Murray–Darling Basin Environmental Water Knowledge and Research Project

Annual Research Plan 2016–17

Prepared by: The Murray–Darling Freshwater Research Centre

December 2016

Final Report

MDFRC Publication 121

Murray–Darling Basin Environmental Water Knowledge and Research Project Annual Research Plan 2016–17

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: The Murray–Darling Freshwater Research Centre (2016) Murray–Darling Basin Environmental Water Knowledge and Research Project Annual Research Plan 2016–17. Final Report prepared for the Department of the Environment and Energy by The Murray–Darling Freshwater Research Centre, MDFRC Publication 121/2016, December 2016, 45pp.

Cover Image: Cumbungi

Photographer: David Wood, MDFRC

Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
Draft V1	27 May 2016	Jessica Davison	Ben Gawne	Initial Internal Draft
Draft V2	17 June 2016	Jessica Davison	Ben Gawne	Revised Internal Draft
Draft V3	6 July 2016	Jessica Davison	Ben Gawne	Internal Final
Draft V4	19 July 2016	Jessica Davison	Ben Gawne	Final
Update Dec_16	20 December 2016	Jessica Davison	Ben Gawne	Final draft
Final	20 January 2017	Jessica Davison	Ben Gawne	Final

Distribution of copies

Version	Quantity	Issued to
Draft V2	1 x Word	Anthony Moore and Nadia Kingham, Department of Environment
Draft V3	1 x Word	Anthony Moore and Nadia Kingham, Department of Environment
Draft V4	1 x Word	Anthony Moore and Nadia Kingham, Department of Environment
Update Dec_16	1xWord	Anthony Moore and Nadia Kingham, Department of Environment and Energy
Final	1xPDF	Anthony Moore and Nadia Kingham, Department of 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 5 ARP (Dec update_16)\FINAL
Author(s):	The Murray–Darling Freshwater Research Centre
Author affiliation(s):	The Murray–Darling Freshwater Research Centre, University of Canberra
Project Manager:	Jessica Davison
Client:	Department of Environment and Energy
Project Title:	Murray–Darling Basin Environmental Water Knowledge and Research Project Annual Research Plan 2016–17
Document Version:	Final
Project Number:	M/BUS/465
Contract Number:	N/A

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.

Contents

1 Introduction

About the project

The Murray–Darling Basin (MDB) Environmental Water Knowledge and Research (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 project aims to collaborate with water managers, environmental asset managers, water planners, scientists and relevant community groups to identify research priorities, and undertake research targeted at addressing those priorities.

Annual Research Plan 2016–17 — December 2016 Update

The Annual Research Plan 2016–17 — December 2016 Update (this document) describes the proposed research activities for the second half of the 2016–17 financial year. The plan represents the outcomes of the process initiated by the Science Advisory Group's (SAG's) feedback on the draft Multi-Year Research Plan (MYRP). The SAG recommended that the four research themes (Vegetation, Fish, Waterbirds and Food Webs) undertake a comprehensive literature review and conceptualisation process that would lead to a revision of the MYRP. This process commenced in 2016 and has continued into the 2016–17 financial year. The process and its outputs have informed the revision of both the MYRP and this Annual Research Plan (ARP).

The ARP proposes activities under four research themes (Vegetation, Fish, Waterbirds and Food Webs) (refer to Figure 1). The research themes seek to address priority research questions determined through a process of consultation with end-users of the research (environmental water managers and environmental asset managers) and researchers working in the Murray–Darling Basin.

The ARP is to be supported by a number of other documents including:

- the Phase 1 Scoping Report, which describes the research planning process, and other Phase 1 reports that describe the planning process in more detail
- the Phase 2 Project Plan, which outlines project management, governance and administrative arrangements
- a Communications and Adoption Strategy
- the Evaluation Strategy
- the MYRP, updated in December 2016.

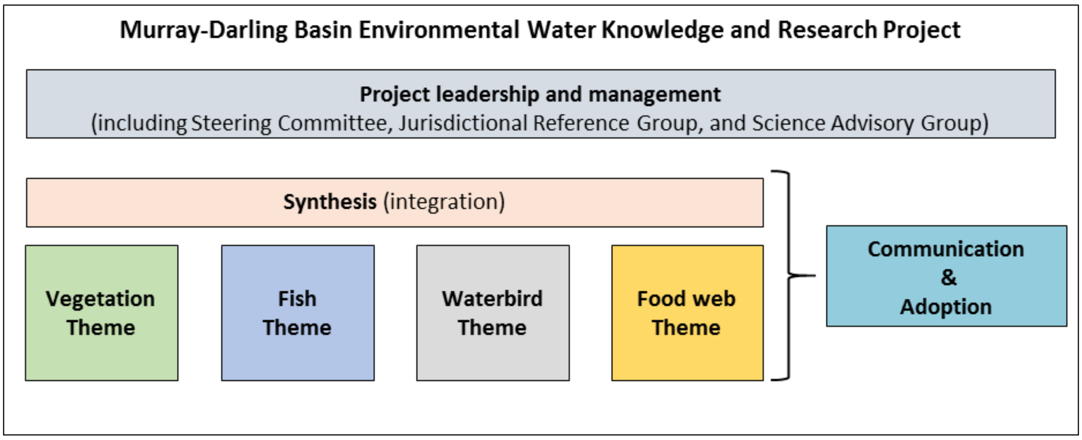

Figure 1-1. Structure of MDB EWKR showing themes and other major components.

As the second year of research activity under MDB EWKR, this Annual Research Plan commences with the completion of the conceptualisation process and the focus moving to the research activities that are anticipated to include a mix of analysis of existing data, field measurements and laboratory experiments. The conceptualisation process has provided a strong foundation for research under the project, as well as valuable research outcomes in their own right (e.g. through the synthesis of existing research and data to inform environmental water management).

2 Vegetation

Authors: Cherie Campbell (The Murray–Darling Freshwater Research Centre (MDFRC)), Sam Capon (Griffith University), Cassandra James (James Cook University), Kay Morris (Arthur Rylah Institute), Jason Nicol (South Australian Research and Development Institute (SARDI)), Daryl Nielsen (MDFRC), Rachael Thomas (NSW Office of Environment and Heritage (OEH))

2.1 Introduction

The Vegetation Theme will enhance our understanding of the effect of flow on wetland and floodplain plants, and how modifiers (e.g. land use, grazing, climatic conditions) influence predicted outcomes from the use of environmental water. Wetland and floodplain plants provide refuge, breeding habitat and an important food source for a wide range of organisms, contribute to ecosystem services (e.g. nutrient and carbon cycling, 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 influence predicted responses.

Research undertaken on the 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.

The Vegetation Theme links through to the Fish, Waterbird and Food Web themes through the provision of energy to support food webs; the provision of habitat and dispersal corridors for fauna; reducing erosion and nutrient run-off; and enhancing water quality. In line with the Priority Research Questions agreed to by the Project Steering Committee (PSC), 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)).

Research priorities have been refined during planning and conceptualisation phases of this project. Please refer to the Refinement of Research Priorities section in the Vegetation Theme chapter of the Multi-Year Research Plan (November 2016) for further details.

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.

2.2 Description of work components

This Annual Research Plan 2016–17 describes the work components that will be undertaken in 2016–17. This plan should be read in conjunction with the Multi-Year Research Plan, which describes the proposed research over the life of MDB EWKR (to 2018–19).

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 (Lower Murray, Upper-Murray, Macquarie Marshes, Lower Balonne). 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.

2.3 Work components and Activities

This section of the ARP provides more detailed descriptions of the activities planned for 2016-17. All activities will be overseen collaboratively by the Leadership Group. Each activity will be led by a member of the Leadership Group in collaboration with other Group members as well as any additional organisations/staff that may be required.

2.3.1 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 research planning. The need for this component arose, in part, from early discussions around defining what was meant by 'vegetation response'. 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 influence predicted responses. In addition, there 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 effect 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

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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.

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.

Activities to date

- Identify, compile and initially review existing conceptual models relating to understorey diversity
- Conceptualisation process reviewed and developed at the Vegetation Theme research workshop (19–20 May 2016)
- Outputs from conceptualisation process discussed with regard to linked activities, particularly Data Integration and Synthesis and Fieldwork Planning
    - particularly regarding the continuation of common themes, such as considering vegetation responses across multiple scales of organisation (e.g. species, communities, vegscapes), multiple types of vegetation traits (e.g. compositional, structural and process) and linking responses to the functional role of vegetation
- Paper outline drafted and tasks assigned to Leadership Group members.

2016–17 objective(s)

- Finalise conceptual framework
- Present outcomes:
    - to the MDB EWKR SAG
    - at the Australian Society for Limnology Conference
    - to water managers
- Incorporate outcomes into the MYRP
- Develop scientific paper(s) and summary paper/fact sheets for managers

Description of 2016–17 activities

The conceptual framework will be finalised with contributions from all members of the theme Leadership Group and will be supported by reference to the existing literature. A series of fact sheets (or other management-focused outputs) will also be developed to communicate the application of the framework to example communities. The key aspects of the conceptual framework will be applied to other activities such as the Data Integration and Synthesis Component and Fieldwork Planning.

Roles

The conceptual framework, scientific paper and fact sheets will be developed by the Leadership Group.

Output

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 the modification and development of some examples in collaboration with managers.

2.3.2 Component V2 — Data integration and synthesis

Description and objectives

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.

Activities to date

- Workshop (4–5 November 2015) and consultation with data custodians, vegetation ecologists, water managers, statisticians and modellers to:
    - identify relevant datasets and their availability
    - identify appropriate analysis techniques and approaches
    - identify hydrologic and complementary data needs
    - engage with relevant stakeholders.
    - development of a Data-share Agreement
    - meet with statistician Jim Thompson (Arthur Rylah Institute) to discuss data analysis approach (20 May 2016)
- Circulation of workshop notes to participants, including:
    - the workshop summary
    - the workshop notes

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

2016–17 activities within this component

- Data collation (see *Activity V2.2* below)
- Data analysis (see *Activity V2.3* below)

Future (2017–19) activities within this component

- Data analysis (continues into 2017–18; see *Activity V2.3* below)
- Reporting (see *Activity V2.4* in the MYRP)

Activity V2.2 — Data collation

Objective

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

Description

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

Roles

MDFRC staff and Dr Cassie James will undertake the initial collection and compilation of existing datasets under the guidance of the Leadership Group and quantitative ecologists. MDFRC will lead the initial requests for data and the establishment of data-share agreements as required.

Outputs

- Collated dataset for analysis
- Associated meta-data acknowledging funding bodies, staff involved in the design, collection and management of data, links to projects and reports and other acknowledgements as required
- Data-share agreements with collaborators as required
- An update as part of the Mid-year Progress Report (February 2017)

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.

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 involve continued consultation with quantitative ecologists to ensure the best available analytical approaches are used to address the main questions and make the best use of the available data.

Roles

The analysis of the datasets will be undertaken by Cassie James with input from relevant quantitative ecologists identified by the project team to have the appropriate skills (funded by MDB EWKR as required), with support from MDFRC.

Outputs

- Progress update (September 2016)
- Update as part of the Mid-year Progress Report (February 2017)
- 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 in terms of what flow regimes 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.

2.3.3 Component V3 — Field site assessment

Description and objectives

The fieldwork component will involve a program of work across the life of MDB EWKR, with fieldwork planning undertaken in 2015–16 and 2016–17, 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 between 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-based assessment will also create opportunities to develop links across 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.

Activities to date

Fieldwork planning at the Vegetation Theme research workshop to:

- review and refine research questions
- develop site selection criteria
- develop field methodology.

2016–17 activities within this component

- Fieldwork planning (see *Activity V3.1* below)
- Field surveys (see *Activity V3.2* below)

Future (2017–19) activities within this component

- Field surveys (continue into 2017–18; see *Activity V3.2* below)
- Reporting (see *Activity V3.3* in the MYRP)

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 2016. 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 to key knowledge gaps.

Site selection criteria and 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
    - emails, phone calls, workshops, opportunity to review the methods document
- Final field methodology document and data sheets

Roles

1. Review and refinement of research questions will be undertaken by the Leadership Group (coordinated by MDFRC).
2. Development of site selection criteria will be undertaken by the Leadership Group (coordinated by MDFRC).
3. Consultation with site managers will be undertaken by MDFRC, with input from Leadership Group members as relevant to the individual site and ongoing involvement in the on-ground assessments.
4. The experimental design program will be developed by MDFRC staff with input, review and approval from the Leadership Group and site managers.

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); specifically, to establish field sites and undertake one round of surveys in autumn 2017.

Roles

Different organisations will be responsible for leading field surveys and the collection of data, plant identifications and data entry at the different field sites:

- Lower Murray: led by MDFRC in collaboration with SARDI
- Upper Murray: led by MDFRC
- Macquarie Marshes: led by NSW OEH
- Lower Balonne/Narran Lakes: led by Griffith University

Output(s)

Outputs from this component will include:

- Collection of data, plant identifications and data entry as specified in the Field Assessment Experiment Design report
- Update as part of the Mid-year Progress Report (February 2017)

How will the output(s) be used?

Outputs will be used to inform component and theme reporting.

2.3.4 Component V4 — Mesocosm studies

The focus of the mesocosm studies will be on 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 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 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?

Activities to date

- Review existing literature specific to seedling recruitment and seedling mesocosm experiments
- Draft pilot study design to assess seedling responses (including seedling root development) to key flow regimes and non-flow driver conditions under controlled conditions
- The intended approach for the seedling mesocosm study was reviewed, discussed and refined at the Vegetation Theme research workshop

2016–17 activities within this component

- Finalise mesocosm planning (see *Activity V4.1* below)
- Seedling experiments (see *Activity V4.2* below)

Future (2017–19) activities within this component

- Reporting (see *Activity V4.3* in the MYRP)

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 avoid duplicating effort[2]. This review will also include an assessment of

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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. .

experimental techniques that have been used to assess seedling responses to ensure techniques applied build on the knowledge of previous work.

Following the outcomes of the workshop in May 2016 and with continual input from the Leadership Group, the experimental design and treatments will be documented in the Seedling experimental design report (Durant *et al*. 2016).

Objectives specific to 2016–17 include:

- Adaptively review and refine research questions as outputs from the following activities as they become available:
    - V1 Conceptualisation
    - V2 Data integration and synthesis
    - Leadership Group communication (workshops, emails, teleconferences)
    - Finalise study design to assess seedling responses to key flow regimes parameters

Roles

1. Review of literature and development of experimental design will be undertaken by MDFRC staff with input and review from the Leadership Group.
2. Refinement and finalisation of the experimental design will be undertaken by MDFRC staff with input, review and approval from the Leadership Group.

Output(s)

Outputs from this component will include the:

- 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).

This will include:

- sourcing and germinating seed
- sourcing equipment and establishing mesocosm tanks and pots
- establishing and maintaining experimental treatments
- collecting data from observational surveys and sacrificial harvesting

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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.

- data entry.

Roles

The seedling mesocosm experiments will be led by MDFRC and will be located at the Wonga Wetlands facility in Albury-Wodonga.

Output(s)

Outputs from this component will include:

- collection of data
- an update as part of the Mid-year Progress Report (February 2017).

How will the output(s) be used?

Outputs will be used to inform component and theme reporting.

2.3.5 Theme planning, coordination and reporting

This component includes:

- theme research coordination, ensuring that the research activities are administered effectively and delivered in a coordinated manner to deliver MDB EWKR objectives, including participation in Annual MDB EWKR coordination workshops and integration between themes
- 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 outputs associated with individual research components and activities)
- reporting, communication and engagement with stakeholders external to the project team as opportunities arise. This fosters collaboration and networks and builds the basis for successful adoption of MDB EWKR research outcomes.

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

Activities to date

- Initial MDB EWKR leadership group workshop (23–24 April 2015, Albury)
- Annual (2014–15) Vegetation Theme research workshop (16–17 June 2015, Sydney)
- Development of draft research plans and associated budgets (August 2015)
- SAG Workshop (27 August 2015, Sydney), presentation of proposed theme research
- Vegetation Theme Data Integration and Synthesis workshop (4–5 November 2015, Canberra)
- Annual Research Plan 2015–16 and Multi-Year Research Plan developed for 2015–16, including revision of budgets (December 2015)
- Research teams contracted
- MDB EWKR, DoEE, JRG and SAG Workshop (10–11 February 2016, Canberra)

- Ad hoc discussion of MDB EWKR and potential links to The Living Murray (TLM) project at the TLM Icon Site Managers Forum (4–5 May 2016, Mildura; cross-project collaboration)
- Queensland Floodplain Vegetation Project Steering Committee Meeting (16 May 2016, Brisbane)
- Lower Murray Regional Workshop (17 May 2016, Buronga)
- Annual (2015–16) Vegetation Theme research workshop (19–20 May 2016 Melbourne)
- Ad hoc updates of MDB EWKR to the NSW Murray Lower Darling Environmental Water Advisory Group (25–26 May 2016, Deniliquin; cross-project collaboration)
- Commonwealth Environmental Water Office (CEWO) Black Box Working Group teleconference, (31 May 2016; cross-project collaboration)
- ARP updated for 2016–17 (May 2016)
- MYRP updated for 2016–17 (May 2016)
- Attendance and input at the NSW OEH Murray Lower Darling Long Term Watering Plan workshop (1–2 June 2016, Albury; highly relevant to the direction and adoption of MDB EWKR outcomes)
- CEWO Black Box Working Group Workshop (24 June 2016, Mildura; cross-project collaboration)
- Annual Research Plan revised following conceptualisation phase (current document; October 2016)
- MYRP revised following conceptualisation phase (October 2016)
- Ongoing project management of the theme and contribution to the broader MDB EWKR project, including:
    - budget
    - contracts
    - Theme Coordinator and Integration teleconference meetings weekly or fortnightly
    - contribution to Annual and Mid-Year progress reports
    - internal Vegetation Theme communication
    - stakeholder consultation (see also section below)
    - theme integration (see also section below).

2016–17 objective(s)

- Update the ARP and MYRP in October as outputs from the following activities become available
- V1 Conceptualisation
- V2 Data integration and synthesis
- V3.1 Fieldwork planning
- V4.1 Mesocosm planning
- Annual Research Plan updated for 2017–18 (May 2017)
- Annual Vegetation Theme research workshop (undertaken as part of the whole-of-MDB EWKR workshop)
- Ongoing project management of theme, including:
    - budget
    - contracts
    - Theme Coordinator and Integration teleconference meetings weekly or fortnightly
    - contribution to Annual and Mid-Year progress reports
    - internal Vegetation Theme communication
    - stakeholder consultation (see also section below)
    - theme Integration (see also section below)
    - communication and engagement with stakeholders as relevant to research components and as opportunities arise.

Stakeholder consultation

There has been stakeholder consultation at various stages throughout the MDB EWKR planning process. Some of this consultation has occurred at the whole-of-project scale and other communication has been more specific to themes. Consultation and communication has occurred through both formal channels (e.g. structured workshops, targeted phone calls) as well as ad hoc/opportunistic communication around other projects and/or attendance at non-MDB EWKR related workshops.

Formal stakeholder consultation planned for 2016–17 includes:

- consultation with data custodians, ecologists and statisticians around the collation, analysis and interpretation of data (*Component V2 Data integration and synthesis*)
- site/regional visits for fieldwork planning (at least four meetings) *(Activity V3.1 Fieldwork planning)*
- site manager input and review of the Field Assessment Experiment Design report (detailing field sites and methodology) *(Activity V3.1 Fieldwork planning)*
- inter-project communication through representation on the Working Group for the CEWO project *Achieving long-term ecological outcomes for Black Box through active groundwater management.*

Theme Integration

Integration between the themes is being planned and managed at a whole-of-project scale. Specific activities that are occurring, or are planned, to facilitate theme integration include:

- fortnightly teleconferences with theme coordinators
- fieldwork planning in consultation with other themes
- integration workshops (at least three planned).

Integration through fieldwork planning

There are opportunities for integration between the themes through fieldwork. The Waterbirds Theme has provided a document detailing field collection variables that are known or thought to be important for waterbirds. This document will be used by the Vegetation Theme when determining variables and vegetation communities to be monitored as part of field surveys. This will create opportunities to share data between themes, minimising duplication of effort and maximising the amount of information collected. In addition, the Waterbirds, Fish and Food Webs themes will be given the opportunity to review and contribute to the Field Assessment Experiment Design report, which will detail the location of field sites and field methodology. Integration between the themes will be an ongoing activity during 2016–17.

2.4 Activity schedule

The following workplan (Table 2-1) 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 2-1. 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	✓	Completed (October 2016	Leadership Group

	V1.3 Reporting: scientific paper(s)/fact sheets		End June 2017	Leadership Group, led by Sam Capon
V2. Data integration and synthesis	V2.1 Planning and Data workshop	✓	Completed (November 2015)	Leadership Group
	V2.2 Data collation		End March 2017	Leadership Group, led by Cherie Campbell
	V2.3 Data analysis		End December 2017	Leadership Group, led by Cassie James
	V2.4 Reporting: scientific paper (s)/fact sheets		End June 2018	Leadership Group, led by Cassie James
V3. Field site assessments	V3.1 Field work planning • Question revision and preliminary design workshop	✓	Completed (May 2016)	Leadership Group
	V3.1 Field work planning • Desktop site selection and refinement with site managers		End March 2017	Leadership Group, led by Cherie Campbell (southern sites) and Rachael Thomas (northern sites)
	V3.1 Field work planning • Field methodology document and data sheets		End March 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 (December 2016)	Leadership Group, led by MDFRC
	V4.1 Mesocosm planning • Literature review	✓	Completed (December 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
	V5.2 Renew/extend contracts		September 2016	MDFRC and external partners
	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		Feb 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
	Underway. On track for completion by planned date.
	Underway but some difficulties. May be completed slightly after the planned date, or scope or approach modified.
	Underway but major difficulties. Unlikely to be completed by planned date. Likely to impact project delivery.
	Yet to proceed. Awaiting completion of prior tasks and milestones.

3 Native fish

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3.1 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.

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: recruitment (high priority), survival and condition (medium priority) and reproduction (lowest priority). The three identified priority areas encompass the entire life-cycle of fish and therefore all potential processes and drivers.

The Leadership Group agreed that attempting to undertake targeted work for all priority areas will result in resources being spread too thinly to address any priority area in a meaningful way. Consequently, the Leadership Group agreed that the focus of the theme will be recruitment and that the remaining two priority areas will only be addressed where reproduction and/or survival condition questions can easily be incorporated into recruitment-focussed activities. The priority recruitment questions for the Fish Theme are:

- What flow regimes best support the reproduction 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 recruitment outcomes?

Ultimately, the theme aims to provide improved capacity to predict fish recruitment outcomes in response to different environmental flow conditions. This will be achieved by 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.

3.2 Description of work components

This section gives an overview of the work components and activities for 2016–17. Component F1 (foundational activities) is almost complete and is summarised below. Components F2 and F3 (2016–17 research activities) are then described in detail. Justification and context for the research activities is provided in the MYRP. Work components and activities in later years are included in summary and will be further defined in future ARPs.

3.3 Work components and activities

All research activities will be discussed, planned and overseen collaboratively by the Leadership Group and will be implemented as collaborations among members of the Leadership Group as well as any additional organisations/staff that may be required to provide additional skills. Each activity will be led by a specific member of the Leadership Group and clear plans will then be developed for each activity that specify the other personnel who will be involved, timelines, deliverables, budgets, linkages to other projects and themes etc.

3.3.1 Component F1 — Foundational activities

In 2016–17, the Fish Theme will complete the foundational activities, including reviewing the current knowledge status and development of conceptual models. This process was 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 adoption outputs.

The conceptualisation process was divided into four components: theoretical (global), management (MDB), non-flow related stressors and threats and an integration of all of these to provide the basis for a management-focussed, MDB-specific conceptualisation of fish recruitment based on the best available science and most up-to-date management information (see Figure 3-1).

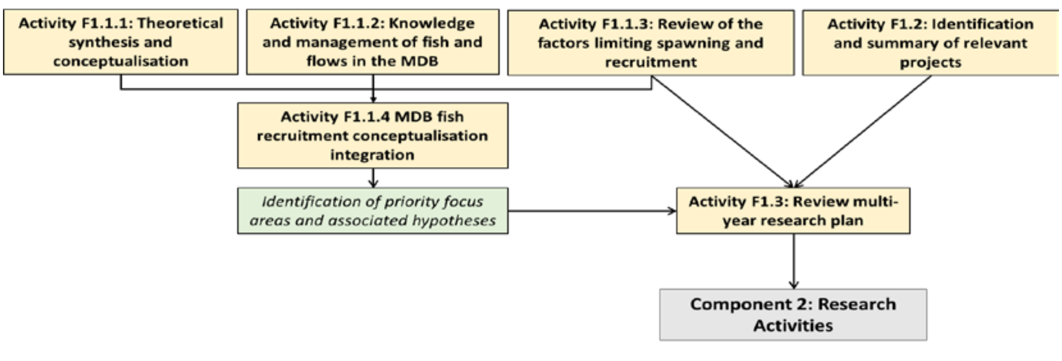

Figure 3-1. Flow diagram depicting the proposed foundational activities and how these relate to the later work components.

The literature review process for all three components was completed in 2015–16. The first major activity in 2016–17 was the integration workshop (July 26–28) and in preparation, the following activities were completed in early July:

- *Activity F1.1.1 Theoretical synthesis and conceptualisation. Synthesis and development of conceptual framework*
- *Activity F1.1.2 Knowledge and management of flows and fish recruitment in the MDB. Identification of key knowledge gaps and flow management needs*
- *Activity F1.1.3 Review and synthesis of the factors limiting spawning and recruitment. Prioritisation of different threats and constraints*
- *Activity F1.2 Identification and summary of relevant projects.*

The outputs from the workshop included a prioritised list of:

- knowledge gaps
- potential activities that included the analysis of existing data, mesocosm experiments and field data collection.

The outputs of the workshop were used to refine the Multi-Year Research Plan and the Annual Research Plan (2016–17). The conversion of the workshop outputs into updated plans was completed in November 2016.

3.3.2 Component F2 — Research activities for 2016–17

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); 2016–2017

Description and objective(s)

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 northern Murray–Darling Basin (NMDB), this study provides an opportunity to enhance our current understanding around the feeding requirements and feeding ecology of early life-stage fish.

The objective 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 stages of NMDB fish and be presented in relation to the application of this knowledge for flow management in the NMDB.

Activity in 2016–17

There will be some planning and liaison with the Queensland researchers undertaken in the early part of 2017. Sampling will commence in July 2017 and a more detailed description of the approach is included in the Multi-Year Research Plan.

Outputs

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). Food availability and temperature are two of the key determinants of growth rates (Houde, 1997; Jones, 2002). Laboratory experiments will be used 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 Opportunistic, Periodic and Equilibrium. This work will be undertaken in 2017–18.

Activity in 2016–17

This activity will commence in 2017/18. A more detailed description of the approach is included in the Multi-Year Research Plan.

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.

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

This sub-component includes three Activities (2.3.1, 2.3.2 and 2.3.3) each of which address different facets of the thermal and nutritional landscape in which larval fish survive and mature.

Objective and description

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.

The work will be broken into three activities:

1. 2.3.1: Detailed assessment of thermal and nutritional patch-level variability among main channel and floodplain habitat patches at one river-floodplain area. 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. This work will be undertaken in 2016-17 and 2017-18.

2. 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.
3. 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 2.3.3 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, but that we lack a clear understanding of the mechanisms underpinning these distribution patterns.

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 been 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 best to 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 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 provided an indication 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 significance for species such as Golden perch (*Macquaria ambigua ambigua* Richardson) and Silver perch (*Bidyanus bidyanus* Mitchell), whose larvae are small and have limited swimming capacity and therefore require conditions conducive to rapid growth, as well as for floodplain species. However, the Beasley et al. 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 the 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.

Activity in 2016–17

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. 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).

Samples will be returned to the laboratory and microinvertebrates separated into size classes. The abundance of microinvertebrates within each size class will then be determined through microscopic examination of subsamples. Where available, existing relationships between size and weight will be used to estimate zooplankton biomass in each of the hydraulic habitats.

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.

Schedule (2016–17)

Table 3-1. Schedule for those tasks in Activity 2.3.1 that will be undertaken in 2016-17.

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Project planning												
Field work												
Laboratory processing of field samples												
Data analysis												
Write-up												

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. 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. This work will be undertaken in 2017–18.

Activity in 2016–17

This activity will commence in 2017–18. The only activity in 2016-17 will be planning as part of the development of the 2017–18 Annual Research Plan.

Output(s)

The results from this sub-component will provide information regarding spatial scale(s) at which the 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; 2016–17

Objective and description

This activity seeks to improve our understanding of the influence of physical habitat complexity on patterns of productivity. A key hypothesis that has arisen from the conceptualisation process is that structural habitat 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 are will not be retained and instead, will be transported downstream. These hypotheses have not, however, been tested.

As part of the National Water Commission (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.

Activity in 2016–17

A desktop study analysing existing data generated by the NWC wetland fish project will be undertaken to provide a preliminary insight 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 by MDFRC researchers using standard univariate and multivariate analytical techniques.

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.

Schedule (2016–17)

Table 3-2. Schedule for those tasks in Activity 2.3.3 that will be undertaken in 2016-17.

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Literature review												
Data analysis												
Write-up												

Activity F2.4 — Investigating the relationship between flow, structural habitat, hydrodynamics and patterns larval settlement and retention (CSU and MDFRC); 2018–2019

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 (*Maccullochella peelii peelii* Mitchell) and Golden perch larvae and passive particles.

Activity in 2016–17

This activity will commence in 2017–18.The only work to be undertaken on this activity in 2016-17 will be planning as part of the development of the 2017–18 Annual Research Plan.

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 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, King *et al.* 2016, 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. We will also consider whether the same approach will work for Golden perch, or whether 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(YoY) (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.

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 Long-Term Intervention Monitoring (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 3-2). 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.

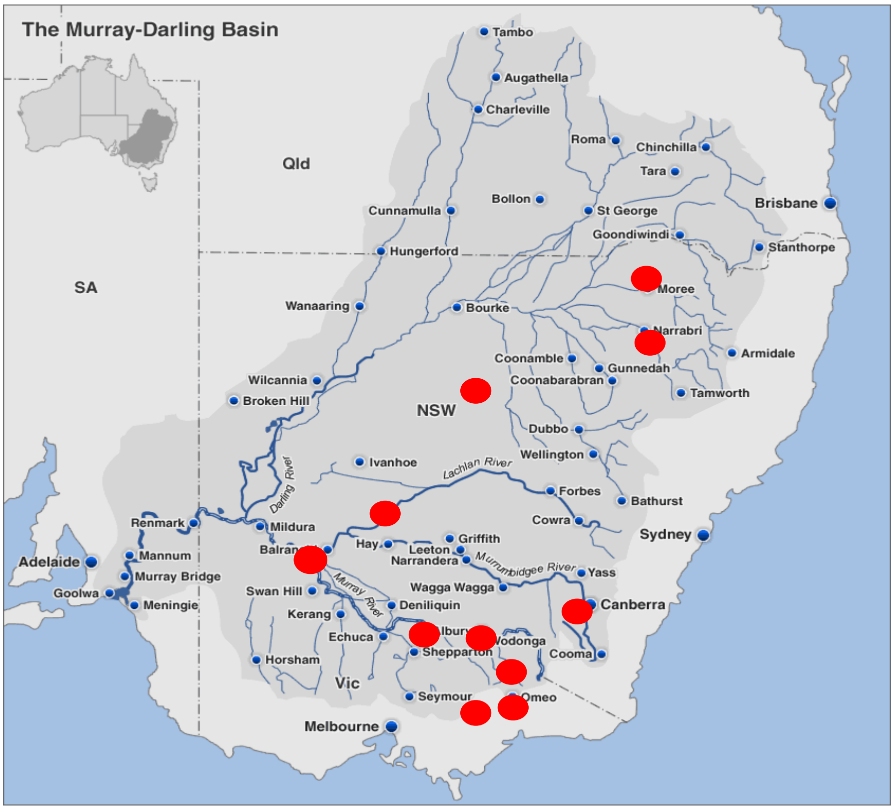

Figure 3-2. Potential regions (red symbol) in the Murray–Darling Basin where Golden perch and Murray cod demographics and recruitment will be investigated.

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 Latrobe University/Arthur Rylah Institute that is using contemporary genetic techniques to explore provenance, movement and connectivity of native fish populations in the MDB.

Activity in 2016–17

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 if water $^{87}Sr/^{86}Sr$ in the upper Darling River is distinct from tributary rivers and the Murray River 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 Murray River, 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.

Schedule (2016–17)

Table 3-3. Schedule for those tasks that will be undertaken in 2016-17, noting that most tasks will be undertaken in 2017-18

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Project planning												
Water sample collection and analysis												
Otolith collection (2017-18)												
Otolith analysis (2017-18)												
Data collation(2017-18)												

Data analysis (2017-18)												
Write-up (2017-18)												

3.3.3 Component F3 — student projects

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

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

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.

3.3.4 Component F4 — Synthesis and model development and management; 2018–19

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 the 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.

3.3.5 Component F7 —Theme planning, coordination and reporting

This component includes:

- 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 Fish Theme and contributions to 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 knowledge gaps.

The Annual Research Plan will be revised in May–June 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.

4 Waterbirds

Authors: Heather McGinness (CSIRO), Veronica Doerr (CSIRO), Richard Kingsford (University of NSW), Kate Brandis (University of NSW), Ralph Mac Nally (University of Canberra)

4.1 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 specific foraging and nesting habitat requirements before, during and after environmental watering events that optimise recruitment success. 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 are required to support recruitment.

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 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 primary 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.

The Waterbirds Theme addresses critical knowledge gaps that were identified through consultation with environmental water managers and scientists, and review of existing literature. These include:

Where and what are the critical foraging habitats during and after breeding events that support recruitment? How might these be affected by water management 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. The high-level questions of relevance for management that this research will address are:

1. Where do juveniles and adults forage *after* a breeding event?
2. Where do adults forage *during* nesting (where are they getting the food for the chicks?)
3. How can environmental flows be managed to better support foraging habitats?

What are critical nesting habitat characteristics we need to maintain and how do these affect recruitment? How do water and vegetation management 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.

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

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

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:

- locations and characteristics of critical foraging habitats for adult and juvenile colonial-nesting waterbirds both *during* and *between* breeding events
- the 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.

4.2 Description of work components

This section first 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) are complete and are summarised. *Activity B2.2* (2016–17 Field research) plans are then described in detail. Work components and activities in later years are included in summary and will be further defined in future Annual Research Plans.

4.3 Work components and activities

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 University of NSW and CSIRO, with additional staff invited to collaborate as necessary.

4.3.1 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.

4.3.2 Component B2 — Field research

Field research activities are proposed in 2015–16, 2016–17 and 2017–18, in the event that waterbird breeding events occur 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).

Activity B2.1 — 2015–16 pilot field research

Field research 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 may have implications for the development of predictive capacity in MDB EWKR. Secondly, the suite of methods proposed will mostly likely need to be refined and the information generated from pilot research during this first year will inform adaptation of the research plan and research activities in later years of the project.

The pilot study was designed to:

1. collect new bird breeding success data, taking advantage of the breeding event occurring in Barmah–Millewa Forest during the 2015–16 summer
2. develop, test and improve survey methods and equipment for future quantification of breeding success and the impacts of associated threats and pressures.

Pilot study fieldwork was conducted in Reed Beds Swamp, Millewa Forest, New South Wales. Other nearby breeding sites, including Boals Deadwoods in Barmah Forest, Victoria, were too inaccessible to attempt within the logistical limits of the pilot study, or not suitable for intensive data collection and analysis because of disturbance by the public or strategic raven predation (following boats).

The nests of three species were monitored: Australian White Ibis (*Threskiornis moluccus* Cuvier) (the most common species), Straw-necked Ibis (*Threskiornis spinicollis* Jameson), and Royal Spoonbill (*Platalea regia* Gould).

The main tasks were:

- on-ground colony mapping and counts, including nest and adult counts, egg and chick counts at tagged nests, and recording nesting habitat characteristics
- setting up, testing and installing motion-sensing and time-lapse cameras, followed by image data extraction and analysis.

On-ground colony mapping and associated counts were conducted during three sessions: November 2015, December 2015, and January 2016.

There were also three primary camera deployments, each with different settings tested:

1. November to December 2015 (30 cameras)
2. December 2015 to January 2016 (29 cameras)
3. January to February 2016 (15 cameras).

We GPS-marked every nest clump and camera location and constructed maps of their locations for each visit.

The results of the pilot study data processing and analysis are described in the September 2016 Annual Progress Report, due in September 2016.

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:

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

Sub-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, University of NSW)
- Scientific licence applications, meetings and reporting (CSIRO, University of NSW)
- Volunteer/student/staff engagement and management (CSIRO, University of NSW)
- Equipment purchase and setup (CSIRO, University of NSW)
- Testing and training in bird capture and satellite device attachment methods including bird harnesses (CSIRO, University of NSW)

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 2016–2017, most likely in either Barmah–Millewa Forest or the Macquarie Marshes (CSIRO and University of NSW). 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

2. 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

3. At the end of the breeding event

- Fieldwork planning, preparation and packing
- Capture, satellite tagging and banding of <u>juvenile</u> 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 University of NSW)
- data analysis: diet/bioenergetics (University of NSW, 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 University of NSW)
- integrative data analyses and interpretation (CSIRO and University of NSW).

The data analysis will identify breeding colony size, including numbers of breeding pairs, eggs, chicks, and fledglings and 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 University of NSW) 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.

4.3.3 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.

4.4 Activity schedule

Work and Deliverables	Institution responsible	Milestone Deliverable Due Date	Task Start	Task Finish	Actual Start	Actual Finish
1. Staff confirmed and satellite tracking equipment ordered.	CSIRO	On execution	1/7/16	1/7/16	1/7/16	1/7/16
2. Monitoring cameras and associated equipment ordered.			1/7/16	1/8/16	1/7/16	1/8/16
3. Execution of CSIRO Letter of Agreement			1/7/16	1/7/16	1/7/16	10/11/16
4. Animal ethics applications completed and approved, and staff engaged	UNSW	On execution	1/7/16			
5. Execution of UNSW Project Agreement			1/7/16			
6. Completion of fieldwork monitoring nests, nesting habitat and water depths with motion-sensing and time-lapse cameras.	CSIRO	28/02/2017	1/10/16	28/2/17	1/10/16	
7. Completion of fieldwork deploying satellite tracking transmitters on birds.			1/10/16	28/2/17	1/10/16	13/2/17
8. Completion of the Waterbird Theme section of the **mid-year progress report** (Milestone 3 (2016-17) of the MDB EWKR Head Agt).			1/2/17	28/2/17		
9. Completion of fieldwork monitoring of tagged nests, water depths and nesting habitat	UNSW	30/03/2017	1/10/16	30/3/17	1/10/16	
10. Completion of fieldwork deploying satellite transmitters on birds, including GSM phone tower trackers and GeoTrak GPS trackers			1/10/16	30/3/17	1/10/16	
11. Completion of fieldwork collection bird regurgitates and other relevant samples for diet analysis			1/10/16	30/3/17	1/10/16	
12. Completion of nesting colony mapping			1/10/16	30/3/17		
13. Completion of data extraction from timelapse camera images			1/2/17	30/3/17		
14. Completion of data extraction from motion-sensing camera images.	CSIRO	30/06/2017	16/1/17	30/6/17	16/1/17	
15. Completion of data summary describing basic results from motion-sensing camera images.			1/5/17	30/6/17		
16. Completion of data summary describing basic results from time-lapse camera images (together with UNSW).			1/5/17	30/6/17		
17. Update to the Waterbird Theme section of the **Annual Research Plan** (Milestone 5 (2016-17) of the MDB EWKR Head Agt.).			16/2/17	30/6/17		
18. Update to the Waterbird Theme section of the **Multi-Year Research Plan** (Milestone 6 (2016-17) of the MDB EWKR Head Agt).			16/2/17	30/6/17		
19. Completion of satellite tracking data downloads and mapping.			1/10/16	30/6/17		
20. Completion of data summary for satellite tracking results (GeoTrak satellite GPS solar trackers).			1/5/17	30/6/17		
21. Completion of 2016-17 **Annual Progress Report** in collaboration with UNSW and UC describing the results of research activities (Milestone 1 (2017-18) of the MDB EWKR Head Agt).			19/6/17	30/6/17		
22. Completion of data summary describing basic results from time-lapse camera images (together with CSIRO)	UNSW	30/06/2017	1/2/17	30/6/17		
23. Completion of data summary for colony mapping, tagged nests, water depths and nesting habitat at Barmah-Millewa and/or Macquarie Marshes for circulation to stakeholders (site managers, MDFRC, DoEE)			1/2/17	30/6/17		
24. Completion of data summary for satellite tracking results (GSM phone tower trackers)			1/2/17	30/6/17		
25. Completion of data summary for bird regurgitate / diet analyses			1/2/17	30/6/17		
26. Completion of 2016-17 **Annual Progress Report** in collaboration with CSIRO and UC describing the results of research activities (Milestone 1 (2017-18) of the MDB EWKR Head Agt			19/6/17	30/6/17		

5 Food Webs

Authors: Darren Baldwin (MDFRC), Nick Bond (MDFRC), Rebecca Lester (Deakin University), Barbara Robson (CSIRO), Darren Ryder (University of New England), Ross Thompson (University of Canberra)

5.1 Introduction

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.

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 **bioenergetics 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 5-1 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 5-1 B).

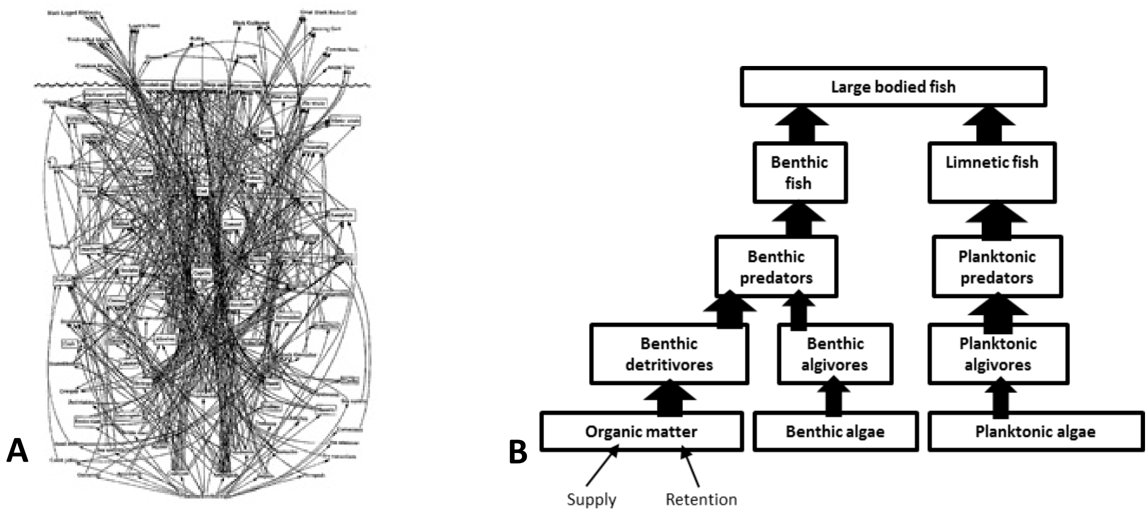

Figure 5-1. Examples of describing food webs A) using species and links and B) using a simpler bioenergetic representation.

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 that 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 (ACEAS 2013), and the commercially available Ecopath with Ecosim (EwE) (Pauly *et al.* 2000).

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 5-2), 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.

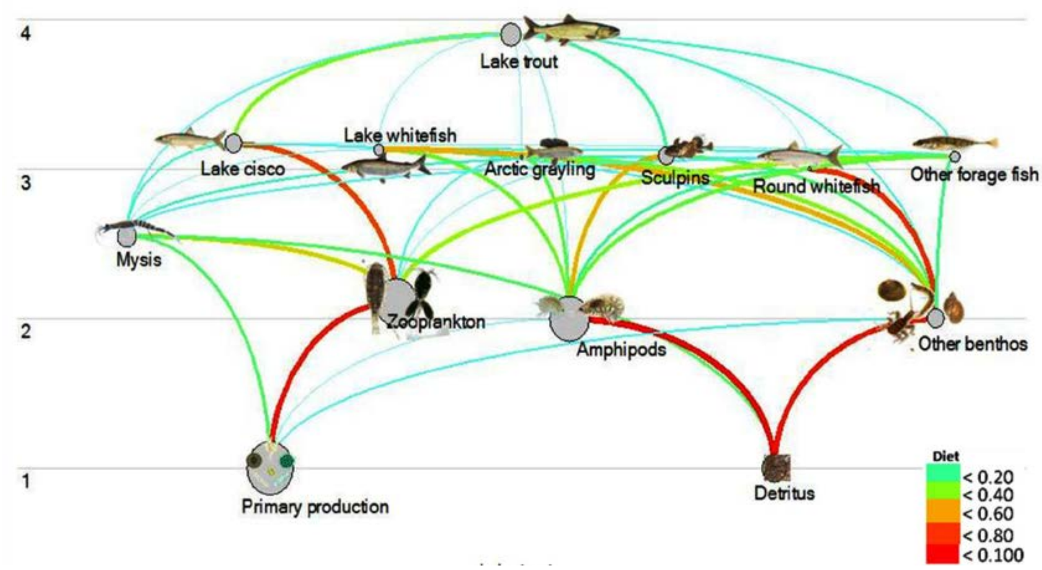

Figure 5-2. A simple bioenergetics model based on the lake fisheries of Great Bear Lake, with different coloured connectors illustrating the proportion of the diet comprised of the food resource.

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 development of useful models and decision support tools for water 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.

Having considered a range of possible options, and having consulted with the other 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 EWKR themes (Figure 5-3). Second it allows development of simple models through the aggregation of species into functional groups.

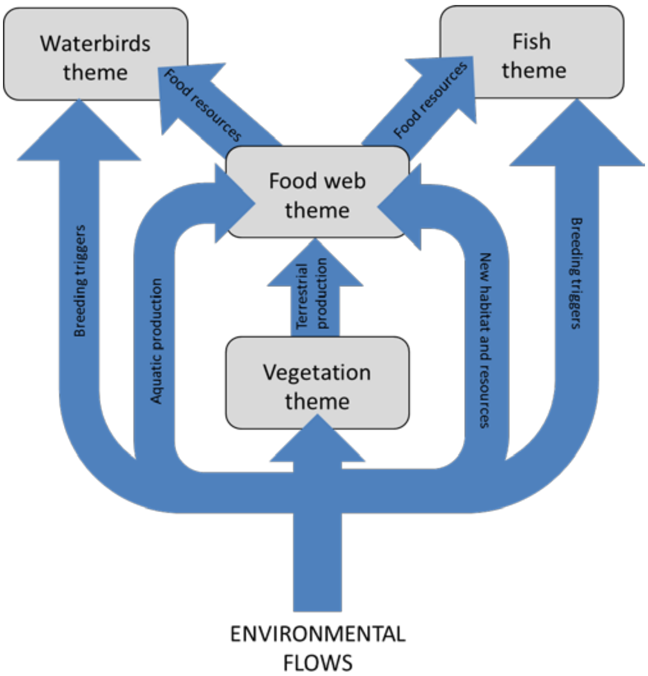

Figure 5-3. Conceptual diagram illustrating the effects of environmental flows on the movement of energy and resources across and between the four themes of EWKR.

5.2 Description of work components

Research Approach

Given the gaps in the current empirical understanding of food web dynamics in the Murray–Darling Basin, we propose to approach the theme in four stages.

1. Review and conceptualisation. This stage identified our current knowledge status and critical knowledge gaps. This stage has been completed.
2. Identifying critical basal resources. Understanding the basal resources underpinning fish and waterbird recruitment is essential to understanding the way that flow may influence fish and waterbird recruitment through its influence on food resources. This component will have both a field and experimental component.
3. Identifying important sites of production. This stage will seek to identify areas that are disproportionally more important in delivering and/or transforming basal resources.
4. Modelling bioenergetics within identified 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.

These questions have been addressed in part by previous work, and Stage 1 and 2, in particular, will focus on summarising existing knowledge and data. Previous work that has taken a similar bioenergetic approach will be focussed on, including international research which has assessed effects of environmental flows on energy flow (e.g. Cross *et al.* 2011), previous empirical work in the MDB (e.g. Kingsford *et al.*, 2015, technical reports from the CEWO LTIM program), and a major recent research initiative of the Australian Centre for Ecological Analysis and Synthesis in this area (ACEAS 2013). The conceptualisations of energy pathways in these systems (which are already well established) will be populated with empirical data over the course of the project, allowing a quantitative assessment of the effects of flows in Stage 4.

Integration with other Themes

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 into 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 has 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?

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

5.3 Work components and Activities

5.3.1 Component W1— Review and conceptualisation

This stage identified our current knowledge status and critical knowledge gaps. 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 will be completed. A particular emphasis was placed on identifying the potential role of basal resources and their interaction with flow (Stage 2), the spatial distribution of resources and the potential for flow to increase the 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.

Approach

The literature review will comprise three activities:

Activity 1.1 The influence of flow on lowland river food webs. The review will inform the 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 be undertaken by University of Canberra and MDFRC and will cover published scientific manuscripts. The review will build on the expertise of the leadership Group and a search of the literature within major scientific databases, including Web of Science and Google Scholar.

Activity 1.2 A review of potential food web indicators that could be incorporated into the monitoring and evaluation of environmental flows. 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 the UC appointed post-doc (Rob Rolls). The 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. The 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.

The reviews were commenced in April 2016. The reviews were used to inform the development of the research plans in October and the manuscripts will then be finalised and submitted for publication by February 2017.

Outputs

1. Conceptual models that express potential energy pathways to taxa of interest (e.g. Figure 5-4)
2. Identification of key knowledge gaps (report and knowledge matrix under preparation)
3. Identification of potential modelling approaches (report under preparation, general approach determined)

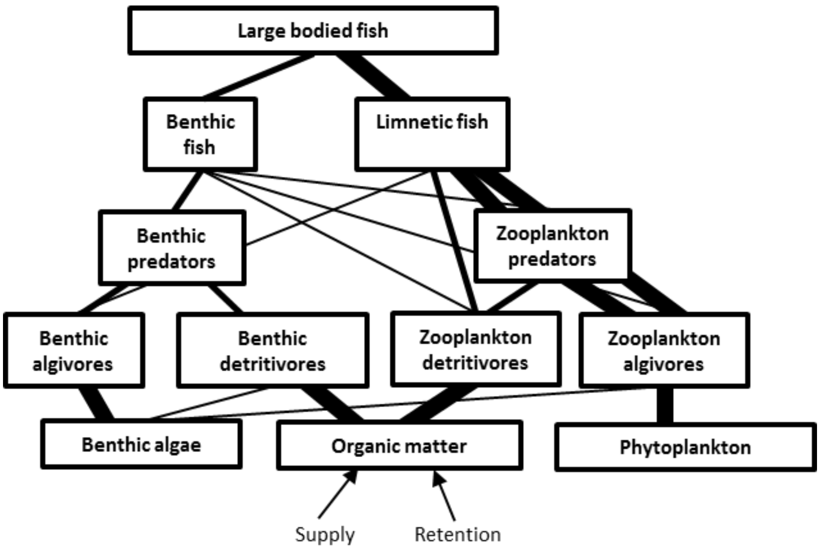

Figure 5-4. A simplified bioenergetic representation of a riverine food web in the Murray River based on Kingsford *et al.* (2015). The width of the lines indicates the magnitude of the energy flows from different sources, which are currently unknown and will be the focus of this research program.

5.3.2 Component W2 — Identifying critical basal resources

Objectives and description

The objective is to improve understanding of the basal resources underpinning fish and waterbird recruitment.

Flow is known to influence the amount and type of organic matter available to the food web, and it is hypothesised that this is one of the critical pathways by which flow influences the recruitment of fish and waterbirds. Understanding which basal resources are supporting fish and waterbird recruitment will enable identification of specific habitats and flow characteristics that will deliver the resources required to support or enhance recruitment.

The Fish Theme is seeking to evaluate the fundamental triad concept, which proposes that fish recruitment is dependent on habitats that provide nutrient enrichment, concentration and retention of both food and fish larvae. Testing this model requires an understanding of the basal resources that support larval recruitment, as these are the enriching resources that will be concentrated. It is also likely that there are interactions between other covariates, such as season and channel form, and environmental flows that influence energetic outcomes for fish. In the figure below we have conceptualised a simple set of predictions around the effects of flows at different times of year. The ability to generate these predictions based on existing data is critical in focussing the activities planned in this component.

Waterbird breeding and recruitment are critically dependent on food resources and, as a consequence, for many species in the southern MDB, breeding takes place when suitable flood and seasonal conditions associated with abundant food prevail (Kingsford and Norman 2002; Leslie 2001). Similarly, the number of breeding pairs or nests increases with increasing flood extent and duration, that are believed to be associated with increases in food abundance (Reid *et al.*, 2013). Thus, reductions in the frequency, magnitude and duration of floods associated with river regulation have had a negative influence on waterbird breeding and recruitment (Brandis et al 2009, Leslie 2001). Improving waterbird recruitment outcomes from environmental flows requires an understanding of basal resources and the associated consumers that support recruitment.

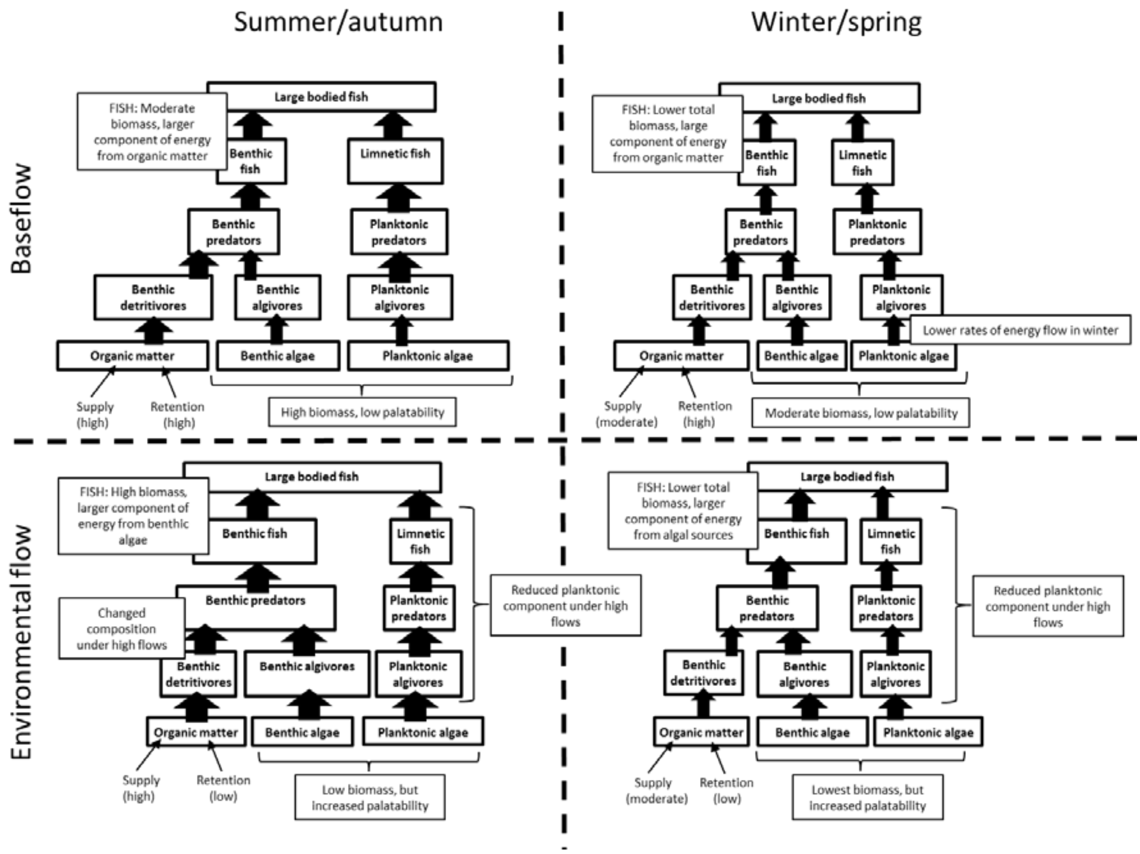

Figure 5-5. A conceptualisation of the way that season and flow interact to influence the basal resources supporting large-bodied native fish.

Approach

This component is comprised of complementary field surveys and mesocosm experiments that are described in the following sections.

Outputs

1. Empirical data that expresses relative magnitudes of energy pathways to taxa of interest (Q1A, Q1D)
2. Empirical data that assesses potential spatial and temporal variability in productivity (Q1B, Q1C, Q1E)
3. Assessment of the potential role of covariates (invasive species, water chemistry, turbidity, substrate availability in determining productivity of different habitats in relation to flow (Q2A and Q2B)

Activity 2.1 — Fish field program

Objective and description

The objective of this activity is to identify the critical basal resources supporting fish recruitment.

This program includes activities that 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 10's m 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.

Activities for 2016–17

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. These proposed activities are described in the Multi-Year Research Plan, 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 the Ovens River. 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

1. Empirical data that expresses relative magnitudes of energy pathways to taxa of interest.
2. 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 scaling up to the Basin scale.

How the outputs will be used?

The data will be used to inform both the refinement of the ACEAS model and development of new models.

Timeline

Table 5-1. Schedule of tasks for Activity 2.1. SIA – Stable Isotope Analysis, TA – Fatty Acid analysis, AA – Amino Acid analysis

Year	Month	Activity	Responsible
2016–17	November	Liaise with Fish Theme regarding design and permits	MDFRC
	Dec-Jan	Undertake sampling in Ovens River	MDFRC
	February–July	Sample analysis (SIA, FA, AA, calorific values)	MDFRC

Activity 2.2 Waterbird field program

Objective and description

This activity seeks to improve our understanding of the food resources required to support waterbird recruitment. It will be undertaken in collaboration with the Waterbirds Theme.

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.

Activities for 2016–17

As described above, the Theme will work with the Waterbirds Theme to collect samples that will enable the identification of prey, and use imagery from nest cameras to quantify feeding behaviour and thus obtain 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.

In 2016–17, the Waterbirds Theme intend to collect regurgitate from about 40 individuals and visually identify 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 waterbird 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. The output from this activity will be a manuscript for submission to a scientific journal for 2016–17. As described in the Communications and Adoption Strategy, the draft manuscript will be made available to water managers and, from this consultation, a customised output will be developed and made available through the MDB EWKR web page or Collaboration Space.

How the outputs will 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. The information will also be used by the Waterbirds Theme in the development of their models of the effects of flow on waterbird recruitment.

Timeline

Table 5-1 Timeline 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

A hold point has been included at the end of 2016–17 to evaluate the outcomes of this Activity.

Outputs

The output from this activity will be a manuscript for submission to a scientific journal for 2016–17. Further outputs for subsequent years will depend on the outcomes of activities undertaken in subsequent years, which will be identified upon reaching the hold point in 2017.

How will these outputs be used

The output from this Activity in 2016–17 will be used by site managers to estimate whether or not there are sufficient resources at their site to support fledging targets. It will also inform managers on the use of environmental water to maximise energy production for bird breeding success.

Activity 2.3 Basal resource transfer efficiency between a range of basal resources and to first-order consumers (mesocosm experiments)

Objective and description

This activity seeks to determine basal resource utilisation and rates of transfer into the food web.

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. The proposed activity will focus on zooplankton as they are a critical food resource for larval fish. The proposed work will complement work undertaken in the MDBA–MDFRC Collaboration Project that is looking at the basal resources supporting macroinvertebrates, but not examining transfer efficiencies.

Activities for 2016–17

Experiments will be undertaken in replicate 75 L tanks, which will be stocked with natural communities of zooplankton. 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 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 microcrustaceans 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 5-2. Schedule for those tasks for Activity 2.3 that will be undertaken in 2016-17 and 2017-18

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

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

Output

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

How will the output be used?

1. The output from this activity will inform future model development (Component 4).
2. The manuscript will provide the basis for presentations to managers and the development of summary material to be made available through the web, as per the process described in the adoption strategy.

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.

Activities for 2016–17

There will be no substantive activities undertaken in 2016–17. Planning meetings will be held with the Fish Theme and consultation with the Monitoring & Evaluation (M&E) providers within the LTIM program to plan activities in 2017–18.

5.3.3 Component W3 — Identifying important sites of production

Objective

The objective of Component 3 is to identify areas that are disproportionally more important in delivering and/or transforming basal resources.

Activities for 2016–17

There will be no activities undertaken for this component in 2016–17 as it will be commencing in 2017–18. Details about this component are outlined in the Multi-Year Research Plan and will be further detailed in the 2017–18 Annual Research Plan.

5.3.4 Component W4 — Modelling bioenergetics within identified production sites

Objective

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

Description

As noted in the overview, the purpose of the Food Webs Theme is to improve our capacity to predict the effects of environmental flows on primary productivity and the passage of that productivity through the food web to vertebrate consumers (fish and birds). In order to achieve this objective, the Food Webs Theme will develop relatively simple models that will predict the movement of energy through the food web and support simulations of management scenarios.

The review and conceptualisation component 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 (ACEAS 2013) and the commercially available Ecopath with Ecosim (EwE) (Pauly *et al.* 2000).

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 which affect particular groups
- identification of groups that are critical to energy flow along particular food chains
- quantified modelling of scenarios and management interventions.

Where possible, the MDB EWKR project is committed to building on existing data and models. Within this context, one of the first activities to be undertaken after completion of the review and conceptualisation process will be to update the code for Murray River fish model (ACEAS) 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 relationships 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. The ACEAS 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; the lead author is 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.

Activities for 2016–17

To complete the ACEAS model, a post-doctoral researcher will undertake the writing of the manuscript while members of the ACEAS team will collaborate with the MDB EWKR leadership team to update the model and code.

The development of the modelling report will be undertaken by Rebecca Lester and Barbara Robson in consultation with the rest of the Food Webs Leadership Group. The two researchers have been leading the review of modelling options and this represents an extension of this work. The work 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. A key component of this stage will be face-to-face meetings to finalise the study questions in the context of what is tractable with the final model selected.

Outputs

1. The completion of the ACEAS model will produce 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.
2. A report evaluating modelling options and model structures.

How outputs will be used

The ACEAS model will be used to evaluate a range of flow scenarios, and the outcomes of these will be summarised and, where appropriate, presented to water managers or made available through the project web page. While the ACEAS model is not intended to be used as a Decision Support Tool (DST), managers may wish to either run their own scenarios or utilise the key relationships within the model for their own purposes. Within this context, an overview of the model and its capabilities as well as instructions for its use will be made available to water managers.

The report on approaches to modelling will be used to inform modelling activities to be undertaken within the Food Webs Theme.

Timelines

Table 5-3. Schedule for those tasks for component W4 that will be undertaken in 2016-17.

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