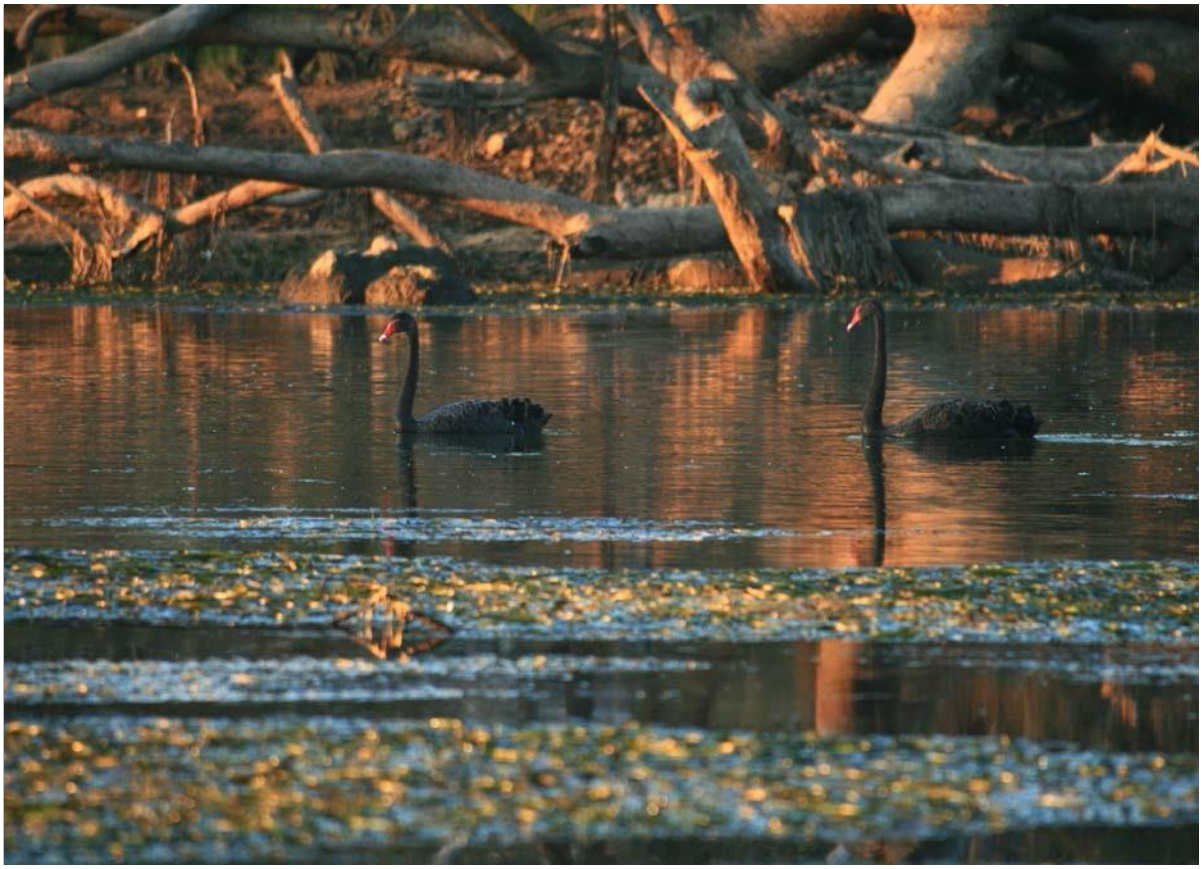
Murray–Darling Basin Environmental Water Knowledge and Research Project

Annual Research Plan 2017–18

Prepared by: The Murray–Darling Freshwater Research Centre



June 2017

MDFRC Publication 160

Murray–Darling Basin Environmental Water Knowledge and Research Project Annual Research Plan 2017–18

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 (2017) Murray–Darling Basin Environmental Water Knowledge and Research Project Annual Research Plan 2017–18. Final Report prepared for the Department of the Environment and Energy by The Murray–Darling Freshwater Research Centre, MDFRC Publication 160/2017, June, 55pp.

Cover Image: Black Swans on the River Murray below Hume Dam

Photographer: Ben Gawne, University of Canberra

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Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
Draft V1	22 May 2017	Jessica Davison	Ben Gawne	Initial Internal Draft
Draft V2	24 May 2017	Jessica Davison	Ben Gawne	Draft for DoEE comments
Final	30 June 2017	Jessica Davison	Ben Gawne	Final in response to comments

Distribution of copies

Version	Quantity	Issued to
Draft V2	1 x PDF	Anthony Moore and Nadia Kingham, Department of Environment
Final	1 x PDF	Anthony Moore and Nadia Kingham, Department of Environment

Filename and path:	G:\SHE - Life Sciences\MDFRC\Projects\DSEWPC\465 MDB EWKR\PROJECT MANAGEMENT\PHASE 2 DELIVERABLES\2017-18 Milestones and Final Documents\2017-18 ARP
Author(s):	The Murray–Darling Freshwater Research Centre
Author affiliation(s):	The Murray–Darling Freshwater Research Centre, La Trobe University, 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 2017–18
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 2017–18

The Annual Research Plan 2017–18 outlines the research activities proposed to be undertaken under the 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 supported by a number of other documents including:

- the Phase 1 Scoping Report, which described the research planning process, and other Phase 1 reports that describe the planning process in more detail
- the Phase 2 Project Plan, which outlined the project management, governance and administrative arrangements
- the Communications and Adoption Strategy
- the Evaluation Strategy
- the Multi-Year Research Plan (MYRP), updated in June 2017.

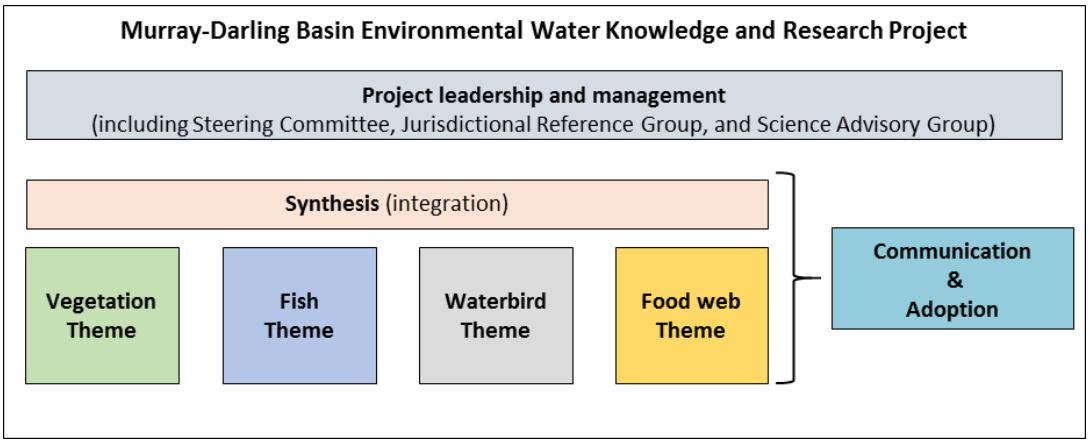

Figure 1-1. Structure of MDB EWKR showing Themes and other major components.

As the third year of research activity under MDB EWKR, this Annual Research Plan builds on the research activities undertaken in 2016-17 and will include a mix of analysis of existing data, field measurements and laboratory experiments. The activities continue to be based on the conceptualisation process which provided a strong foundation for the research.

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

Wetland and floodplain plants provide refuge, breeding habitat and an important food source for a wide range of organisms. They 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 use, they require a clear understanding of the vegetation response objective, the effect of flow on vegetation response, and an understanding of how modifiers influence predicted responses. The MDB EWKR Vegetation Theme will enhance our understanding of the effect of flow on wetland and floodplain plants, and how modifiers (e.g. land use, grazing, and climatic conditions) influence predicted outcomes from the use of environmental water.

Our research framework will focus on the definition and conceptual understanding of the types of vegetation responses that occur among vegetation traits (compositional, structural and process), at different levels of ecological organisation (species, community and vegscape), and across different spatial and temporal scales. Using this framework as a guide, research will focus on a number of key vegetation response types. We will investigate key vegetation responses in relation to nested flow regimes that can occur over varying temporal scales from long-term (decadal) to short-term (annual to one decade) to a single flow event. The key vegetation response types 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 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. The overarching research aim of the Vegetation Theme is to address the following question:

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

This aim aligns with the Priority Research Questions agreed to by the Project Steering Committee (PSC). Through our conceptualisation process we identified the following nested questions:

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

We will apply our principal aims to two main 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)).

We refined our research priorities during planning and conceptualisation phases of this project detailed in the Multi-Year Research Plan (MYRP) (December 2016) – Vegetation Theme chapter – Refinement of Research Priorities section.

2.2 Description of work components

We will implement our research through a series of four research components: *Conceptualisation, Data integration and synthesis, Field site assessments and a Mesocosm study.* This 2017–18 Annual Research Plan describes the work components that will be undertaken in 2017–18 and should be read in conjunction with the MYRP (2016–19).

Our four research components will be supported by planning and coordination activities to address the research topics and aims. To align with the 'one-project' approach of MDB EWKR, our research components will complement each other and combined with Theme planning, coordination and reporting will bring together holistic outputs.

Component V1: Conceptualisation

Conceptualisation will organise existing knowledge and new ideas into a conceptual framework to provide a strong theoretical basis that underpins research planning. Here we develop our thinking on the 'why and what' of vegetation responses to flow. We 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 use existing vegetation survey datasets to explore relationships and interactions between vegetation responses, flow and 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, and 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 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 the 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 2017-18. 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 organised existing knowledge and new ideas into a conceptual framework to provide a strong theoretical basis to support research planning. 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 2016-17 the activity reviewed existing conceptual models relating to understorey diversity and used the review as a basis for 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. This led to the development of a conceptual framework which was presented to the MDB EWKR SAG, the Australian Society for Limnology Conference and water managers (at EWAG and Long-term Watering Plan meetings).

The objectives for 2017-18 are to finalise scientific paper(s) and appropriate adoption outputs including summary paper/fact sheets for managers.

Activity V1.1 – Workshop

Complete

Activity V1.2 – Preliminary reporting to inform research components

Complete

2017–18 activities within this component

- reporting (see Activity V1.3 below)

Activity V1.3 - Reporting

Objective

- to report the results of research undertaken in the Conceptualisation

Description

A scientific paper and summary fact sheets describing the conceptual framework will be finalised with contributions from all members of the Theme 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.

Schedule (2017-18):

Component	**Activity**	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
V1. Conceptualisation	Reporting	Manuscript (31/07/17)												
V1 Conceptualisation	Reporting	Summary fact sheets (31/10/17)												

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 through 2016-17 sought to identify and secure access to relevant data sets, including hydrological information to enable planning of the analysis phase. Analysis of the Hattah Lakes floodplain data was commenced as a pilot activity that would inform the analysis phase.

Activity V2.1 – Planning and Data workshop

Complete

Activity V2.2 – Data collation

Complete

2017–18 activities within this component

- data analysis (see *Activity V2.3* below)
- reporting (see Activity V2.4 below).

Future (2018–19) activity within this component

- reporting (continues into 2018-19; see *Activity V2.4* below).

Activity V2.3 — Data analysis

Objectives

- 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

The first phase of data analysis 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.

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.

Upon completion of the first phase, the advice and outputs of the Hattah Lakes analysis will be used to draft an analysis plan for the larger collated dataset. The approach will be discussed by the Leadership Group and advice sought from Jane Roberts (member of the project's Scientific Advisory Group) before initiating the second phase of the analysis.

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

- update as part of the Annual Progress Report (August 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.

Activity V2.4 — Reporting

Objective

- to report the results of research undertaken in the DISC

Description

- a peer-reviewed scientific publication(s) describing the results of the analysis — aimed at a scientific audience
- appropriate adoption outputs that will support application of new knowledge to environmental flow decisions.

Roles

The reporting will be led by Cassie James with input from the Leadership Group and external collaborators as relevant.

Output(s)

Results from the DISC will be developed into a publication(s) in a peer-reviewed scientific journal, and appropriate adoption outputs aligned to support the application of the new knowledge to environmental flow decisions.

How will the output(s) be used?

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

Schedule (2017-18):

Component	Activity	Output	J	A	S	O	N	D	J	F	M	A	M	J
V2. Data integration and synthesis	Data analysis	Progress update (31/08/17) Data outputs (31/12/17)												
	Reporting	Manuscript (30/06/2018)												

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 field surveys, data collection, analysis and reporting in subsequent years.

Field site assessments are being 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 through 2016-17 sought to refine the research questions, undertake desktop mapping and site selection and develop the field methodology. For more information on selected sites and field methods refer to *Field Assessment Experimental Design Report* (Campbell et al 2017).

Activity V3.1 – Field work planning

Complete

2017–18 activities within this component

- field surveys, including germination experiments (see Activity V3.2 below)

Future (2018–19) activities within this component

- reporting (see Activity V3.3 in the MYRP)

Activity V3.2 — Field surveys

Objective

- to undertake field surveys and germination experiments as detailed in the *Field Assessment Experiment Design Report* (Campbell *et al.* 2017)

Description

To set-up germination experiments using the soil collected from the first round of surveys, and to undertake the second round of field surveys in autumn 2018. For more information on selected sites, field survey and germination experiment methods refer to *Field Assessment Experimental Design Report* (Campbell et al 2017).

Roles

Different organisations will be responsible for leading field surveys, germination experiments 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 Annual Progress Report (August 2017).

How will the output(s) be used?

Outputs will be used to inform component and Theme reporting.

Schedule (2017-18):

Component	Activity	Output	J	A	S	O	N	D	J	F	M	A	M	J
V3. Field site assessments	Field surveys (Germination experiments)	Progress update (31/08/17) Collection of data complete (28/02/18)												
	Field surveys (2nd round of assessments)	Progress update (31/08/17) (1st round of assessments) Progress update (28/02/18) Collection of data (31/05/18)												

2.3.4 ***Component V4 — Mesocosm studies***

Description and objectives

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:

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

Activities through 2016-17 included the review of existing literature and workshops to inform and finalise the experimental design. Seedlings were germinated in late September 2016. Once the seedling establishment phase was complete, the experiment began in early December 2016 and was completed in early May 2017. Sacrificial harvests occurred at the beginning, middle and end of the experiment with two additional observational surveys in the middle of the early phase (January 2017) and the late phase (March 2017).

Activity V4.1 – Mesocosm planning

Complete

Activity V4.2 – Seedling experiments

Complete

2017–18 activities within this component

- Data analysis and reporting (see *Activity V4.3* below)

Activity V4.3 — Data analysis and reporting

Objective

- to analyse and report the results of research undertaken in the seedling mesocosm component

Description

- a peer-reviewed scientific publication(s) describing the results of the experiment — aimed at a scientific audience
- appropriate adoption outputs that will support application of new knowledge to environmental flow decisions.

The analysis and reporting for this components will focus on the effect of different water regime treatments on seedling growth of the four key woody species: River Red Gum, Black Box, Coolibah and Lignum. The water regime treatments focus on the effect of multiple wetting and drying periods, inundation during early seedling life phases, inundation during later seedling life phases and either permanently wet or permanently dry. Seedling growth will be assessed in relation to mortality, seedling height, leaf number and area, root length and biomass of above ground and below ground components. For further details of the experimental design please refer to the *Recruitment of long-lived floodplain vegetation: Mesocosm study experimental design* (Durant et al 2017).

Roles

MDFRC will lead the collation of data. The Leadership Group will provide input into analysis and interpretation of results. The scientific paper and fact sheets will be developed by the Leadership Group, led by MDFRC.

Output(s)

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

How will the output(s) be used?

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

Schedule (2017-18):

Component	**Activity**	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
V4. Seedling mesocosm studies	Data analysis and reporting	Manuscript (31/05/18)												

Schedule (2017-18):

Component	Activity	Output	J	A	S	O	N	D	J	F	M	A	M	J
V5. Theme coordination	Theme coordination	Progress update (31/08/17) Progress update (28/02/18)												
	Budget and work plan review	Reviewed and updated (30/04/18)												
	ARP + MYRP review	Reviewed and updated (30/04/18)												
	Progress reports	Annual Progress update (31/08/17) Mid-year Progress update (28/02/18)												
	EWKR project wide workshop	Workshop (28/02/18)												
	SAG, JRG Regional workshops	Attendance and/or input to workshops as required (TBC)												

3 Native fish

Authors: Amina Price (MDFRC), Stephen Balcombe (Griffith University), Lee Baumgartner (MDFRC), Paul Humphries (Charles Sturt University), Alison King (Charles Darwin University), Brenton Zampatti (SARDI)

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 (highest priority area) 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 proposed work components and activities over the life of the project. Component F1 (foundational activities) are almost complete and are summarised below. Components 2 and 3 (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, or those which have already been completed, are included in summary and will be further defined in the final (2018-19) ARP.

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 (Jan 2016-Oct 2017)

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

The refinement of our conceptual understanding was a critical component of the research plan and was comprised of a number of activities that informed the refinement of both the MYRP and the ARP (2016-17). The review and synthesis activities were completed in 2016/17 and following some delays, the final outputs will be produced in 2017/18 as follows:

- the Knowledge and Management of Flows and Fish Recruitment scientific publication will be submitted by July 2017
- the theoretical synthesis and conceptualisation paper will be submitted for publication by the end of August 2017
- the review and synthesis of the factors limiting spawning and recruitment publication will be submitted by the end of October 2017 (this paper cannot be submitted until the other foundational papers have been submitted)

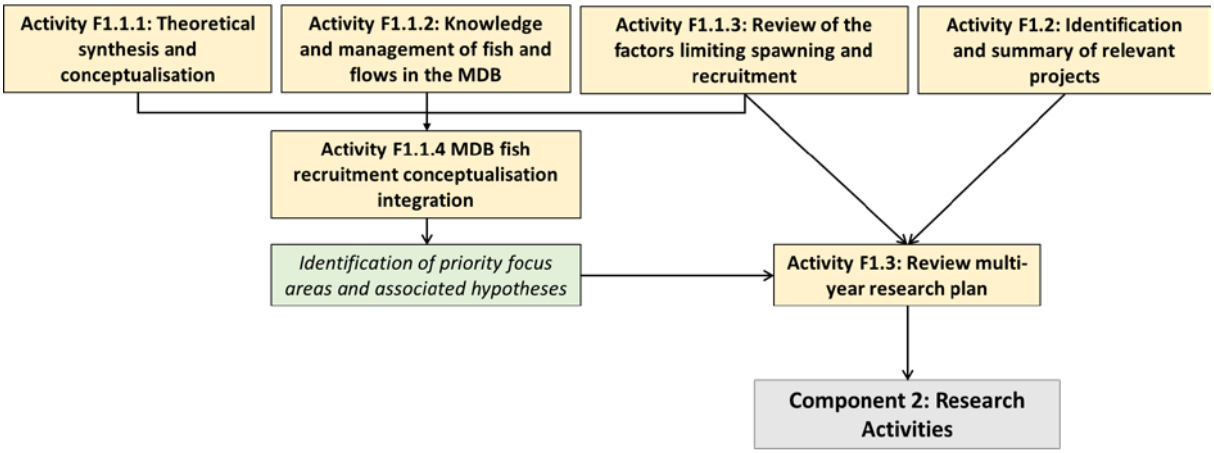

Figure 3-1 Flow diagram depicting the proposed foundational activities and how these relate to the later work components

3.3.2 Component F2 – Research activities

Activity F2.1 Understanding the feeding requirements of larval fish in the northern Murray-Darling Basin (NMDB) (Griffith University); 2016-2018.

Description and objective(s):

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

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

This project complements work that will be undertaken by the Department of Science, Information Technology and Innovation. It is proposed that sampling will be undertaken monthly in three locations (upstream middle downstream) within two waterholes (Narran and Culgoa) over a 12-month period. Sampling will target both fish larvae (using larval tows, and box traps and potentially larval light traps) and potential prey (zooplankton – plankton net). The project is planned to commence in July 2017 to coincide with increasing water temperatures and associated early spawning events as the system moves from winter to spring. Larvae will be identified and counted with a sub-sample retained for diet analysis and one for body condition. Zooplankton will be enumerated and identified and assessed for size structure. Larval diets will be assessed for both volume and prey size to examine both ontogenetic variability and variation through the sampling season. We will undertake the diet analysis on two to four species with contrasting reproductive traits in relation to flow triggers (those that spawn with flow as a trigger such as spangled perch or Hyrtl's tandan; those that spawn independently of flow such as bony bream and Australian smelt;

those that spawn in both the absence or presence of flow such as Golden perch). Final species selection will depend on numbers of larvae collected, integration with the species that are being examined in other work components and species for which our dietary knowledge is poorest. We aim to analyse between 500-1000 individual larvae (which will cover both temporal ontogenetic and larval species differences). The exact nature of the dietary analysis will be determined based on prey abundance and larval diversity following the first four sampling periods (to ensure we have sufficient individuals/species to run a complete ontogenetic analysis).

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

Outputs

Improved understanding of the dietary and nutritional requirements of the fish larvae of a number of contrasting MDB species. The outputs from this work will be written up in scientific manuscript and associated adoption outputs that will be described in the 2018-19 ARP.

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 Web Theme and will be used to inform the predictive model that will be developed at the end of the project.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Project planning	Progress Report (10/10/17)												
Field work	Progress Report (10/02/18)												
Laboratory processing of field samples	Progress Report (10/06/18)												
Data analysis	Planned for 2018-19												
Write-up	Manuscript												

Activity F2.2: Examination of the relationship between food density, temperature and early-life stage growth and survival (MDFRC); 2017-2018.

Objective and description:

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

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

- Periodic species e.g. Golden perch
- Equilibrium species e.g. Murray cod
- Opportunistic species (good dispersers) e.g. carp gudgeons, Australian smelt
- Opportunistic species (poor dispersers) e.g. southern pygmy perch

We propose to obtain larvae and juveniles from a range of sources. We will source large-bodied species from the Narrandera hatcheries program, opportunistic species (good dispersers) from local rivers and opportunistic species (poor dispersers) from captive breeding programs if available. Species selection (number of species and which species) will be based on availability of eggs or larvae and logistical and budgetary considerations. These decisions will be made followed detailed project planning and the finalisation of the experimental design. The experiment will be a gradient design to enable measurement of growth and survival at fourteen food densities and five temperatures. The ranges of prey densities that will be used will be determined based on existing literature of natural prey densities across the MDB. The range of temperatures that will be used will be based on both the current knowledge of the lethal minimum and maximum temperatures for the fish species that will be used and the natural temperature ranges experienced across the MDB during the breeding season.

Outputs

Quantitative models describing growth and survival as a function of food density and temperature and how these factors interact. The models will be written up in scientific manuscript and associated adoption outputs that will be described in the 2018-19 ARP.

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. The integration between outputs from Activity

2.2 and 2.3 will provide information to managers about the types of hydraulic patches required for fish recruitment and this information will help inform flow allocation decisions. The outputs will also be integrated with outputs from the Food web theme and inform development of the Food web modelling activity.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Project planning and set-up	Refined Plan (30/11/17)												
Laboratory trials	Progress Report (30/03/2018)												
Data analysis and model development	Planned for 2017-18												
Write-up	Manuscript Planned for 2017-18												

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

This activity aims to describe the spatial heterogeneity in the thermal and nutritional landscape at multiple spatial scales to determine at what scale and to what extent thermal and nutritional habitat quality for early life-stages varies. The activity is being undertaken collaboratively with the Food web theme. The fish theme is focussing on issues of food abundance while the Food web theme is addressing questions about the basal resources on which the food are reliant.

The work will be broken into three activities:

1. Detailed assessment of thermal and nutritional patch-level variability among main channel and floodplain habitat patches at one river-floodplain area. The first year's sampling was undertaken in the Ovens River in early 2017 and further sampling will be undertaken during spring, summer and autumn of 2017/18. It is hoped that this will allow us to gain insights into how patterns vary seasonally and with respect to flow and the degree of floodplain connectivity (see Activity 2.3.1).
2. Identification of optimal thermal and nutritional zones, and the scales at which they function within a lowland river system. The work will be undertaken during spring, summer in 2017/18 (see Activity 2.3.2).
3. Preliminary investigation into variability in larval food availability in relation to different structural habitat types using existing data. This was undertaken in 2016/17 (see Activity 2.3.3).

This activity is focused on temperature and food density and does not include associated fish sampling. The rationale for this is that the distribution and abundance patterns of larvae is relatively well-understood and that it is the mechanisms underpinning these distribution patterns which we lack a clear understanding of.

Activity F2.3.1: Comparison of the thermal and nutritional regimes among main channel and floodplain habitat patches; 2016-2018.

Objective and description:

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

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

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

1. Sampling that will include deployment of temperature loggers to assess thermal differences and collection of planktonic and epibenthic microinvertebrate samples in each patch to determine the biomass of different size fractions. Sampling has occurred during the peak breeding season (Dec-Feb) in 2016/17 and this will be repeated in 2017/18 (if this is a non-flood year). In 2016/17, six replicates of each habitat type were sampled. Decisions regarding the number of replicates for the 2017/18 season will be determined following the analysis of the previous year's samples.
2. Analysis of planktonic and epibenthic microinvertebrate samples to determine densities of different prey types (size fractions).
3. Analysis of data.

Outputs

The results from this sub-component, coupled with results from component F2.2, will inform us about the potential role of the floodplain versus the main channel for growth and fish recruitment for different species. The results from Activity F2.3.1 in 2016-17 and 2017-18 will be integrated with the outcomes of Activities F2.2 to develop a model of the influence of food and temperature on

larval recruitment. The results from the field sampling will be published in a scientific manuscript and associated adoption outputs.

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 (2017-18):

Results from the sampling in 2016-17 will inform refinements of the sampling and analysis plan for 2017-18. The hypothesis generation activities described in Activity F2.3.2. may also influence the final sampling design.

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Project planning	Updated plan (30/11/2017)												
Field work	Progress Report (30/3/2018)												
Laboratory processing of field samples	Progress Report (30/6/2018)												
Data analysis													
Write-up	Manuscript												

Activity F2.3.2: Identification of optimal thermal and nutritional zones, and the scales at which they function within a lowland river system; 2017-2018.

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

This activity aims to test key elements of the fundamental triad model which predicts significant spatial heterogeneity in the thermal and nutritional landscape at multiple spatial scales. The sampling will test hypotheses about where in the landscape, at what scale and to what extent thermal and nutritional habitat quality varies for early life-stages varies. This activity will be undertaken in the Ovens River and will include the following steps:

1. Generation of hypotheses regarding the location and scale of functional zones for fish recruitment generation based on existing of river ecosystem models. These hypotheses will be used to determine the types, locations and scales that sampling will be undertaken.
2. Sampling design and planning.
3. Sampling that will include deployment of temperature loggers to assess thermal differences and collection of planktonic and epibenthic microinvertebrate samples in each patch to determine the biomass of different size fractions. Sampling will occur during the peak breeding season (December to February) in 2017/18.
4. Analysis of planktonic and epibenthic microinvertebrate samples to determine densities of different prey types (size fractions). Analysis of prey quality will be undertaken if the budget permits.
5. Analysis of data.

Output(s)

The results from this sub-component will enable evaluation of the fundamental triad model and inform its application to the management of environmental flows. The results from Activity F2.3.2 combined with the outcomes of Activities F2.3.1 and F2.2 will inform development of a model of the influence of food and temperature on larval recruitment. The results from the field sampling will be published in a scientific manuscript and associated adoption outputs.

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.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Hypothesis generation	List of hypotheses (30/09/2017)												
Project planning	Updated Plan (30/11/2017)												
Field work	Progress Report (30/3/2018)												
Laboratory processing of field samples	Progress Report (30/6/2018)												
Data analysis	Conference Presentation												
Write-up	Manuscript												

Activity F2.3.3: Preliminary assessment of the influence of structural habitat on prey composition and density; 2016-2017.

This Activity was completed in 2016/17.

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 and Golden perch larvae and passive particles. The work has been broadly planned and a budget developed and agreed by the Leadership Group. The field work will involve a number of short-term field experiments. It is not envisaged that the field work or sample analysis will take more than a few months. A full description of the proposed activity will be included in the 2018/19 ARP and undertaken in 2018/19.

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); 2016-2018.

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 Murray-Darling Basin (MDB) 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

often 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-River Murray 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.

This project aims to elucidate spatio-temporal relationships between flow and key population processes for one to two long-lived, large-bodied species in order to improve large-scale flow management to improve population outcomes for species whose populations operate at larger spatial scales. The project will be undertaken in two stages:

1. Initial planning and preliminary analyses of water samples.
2. Basin-wide collection and analysis of otoliths.

Stage 1, the initial planning and preliminary analyses of water samples, will determine the number and location of sites, the specific methodologies and the number of species that can be included. The work that will be undertaken during this stage will comprise:

- Sr analysis of existing northern Basin water samples: Conduct ^{87}Sr:^{86}Sr analysis of ~40 water samples collected in 2015/16 and 2016/17 from rivers in the northern MDB to determine spatio-temporal variability in water ^{87}Sr:^{86}Sr as a precursor to fish otolith Sr investigations. These analyses will be undertaken by Melbourne University. This will be completed by 31st July 2017.
- Project Planning Workshop: Workshop of the key project participants to determine final project design and contemporary field projects that can contribute data to Stage 2 of the project. This will be completed by 30 June 2017.
- Revision of Research Plan: Revise research plan (including budget) in light of above activities and available budget ($400K). This will be completed by 18 August 2017.

If the initial planning stage identifies that there is only capacity to undertake work on one species, the project will focus on Golden perch. If however, there is capacity to undertake some additional work on a second species, then we propose to include Murray cod.

Golden perch and Murray cod are the largest and longest-lived native freshwater fishes in the MDB. They are culturally important for aboriginal 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? And will the same approach work for Golden perch, or do factors outside of the reach also need to be considered?

For Stage 2 of the project, Basin-wide collection and analysis of otoliths, our specific objectives are to:

- 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).
- 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
- 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
- use this understanding to inform environmental water management at larger spatial scales.

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.

Study sites and methods

The specific sites and methods for stage two will be described in the revised Research Plan, which will be delivered by 18 August 2017.

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
- the patterns of spatio-temporal variation in these parameters and whether dispersal between regions influences population dynamics
- a scientific manuscript and associated adoption outputs that will be described in more detail in the 2018-19 ARP.

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 (2017-18):

Activity	Output	J	A	S	O	N	D	J	F	M	A	M	J
Preliminary analysis of water samples													
Revision of Research Plan	Revised Research Plan (14/08/2017)												
Water sample collection and analysis	TBA												
Otolith analysis	TBA												
Data collation	TBA												
Data analysis	TBA												
Write-up	TBA												

3.3.3 Component F3 – Swimming capacity and settlement cues and environmental tolerances of the early life stages of Murray-Darling Basin fishes (student project)

Water infra-structures and challenges for fish conservation: Larval trait-based analysis to foresee fish recruitment in regulated rivers (2016-2018)

Objective and description:

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

Trait analysis and species selection will be completed by 2016/17 and swimming experiments will be undertaken in 2017/18. 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). Lorena has completed a literature review and trait analysis and has selected Murray cod and Golden perch as study species for this season with the potential for either carp or two small-bodied species in the following year.

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 using field experiments to examine larval transport and retention 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 and*
   - *flow scenarios.*
2. *How can water manager's best manage delivery of environmental water to target the most appropriate recruitment drivers for the species and system of interest?*
3. *What non-flow related factors are likely to impact on the key recruitment drivers and how? What complementary actions can be used to improve recruitment outcomes?*

4 Waterbirds

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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 MDB 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 <u>after</u> a breeding event?*
2. *Where do adults forage <u>during</u> nesting (where are they getting the food for the chicks?)*[1]

[1] In the first year, we have limited data to answer Question 2 above, because only two birds definitely continued to nest or re-nest post-capture (others may have but we can't be sure). If birds with trackers survive until subsequent breeding events this will allow more data collection. However most adults leave the nesting area after capture and tagging

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[2]
- waterbird diet composition, quality, and changes over time (with the Food Webs Theme)[3]
- 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.

[2] In the first year, the juvenile mortality rate was 100%. While tracking data can be used to document where they go after fledging, it will not be possible to establish whether these birds would have returned to their natal site.

[3] Logistical issues have prevented collection of regurgitate samples for analysis of diet quality. UNSW Honours student Emily Webster has analysed the content of scat samples from chicks, however the usefulness of these data was limited and this will not be repeated. A new plan for a collaborative bioenergetics project has been designed for the 2017-18 breeding season. More detail is described in the section for Sub-Activity B2.3.2.

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 2016–19). 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 ARPs.

4.3 Work components and activities

Our intent is to conduct all research activities as collaborations among the personnel involved in the Leadership Group and the organisations/staff selected for the Implementation Teams. Activity leaders will be assigned clear roles and responsibilities for each field and desktop activity. The Leadership Group will then oversee development of plans for each activity that specify staff, timelines, deliverables, budgets, specific links to other activities and Themes etc.

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

This activity is now complete. 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.
- The final literature review pdf is available on the MDB EWKR website, via the Waterbird Theme page.

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. The information will also be summarised into adoption outputs for water managers.

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 undertaken in 2016–17 will be adapted in 2017-18 in response to lessons learnt in 2016-17. 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 B2.3 — 2017–18 field research

Activity B2.3 will build on the successful field work undertaken in 2015-16 and 2016-17. The major areas of data collection across these two field seasons were:

- on-ground colony mapping and counts, including nest and adult counts, egg and chick counts at tagged nests, and recording nesting habitat characteristics
- motion-sensing and time-lapse cameras, followed by image data extraction and analysis to document egg, chick, and fledgling survival and mortality, predation, nest defence and feeding rates by parents over time for selected species
- satellite tracking of adults and juveniles at Barmah-Milawa and Macquarie Marshes.

Details of these activities are described in more detail in the MDB EWKR Waterbird Annual Research Plan 2016-17. The activities planned for 2017-18 involve essentially the same activities as those conducted during the previous year, with modifications based on results to-date. These are described below.

Sub-Activity B2.3.1 — Preparation and equipment purchase

Objective

- to prepare for field data collection activities

Description

- engagement with stakeholders (e.g. travel, phone meetings)
- animal ethics applications, amendments, 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)
- revision of 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 (*B2.3.2*) and other research activities.

Schedule (2017-18):

Component and activity	Outputs	J	A	S	O	N	D	J	F	M	A	M	J
Sub-Activity B2.3.1 — Preparation	• Equipment ready for use in field data collection • Fieldwork planned and ready to implement												

and equipment purchase													

Sub-Activity B2.3.2 — Field data collection

Objective

- to collect field data describing waterbird recruitment and movement and their drivers

Description

A minimum of three main field data collection trips are planned for the summer of 2017–2018, 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.

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).

Following consideration of the outcomes of the 2016-17 fieldwork, the following changes are *planned for the 2017-18 field season:*

- Discontinuation of on-ground foraging habitat surveys. Instead, foraging habitats will be described using a combination of existing mapping and remote sensing data. Foraging efficiency and habitat surveys were conducted last season, but with limited opportunities. In particular, it was difficult to locate foraging birds during the nest season as intended, when time was available for surveys. The tracked birds did not remain in the area for long enough for the team to use their locations. In addition, to be useful, foraging habitat data ideally need to compare foraging sites with non-foraging sites. A Citizen Science grant proposal has been submitted in collaboration with the MDFRC, also incorporating some brolga work in N-W VIC, in order to support local surveys of foraging habitats where tracked birds are located across the Murray-Darling Basin.
- Discontinuation of regurgitate and scat sample collection for diet/bioenergetics research. Instead, bioenergetics will be modelled based on chick allometry (weights and measurements at two different ages), a literature review and data for similar species from overseas. Logistical issues have prevented collection of regurgitate samples for analysis of diet quality. Sampling for regurgitates was unsuccessful, with the UNSW Honours student unable to obtain samples from chicks. UNSW Honours student Emily Webster has analysed the content of scat samples from chicks, however the usefulness of these data was limited and this will not be repeated. An MDFRC summer student tested a method of extraction of feeding frequency data from the previous year's cameras. Methods and issues were identified that will inform analyses from this year's images from the new cameras. A new plan for a collaborative bioenergetics project has been designed for the 2017-18 breeding season – see the Food Web Theme research plan for more detail.
- Earlier camera deployment at known nesting clumps used by birds in the past two seasons, potentially before birds arrive and lay eggs, in order to reduce the number of disturbances during nesting.

- Ceasing camera deployment and image analysis when chicks are at 'flapper' stage. At this age onward, it is difficult to tell which nest chicks come from – particularly for ibis.

Changes in the total numbers of waterbirds to be tracked and addition of a second species to be tracked. Combining recovered transmitters from last season, discounts, efficiencies and purchase of some cheaper transmitters, it will be possible to expand the number of transmitters to be deployed in the 2017-18 season. Following extensive exploration of various options, the Waterbird Theme Leadership has decided the following (subject to approval of the relevant Animal Ethics Committee):

- juveniles will be tracked again in order to facilitate data analyses describing recruitment outcomes and drivers of mortality i.e. if we really want to boost recruitment, at the moment the greatest scope seems to be through boosting juvenile survival
- where possible, smaller/lighter transmitters will be used and older juveniles will be caught
- Argos Geotrak type satellite transmitters will be deployed on juveniles, in order to enable establishment of individual fates (these transmitters have full Australian and worldwide coverage)
- GSM phone network transmitters will be deployed on adults for long-term data collection – if the appropriate technology is ready for the networks available by mid-2017. Otherwise Geotrak Argos type transmitters will be used (but fewer).
- more juveniles will be tracked than adults (if approved by animal ethics committee)
- if circumstances allow (flooding, breeding and accessibility), two species will be tracked: straw-necked ibis and royal spoonbills. Royal spoonbills are more dependent on surface water for foraging than straw-necked ibis, and have other advantages described elsewhere.
- including the 10 recovered transmitters and satellite/network costs, we should be able to track approx. 40-50 birds, including the following numbers of each species and age group:

	Juveniles	Adults
Straw-necked ibis	10-15	5-10
Royal spoonbill	10-15	5-10

- we will make a final decision on numbers of GSM phone network vs Argos Geotrak transmitters in late June, when we know a) if e-obs transmitters will be ready; b) if tracking juveniles is still approved by AEC
- tracking will be conducted from Barmah-Millewa or Macquarie Marshes as priority sites. Other sites will be considered depending on conditions if the latter two sites are not hosting breeding colonies.
- catching this many birds will be dependent on purchase and Animal Ethics Committee approval of a net gun for capture.

Outputs

- datasets describing colony size, location, nest, egg and chick counts, and fledging rates
- datasets describing nesting habitat characteristics
- chick allometry data for bioenergetics modelling
- 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

- data describing foraging movements of immature and adult waterbirds.

How will the output(s) be used?

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

Schedule (2017-18):

Component and activity	Outputs	J	A	S	O	N	D	J	F	M	A	M	J
Sub-Activity B2.3.2 — Field data collection	• Datasets describing colony size, location, nest, egg and chick counts, and fledging rates • Datasets describing nesting habitat characteristics • Chick allometry data for bioenergetics modelling • 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 • Data describing foraging movements of immature and adult waterbirds												

Sub-Activity B2.3.3 — Data processing and analysis

Objective

The objective of this activity is to analyse data collected in *Activity B2.3.2*.

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: bird allometry/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, University of NSW and University of Canberra)
- integrative data analyses and interpretation (CSIRO, University of NSW and University of Canberra).

The data analysis will identify breeding colony size, including numbers of breeding pairs, eggs, chicks, and fledglings and address the following questions:

1. *What are the locations and characteristics of foraging habitats? — e.g. vegetation type, distance from colony? (The focus for this question will now be on foraging between breeding events. In the first year, we have limited data for this question for adults during nesting, because only two birds definitely continued to nest or re-nest (others may have but we can't be sure). If birds with trackers survive until subsequent breeding events this will allow more data collection. However most adults left the nesting area after capture and tagging in the first year).*
2. *How do nesting habitat characteristics influence the numbers of fledglings produced?*

3. *How much does physical accessibility to predators (nest position, water level) affect fledging rates?*
4. *How much does nesting habitat influence exposure of chicks to extremes in temperature or weather?*
5. *How much predation takes place on eggs and chicks and which species are responsible?*
6. *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 B2.3.4.*

How will the output(s) be used?

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

Schedule (2017-18):

Component and activity	Outputs	J	A	S	O	N	D	J	F	M	A	M	J
Sub-Activity B2.3.3 — Data processing and analysis	Data analysis outputs to support Activity B2.3.4.												

Sub-Activity B2.3.4 — Reporting

Objective

- to report the results of research conducted during the 2017–18 year

Description

The process and outcomes of activities undertaken during the 2017–18 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 2017–18 field research and inform research activities to be undertaken in following years.

Schedule (2017-18):

Component and activity	Outputs	J	A	S	O	N	D	J	F	M	A	M	J
Sub-Activity B2.3.4 — Reporting	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.												

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 and will be included in the 2018-19 ARP.

5 Food Webs

Authors: Paul McInerney (MDFRC), Nick Bond (MDFRC), Rebecca Lester (Deakin University), Barbara Robson (CSIRO), Darren Ryder (University of New England), Ross Thompson (University of Canberra), Ben Gawne (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 for 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; Gree*t 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 taxa 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).

Much less clear is the role of flow in generating the required resources for key life-history events, which result in recruitment of plants and animals into breeding populations (Shenton *et al.* 2012). For example, there are a number of documented cases of bird breeding triggered by flow events where 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).

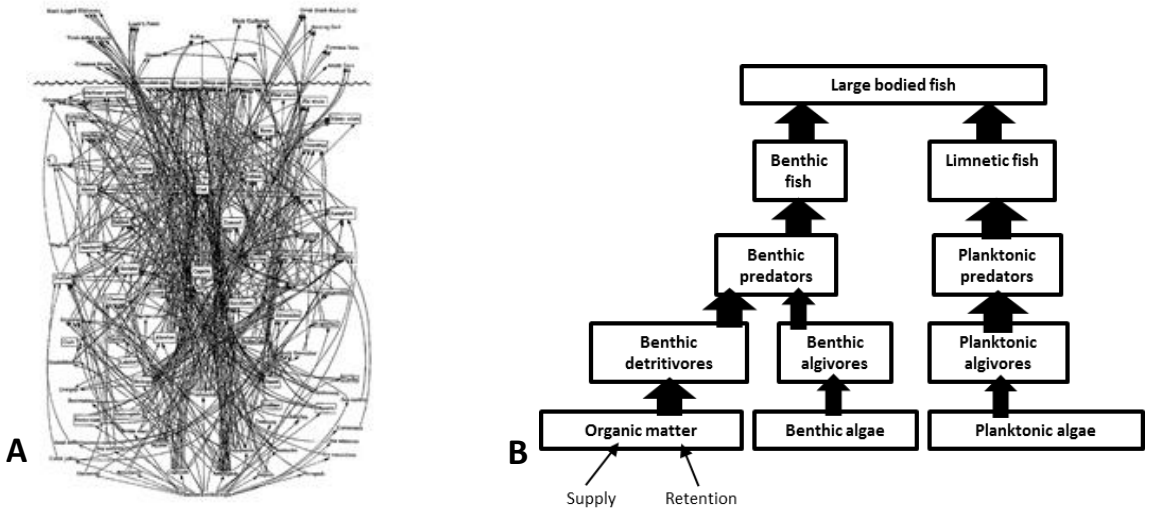

Figure 5-1 Examples of describing food webs A) using species and links, illustrating the complexity and associated challenges in dealing with species interactions within an ecosystem and B) using a simpler bioenergetic representation.

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:

- able to determine pathways of energy through the food web to the species of interest
- relatively simple to implement and have been subjected to peer-review
- 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), constructed to identify nodes and links in the bioenergetics model (Bond et al. in press). Species are grouped together functionally and the size of the font in the figure indicates biomass of each compartment.

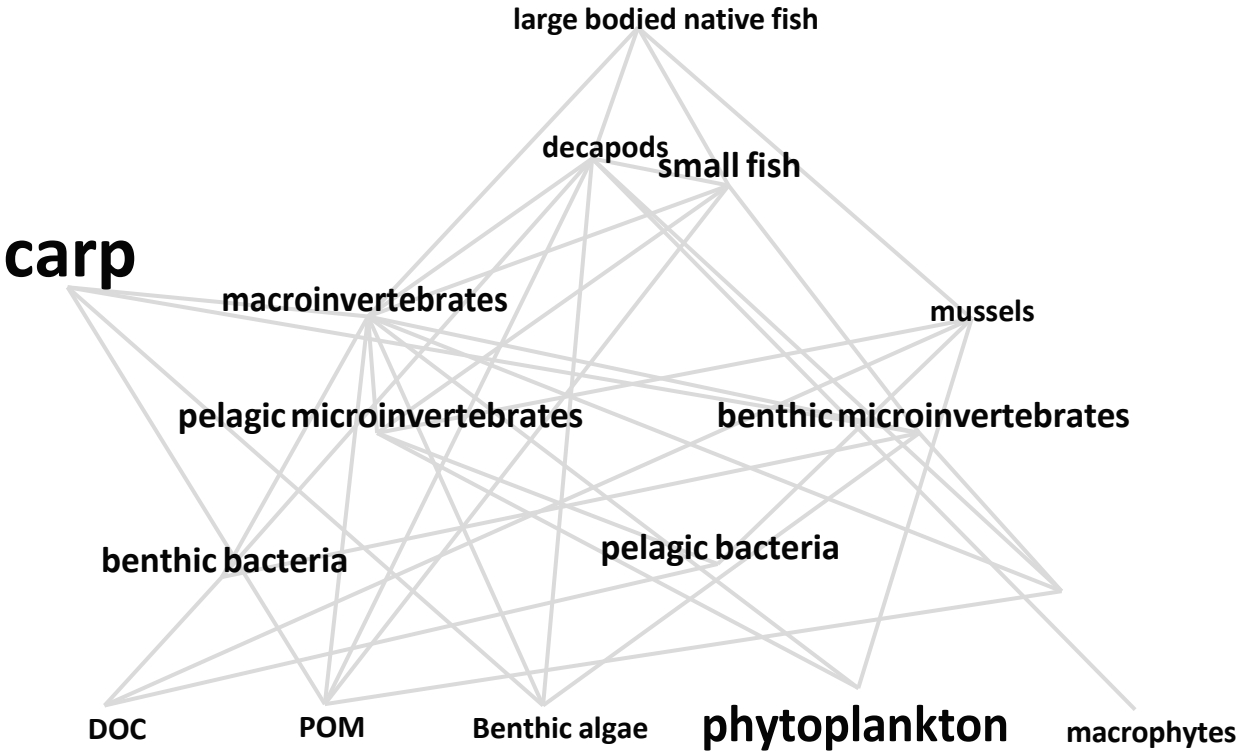

Figure 5-2 Contemporary food-web constructed to identify nodes and links in the bioenergetics model within the MDB (Bond et al. in prep).

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, and 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.

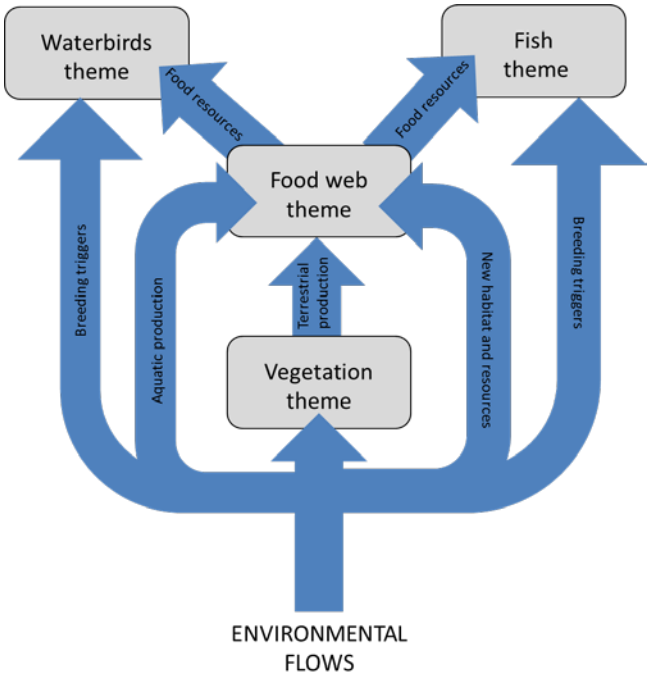

Figure 5-3. Conceptual diagram illustrating the effects of environmental flows on the movement of energy and resources across and between the four Themes of MDB EWKR.

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. This stage is currently underway.

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. This component will be undertaken in collaboration with Fish and Waterbird Themes
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 has been 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.

Outputs

Component W1 produced three draft scientific manuscripts that have been submitted to scientific journals.

1. **Concept**
   Rolls, R. J., Baldwin, D. S., Ryder, D. S., Bond, N., Gawne, B. Lester, R. E., Robson, B. J., & Thompson, R. M. Hydrological drivers of river-floodplain foodwebs: implications and opportunities for predicting ecological outcomes of environmental flows. Submitted to: Biological Reviews.

2. **Indicators**
   Rolls, R. J., Baldwin, D. S., Watson, G., Bond, N., Gawne, B. Lester, R. E., Robson, B. J., Ryder, D. S., & Thompson, R. M. Monitoring and evaluating trophic dynamic responses to hydrological manipulations in riverine systems. Submitted to: Journal of Environmental Management.

3. **Modelling**
   Robson BJ, Lester RE, Baldwin DS, Bond NR, Drouart R, Rolls RJ, Ryder DS, Thompson RM. Modelling food-web mediated impacts of hydrological variability and environmental flows. Submitted to: Water Research

Key information contained within the manuscripts included:

1. Conceptual models that express potential energy pathways to taxa of interest (Figure 5-4).
2. Identification of key knowledge gaps.
3. Identification of potential modelling approaches.

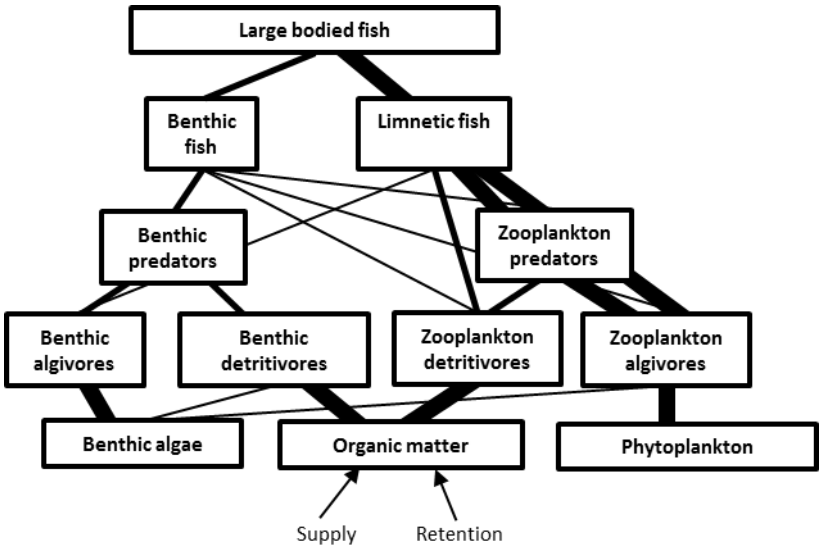

Figure 5-4. A simplified bioenergetic representation of a riverine food web in the Murray River based on Kingsford *et al.* (2015). The width of the lines indicates the magnitude of the energy flows from different sources, which are currently unknown and will be the focus of this research program.

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.

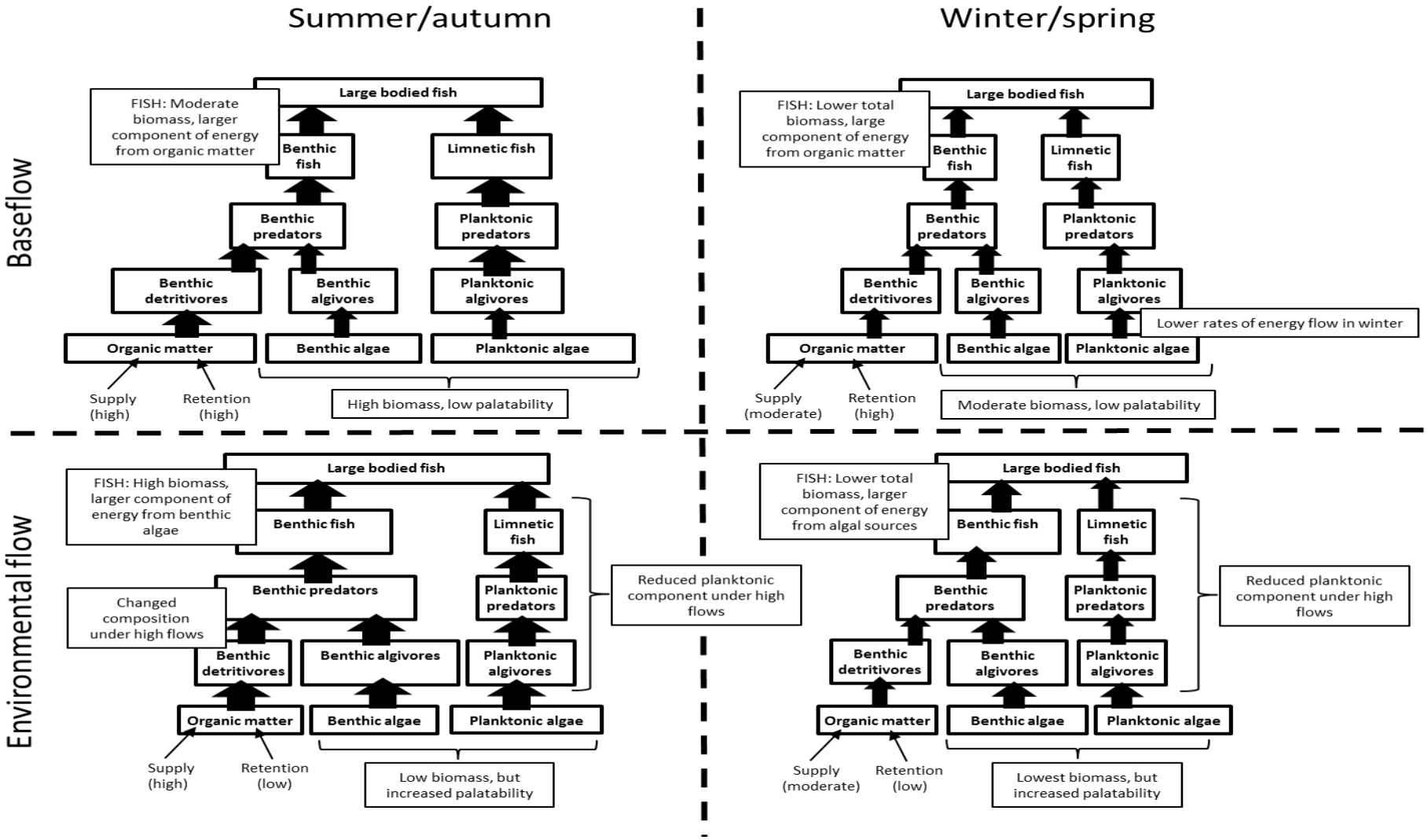

Figure 5-5. A conceptualisation of the way that season and flow interact to influence the basal resources supporting large-bodied native fish.

Approach

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

Outputs

- empirical data that expresses relative magnitudes of energy pathways to taxa of interest (Q1A, Q1D)
- empirical data that assesses potential spatial and temporal variability in productivity (Q1B, Q1C, Q1E)
- 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 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 activity aims to describe the spatial heterogeneity in the thermal and nutritional landscape at multiple spatial scales to determine at what scale and to what extent thermal and nutritional habitat quality for early life-stages varies.

The Fish Theme have broken this component into three activities:

1. Detailed assessment of thermal and nutritional patch-level variability among main channel and floodplain habitat patches at one river-floodplain area. The work will be undertaken during spring, summer and autumn and will be undertaken over two years (2016/17 and 2017/18).
2. Identification of optimal thermal and nutritional zones, and the scales at which they function within a lowland river system. The work will be undertaken during spring, summer in 2017/18.
3. Preliminary investigation into variability in larval food availability in relation to different structural habitat types using existing data. This was undertaken in 2016/17.

The Food Web Theme mirrored the sampling effort of the Fish Theme (spatially and temporally) in 2016-17, but collected a range of samples from multiple trophic positions (Table 5-1). The Food Web team are seeking to identify critical basal resources supporting fish recruitment and aim to trace the flow of energy through these ecosystems. Stable isotope composition and fatty acid profiles of material from a range of compartments within food webs of wetlands, anabranches and river channels will be determined.

In 2016-2017 three field trips were conducted in collaboration with the Fish Theme from December 2016 to February 2017. During each trip basal resources and zooplankton were sampled from 18 sites comprised of 6 River Channel, 6 Anabranch and 6 Permanent Wetland sites on the Ovens River floodplain. Food Web and Fish Themes worked collaboratively to sample a broad range of metrics listed in Table 5-1.

Table 5-1 Samples collected in 2016-17 field work with Fish Theme and proposed analyses. SIA – Stable Isotope Analysis, TA – Fatty Acid analysis

Samples	Analyses
Chlorophyll-*a*	Concentration
Seston	SIA, TA
Biofilm	SIA, TA
Filamentous algae	SIA, TA
Terrestrial litter	SIA, TA
DOC	Concentration
Benthic Zooplankton	SIA, TA
Pelagic Zooplankton	SIA, TA
Macroinvertebrates	SIA, TA
Macrophytes	SIA, TA
Periphyton	SIA, TA

Determination of stable isotopes and fatty acid profiles is expensive, and therefore sub-samples of material collected in 2016/17 will determine if analysis of all samples will proceed. Preliminary results of this work and the amount of funding set aside for the basin wide sampling activity (component W3) will also determine if the Food Web Theme will collaborate with the Fish Team in field activities 1 and 2 listed above planned, for spring-summer 2017-18.

Figure 5-6 Food Web and Fish Theme groups field sampling on the Ovens floodplain in December 2016; Richard Kopf and Kyle Weatherman collecting zooplankton from (a) wetland site 2 (b) wetland site 1 (c) anabranch site 2 and (d) Mike Dunn and Paul Humphries measuring flow at river channel site 4. Photos by Rochelle Petrie.

Activities for 2017–18

Samples collected in the field in 2016-2017 will be processed and analysed in 2017-2018. Processing has commenced and samples are being analysed for stable isotope and fatty acid composition. Preliminary results from these samples will determine the total number of samples collected that will be processed.

The focus of field sampling in 2017-18 with the Fish Theme will be determined from evaluation of the preliminary results from 2016-17 and the hypotheses generated by the Fish Leadership Group.

Outputs

1. Empirical data that expresses relative magnitudes of energy pathways to taxa of interest.
2. Appropriate adoption outputs 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. This work will be applicable to the forested floodplains in the southern-connected Basin. Work to enable this to be scaled up is included in Activity 2.4
3.

Manuscript

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.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Laboratory processing of field samples for (SIA and TA)	N/A												
Sub-sample set for preliminary analysis	Data												
Data analysis	Progress Report												
*Sampling Ovens River	Samples												
*Laboratory processing of field samples for (SIA and TA)	N/A												
*Data analysis	Data												
*Write –up (2018-19)	Draft Manuscript												

*subject to results generated from 2016-17 data analysis

Activity 2.2 Waterbird food requirements research 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.

As described previously, the Waterbird Theme have discontinued regurgitate and scat sample collection for diet/bioenergetics research. Instead, bioenergetics will be modelled based on chick allometry (weights and measurements at two different ages), a literature review and data for similar species from overseas. Collection of regurgitate samples for analysis of diet quality. Sampling for regurgitates was unsuccessful and the judgement of the Waterbird Leadership Group was that changing the method to ensure its success would be too stressful for the birds and would not receive ethics approval.

UNSW Honours student, Emily Webster, has analysed the content of scat samples from chicks from the 2016-17 breeding season, however the usefulness of these data was limited and this sampling will not be repeated. An MDFRC summer student tested a method of extraction of feeding frequency data from the previous year's cameras. Methods and issues were identified that will inform assessments of feasibility and analyses for subsequent years. A new plan for a collaborative bioenergetics project using a different approach has been designed for the 2017-18 breeding season (refer to the Waterbird section of the ARP for further detail).

Activities for 2017–18

Two primary activities are planned for 2017-2018. These may be conducted separately or concurrently:

A. Colonial-nesting waterbird allometry (2017-2018 summer)

1. Field measurements of straw-necked ibis chick weight, bill length, head-bill length, tarsus length, wing length, tail length at two age stages: Hatchling/squirter and flapper/flyer. The Waterbird Theme can probably incorporate measurements into existing fieldwork if done only at hatchling/squirter and flapper/flyer stages, since hatchlings/squirters are regularly visited anyway and flappers/flyers will be caught for satellite tracking. A subset of hatchlings/squirters may be colour-marked as individuals and monitored with motion-sensing and time-lapse cameras to gather growth and survival data. A subset of flappers/flyers caught will also be tagged with satellite GPS trackers (as part of the main Waterbird Theme research program).
2. Statistical analysis of the resulting database.
3. Drafting a scientific journal paper.

B. Colonial-nesting waterbird allometry and energy requirements: literature review and model development

1. Review of both local and international literature and construction of a database describing the allometry, feeding frequency and energy requirements of colonial-nesting waterbirds, focusing on species similar to Australian ibises and spoonbills.
2. Development of a model based on the above database for Australian colonial-nesting waterbird species.
3. Drafting a scientific journal paper.

It is expected that this work could either be all completed by an honours student OR part completed by a summer cadet at MDFRC in summer 2017-18. A decision has yet to be made on which option is preferred, but it is expected that the Food Web Theme would contribute to funding, supervision and/or analysis.

Outputs

- Honours thesis/cadet report
- manuscript

How the outputs will be used?

The data will be integrated with outcomes from the Waterbird Theme to identify critical foraging habitats and the bioenergetics data will help improve water requirements to support waterbird recruitment. This knowledge will inform managers how to use environmental water at their sites to maximise energy production for bird breeding success.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Appoint honours student to do parts A,B and C	N/A												
Literature review													
Field and lab measurements	Data generation												
Analysis	Thesis/report												
Write up	Manuscript												
*Appoint Summer cadet All work to be completed in 10 weeks over summer 2017-18	Report												

*If suitable honours student not secured

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:

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

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 2017–18

Pilot experiments have begun in replicate tanks, which have floodplain sediments inundated for up to 40 days to determine temporal patterns of microinvertebrate succession (Figure 5-7). Sediments have been sourced from the floodplains of the Warrego, Gingham and Gwydir Rivers and drying channels of the Mehi and Moomin Rivers. Dominant taxonomic groups (rotifer, copepod, ostracod, cladoceran) have been harvested from mesocosms to attempt to grow a monoculture of each taxonomic group on differing food sources. Monocultures have been established of a unicellular (Chlorella, Euglena) and filamentous (Oedogonium) green, unicellular (Microcystis) and filamentous (Oscillatoria) cyanobacteria from commercial suppliers. In addition we are growing natural biofilms on redgum blocks in the Gwydir River, and created a stock DOC solution of DOC from red gum leaf leachate. The pilot cultures of unicellular (and filamentous algae/cyanobacteria have been sourced from commercial suppliers and successfully grown under glasshouse conditions. Attempts to maintain cultures of rotifers, copepods and octracods with DOC and biofilm as sources, and cladocera with algal and cyanobacterial sources are underway so that zooplankton fed to fish in later trials have nutritional qualities that reflect food sources.

To evaluate the utilisation, transfer efficiency and effect on larval fish growth of different basal resources, wood biofilm communities, green algae, cyanobacteria and DOC from leaf leachate will be provided as discrete food sources for rearing zooplankton communities of known composition; a) rotifer/copepod, b) cladocera, c) rotifer/copepod /cladocera d) rotifer/copepod /cladocera/ostracoda. Each of these treatments will provide zooplankton communities reared on appropriate food sources with differing energetic and nutritional value. Larval Murray cod (approximately 12-14 days post yolk sac) will be added to each treatment that will enable identification the critical basal resources supporting zooplankton productivity and the relative efficiency with which this is converted to zooplankton biomass, and their influence on larval fish growth in lowland rivers.

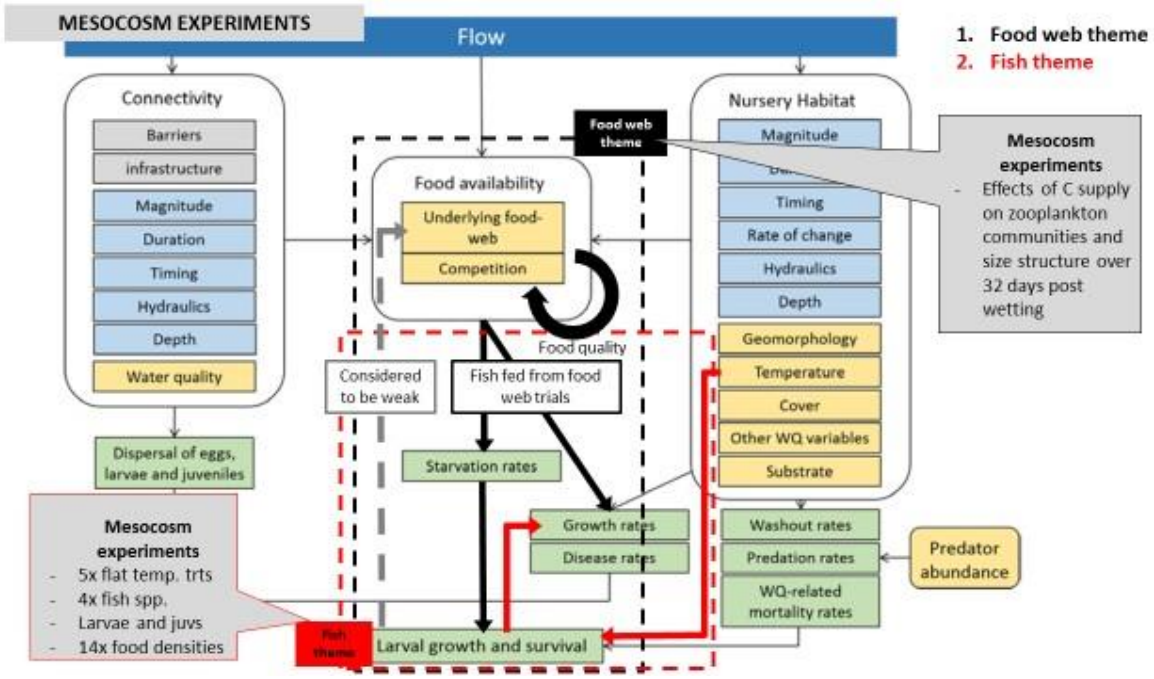

Figure 5-7 Conceptualisation of Food Web and Fish Theme mesocosm experiments, highlighting synergies between the two Themes.

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 (e.g. Figure 5-8).

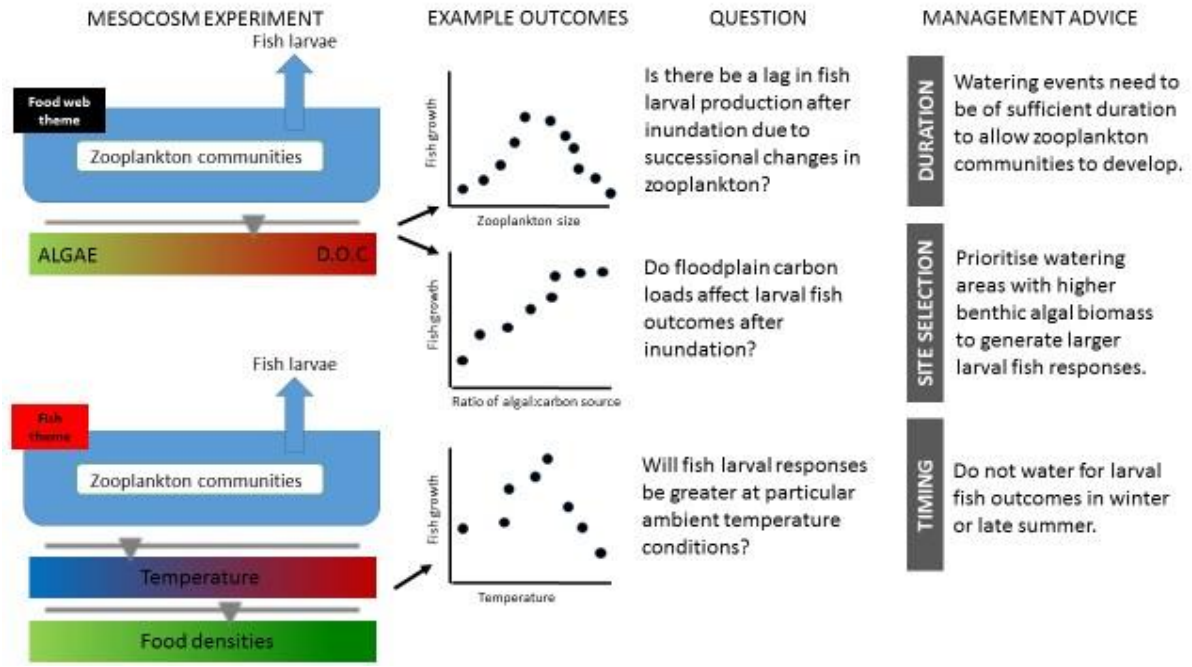

Figure 5-8 Examples of potential outcomes from mesocosm experiments

Quantitative subsamples for zooplankton community, Chlorophyll a and DOC analysis will be taken periodically (Table 5.2). 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 2017-18 to make funds available for the broad research program associated with flooding in 2016.

Table 5-2 Example of possible mesocosm design scenarios to be informed by pilot study

Scenario	Species	Treatments	Replicates	Time (32d)	Samples
ONE	**1**	**4**	**3**	**4**	**48**
TWO	**2**	**4**	**3**	**4**	**96**
THREE	**2**	**4**	**3**	**6**	**144**
FOUR	**2**	**4**	**4**	**4**	**128**

Schedule (2017-18):

Activity	Output	J	A	S	O	N	D	J	F	M	A	M	J

Prepare for mesocosm experiment	N/A												
Conduct mesocosm experiment	Data												
Sample analysis													
Data analysis and preparation of manuscript	Progress Report (in Collaboration with MDFRC) Manuscript												
Hold Point	Material to support Communication and Adoption of research outputs												

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 Communications and Adoption Plan.

Activity 2.4 Basin scale resource use by fish

Objective and description

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

This activity will be integrated with a number of other MDB EWKR activities and external projects, including;

- Fish Theme activity F2 - Understanding the feeding requirements of larval fish in the northern Murray-Darling Basin. This activity seeks to improve our understanding of larval fish diets in the Northern Basin. The planned activity provides the Food Web Theme with an opportunity to undertake complementary sampling that would help identify the basal resources supporting larval fish recruitment in these systems.
- Fish Theme 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. This activity seeks to develop a river-scale understanding of Golden perch and Murray cod life-history, movement and population dynamics, and response to flow. A key component of this work will be identifying the environmental conditions associated with successful recruitment. Food Web sampling in areas known to be important for recruitment would both help identify the basal resources supporting recruitment for comparison with the results from the Ovens River.

- CSU funded post-doctoral fellowship (Keller Kopf) project on the influence of flow mediated food web changes on carp invasion. Keller's project is comparing diets of native fish and carp under different flow regimes. The results of Keller's work will be of direct relevance to the Food Web Theme and provide insight into the influence of one of the major stressors on MDB rivers (invasive carp).
- CEWO Long-Term Intervention Monitoring (LTIM) project at seven areas across the Basin. Monitoring undertaken by the LTIM program of both adult and larval fish provides an opportunity for complementary sampling to be undertaken in collaboration with the Area monitoring teams. The complementary monitoring would seek to identify the critical basal resources supporting fish recruitment.

Activities for 2017–18

The Food Web Theme will liaise with the collaborating projects to secure adult fish tissue, larval fish and basal resource samples from sites across the MDB that represent both a range of flow regimes but that are also believed to be important native fish recruitment areas.

Once samples have been collected, a similar process to that described in The Ovens River field sampling will be undertaken to identify the samples that will be analysed for stable isotopes and fatty acid composition to provide insight into variations in basal resource use by fish across the MDB.

Negotiation with the collaborating projects will be undertaken through May, June and July of 2017. It is expected that samples will be collected from August through to January with the Basin scale fish sampling due to be undertaken in March 2018. Once samples have been collected the Leadership team will review the available samples and decide on those to be analysed. This decision will be influenced by the prevailing flow conditions and the samples that have been collected by the various projects.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Workshop													
Either process tissue samples or collect basal resources	Samples												
Sample analysis	Data/ Progress Report												
Write up	Manuscript												

5.3.3 Component W3 — Identifying important sites of production.

Objective and description

This work will seek to integrate information generated by all four research Themes to identify critical sites of production. The information generated by each of the Themes will be identification of:

- Vegetation: habitats associated with high plant biomass
- Fish: habitats associated with high fish food resources
- Waterbirds: critical foraging habitats
- Food Webs: critical basal resources

The Food Web Leadership Group will seek to synthesise the outputs from the four research Themes to identify areas that are important due to their productivity or their role in making food available to higher trophic levels.

Activities for 2017–18

No explicit activities will be undertaken in this area in 2017-18 as it is dependent on the outputs from the other research Themes. There will, however, be ongoing communication with the other Themes to enable the work to be planned. Activities undertaken in the Food Web modelling activity will also inform the activities to be undertaken in 2018-19 in this area in terms of both potential approaches and their feasibility.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Planning	18-19 ARP												
Write up (June 2019)	Manuscript												

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 support recruitment of fish and birds. In order to achieve this objective, the Food Webs Theme will integrate outputs from Food web activities and the other research Themes to improve capacity to predict the outcomes of environmental flows.

Activity W3 takes this process one step further by seeking to conceptually identify areas that may be critical to the provision of food for waterbirds and fish. Activity W4 seeks to take another step through the development of a quantitative model that will enable predictions of flow's effects on the food webs supporting recruitment.

The Food Web Theme has already committed to building this predictive capacity through the update and publication of the Murray River fish model (ACEAS). The ACEAS model is a bioenergetic model that predicts the biomass of fish that can be supported under different flow regimes. The model evaluates annual flow regimes and considers the system at the reach scale. Publication and refinement of the model will enable the project team to test hypotheses about the outcomes of environmental flows which will be used to provide advice to water managers.

The ACEAS model does not, however, enable prediction of recruitment outcomes as the output variable is the total biomass of fish, not survival of larval and juvenile fish or waterbird recruitment. The ACEAS model is also too coarse in terms of both its temporal and spatial resolution to inform predictions about recruitment. In order to develop this predictive capacity, the Food Web Theme proposes to integrate outcomes from LTIM, the four research Themes and key relationships within the ACEAS model develop a model that predicts the amount and type of food available to support recruitment processes.

Activities for 2017–18

To support the evaluation of flow scenarios a post-doctoral researcher will undertake the modification of the ACEAS code.

For the development of the recruitment model, the Leadership team will work with the other Research Themes to confirm the types of outputs they envisage producing and from this refine the conceptual design of the proposed model. Once this has been completed, a review will be undertaken of the model's data requirements and the extent to which data has already been compiled through activities including the ACEAS model and LTIM monitoring and evaluation. A similar activity will have to be undertaken to review available hydrological and hydraulic data that enables flows to be converted to relevant metrics. Completion of these activities will inform a data acquisition plan that will prioritise access and collation of data sets. It is likely that this process will be limited by available resources and so this may require some adaptation of the model or identification of alternative means for describing specific relationships.

Once data has been collated, analysis will be undertaken to describe key relationships and the model constructed. Because the model will depend on outputs from the other MDB EWKR research Themes it is anticipated that model testing and subsequent evaluation of the outcomes of different flows will occur in 2018-19.

It is anticipated that the data collation and some of the analysis will be completed in 2017-18. This will ensure that if any major knowledge gaps are identified that there will be time to either, undertake some targeted data generation or to adapt the model structure in 2018-19.

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 work plan for undertaking integration and analysis of MDB EWKR outputs to improve predictive capacity.

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. It is anticipated that the work will identify flow regime characteristics that would support improvements in native fish populations.

The model concept and data acquisition plan will be used to inform development of the recruitment model in 2018-19.

Schedule (2017-18):

Activity	**Output**	J	A	S	O	N	D	J	F	M	A	M	J
Refine ACEAS model code													
Model design	Model description												
Data collation	Data summary												
Hydrology data collation	Data summary												
Analysis													

6 Theme planning, coordination and reporting

Each of the research themes have a theme planning, coordination and reporting activity which includes the following:

- 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 Research Forum and integration between themes
- theme research planning, including contributions to budgets, workplans and subcontracts
- development and refinement of the ARP and MYRP. The ARP will be revised each year to reflect proposed activities for the forthcoming year. The MYRP will be undated each year if any significant changes are required.
- project reporting, including contributions to:
    - mid-year and annual progress reporting
    - Scientific Advisory Group (SAG) Workshops
    - Jurisdictional Reference Group (JRG) Workshops
    - Regional Adoption Workshops
- theme level reporting, including the theme Final Research Report, 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.

2017–18 Objective(s)

- Annual Research Forum (February 2018)
- JRG workshop (~March 2018)
- SAG workshop (~April 2018)
- Annual Research Plan updated for 2018–19 (May 2018)
- MYRP updated for 2018-19 (May 2018)
- Ongoing project coordination of each theme, including:
    - development and monitoring of annual budget
    - monitoring the delivery of subcontract ‘work deliverables’, invoicing
    - Theme Coordinator and Integration teleconference meetings (fortnightly)
    - Theme contribution to Annual and Mid-Year progress reports
    - internal theme communication
    - integration across themes
    - 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 individual themes. Consultation and communication has occurred through both formal channels (e.g. structured workshops, targeted phone calls) as well as ad hoc/opportunistic communication. Stakeholder consultation planned for 2017–18 includes:

- ongoing consultation with data custodians, ecologists and statisticians around the collation, analysis and interpretation of data
- ongoing consultation with site managers/landowners regarding field site assessments