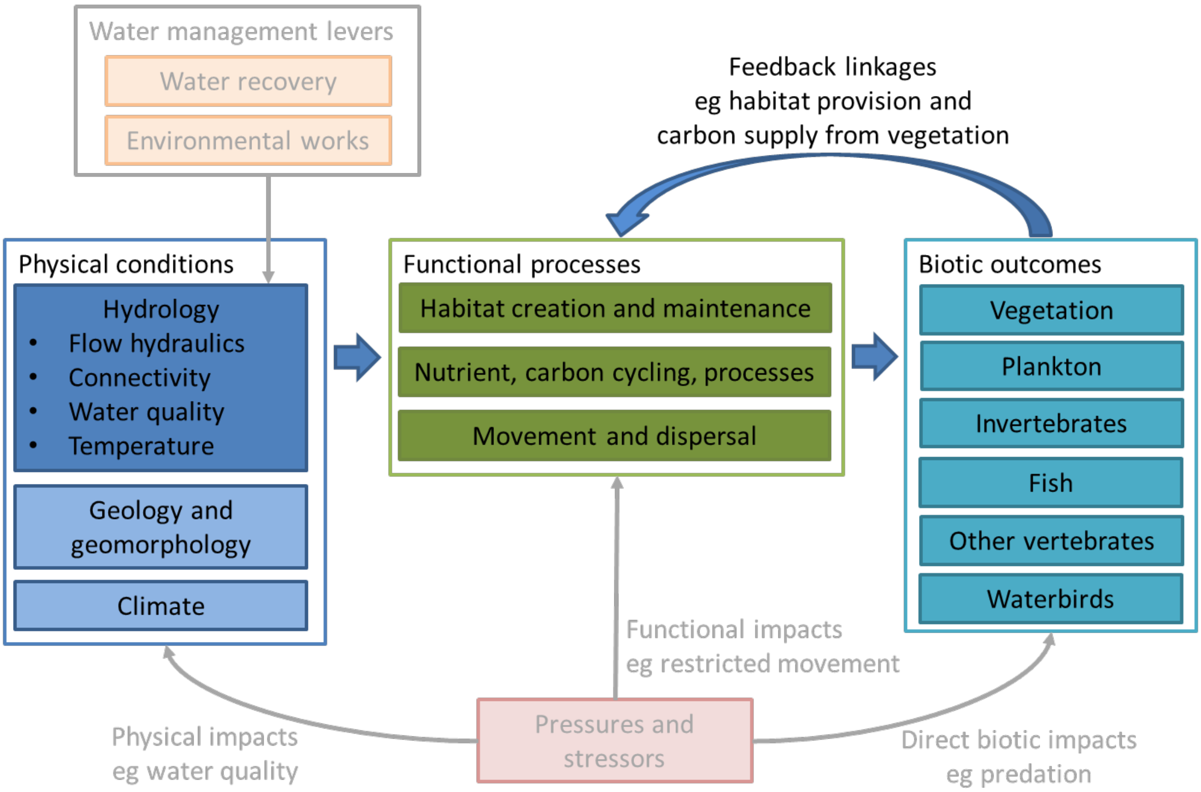

Figure 6-1. Conceptual diagram showing the influence of water management levers on physical conditions in aquatic ecosystems and the subsequent impacts on functional processes and biotic outcomes, together with the influence of pressures and stressors.

The prioritisation process identified four research themes for MDB EWKR: water-dependent vegetation, native fish, waterbirds and food web processes. Research under these themes will be planned and delivered in a coordinated manner, using a 'one-project' approach. The priority research questions for these themes are set out below. These are expressed at a relatively high level, allowing further development during the next stage of project planning, and may be refined or further prioritised during the next stage of project planning with research collaborators.

Vegetation

What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?

<u>Diversity of understorey and wetland plant communities</u>

1. What flow regimes best support the diversity of understorey and wetland plant communities?
    - How significant are the individual drivers (habitat area, habitat heterogeneity, connectivity heterogeneity, and disturbance) on diversity?
    - How do key drivers interact to influence outcomes?
    - How should flows be managed to enhance drivers and thereby diversity?
2. How do threats impact on the drivers and diversity outcomes?

<u>Survival and condition of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum)</u>

1. What flow regimes (particularly frequency, period between follow-up watering, event duration) best support the survival and condition of floodplain vegetation populations?
    - How do site characteristics (soil type, climate, and groundwater) influence these flow requirements?
2. How do threats (increased temperature, changes in rainfall seasonality) influence flow requirements?

<u>Recruitment of long-lived floodplain vegetation (River Red Gum, Black Box, Coolibah, Lignum)</u>

1. What flow regimes best support recruitment within populations of long-lived floodplain vegetation species?
    - How significant are the individual drivers (habitat availability, connectivity-dispersal) on recruitment?
    - How do key drivers interact to influence outcomes?
    - How should flows be managed to enhance drivers and thereby recruitment?
    - How do the characteristics of sites (soil type, climate etc.) influence these flow requirements?
2. How do threats impact on the drivers and recruitment outcomes?

Threats to be considered in research

Consultation activities identified the threats listed below as most significant in terms of their potential impact on vegetation outcomes across the Basin. These threats will be assessed in further detail during project planning to identify those considered most significant at the research sites, and for which further research under MDB EWKR can provide the most useful outputs to support environmental water and complimentary natural resource management, and Basin Plan reporting.

<u>Flow-independent threats</u>

- Invasive species
- Grazing
- Habitat loss/land use

<u>Flow-related threats</u>

- Climate change
- Groundwater/salinization
- Water quality

Native fish

What are the drivers of sustainable populations and diverse communities of native fish?

Survival and condition of native fish populations

1. What flow regimes best support the survival and condition of native fish populations?
   - How significant are the individual drivers (habitat availability, connectivity-movement and processes/food webs) on survival and condition?
   - How do key drivers interact to influence outcomes?
   - How should flows be managed to enhance drivers and thereby survival and condition?
2. How do threats impact on the drivers, and survival and condition outcomes?

Reproduction of native fish populations

1. What flow regimes best support the reproduction of native fish populations?
   - How significant are the individual drivers (habitat availability, cues) on reproduction?
   - Under what conditions do these individual drivers influence outcomes?
   - How should flows be managed to enhance drivers and thereby reproduction?
2. How do threats impact on the drivers and reproduction outcomes?

Recruitment of native fish populations

1. What flow regimes best support the recruitment of native fish populations?
   - How significant are the individual drivers (habitat availability, connectivity-movement and processes/food webs) on recruitment?
   - How do key drivers interact to influence outcomes?

Threats to be considered in research

Consultation activities identified the threats listed below as most significant in terms of their potential impact on native fish outcomes across the Basin. These threats will be assessed in further detail during project planning to identify those considered most significant at the research sites, and for which further research under MDB EWKR can provide the most useful outputs to support environmental water and complimentary natural resource management, and Basin Plan reporting.

Flow-independent threats

- Invasive species
- Exploitation

Flow-related threats

- Climate change
- Water quality — temperature and dissolved oxygen
- Seasonal flow reversal, particularly through increases in inter-valley tra

Waterbirds

What are the drivers of sustainable populations and diverse communities of waterbirds?

Recruitment of waterbird populations

1. What flow regimes best support the recruitment of waterbird populations?
   - How significant are the individual drivers (habitat availability, connectivity-movement and processes/food webs) on recruitment?
   - How do key drivers interact to influence outcomes?
   - How should flows be managed to enhance drivers and thereby recruitment?
2. How do threats impact on the drivers and recruitment outcomes?

Threats to be considered in research

Consultation activities identified the threats listed below as most significant in terms of their potential impact on waterbird outcomes across the Basin. These threats will be assessed in further detail during project planning to identify those considered most significant at the research sites, and for which further research under MDB EWKR can provide the most useful outputs to support environmental water and complimentary natural resource management, and Basin Plan reporting.

Flow-independent threats

- Invasive predators
- Habitat loss

Flow-related threats

- Climate change

Food webs

The role that floodplain connectivity plays in mobilising carbon and nutrients (from vegetation and soils), and the contribution that this carbon and nutrients provides to support aquatic food webs and ultimately outcomes for fish and waterbirds was a key question posed by both environmental water managers and researchers. Accordingly, food webs is proposed as a fourth research theme.

The Food Webs Theme will pick up relevant aspects of the research priorities identified in the Native Fish and Waterbirds themes above. By grouping these related components under a separate theme, it will allow them to be explored more effectively using targeted resources and expertise. The linkages and boundaries between these themes (Food Webs and Fish/Waterbirds) will require detailed consideration in project planning to ensure activities remain coordinated.

Proposed research questions

1. What flow regimes best support food webs that contribute to outcomes for native fish and waterbirds?
    - How do food web processes and the dominant carbon-nutrient-energy pathways vary according to flow conditions?
    - How significant is floodplain inundation and the associated carbon-nutrient cycling to the achievement of biotic outcomes?
    - Under what conditions do food web processes drive outcomes, compared to other processes?
    - How should flows be managed to influence food webs to support native fish and waterbird outcomes?
2. How do threats impact on food web processes and the achievement of native fish and waterbirds outcomes?

Attachment B: Approach to research at the four research sites

A key requirement within the Murray–Darling Basin Environmental Water Knowledge and Research project (MDB EWKR) funding agreement is that the project will undertake research at up to four sites within the MDB. It is important that there is consistency around how this requirement is interpreted for the development and implementation of the Multi-Year Research Plan (MYRP).

This paper seeks to identify and avoid any issues that may potentially arise when assessing whether the MYRP complies with the contract, by clarifying the interpretation of the four site-requirement as agreed upon by the MDFRC and the Department.

Context

The MDB EWKR project is designed to support environmental water management, and thereby contribute to achieving Basin Plan objectives, which are set at the Basin scale. Thus, the MDB EWKR contract requires that the research be conducted 'at up to four aquatic asset sites/river reaches in key geographical locations in the northern and southern Murray–Darling Basin' in order to ensure that the project generates knowledge that has Basin-wide relevance and applicability. Further, the agreement requires that the project 'Apply consistent research methods within the project to enable comparison of results within and between research sites, both spatially and temporally, as appropriate, and to ensure tools developed provide consistency and compatibility.' Within this context, the four sites were selected, in consultation with managers, using the following criteria:

1. Recognised environmental significance, including in relation to the priority questions
    a. recognised values at the Basin scale
        i. Vegetation
        ii. Fish
        iii. Waterbirds
    b. formal recognition of significance — Ramsar listing and The Living Murray icon site
    c. other indicators — likely achievement of criteria for identifying environmental assets (Schedule 8 of the Basin Plan)
2. Existing data and knowledge to support the research questions and activities
    a. availability of hydraulic modelling
    b. historical modelling
    c. past monitoring of responses to watering actions
3. Alignment and opportunities to complement and add value to current and future monitoring programs
4. Geographic spread of sites.

Rationale

The MDB EWKR project was funded to support the management of environmental flows in support of achievement of Basin Plan objectives. Given that environmental flows are delivered to specific areas of the Basin for limited periods of time, the requirement to undertake research at four sites is not to support management of environmental flows at the Basin scale. The four site-requirement was included to ensure that the outputs of the research would support environmental flow management across the Basin and their application would not be constrained to only parts of the Basin. The four sites should allow the effects of different environmental watering regimes on a wide range of different biological, functional and hydrological characteristics to be studied.

In light of this, the MDB EWKR project should plan and undertake research to improve predictive capacity across the Basin. The four sites become an important component in providing guidance in how project outputs can be most effectively applied at different areas across the Basin. A major benefit of undertaking research at all four sites will be to confirm that the same drivers are in play within different environmental settings. If different drivers are important in different areas, then outputs developed at one site will not be applicable to other sites.

As a consequence of this, it will be important that variation in responses to flows be explicitly considered in the conceptualisation process, as this will provide a foundation for determining the activities and relative effort to be expended at the four sites. Approval of the research plans and the proposed activities at the four sites will depend on consideration of the variation among the sites and the implications for applying the proposed predictive capacity at each site and then the Basin more broadly.

Agreed interpretation of the four site-requirement

In light of the above, MDFRC and the Department have discussed and agreed on how the four site-requirement should be interpreted at both the theme and project levels:

- ***Wherever possible, research activities should be undertaken at the four selected sites*.** There are two major reasons for this:
    a. the sites were selected to support achievement of the project objectives in a cost effective manner, building on the existing data available for the sites
    b. use of the sites across the themes will facilitate integration across the themes.

- ***Research activity across the sites should ensure that it supports achievement of the project's objective of improving predictive capacity across the whole Basin.*** As a consequence, investment in on-ground research within each of the four MDB EWKR sites is expected to support achievement of this objective.
- ***All themes are not expected to undertake research at all four sites.*** Requiring all themes to do research at all sites would likely compromise the project's capacity to achieve its objectives. Firstly, the project themes have limited resources and spreading these across all four sites may reduce the value of the research overall. Secondly, the selected sites do not have equal significance to all four themes. For example, the Lower Murray site is not recognised as being a significant waterbird breeding site and so Waterbirds Theme activities should select and focus on the subset of sites that will allow it to best deliver on project objectives.
- ***Themes are unlikely to expend equal effort across all the sites at which they undertake research.*** If the theme research plans clearly demonstrate that research outputs will improve predictive capacity across the Basin, and that greater investment at one or two of the sites is the most cost effective means of achieving this objective, then equal effort would not be required.
- ***Themes need to apply consistent research methods across the sites at which they are active; however, this does not mean that the same suite of activities will necessarily be undertaken at each active site.*** If themes' investment is not equal across sites (i.e. due to dot point 3 above), then it is possible that not all methods will be employed across sites. It is expected that those methods that are undertaken at multiple sites would be standardised and consistent.
- ***Components of work that utilise existing datasets would be expected to use any relevant and available MDB data, and are not limited to datasets from the selected sites.***

Attachment C: In-channel versus overbank flow

Purpose

To provide a rationale for the types of flow (in-channel versus overbank) on which the MDB EWKR theme research will focus.

Issue

The project needs to ensure it focusses on areas of management interest, to ensure that the outputs lead to improvements in management decision making. Ensuring that the project meets its objectives includes consideration of the types of flow that the project chooses to focus on.

Background

In their review of the draft Multi-Year Research Plan (MYRP) in August 2015, the Science Advisory Group (SAG) has recommended that the project focus on overbank flows due to their importance in sustaining healthy rivers. In acknowledging the project’s response to this advice, consideration needs to be given to the effect that focussing on overbank flows would have on the project’s ability to achieve its objectives. In considering the recommendation, it has become apparent that there may be a trade-off between a focus on the flows that are most frequently delivered by managers (in-channel) and those recommended by the SAG (overbank). This issues paper explores the ramifications of this trade-off for the MDB EWKR project in order to ensure that both the project team and external stakeholders can be informed of the project’s focus and approach to achieving its objectives, including its relevance to management.

Discussion

The pros and cons of focussing on in-channel versus overbank flows are summarised in Table 6-7. To some extent, however, the issue has been resolved in the choice of questions, in that the Waterbird and Vegetation themes will have a focus on overbank flows because wetlands and floodplains are the critical habitats supporting vegetation diversity and waterbird recruitment, respectively. The Fish Theme has a focus on in-channel recruitment. This may include both overbank and within-channel flows if the overbank flows have an influence on in-channel recruitment.

It would appear therefore, that providing a recommendation on whether to focus on in-channel or overbank flows may actually provide a distraction to the research teams and that their prime objective should remain answering the research questions they have been set. The implications for each of the themes are then:

- Vegetation: continues to focus on overbank flows, but should consider in-channel habitats within their overall portfolio
- Fish: continues to focus on in-channel habitats with the potential to examine the influence of both in-channel and overbank flows
- Waterbirds: continues to focus on overbank flows
- Food Webs: will include a mix of overbank and in-channel flows as required to support the Fish and Waterbirds themes.

Table 6-1. Summary of the issues associated with focussing on in-channel and overbank flows for several key criteria and for each of the MDB EWKR themes.

Criteria	**In-channel**	**Overbank**
Management relevance	Most flows delivered in-channel	Operationally, managers have a limited influence over large floods; however, overbank flows are the focus of sustainable diversion limit (SDL) measures and constraints management, and will be important in the evaluation of the outcomes of environmental flows
Ecological significance	Influences habitat and refuge availability and longitudinal connectivity within the channel	Major driver of habitat, connectivity and function for in-channel, wetland and floodplain habitats
Predictive capacity	Many opportunities for field data — gradient analysis	Limited opportunities for field data — flood vs. no flood
	Outcomes variable — opportunities to explain variation in expected/unexpected outcomes	Outcomes variable — explanation would require speculation due to large number of factors that vary and the limited number of observations
	Improvements in predictive capacity and alignment with management levers	Improvements in predictive capacity are hard to forecast due to the outcomes of floods being uncertain
Vegetation	Minor	Critical
Fish	Focus of current planned research	Believed to be an important driver
Waterbirds	Minor	Critical
Food webs	Important for fish	Important for waterbirds and potentially fish
Integration	Important	Important

Recommendation

It is recommended that the MDB EWKR project focus on answering the questions developed through the Phase 1 consultation process as this will:

- Ensure management relevance as the questions were derived through engagement with managers.
- Guide the types of flows that will be considered. In the case of fish recruitment (Fish and Food Webs themes), the focus will remain in channel, however if:
    - the conceptualisation process identifies overbank flows as being a priority
    - opportunities to examine the influence of overbank flows occur, and
    - the research links clearly back to available management levers, then
      overbank flows will be among the flows examined by the research.