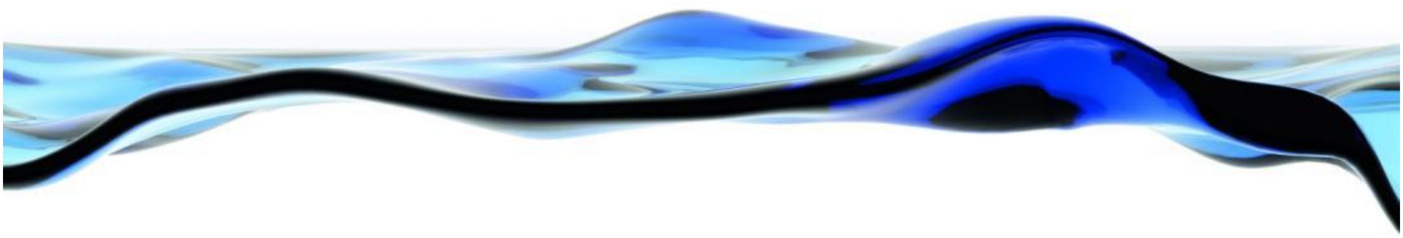
Evidence Based Approaches to Condition Assessment of Fish Communities in the Lake Eyre Basin, Central Australia

David Schmarr, David Cheshire, Rupert Mathwin, Dale McNeil, Travis Howson, Bernie Cockayne and Angus Duguid



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The LEBRA project requires the cooperation and contribution of many people in Lake Eyre Basin itself and throughout Australia including: the Ministerial Forum; the Community Advisory Committee (CAC), the Scientific Assessment Panel (SAP) and jurisdictional Senior Officers and technical staff. The authors would also like to thank all senior scientists and field technicians involved in sampling, data management and reporting for LEBRA. The owners and managers of several stations in South Australia are acknowledged for their help, in addition to the many park rangers that we work with, particularly Erik Dahl and the team at the Innamincka Regional Reserve.

Executive Summary

The Lake Eyre Basin (LEB) is home to some of most naturally variable river systems in the world. The system is largely unregulated and is understood to have had very low anthropogenic impacts in contrast to many other systems in Australia and globally. The aquatic biota of these rivers are adapted to the naturally variable hydroclimatic regime characteristic of the system. Increased agricultural and industrial development in the basin poses a potential threat that emphasises the importance of improving our knowledge of how this system works and to produce methods for monitoring condition. Despite efforts to establish baseline condition of the Lake Eyre Basin ecosystem over the last two decades, the variability of the climate and associated biota made establishing ecosystem condition difficult. The Lake Eyre Basin Rivers Assessment (LEBRA) provided the impetus and long-term focus to facilitate ecosystem condition assessment in the Basin.

This project was funded by the Goyder Institute for Water Research to develop evidence-based approaches to assess the condition of fish communities in the LEB. It is anticipated that the analyses and model development undertaken in the current report will help guide the development of environmental condition reporting in the LEB in a manner consistent with Commonwealth and jurisdictional objectives for managing the aquatic ecosystems and water resources of the LEB. Specifically, it will help inform the LEB Ministerial Forum and the National Partnerships Agreement (NPA) Bioregional Assessment process.

The Lake Eyre Basin Inter-governmental Agreement brings together the Australian, Queensland, South Australian and Northern Territory Governments to ensure the sustainability of the Lake Eyre Basin river systems, in particular to avoid or eliminate cross-border impacts. Under this Agreement, the Lake Eyre Basin Ministerial Forum is required to review the condition of all watercourses and catchments within the Lake Eyre Basin Agreement Area.

The Independent Expert Scientific Committee (IESC) was established as a statutory committee in 2012 by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) in response to community concerns about coal seam gas and coal mining. The Bioregional Assessment Program is focusing on regions with significant coal deposits, such as the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion. Under this program, bioregional information will be collated and presented to assess how the direct, indirect and cumulative impacts and risks to water-dependent assets arising from mining and coal seam gas extraction can be determined.

Using data from LEBRA in conjunction with several other related projects, we set out to develop and refine methods to establish the condition of the Lake Eyre Basin aquatic ecosystem based on the health of the fish community in the context of spatial and temporal variability within the basin. Spatio-temporal variation within LEB data presents one of the greatest challenges for condition assessment, particularly where attempting to detect departures from natural variation. This does not imply that atypical variation is necessarily detrimental, nor does it imply that it is always unnatural. Separating atypical from natural variation is imperative to assessing the condition of a system particularly during periods of different hydroclimatic disturbance, which will improve our ability to determine what impacts are occurring within the system.

To do this we created models to:

1) describe how flow changes over time and how this correlates to fish community structure,

2) describe how and why fish populations change in response to variable flow, and

3) describe how fish communities vary spatially and temporally within the basin.

Using the findings from these models we modified an existing and proven condition assessment methodology (the biological condition gradient or BCG) to create a transferable and adaptive trait-based condition assessment tool specific to the spatial and hydroclimatic contexts present in Lake Eyre Basin.

We modelled trait-based fish population response to flow using generalised linear mixed modelling. This provided us with nine ecologically relevant fish trait groups for which we were able to characterise response to several flow metrics. The models revealed that trait groups responded to antecedent flow according to their relative resistance and resilience traits. Trait groups with known resistance traits were associated with flow metrics reflecting long-term flow disturbance (drought) while trait groups with known resilience traits were associated with flow metrics enabling dispersal and migration.

Using long-term data collected across the basin we described spatial and temporal variability using state-transition modelling. This approach classified community states and followed the transitions that each state underwent through time. The trajectory of transitions enabled the creation of ecoregions within catchments that reflect the dynamics of fish populations in space over time. This approach was implemented for several catchments and we present the most robust Cooper state-transition model here.

To further explore the relationship between flow pattern and fish community states the Neales River catchment was considered. Patterns of wetting and drying were analysed against state and transition modelling outputs and found antecedent metrics which related to timing, rate of change, duration and not just amount of water relate to patterns in fish community state. Using all available flow data in the basin, volume related metrics were generated to determine if the trends observed in the Neales appeared to hold true across other catchments and ecoregions. This did not appear to be the case although some parallels may be drawn.

Having established spatial and hydrological patterns in fish communities, model outputs were used to modify the BCG methodology for use within a spatial and temporal context which allowed predictable responses despite the unpredictability of the basin as a whole. Species trait groups established in the ecological response modelling were assigned as attributes. Ecoregions identified in state-transition models were used to create spatially relevant BCG rules while hydroclimatic phases identified in state-transition models and hydrological analyses were used to create temporally relevant “dispersal”, “boom” and “bust” phase assessments. These rules were validated using fish community data in worked examples for the Upper and Lower Cooper and found to account for natural spatial and temporal variation adequately. The broad range of traits exhibited by fish species in LEB was matched by the broad range of flow metrics contributing to the trait richness model. The general pattern from these metrics is that flow conditions supported species adapted to short-term dispersal and long-term survival of disturbance. Flow supporting dispersal highlighted the importance of resilience strategies, while flow resulting in long-term disturbance highlighted the importance of resistance strategies. This highlights the importance of both flood and drought in the maintenance of fish diversity in LEB.

The aim of this report is not to analyse every hypothetical scenario put forward within (McNeil et al., 2015), rather to provide an empirical framework of baseline ecological patterns which can then be used as a guide for developing condition assessment methodologies. A range of further studies and more in depth analyses are required to test the remaining hypotheses and continue tailoring and updating the approaches for condition assessment detailed within this report; using indicators and thresholds based on factors such as recruitment, hydrology and water chemistry as well as vector analyses of fish community relationships to various hydrological events, geomorphological traits, hydrochemical changes and anthropogenic impacts.

The modelling approaches used here have benefited significantly from the data collected by LEBRA and associated projects. However, the present dataset has not collected monitoring data over the full boom/bust cycle and as such, we cannot be confident that a full range of hydroclimatic conditions have been incorporated into the models. Updating the models developed in this project with complete hydroclimatic data will underpin development of thresholds of potential concern (TPCs). Additional LEBRA monitoring continuing into the next large flood in the Cooper or Diamantina is the minimum requirement to complete this cycle.

The condition assessment methods developed here are suitable for application to all rivers in the LEB although revision following incorporation of a complete hydroclimatic cycle is advised. It is recommended that once ratified, the BCG methodology is used in combination with other assessment tools to inform the LEBRA State of the Basin reporting to be conducted in 2017/18.

Acronyms

AIC	Akaike Information Criterion
BCG	Biological Condition Gradient
CAP	Canonical Analysis of Principal Coordinates
CPUE	Catch per Unit of Effort
CT	Common Transitions
DEWNR	SA Department of Environment, Water and Natural Resources
DLRM	Queensland Department of Land and Resource Management
DstLm	Distance-based Linear Modelling
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Authority
GLMM	General Linear Mixed Models
LEB	Lake Eyre Basin
LEBRA	Lake Eyre Basin Rivers Assessment
LEBMF	Lake Eyre Basin Ministerial Forum
LEBRM	Lake Eyre Basin Rivers Monitoring Knowledge Project
LEBSAP	Lake Eyre Basin Scientific Advisory Panel.
NRM	Natural Resource Management
PS	Provisional State
Qld	Queensland
R	R Programming Language
SA	South Australia
SAAL	South Australian Aridlands Natural Resources Management Board
SAM	Strategic Adaptive Management
SARDI	South Australian Research and development Institute
SEAP	Queensland Stream and Estuary Assessment Program
SEWPaC	Commonwealth Department of Sustainability, Environment, Water, Population and Communities
SIMPER	Similarity Percentages Analysis
SS	Stable State
STM	State Transitional Matrix Records
TP	Transitional Phase
TPC	Threshold of Potential Concern
TCM	Temporal Classification Model
USEPA	United States Environmental Protection Agency

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Chapter 1: An Introduction to LEB Condition Assessments

Authors: Dale McNeil, Rupert Mathwin, David Schmarr, Bernie Cockayne and Angus Duguid

In engineering, condition monitoring is the process of monitoring parameters of condition in machinery in order to identify a significant change which is indicative of a developing fault, and in doing so, preventing catastrophic failure of the machine. In other words, finding small faults early prevents failure later. In much the same way, ecological condition monitoring seeks to monitor parameters of condition in the environment in order to identify changes indicative of environmental degradation, thus providing an opportunity to prevent irreversible damage to the environment. The environment is far more complex and dynamic than a machine. Knowing which parameters to monitor, what is a significant change in these parameters and how to assess these changes in the context of natural variability are the key questions facing any project that monitors ecological condition. The following report deals with these key questions in the context of Lake Eyre Basin.

Background and Scope

The Lake Eyre Basin (LEB) is Australia's largest endorheic basin, with Lake Eyre being the fifth largest terminal lake in the world (Knighton and Nanson, 2001, McMahon et al., 2008). The Basin covers a largely arid and semi-arid area of 1,140,000 km^2 and encompasses some of Australia's largest rivers: Cooper Creek, the Diamantina River, the Georgina River (a tributary of Diamantina) and Warburton Creek (connecting channels between Diamantina and Lake Eyre). Both the Diamantina River and Cooper Creek drain the north and eastern areas of the catchment, and contribute much of the water that fills Lake Eyre (McMahon et al., 2008). To the west and northwest of Lake Eyre are the Neales-Peake and Macumba Rivers. Additional LEB sub-catchments include the Finke, Todd, Hay and Hale Rivers, which drain into the Simpson desert and do not contribute to the filling of Lake Eyre (McMahon et al., 2008), and the Frome catchment to the south of Lake Eyre.

The hydrology of the LEB is indeed unique, with some of the most variable flow patterns observed anywhere in the world (Puckridge et al., 1998). A number of studies have highlighted differences between the LEB to other catchments within Australia and overseas (Puckridge et al., 1998, Knighton and Nanson, 2001, Costelloe et al., 2005, McMahon et al., 2008). Rainfall patterns across the region are extremely variable, with El Niño-Southern Oscillation (ENSO) driving infrequent, high rainfall events (Puckridge et al., 2000, McMahon et al., 2008). Variability in rainfall is approximately 60% greater than other arid zone catchments and Variability in rainfall is approximately 60% greater than other arid zone catchments and there are longer continuous dry periods (McMahon et al., 2008). Values for coefficient of variation (standardised measure of variability) of annual discharge are among the highest observed in the world (Puckridge et al., 1998, McMahon et al., 2008) and twice the amount of flow variability on average compared to global arid zone rivers (McMahon et al., 2008). Runoff is dispersed over 1,140,000 km^2 and flow travels along complex paths often into endorheic sub-catchments or through regions with very high transmission loss (McMahon et al., 2008). Although various studies have highlighted the uniqueness of the LEB when compared to other catchments within Australia and overseas, comparatively little understanding exists of the hydrological drivers of biotic differences within, and between, catchments of the LEB.

Knowledge of the LEB fish fauna (Appendix A) has been developed over the last 50 years, progressing from sporadic anecdotal observations of early explorers and naturalists (Eyre, 1845, Sturt, 1849, Babbage et al., 1858, Stuart, 1865, Waterhouse, 1863, Gosse, 1874) to the current understanding of the taxonomy, distribution, assemblage structure, spawning and recruitment patterns, and fish ecology. This knowledge base has been compiled from spatially and temporally restricted sampling regimes. Existing LEB literature highlights extreme variability in climate, hydrology, habitat inundation, riverine connectivity, fish abundance, population assemblage, colonisation, spawning and recruitment, both through time, between catchments and within reaches. The literature consistently presents the LEB as a comparatively intact ecosystem in which native fish populations are abundant, diverse and reflective of exceptionally good environmental condition (LEBSAP, 2008). This high level of natural value reflects low levels of anthropogenic river regulation, ecological connectivity and fidelity of aquatic habitats, including refuge waterholes, floodplains, ephemeral waterbodies and springs (Morton *et al*. 1995). These qualities are further enhanced by high levels of endemicity in the fish fauna (Hale, 2010, Fensham et al., 2011, Hale and Brooks, 2011, AETG, 2012). The LEB remains relatively free from large scale development of water resource infrastructure and urbanisation that has resulted in plunging ecological condition across Australia's river catchments since European settlement (Walker et al., 1997). The body of literature presents the LEB as one of the most unique naturally variable river systems in world (Puckridge et al., 1999, Puckridge et al., 2000) where the life history requirements of fish remain intrinsically linked to the natural climatic and hydrological cycles to which species have evolved. Despite the presumed natural status of the system, a number of threats have been identified to the LEB fish assemblage (Clifford et al., 2010) and to the human values that we associate with a robust and natural native fish assemblage (Macdonald and McNeil, 2012).

Given the consistent theme of generally good ecological condition based on fish communities, alignment of fish data with trajectories of anthropogenic impacts is likely to be challenging. Instead, fish data is likely to represent the desirable baseline or reference condition against which undesirable trajectories of change must be predicted and quantified. The Strategic Adaptive Management (SAM) approach adopted by the LEB Ministerial Forum (LEBMF) dictates that thresholds of potential concern (TPCs) be developed to indicate when undesirable states are heralded by trends in monitoring data. Ultimately, even with adequate spatial and temporal coverage, quantifying the variability for the purposes of assessing condition within the LEB system is an inherently difficult task (Sheldon, 2005), one that will require a specialist, tailored analytical approach, coupled with tailored, adaptable assessment methodologies.The challenge for developing fish based condition assessment approaches therefore are likely to include the development of meaningful TPCs that reflect the key indicator classes highlighted in the literature.

From the literature, a number of key indicator classes can be established, these represent the major aspects of the ecology of fish in the LEB. These indicators include aspects of the climate and hydrology of the basin's river systems, the structure and function of aquatic habitats (especially refuge waterholes and inundated floodplains), connectivity across habitats, reaches and catchments, species assemblages and abundance, patterns of spawning and recruitment, environmental tolerances to water quality impacts, resource use and food webs and prevalence of disease. To affectively apply this knowledge base to assessments of environmental condition, methodologies must account for the specific aspects of climate and hydrology present, the type of habitats targeted (nested within hydro-climatic context) and the anticipated status of fish-based ecological indicators.

The aim for developing condition assessment indicators and thresholds must therefore address:

1. The climatic conditions under which monitoring was conducted (focussing on connectivity)
2. The spatial context of site locations (e.g. catchment, reach)
3. The type of habitat sampled (e.g. refuge waterhole, floodplain, saline pool, spring).
4. Identification of specific indicators that reflect the expected patterns in monitoring data (e.g. assemblage, abundance, recruitment, disease) within this climatic, spatial and temporal context.
5. Sample error, limitations for sampling and unexplained natural variation.

The degree to which available data sources are likely to inform across all aspects of climate, hydrology, geography and habitat are expected to be limited based on the patchiness of the data presented in the literature across space and time. As a result, a series of conceptual models were collated and developed to capture and describe expected patterns in monitoring data that could inform environmental condition (McNeil et al., 2015). The suite of conceptual models incorporate published models from the scientific and government literature and new models developed from various publications and expert opinion to fill knowledge gaps. The conceptual modelling framework was built around the role of climate and hydrology in driving the ecology of aquatic habitats and biota. Central to this concept is the role of climate and hydrology in influencing refuge habitat dynamics and the response of this variability on a suite of biological life-history traits that drive processes of population resilience and resistance. The focus of analyses in the present paper is to explore and develop knowledge around climate, flow, habitat variability and the response of fish assemblages across the Basin. The degree to which analyses will inform various conceptual models will be dependent on the nature of available data and the ability to test scientifically valid hypotheses expressed through the conceptual modelling process. The conceptual framework (McNeil et al., 2015) has been used to drive the analytical tasks presented in this report and an understanding of these models will assist in the interpretation and context of the results presented in this report.

Where appropriate data exists, these conceptual models can be attributed with more specific TPCs that reflect more quantitative indications of threshold values. This approach is consistent with the integration of science and management to inform the SAM of aquatic habitats in the LEB (McNeil and Wilson, 2015) and is consistent with the approaches adopted for current Lake Eyre Basin Rivers Assessment (LEBRA) monitoring (McNeil and Costelloe, 2011) and Commonwealth Bioregional Assessments program (Barrett et al., 2013). It is anticipated that the analyses and model development undertaken in the current report will help guide the development of environmental condition reporting in the LEB in a manner consistent with Commonwealth and jurisdictional objectives for managing the aquatic ecosystems and water resources of the Lake Eyre Basin.

Building Knowledge for Condition Assessment

The Lake Eyre Basin Intergovernmental Agreement brings together the Australian, Queensland, South Australian and Northern Territory Governments to ensure the sustainability of the Lake Eyre Basin river systems, in particular to avoid or eliminate cross-border impacts. The Agreement was signed by Ministers of the Australian, Queensland and South Australian governments in October 2000, the Northern Territory signed in 2004. The purpose of the Agreement is to provide for the development or adoption, and implementation of Policies and Strategies concerning water and related natural resources in the Lake Eyre Basin Agreement Area to avoid or eliminate so far as reasonably practicable adverse cross-border impacts.

Under the Agreement, the Lake Eyre Basin Ministerial Forum is required to review the condition of all watercourses and catchments within the Lake Eyre Basin Agreement Area. The Lake Eyre Basin Rivers Assessment will examine the condition of the catchments, including the rivers, floodplains, overflow channels, lakes and wetlands in the area covered by the Lake Eyre Basin Agreement.

The Independent Expert Scientific Committee (IESC) was established as a statutory committee in 2012 by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) in response to community concerns about coal seam gas and coal mining. The Bioregional Assessment Program is focusing on regions with significant coal deposits, such as the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion.

Bioregional information will be collated and presented to assess how the direct, indirect and cumulative impacts and risks to water-dependent assets arising from mining and coal seam gas extraction can be determined.

LEBRA operates in the framework established by the Lake Eyre Basin Intergovernmental Agreement.

The history of LEBRA includes past assessment based on pre-existing data, and work to design a monitoring program (e.g. Sheldon et al., 2005). A comprehensive monitoring plan was prepared in 2009, 'Lake Eyre Basin Rivers Assessment Implementation Plan and business governance model' (Kiri-ganai Research, 2009; Price et al., 2009). The plan was endorsed by the Ministerial Forum in 2010, but the full plan could not be implemented due to insufficient resources. Representatives of the jurisdictions developed a 'no regrets monitoring' plan with reduced scope to fit the available resources, which consisted of funds from the Ministerial Forum and associated contribution from each jurisdiction. The 2011 and 2012 LEBRA project plans (SEWPaC 2011) specify the indicators to be assessed in the current phase of LEBRA as:

- hydrology
- water quality
- fish assemblage and population structure.

Hydrology monitoring at pre-existing government gauging stations has been supplemented by the installation of additional water data loggers (non-telemetered) and bathymetric surveys of waterholes.

The fish theme was considered the most important monitoring component of the biotic indicators (fish, macroinvertebrates, birds and fringing vegetation) because they could be used to report on regional catchment scale impacts while macroinvetebrates reported at the more local scale and birds at the basin and inter-basin scale.

These condition indicators were endorsed by the LEB Oversight Group in November 2010, and are a subset of those in Kiri-ganai's Implementation Plan (Thoms et al., 2009).

Advice form the Lake Eyre Basin Scientific Advisory Panel (LEBSAP) indicated that the knowledge base available for data driven assessment of condition was insufficient to inform the initial State of the Basin report (LEBSAP, 2008) and that significant effort was needed to develop scientific understanding and monitoring data to improve the basis for condition assessments. The State of the Basin report (LEBMF, 2008) acknowledged the paucity of reliable scientific data to inform condition assessment and relied strongly on a data-informed rather than a data-driven process.

Despite the historical level of scientific information for the Lake Eyre basin being exceedingly patchy and sparse (LEBSAP, 2008), a significant number of publications relating to the ecology and hydrology of rivers and aquatic habitats have been produced in recent times (e.g. (Bunn et al., 2003, Bunn et al., 2006, Arthington et al., 2005, Arthington et al., 2010, Arthington and Balcombe, 2011, Balcombe et al., 2005, Balcombe et al., 2007, Balcombe and Arthington, 2009, Costelloe et al., 2004, Costelloe et al., 2009, Costelloe et al., 2010, Costelloe and Russell, 2014, Fensham et al., 2011, Kerezsy et al., 2011, Kerezsy et al., 2013, Kerezsy et al., 2014). However, much of this work is not spatially or temporally comprehensive or monitored consistently. The vast majority of aquatic science has focussed on the Queensland section of Basin, and in particular the Cooper Creek. Whilst the Cooper Creek remains the most studied catchment, Thoms et al. (2009) emphasize that the scientific information available is still very low compared to other river systems in Australia.

The annual LEBRA monitoring program (LEBRA Implementation Plan 2010-2018') commenced in 2010/11 collecting data on fish, water quality and hydrology. The monitoring program targeted major waterholes in the five major catchments of the Basin being the Cooper, Diamantina, Neales, Macumba and Finke River catchments (LEBRA Implementation Plans 2011-14). The reduced LEBRA monitoring program has produced the most significant set of continuously monitored fish, water quality and hydrologic data to date. Whilst annual reports summarise and discuss the findings of the monitoring program in detail (Cockayne et al., 2012, Cockayne et al., 2013, Sternberg et al., 2014, Mathwin et al., 2015), the degree of data analysis, modelling and exploration of the accumulating data sets required to develop a scientific basis for a second State of the Basin Assessment has been out of scope.

Challenges for Informing Condition Assessment

To effectively inform an assessment of the environmental condition of the LEB this patchwork of knowledge and data must be co-ordinated and collated to enable analysis of long term patterns across cycles of climatic drying and flooding. The spatially discontinuous nature of the knowledge base also requires that a large number of sites at the broadest possible spatial scale be integrated to enable the idiosyncrasies of various catchments and reaches to emerge and to begin the process of identifying consistencies and generalities through which management goals, and thresholds can be determined.

The combination of short time-scale studies scattered across catchments and reaches, largely with a local focus around a particular feature (e.g. the mid-Cooper Floodplain, Coongie Lakes) renders analyses of historical data extremely challenging, if not prohibitive. Furthermore, the methodologies used and meta-data characteristics from various studies are incompatible for a wide range of analytical approaches. Finally, access to raw data for the LEB is often complicated by custodianship of the various data sources across private collections, museum archives, university groups across Australia and internationally, and State and Commonwealth jurisdictions.

The lines of evidence presented in the literature however, lend themselves to the development of hypotheses and models that can be tested with available data sets where possible. This approach may allow the analysis of specific hypotheses to be undertaken by addressing data from specific climatic periods or in reaches where particular data sets are available. It is therefore recommended that future analyses of fish ecology in the LEB undertake a multiple lines of evidence approach (Downes et al., 2002) based on conceptual models derived from the literature (McNeil et al., 2015) and tested where possible with available spatially defined, quality checked data sets with excellent standards of meta-data to describe sampling design objectives, data entry processes and transformations. This is potentially undermined by dependence on secondary data such as hydrological and remote sensing data that may be even patchier over time and space than the fish data. Fish analyses may therefore be limited not only by the shortcomings of the fish data set but by limitations to the distribution, density and accuracy of flow gauges or satellite imagery.

Spatio-temporal variation within LEB data presents one of the greatest challenges for condition assessment, particularly where attempting to detect departures from natural variation. For the purposes of this exercise, “atypical” variation is defined as variation within the data that cannot be explained by natural variability alone. This does not imply that atypical variation is necessarily detrimental, nor does it imply that it is always unnatural. Atypical variation can be simply characterised either by immediately noticeable factors not typically associated with a pristine, unaltered system, such as the presence of exotic species, or anomalous behaviours that are not consistent with the degree of variation observed thus far (extreme outliers). Separating atypical from natural variation is imperative to assessing the condition of a system and the more data collected over time provide a better understanding of the natural variation within the system, particularly during periods of different hydroclimatic disturbance, which will improve our ability to determine what impacts are occurring within the system. Using the assessment approach provided in this report, researchers must rely on existing knowledge, literature and what little data there is to determine what is natural and what is unnatural, however, over time as more data are collected, the data itself should be able determine the natural variability of the system in its own right using iterative adaptive techniques. This strategy will be of particular importance in monitoring the effects of climate change over time within arid and semi-arid ecosystems, due to a degree of atypical change that may be so gradual as to be mistaken for natural variation.

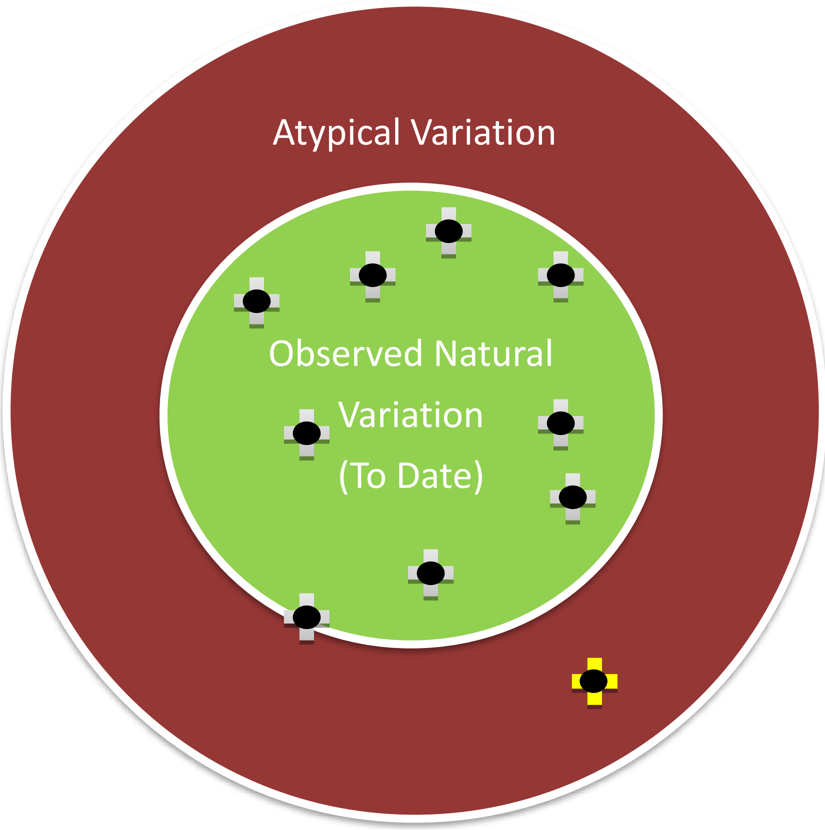

Figure 1. Conceptual diagram displaying the extent of observed natural variation vs atypical variation within the current dataset, grey markers indicate samples assumed to be within natural limits, yellow markers are samples known to have been affected by non-natural factors.

Objectives

To assist in developing our understanding of LEB ecosystems and facilitate the assessment of environmental condition through LEBRA, the Goyder Institute for Water funded a research program entitled "Development of integrated indices to assess condition, identify vulnerabilities and forecast risks to the aquatic ecosystems of the Lake Eyre Basin". This program had six tasks:

1. Identification of condition, damaging processes and key predictive indicators

2. Collation and analysis of ecological monitoring/condition datasets

3. Development of indicators of condition for the Lake Eyre Basin at multiple scales

4. Nutrient Sources

5. Population and Connectivity Metrics of aquatic biota

6. Cultural indicators of water resource and aquatic health and sub-regions

A critical step in understanding the dynamics of highly variable ecosystems such as the Lake Eyre Basin wetlands was to develop a conceptual understanding of the key processes driving ecosystem function, and the responses of biota and ecosystem components to those factors. A number of conceptual models were produced to help scientists and managers understand the complex climatic, hydrological and ecological processes that interact to drive the ecology of Lake Eyre Basin (LEB) waterways. These were presented in task 1 by (McNeil et al., 2015) with the aim of capturing the climatic, hydrological, and ecological processes important to LEB ecology and to develop testable models and hypotheses to which existing data sources could be applied.

This report constitutes task 2 of the above project. The intended outcome of this task is to develop and inform on variables that may be good indicators of ecological or environmental condition and could be used to support condition assessments in the LEB. The systematic process undertaken within this report to develop condition assessment methodologies for the LEB is outlined below (Figure 2). The techniques used in this report may be used to develop TPCs for fish communities and also to guide TPC development for other aspects of environmental health. This report presents analyses of key hypotheses, derived from conceptual understanding of fish communities within the Lake Eyre Basin presented in task 1 (McNeil et al., 2015), providing an empirical understanding of ecological patterns, from which new and existing condition assessment approaches were developed and revised, creating an effective, adaptable and universal framework for condition assessment within the Lake Eyre Basin.

The intent of the current report is to:

- Review the existing knowledge of fish ecology in the Lake Eyre Basin.
- Identify Basin-scale research questions to build on the existing knowledge base and inform key conceptual models.
- Collate available datasets for fish, hydrology and water quality in the LEB.
- Assess the compatibility of various data sources and their utility for analysing key research questions/conceptual models.
- Develop key analytical processes required to generate an understanding of patterns in aquatic habitat functionality, fish ecology and hydrological drivers of ecological variability, required to undertake evidence based condition assessments.
- Provide detailed examples of key analyses using catchments that contain comprehensive temporal and spatial data sets that capture a range of hydroclimatic conditions.
- Utilising these examples, develop methodologies for assessing the condition and establishing thresholds of potential concern within the Lake Eyre Basin.

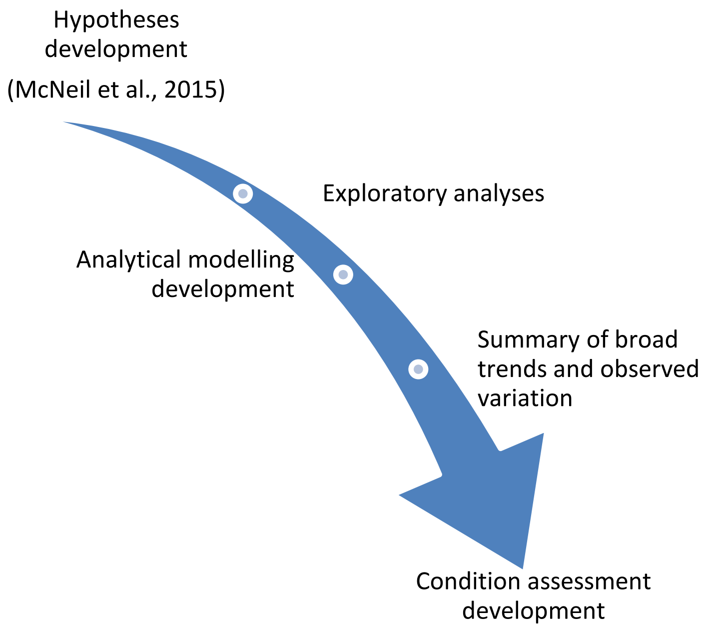

Figure 2. Process required for condition assessment development.

The aim of this report is not to analyse every hypothetical scenario put forward within (McNeil et al., 2015), rather to provide an empirical framework of baseline ecological patterns which can then be used as a guide for developing condition assessment methodologies. A range of further studies and more in depth analyses are required to test the remaining hypotheses and continue tailoring and updating the approaches for condition assessment detailed within this report; using indicators and thresholds based on factors such as recruitment, hydrology and water chemistry as well as vector analyses of fish community relationships to various hydrological events, geomorphological traits, hydrochemical changes and anthropogenic impacts.

Condition assessment analyses and methodological development were undertaken following the development of LEB conceptual models (McNeil et al., 2015). This process, outlined in Figure 3, involved exploratory analyses of both AridFlo and LEBRA data sets, from which analytical modelling methodologies were conceived based on methods presented in (McNeil et al., 2015) and (Diggle, 2007), using approaches that were adapted and tailored to the LEB. Results of these analyses were used to quantify parameters that explain ecological variation and form temporal, spatial and biological criteria. These parameters were used to develop the Biological Condition Gradient (BCG) framework devised by (Davies and Jackson, 2006, Mathwin et al., 2014, McNeil et al., 2011a). Worked examples of the BCG application to assess sites within the LEB are included. These include methods for the identification of ecological trends, significant outliers and the development of an adapted (BCG) model that provides condition scores.

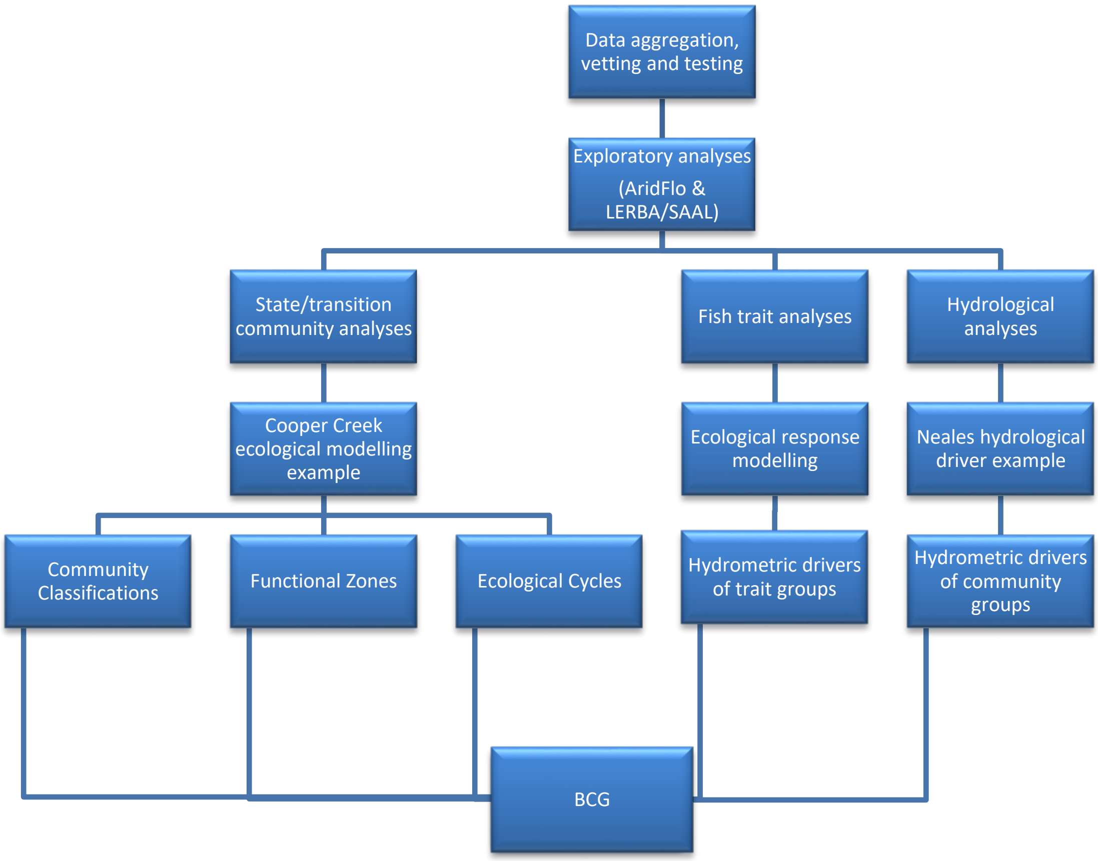

Figure 3. Analytical processes undertaken to describe ecological patterns, biological traits and quantify ecological and hydrological variability within the system.

Chapter 2: Species Traits and Hydro-Climatic Variation

Authors: David Schmarr, Rupert Mathwin and David Cheshire.

Introduction & Methods

Ecological Response Modelling

Ecological response modelling for the fish community in the LEB was conducted using generalised linear mixed modelling (GLMM), a similar approach to that undertaken recently for the Goyder Mount Lofty Ranges water allocation project (Maxwell et al., (in prep)). This process sought to establish relationships between fish trait groups and flow metrics, thereby linking fish community composition with antecedent flow.

Trait analysis

The first step in this process was the classification of fish species into similar trait groups. Trait analysis was used to group fish species with similar traits. This allowed the spatial comparison of fish-flow response based upon functionally similar fish trait groups rather than comparing only samples that shared exactly the same taxa, thus expanding the number of samples included in the analysis. This also allowed a more direct link to environmental gradients and ecosystem function for the ecological response model. A range of biological traits were identified from available literature (Allen et al., 2002, McNeil et al., 2013) and online databases (Fishbase, Fishes of Australia and Atlas of Living Australia). A dataset of 24 traits were aggregated representing fish survival, morphology, habitat, reproductive characteristics and environmental tolerances. Trait examples are included in Appendix B. Each trait category was scored using a binary score then the scores were and clustered using Gower's dissimilarity index using PRIMER multivariate statistical software. Trait group composition was verified for ecological validity based on expert opinion.

Response Modelling

Daily discharge data (ML/day) was available from hydrological monitoring gauges situated throughout the LEB. The data from these gauges was sourced from State jurisdictions via online data portals (South Australian Surface Water Archive, Northern Territory Water Data Portal and Queensland Water Monitoring Data Portal). Linear modelling was undertaken for all nine trait groups and two community metrics (species richness and trait richness) against four flow metrics (zero flow days, mean daily flow, coefficient of variation and number of flood days) over 90 days, one year, 2 years, 5 years and 10 years. Prior to modelling flow responses, flow variables were examined for correlation to ensure that observed effects were not compounded by correlating variables. Correlations of over 90% were investigated and one of the correlated variables removed from the analysis. Trait groups as well as species and trait richness measures were used to populate quantitative response models based on hydrological metrics using GLMMs in R statistical software (Crawley, 2007) using the lme4 package (Bates *et al*. 2014). For each response model the predictor variables that showed an interaction were compiled into a single mixed model. Significant factors identified with the linear modelling along with several spatial, temporal and land use factors were analysed using GLMMs. Site, project and catchment were included as random factors in an attempt to generalise results across the basin and from projects using differing sampling methods. Stepwise removal of factors based on minimising the Akaike information criterion (AIC) using the method set out in (Crawley, 2007) until the simplest model that explained the most variation was determined resulted in selection of the most parsimonious model for each trait group and the species and trait richness measures. The final model code is available on request from the author.

Results

Trait Analysis

Nine trait groups were identified with 70% similarity (Figure 4). Trait group composition was considered to be ecologically valid based on expert opinion. Trait group A consisted of three catfish species (*Neosiluroides cooperensis*, *Neosilurus hyrtlii* and *Porochilus argenteus*); trait group B was golden goby (*Glossogobius aurius*) and sleepy cod (*Oxyelotris lineolatus*) ; trait group C was desert goby (*Chlamydogobius eremius*), Finke goby (*Chlamydogobius japalpa*) and Finke Mogurnda (*Mogurnda larapintae*); trait group D was eastern gambusia (*Gambusia holbrooki*) and carp gudgeon (*Hypseleotris* spp.); trait group E was desert glassfish (*Ambassis mulleri*) and desert rainbowfish (*Melanotaenia splendida tatei*); trait group F was two species of hardyhead (*Craterocephalus eyresii* and *Craterocephalus centralis*) and smelt (*Retropinna semoni*); trait group G was barred grunter (*Amniataba percoides*), spangled grunter (*Leiopotherapon unicolor*) and bony herring (*Nematalosa erebi*); trait group H was goldfish (*Carrasius auratus*); and trait group I was Lake Eyre golden perch (*Macquaria* sp. B), Welch's grunter (*Bidyanus welchi*) and Barcoo grunter (*Scortum barcoo*).

Ecological response modelling

Due to limited hydrological data at many sites, linear modelling limited the number of samples at sites with valid data to 249. The significance levels of linear relationships between trait groups and flow metrics are presented in Table 1.

The factors contributing to each final trait group model are presented below (Table 2). Residual plots indicated that unexplained variance for Trait group B was biased and heteroscedastic so should not be considered for further analysis. This is most likely because this group comprised of two relatively rare species so there was insufficient data to establish a relationship between flow metrics and fish presence. Four other trait groups (C, D, F and H) displayed slight bias and/or heteroscadasticity in the residual plots, so interpretation of results for these groups should be treated with caution.

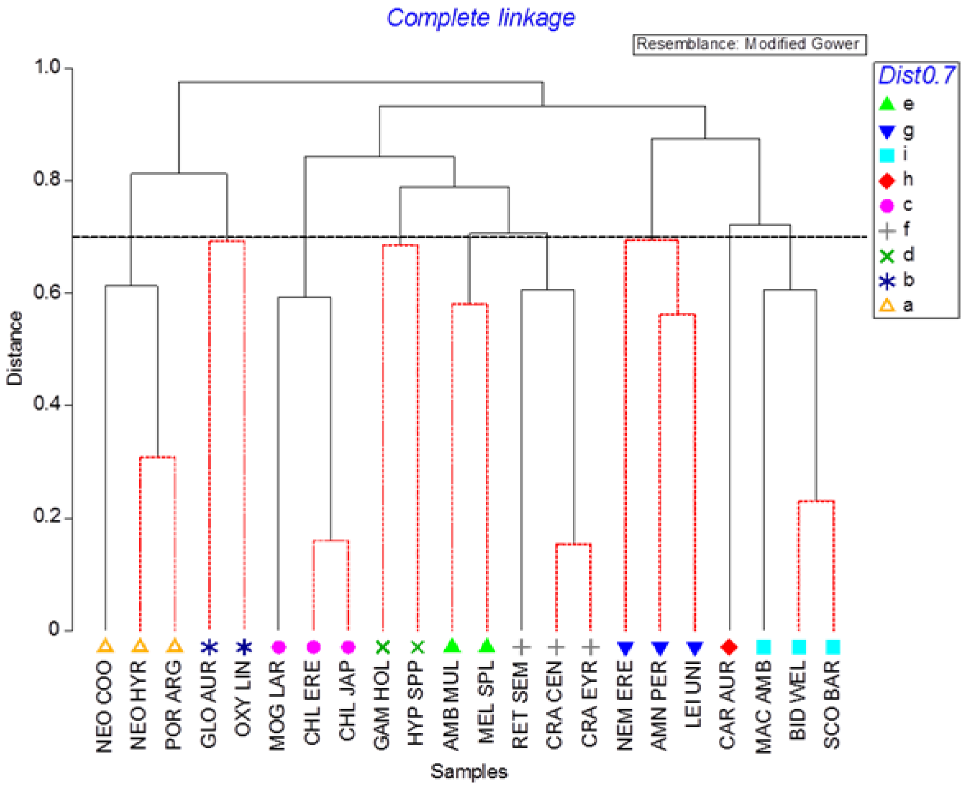

Figure 4. Dendrogram displaying hierarchical cluster analysis of species based on species traits.

Table 1. Factors contributing to fish community and trait group models (- signifies negative relationship, *** p<0.001, ** p<0.01, *p<0.05, ^p<0.1, o signifies not significant but added into mixed model).

Metric	Period	SR	TR	A	B	C	D	E	F	G	H	I
Zero Flow Days	90 days	-***	-***			**			**	***	-*	-***
	1 Year	-***	-***	-**	^	***	-*		***	***	-*	-*
	2 Years	-***	-***	-***		***	-**		***	***	-***	-**
	5 Years	-***	-***	-***		***	-**	*	***	***	-**	-***
	10 Years	-***	-***	-***		***	-^	^	**	***	-*	-***
Mean Daily Flow	90 days	**	*	*					-**	-*		*
	1 Year	***	***	**		-*			-**	-***		^
	2 Years	***	***	***		-*	*		-**	-***	**	*
	5 Years	***	***	***		-**	*	-**	-**	-***	**	***
	10 Years	***	***	***		-**		-***	-***	-***	**	***
Coef. Of Var	90 days		-*		***	-*	-^					-^
	1 Year				***		-*				-*	-*
	2 Years	-^	-*		*		-*			^	-**	-**
	5 Years	-*	-***							*		-**
	10 Years					*						-*
Flood Days	90 days	*	**				.		-^			^
	1 Year				-^		**		-*			o
	2 Years	**	***		-^		**		-**		**	o
	5 Years	***	***	***		-*	*		-^	-***	**	o
	10 Years			***		**	**		-**			o

Table 2. Final model output displaying variables and interactions contributing to community richness measures and trait group response, initial versus final AIC and model degrees of freedom (Df) (- signifies negative relationship, X).

Response Model	Final Model Variables	Initial vs Final AIC	Df
Species Richness	Zero flow days (5 Years) Zero flow days (2 Years) (-) Flood days (90 days) Reach	1040.8/1019.9	241
Trait Richness	Zero flow days (5 Years) Zero flow days (2 Years) (-) Coef. Of Var (5 Years) (-) Coef. Of Var (2 Years) Coef. Of Var (90 days) (-) Mean daily flow (90 days) (-) Flood days (90 days) Season (-) Reach (-)	1854.4/1838.9	236
Trait A	Zero flow days (5 Years) (-) Zero flow days (2 Years)	372.5/358.1	241
Trait B	Coef. Of Var (90 days) Flood days (1 year) (-)	61.6/56.4	243
Trait C	Zero flow days (5 Years) Mean Daily Flow (5 Years) (-) Coef. Of Var (10 Years) (-) Flood days (10 Years) Year	125.42/108.8	239
Trait D	Zero flow days (1 Year) (-) Flood days (1 Year) (-) Reach (-) Zero flow days (1 Year) X Reach Flood days (1 Year) X Reach	233.56/217.6	240
Trait E	Mean Daily Flow (10 years) (-) Mean Daily Flow (5 Years) Season (-)	393.08/382.9	242
Trait F	Zero flow days (5 Years) Zero flow days (1 Year) (-) Mean Daily Flow (1 Year) (-) Flood days (10 Years) Flood days (90 days) (-) Year	216.24/198.8	239
Trait G	Zero flow days (5 Years) Mean Daily Flow (10 years) (-) Mean Daily Flow (10 years) X Zero flow days (5 Years) (-)	594.49/575.14	241
Trait H	Zero flow days (5 Years) (-) Zero flow days (2 Years) Mean Daily Flow (5 Years) Flood days (5 Years) Zero flow days (5 Years) X Zero flow days (2 Years)	62.0/58.5	240
Trait I	Zero flow days (90 days) (-) Coef. Of Var (90 days) (-) Mean Daily Flow (5 Years) Flood days (10 Years) Flood days (5 Years) (-) Year (-)	516.33/489.5	239

Discussion

There are a number of outputs from the model that correspond with observations of fish behaviour and distribution. The flow metrics used in the model can be broken down into their effect on two main factors: dispersal and disturbance. Varying levels of mean annual flow, number of flood days, coefficient of variation of flow and zero flow days all contribute to how well fish can survive disturbance and then disperse to new habitats. In general, most trait groups were associated with at least one, five or ten year flow metric indicating the influence of flow on long-term fish population health.

The model suggests species such as gobies (trait group C) and hardyhead (trait group F) are adapted to maintain healthy populations in the harsh conditions presented by periods of long drought disturbance (high number of zero flow days), but are less suited to large flows (mean annual flow and flood days). This is reflected in their distribution in the lower reaches of catchments in LEB that receive less frequent and lower magnitude flows.

Some species are adapted to stable conditions conducive to maintaining deep freshwater habitats over long time periods (low number of zero flow days) but can tolerate some shorter term flow disturbance, as is the case with the catfish trait group (trait group A). These species tend to inhabit waterholes higher up in LEB catchments.

Desert glassfish and desert rainbowfish (trait group E) tended to require predictable stable high flows (seasonal and high mean daily flow) to allow regular spawning and recruitment in inundated floodplain habitat with high amounts of submerged aquatic vegetation.

Fish with very short life spans such as eastern gambusia and carp gudgeon (trait group D) required stable recent flow (low number of zero flow days and high number of recent flood days). These species are adapted to rapidly respond to flood conditions but thrive in conditions with periods of prolonged flow increasing the availability of submerged vegetation.

The highly resilient species with widespread distributions in trait group G (barred grunter, spangled grunter and bony herring) were associated with indicators of long-term low flow and drought disturbance (low mean daily flow and high zero flow days). The widespread and frequent occurrence of low flow and drought conditions in LEB may explain the distribution and dominance of these species.

Goldfish (trait group H) presence was most associated with high flow and reduced drought disturbance in the preceding five years (high mean daily flow and flood days, low zero flow days). These conditions are only seen through exceedingly wet periods and may explain the patchy occurrence of goldfish in LEB.

The large-bodied species in the Welch's and Barcoo grunter and Lake Eyre Basin golden perch trait group (trait group I) required flow metrics facilitating short-term dispersal (low recent zero flow days and low flow variation) and long-term migration (high long-term flood days and high medium term mean daily flow). These flow conditions allow consistent flow for these species to migrate rapidly during flood periods for spawning (Cockayne et al 2015) as well as slowly recolonise drought affected reaches upstream and correspond with observations on the distribution of these species.

The broad range of traits exhibited by fish species in LEB was matched by the broad range of flow metrics contributing to the trait richness model. The general pattern from these metrics is that flow metrics supporting short-term dispersal (i.e. over the previous 90 days to one year) and survival through long-term disturbance (i.e. over two to ten years) influence the overall richness of traits and species in the LEB fish assemblage. Flow metrics supporting dispersal facilitate fish species movement for spawning and recruitment highlighting the importance of resilience strategies for these species. On the other hand, flow metrics supporting long-term disturbance highlight the importance of resistance strategies. This highlights the importance of both flood and drought in the maintenance of fish diversity in LEB.

The bias and heterogeneity of variance observed for some of the traits groups was due to three interacting factors. First, some of the species contributing to trait groups were exceedingly rare making it very difficult to capture them often enough to observe a relationship to flow. Second, the time series of data collected through LEBRA is still relatively short. This will improve with continued LEBRA monitoring. Finally, the broad spatial coverage of LEBRA monitoring made sampling species with restricted ranges quite difficult. This last point highlights the importance of conducting complementary short-term fine spatial scale studies such as the SAALNRM Board Neales, Cooper and Diamantina Critical Refugia projects. Such studies are recommended for the upper reaches of Cooper Creek and Diamantina Catchments.

Despite the apparent success of the ecological response models in explaining some of the observed pattern of fish distribution in LEB, upon expert review of both the model code and outputs, it is clear that the model fit could be improved (Bill Venables pers. comm.). Currently the models have a Poisson fit (species and trait richness) and binomial fit (trait groups) to the distributions. It is likely that a negative binomial fit will better serve the ecological response model. Given the complexity and time taken to rework the models, it is not possible to present new models with a negative binomial fit in this report. However, work in the immediate future will concentrate squarely on revising the models. This will then lead to the application of the models in a predictive capacity to inform water allocation planning.

Implications for Condition Assessment

This analysis established the relationship between fish trait groups and antecedent flows. The Trait groups derived from these models can be used to associate species' resistance and resilience strategies with natural variation within the system based on ecological responses, particularly those driven by specific hydrological events, be they flooding (dispersal and resilience) or drought (resistance). Ultimately this allows researchers to determine the natural range of species response to flow regime and tailor an assessment to each trait group. Having established the validity of these trait groups and their relationship to antecedent flow, they will be referred to in the condition assessment methods described in chapter 5.

Chapter 3: State/Transition Community Analyses

Authors: David Cheshire, David Schmarr and Rupert Mathwin

State/transition analyses (Diggle, 2007) were used to analyse fish community dynamics in the LEB Rivers. State/transition modelling is used to examine changes in ecological communities over spatial and temporal ranges and to identify the species which characterise community assemblage states. Once identified, these factors may be analysed against relevant abiotic variables such as hydrology or geomorphology (to identify ecoregions which encompass geophysical and biotic boundaries) or against comparable ecosystem data such as vegetation or macroinvertebrate populations (to identify commonalities in ecological responses between taxa).

Although this process was completed for all catchments in the LEB, to best display the capabilities of state/transition modelling to analyse catchments in the LEB, the Cooper Creek catchment is presented. This catchment was selected as it contained the most fish samples both spatially and temporally, in addition it displays a high level of variability between upper and lower reaches. State/transitions generated for the Neales and Peake catchments are not reported here but have been used to explore the relationship between flow and fish community dynamics in chapter four, Similarity Percentages (SIMPER) outputs are reported there.

Methods

State/Transition Modelling

Fish community data from each major catchment were analysed separately. Each sample was standardised to Catch Per Unit of Effort (CPUE) according to methods described in Schmarr et al. (2013) and a square root transformation was applied to standardise CPUE data prior to analysis, to normalise the data. Hierarchical Cluster Analysis, Canonical Analysis of Principal Coordinates (CAP) and Similarity Percentages (SIMPER) analysis were carried out using PRIMER 6.1 with (Permanova+ 1.0.2 add-on).

Cluster analyses were performed using Bray-Curtis similarities and cluster groups were derived with a minimum of 40% similarity that generated no more than 15 cluster groups (presented as groups "*a*" through "*o*"[1]). Exploratory CAP analyses were performed, to determine whether reclassification of multivariate groups based on canonical correlations reduced the misclassification error, if so, samples were redefined according to CAP analyses recommendations, if not, a reduced level of similarity was chosen and the process repeated.

The newly defined groups were then mapped into a state/transition matrix (STM) (Table 3) which tracks changes in multivariate groupings between consecutive samples over time. The accumulated transitions are calculated as a percentage of change. This value is used to determine the stability of each group. Different STMs were generated for each type of consecutive sampling (i.e. biannual samples were considered in one STM and annual samples considered in a separate STM). Non-consecutive samples were not considered. After reviewing STMs from several catchments in the LEB it was determined that four classifications best described the states observed. These were stable states (SS), provisional states (PS), common transitions (CT) and transitional phases (TP) (Table 3).

[1] Although labelled similarly (alphabetically), these groups currently bear no relation to the multivariate groups used in fish trait analyses (Chapter 2).

Table 3. State/transition matrix (STM) of Cooper Creek fish communities. The top half of the matrix shows the states that each community type transitioned into. The bottom half of the matrix shows the proportion of each transition and the resultant state classification (SS, PS, CT or TP) allocated to each multivariate grouping.

		Changed From									
	S/T Records	**a**	**b**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Changed To	**a**										
	b		1								1
	d						1				
	e						1				
	f						1				
	g	1					25	7	1	1	
	h				1	1	2	7		3	2
	i										
	j						2				
	k		1			1	1	3		1	6
	Percentage	**a**	**b**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
	a										
	b		50%								11%
	d						3%				
	e						3%				
	f						3%				
	g	100%					76%	41%	100%	20%	
	h				100%	50%	6%	41%		60%	22%
	i										
	j						6%				
	k		50%			50%	3%	18%		20%	67%
	State/Trans	**TP1**	**TP2**	**TP3**	**TP4**	**TP5**	**SS1**	**CT1**	**TP6**	**CT2**	**PS2**

States were defined separately for each catchment using three criteria; the total number of times a multivariate group was observed, the number of STM records and the percentage of stability (how many times a group remained the same). Stable states were deemed to be any group with more than four STM records and a stability level greater than 70%. Provisional states are those sites with more than four STM records and a stability level between 51% and 70%. Stable states and provisional states were numbered according to their stability rank regardless of classification; e.g. the state with the highest stability was allocated as SS1, the next highest might be PS2 or SS2. Common transitions were deemed to be any group observed five or more times that were unstable (less than 51%). Transitional phases were deemed to be any group observed four or fewer times, irrespective of stability. Transition phases tended to be the least similar samples in the cluster analysis and were typically separated in groups of four or fewer samples. Transitional states were numbered separately to each other, with common transitional phases numbered according to their frequency of occurrence and temporary transitional phases numbered sequentially from left to right in the STM.

The STM outputs for the Cooper Creek (Table 3) were used to create a temporal map of states observed in the Cooper Creek catchment (Table 4). This table displays how sites differ throughout the catchment and how they change in response to phases of hydrological disturbance, *i.e.* the supra-seasonal flood observed in the Cooper Creek between 2010 and 2012 (Figure 5). It is worth noting that the coarse seasonal phases are not entirely consistent, as many sites at either end of catchments tended to have a more rapid turnover in ecological disturbance patterns, for example, the Upper Cooper sites displayed little to no flood disturbance and no resistance patterns (at the chosen level of magnification), whilst the Lower Cooper displayed a high degree of rapid change in response to flood disturbance, with almost immediate resistance disturbance patterns followed thereafter. These phases do not take into account annual flow cycles as this analysis is looking to discern ecological responses to supra-seasonal flow events. Ecological responses to seasonal flow patterns are accounted for whilst defining functional zones; however, a lack of data (particularly spatial coverage) during drier years means that seasonal variability is often difficult to decipher.

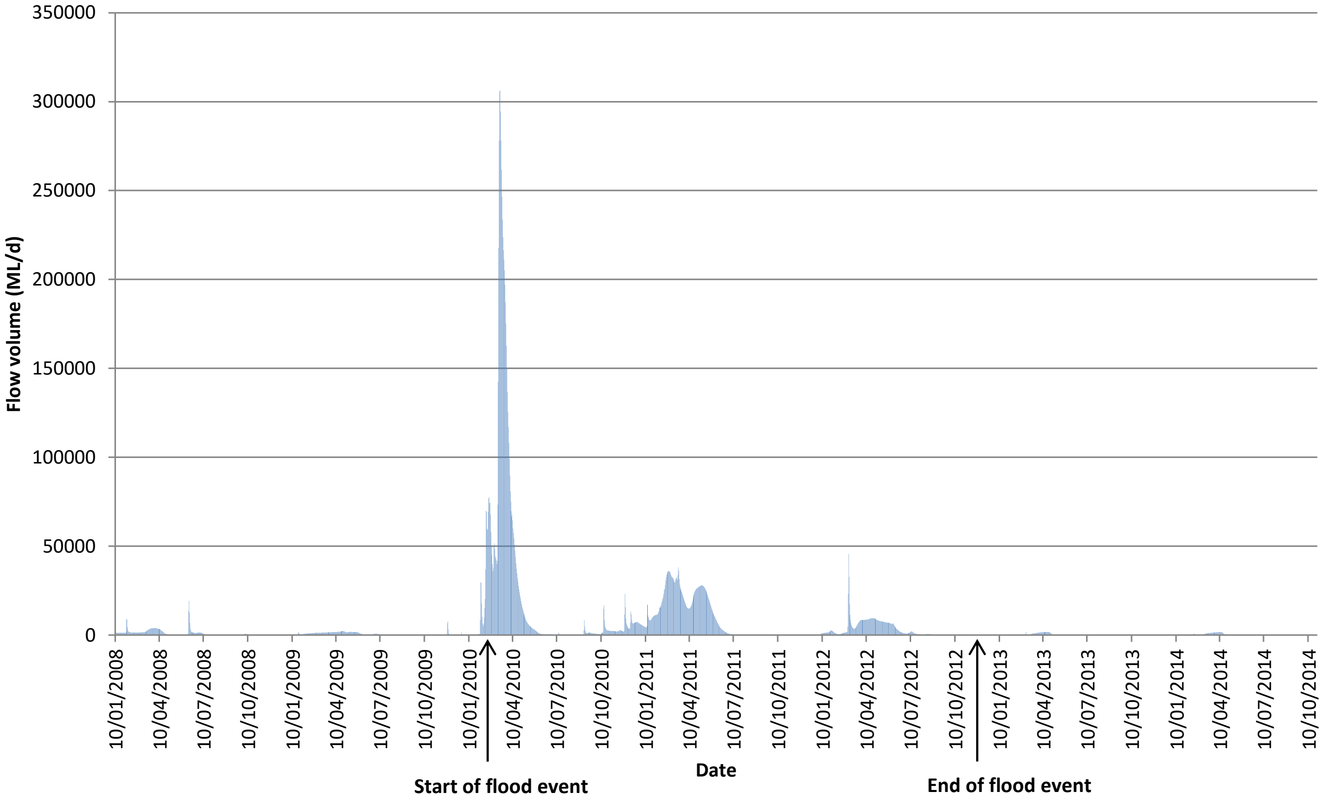

Figure 5. Cullyamurra flow volume recorded daily total 2008-2014, supra-seasonal flood events are grouped into flood years.

Table 4 State transition matrices (STMs) were used to create a temporal model of fish community states between 2008 and 2015. Cells shaded pale orange represent a drought period in the LEB. Cells shaded bright blue represent a supraseasonal flood and cells shaded pale blue represent a drying of the landscape following flood. Cells shaded red were dry at the time of sampling. Samples collected during 2015 are included but were not used during analysis. The proportion of transitions observed was used to define ecoregions within the Cooper Creek catchment. All sites locations are included in Appendix C.

		2008	2008	2009	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015
	Site	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st
Upper Cooper	Lammermoor							PS1		PS1		PS1		PS1		
	Bowen Downs							PS1						PS1		
	Ag College Waterhole							PS1		PS1	SS1	SS1	PS1	SS1		
	Darr							SS1		SS1		SS1		SS1		
	Blackall							PS1								
	Avington Rd										SS1	PS1		SS1		
	Killman Waterhole							SS1		PS1		PS1	PS1	PS1		
Upper-mid Cooper	Noonbah							SS1		SS1		SS1		SS1		
	Stonehenge							TP6		SS1		SS1		SS1		
	Retreat							SS1		SS1	SS1	SS1	SS1	SS1		
	Windorah Bridge								TP1	SS1	SS1	SS1	SS1	SS1		
	One Mile									SS1		SS1		SS1		
	Tenham							TP4								
	Durham Downs								TP1	PS1		SS1		SS1		
	Noccundra								TP7	TP7		PS1		SS1		
	Nappapethera								SS1				X			
	Cullyamurra	TP6		SS1			SS1	TP7	SS2	PS1	SS1	SS1	SS1	SS1	SS1	SS1
Lower-mid Cooper	Burke's Waterhole							TP7		PS1						
	Innamicka Causeway			TP6												
	Minkie Waterhole						SS1	TP7		PS1						
	Yaningurie					X	TP7	SS1		TP3	X					
	Gidgealpa					X	SS1	TP5		SS2	X					
	Tirrawarra								SS2	PS1						
	Kudriemitchie									PS1						
	Coongie Inflow								PS1	PS1		SS1		SS1		SS1
	Toontawarannie								SS2							
	Lake Daer Inlet									PS1						
	Embarka Outflow							TP5								
	Embarka Waterhole								PS1	PS1						
	Narie								PS1	TP7						
	Cuttapirrie Corner									PS1						
	Beach Bridge								TP4							
	Eaglehawk							PS1								
Lower Cooper	Lake Hope Inlet							TP5		PS1						
	Lake Hope						SS1	SS2	PS1	SS2	SS2	SS2		TP2	TP2	X
	Red Lake									SS2						
	Pandruannie								SS2							
	Gwydir's Crossing					X	SS1	TP4	PS1	SS2	X					
	Lake Kopperamanna					X	SS1			SS2						
	Mkillalpaninna Mission						PS1	PS1	PS1	SS2		SS2	SS2	SS2	SS2	TP2
	Tilla Tilla Crossing					X	SS1									
	Cuttapirra Waterhole					X	SS2	TP2	SS2	SS2	X					

Results

Cooper Creek state/transition modelling outputs

Exploratory analyses were performed using CPUE data from all 138 fish samples to track changes in fish assemblage over time, which could then be analysed against vectors such as flow and water chemistry. Samples were initially grouped in PRIMER using a slice at a resemblance level of 42% similarity, which generated a list of 11 sample groups listed simply as "a" through "k". The CAP analysis determined that 87% (120/138) of samples were correctly classified with a misclassification error of 13%. The remaining 18 samples were changed according to the re-classifications recommendations which eliminated group "c". This was then inserted into a TCM which was then used to generate a list of STM records displayed in the state/transition matrix (Table 3), which resulted in one stable state, one provisional state, two common transition phases and six temporary transition phases, derived according to the definitions outlined in the methods. One additional state ("X") was added for sites which were dry.

The percentage of contribution derived from SIMPER analyses was used to establish which species were driving each state or phase[2]. SIMPER contributions are as follows:

- Stable state 1 (SS1) – bony herring (26%), Hyrtl's tandan (19%), Lake Eyre Basin golden perch (17%) and silver tandan (8%).
- Provisional state 2 (PS2) – bony herring (43%), carp gudgeon (19%), Lake Eyre hardyhead (12%) and eastern gambusia (11%).
- Common transition 1 (CT1) – bony herring (20%), desert rainbowfish (19%), carp gudgeon (17%) and desert glassfish (15%).
- Common transition 2 (CT2) – spangled grunter (29%), desert glassfish (22%), desert rainbowfish (11%), Hyrtl's tandan (9%), goldfish (8%) and bony herring (8%).

The remaining transitional phases 1-6 were predominantly characterized by one or two species, where other species were either absent all together or the numbers of one species were in such proportions as to dramatically lower the overall diversity of the site. These groups included fish communities with a very high abundance of silver tandan (TP1 – 76%) and Lake Eyre hardyhead (TP2-90%), a high abundance of eastern gambusia (TP3-N/A, TP5-62%), high abundances of spangled grunter, bony herring and desert rainbowfish (TP4 – 43%, 31% and 11%) and Hyrtl's tandan and Lake Eyre Basin golden perch (TP6 – 28% and 25%).

States/phases mapped into an STM (Table 5) presents a modelled representation of how the Cooper system changes from upstream to downstream over time according to various stable and transitional elements. Figure 5 displays the hydrological period over which this model was mapped, with early 2010 indicating the start of a major supra-seasonal flood event, lasting through to mid-late 2012.

Ecoregions were derived from the state/transition model based on patterns in community assemblages, both spatially and temporally, these groups would later be compared with geomorphological characteristics of the Cooper Creek. Functional group 1 upper Cooper is defined by groups of sites that are consistently dominated by CT1 fish communities, functional group 2 upper-mid Cooper sites are defined by consistent SS1 communities, functional group 3, lower-mid Cooper is defined by a number of transitional phases mixed with CT1 and CT2 communities and functional group 4, lower Cooper is defined by a number of transitional phases mixed with PS2 communities.

[2] These figures are *not* representative proportions of abundance; they indicate the percentage that each species contributed towards defining each group based on the variation within the data.

Table 5.Cooper Creek spatio-temporal state/transition model. States and hydrological phases mapped by site (upstream to downstream) and date. Colours indicate hydroclimatic phases white=dry, green=resilience and orange=resistance. Grey cells indicate community types observed in 2015 sampling but were not incorporated into multivariate analyses.

Zone	Site	2008	2008	2009	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st
Upper Cooper	Lammermoor							CT1		CT1		CT1		CT1		
	Bowen Downs							CT1						CT1		
	Ag College waterhole							CT1		CT1	SS1	SS1	CT1	SS1		
	Darr							SS1		SS1		SS1		SS1		
	Blackall							CT1								
	Avington Rd										SS1	CT1		SS1		
	Killman Waterhole							SS1		CT1		CT1	CT1	CT1		
Upper-Mid Cooper	Noonbah							SS1		SS1		SS1		SS1		
	Stonehenge							TP6		SS1		SS1		SS1		
	Retreat							SS1		SS1	SS1	SS1	SS1	SS1		
	Windorah bridge								TP1	SS1	SS1	SS1	SS1	SS1		
	One Mile									SS1		SS1		SS1		
	Tenham							TP4								
	Durham Downs								TP1	CT1		SS1		SS1		
	Noccundra								CT2	CT2		CT1		SS1		
	Nappapethera								SS1				X			
	Cullyamurra	TP6		SS1			SS1	CT2	PS2	CT1	SS1	SS1	SS1	SS1	SS1	SS1
Lower-Mid Cooper	Burke's Waterhole							CT2		CT1						
	Innaminka Causeway			TP6												
	Minkie Waterhole						SS1	CT2		CT1						
	Yaningurie					X	CT2	SS1		TP3	X					
	Gidgealpa					X	SS1	TP5		PS2	X					
	Tirrawarra								PS2	CT1						
	Kudriemitchie									CT1						
	Coongie Inflow								CT1	CT1		SS1		SS1		SS1
	Toontoowarannie								PS2							
	Lake Daer Inlet									CT1						
	Embarka Outflow							TP5								
	Embarka WH								CT1	CT1						
	Narie								CT1	CT2						
	Cuttapirrie Corner									CT1						
	Beach Bridge								TP4							
	Eaglehawk							CT1								
Lower Cooper	Lake Hope Inlet							TP5		CT1						
	Lake Hope						SS1	PS2	CT1	PS2	PS2	PS2		TP2	TP2	x
	Red Lake									PS2						
	Pandruannie								PS2							
	Gwydir's Crossing					X	SS1	TP4	CT1	PS2	X					
	Lake Kopperamanna					X	SS1			PS2						
	Killalpaninna Mission						CT1	CT1	CT1	PS2		PS2	PS2	PS2	PS2	TP2
	Tilla Tilla Track Crossing					X	SS1									
	Cuttapirra Waterhole					X	PS2	TP2	PS2	PS2	X					

Discussion

Community Classifications

Whilst selection of monitoring sites across the LEB had an emphasis on permanent waterholes, the sampling strategy for fish monitoring was based on establishing a network of reliable fixed sites that are representative of aquatic habitat variation within the Lake Eyre Basin and which occur over a broad geographic range. Specific site selection criteria are presented in Cockayne *et al* (2011), but there is a notable emphasis on having sites representing a range of refuge types. In this instance the refuge types refer to the conceptual waterhole classifications; Ark, Disco and Polo Club habitats adapted from Robson et al. (2008). These refuge types are defined as:

Ark Refugia = used to describe waterbodies where conditions are appropriate for resident individuals to form a secure, viable complement of males and females in numbers sufficient to assure that there is a capacity for survival, breeding, dispersal and recovery of a population following drought disturbance. The complement would also preserve most if not all of the regional genetic diversity typical of the species. In wetter areas, or in wet periods, many waterholes may serve as Ark refugia, but during drought, only a very few habitats may be available for all species to survive. Ark refugia are critical in preventing local extinction as a result of dry periods.

Disco Refugia = used during good times, especially during recovery from drought. They protect fish through short dry seasons, but dry out completely during long periods of drought. As such they are waterholes where fish migrate, access booming resources and reproduce to rebuild populations following drought. Disco waterholes are critical to build resilience between drought periods.

Polo Club Refugia = Harsh waterholes (e.g. very saline) where only a select group of species can tolerate environmental conditions. Most species cannot persist in these habitats during drought, but may be able to move in during wetter periods when water quality may improve due to fresh inflows. These waterholes are very important for those tolerant species that use them as they can build up populations without competition and predation from less tolerant species.

These refuge habitats can also be defined by particular fish assemblages and associated traits, which are in-turn associated with abiotic factors that relate to permanency such as hydrological variability (Chapter 4). The fish community classifications and descriptions resulting from state/transition modelling can be compared and matched to these conceptual classifications in order to provide a more descriptive framework that can be used to qualitatively compare catchments throughout the Lake Eyre Basin.

SS1 was the most commonly observed state in sites monitored in the Cooper Creek catchment and was consistently found each year throughout the upper mid-section of the Cooper Creek, from AG College Waterhole downstream to Cullyamurra. SS1 communities within the Cooper are best described by large to medium bodied, freshwater species that occupy the channel country of mid Cooper reaches. These communities are extremely stable throughout both wet and dry periods; conceptually these assemblages appear to be Ark-like communities. Sites commonly containing these community types are therefore of particular significance when condition is being assessed, as the implications associated with detrimental impacts are much greater due to the ecological value of these sites and the potential implications associated with the loss of source populations.

PS2 communities were most often observed in sites sampled from the lower reaches of the Cooper, from Lake Hope, downstream to Cuttapirra Waterhole. PS2 is described by stable fish populations of various sizes, including some more tolerant species (*C. eyresii* and *G. holbrooki*), predominantly found in the mid-lower reaches of the cooper within ephemeral habitats (most notably in terminal Lakes), around 12 to 18 months after the initial flooding event. The high frequency of PS2 states in the lower Cooper reflects the ephemerality of this reach and the infrequency of regular flow events. These states are most readily defined as a pre-terminal senescent state that may be in gradual decline. They display increasing resistance factors as indicated by the higher contribution of resistant fish species, and are only ever observed transitioning into salt tolerant (Polo Club) or reverting back to fresh ephemeral (Disco) like communities. Communities such as this are best termed Resistant Ephemeral Communities (REC's). The lower mid-section of the Cooper was characterised by a range of different states and temporary transitional phases during the 2010-12 flood periods, with CT1's dominating the classification assemblage during this time.

CT1 communities principally resemble a transitional phase that is prevalent amongst significant disturbance within the more ephemeral reaches of the Cooper Catchment (upper and lower reaches), they are observed frequently 6-18 months post initial flood in downstream reaches of the catchment and consistently observed over time within the uppermost reaches of the catchment. These communities contain a mix of large and small bodied resilient fish species (Chapter 2), and are shown to be driven by the onset of flows (Chapter 4), closely resembling a mature disco community according to conceptual definitions (McNeil et al., 2015). CT2 is an archetypal transition phase; it was observed multiple times and rarely remained the same, only appearing in the mid reaches of the Cooper during wet periods. CT2, along with TP4 are defined by known colonizers (McNeil and Schmarr, 2009) and flow responders; these groups are best described as fledgling disco communities.

TP3 and TP5 communities are dominated by eastern gambusia, with TP5 communities only occurring within swamp and off channel flood outs in the lower mid Cooper during autumn 2011 (6-12 months post initial flood) at the height of the floods, whilst a TP3 community was observed once at Yaningurie just prior to it drying out completely. These two communities are driven by opposing traits that this species exhibits, with TP5's accenting resilience of eastern gambusia with their ability to take advantage of the wet conditions, multiplying to plague proportions, and TP3's displaying the resistance traits of eastern gambusia with their ability to dominate a depauperate conditions. TP2 is defined by high numbers of salt tolerant species, which has only been observed to occur after a PS2 state, this is most readily described as a true Polo Club state.

Hydroclimatic Phases

Hydroclimatic phases derived from the spatiotemporal state/transition model were labelled according to our conceptual understanding of the boom-bust cycle within the LEB, using conceptual models presented in (McNeil et al., 2015)(Figure 6 and Figure 7).

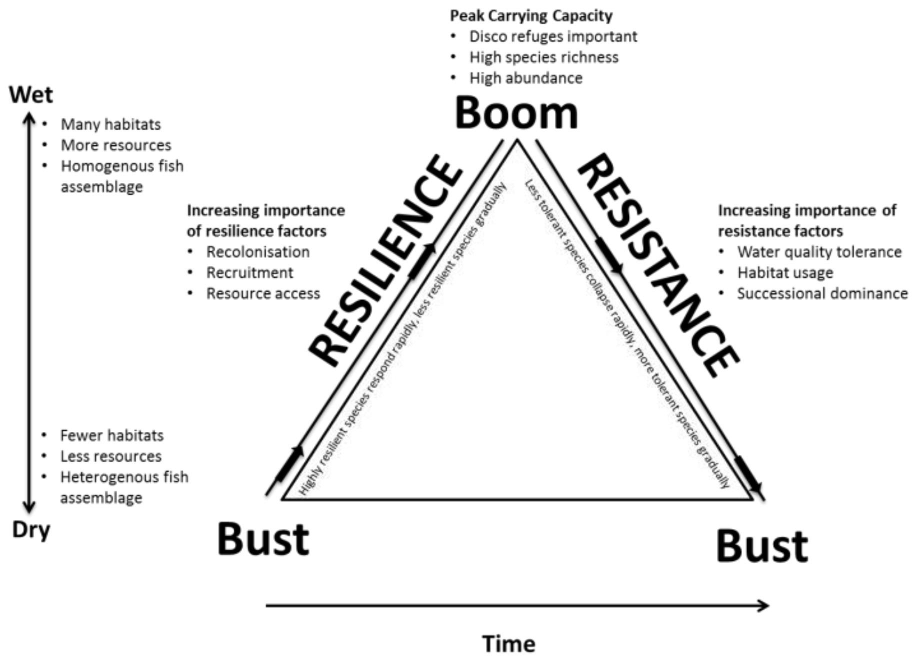

Figure 6. Conceptual understanding of fish community resilience and resistance traits through boom-bust hydro-climatic cycle.

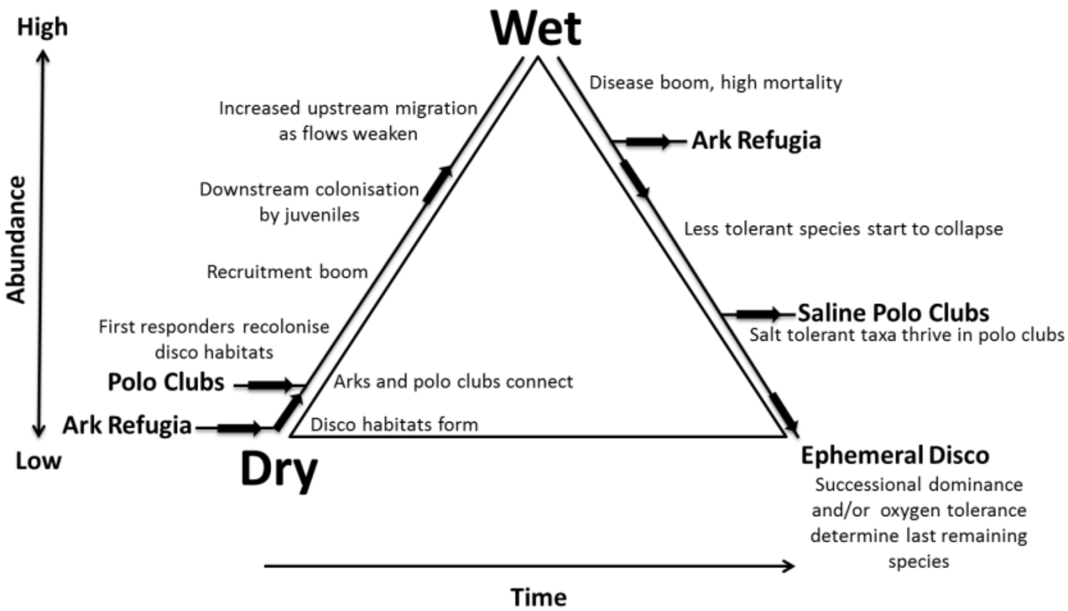

Figure 7. Conceptual understanding of ecological drivers influencing changes in fish abundance and the role of refugia during wet-dry cycles. This model can be applied over annual, decadal and potentially 20-30 year time scales. See Table 2 for refugia type terminology .

During the initial flood (late 2010), two thirds (66%) of downstream sites (lower-mid and lower cooper) were classified as SS1 communities, this indicates that this period is likely to be the start of the “resilience” phase, which has been identified as a new conceptual definition, the initial “dispersal” period, as fish assemblages appear to migrate downstream from the Ark refugia that are normally associated with SS1 communities. Subsequent flows in 2011 appear to have extended the resilience period, with a number of different transitory phases observed, which in the first half of 2011 comprised 63% of the upper-mid to lower Cooper Creek sites. The second half of 2011 saw a change to a slightly more uniform community assemblage containing many more disco communities. Although not quite fully established, this is the last period that resilience phase patterns were observed, with disco communities prevalent and the appearance of a few resistant ephemeral communities indicating weakening flood disturbance patterns. Autumn 2012 saw yet more stability and a notable division in communities between functional zones throughout the catchment, with 86% of lower Cooper sites having established themselves as stable REC's and 73% of midstream sites as established as disco communities. At this time, the fish communities within each respective zone appear relatively homogenous, indicating that for many areas of the catchment this is the peak of the "boom" period with early resistance factors appearing to begin driving successional changes from now on. This semester is considered the beginning of the "Bust" phase as the prevalence of so many REC's indicates that many communities downstream appear to have begun to decline. This is immediately followed by a harsher period of increased resistance and drying during late 2012, smaller ephemeral sites such as Cuttapirra and Gidgealpa have already dried out and the larger terminal lakes have entered a steady, yet steepening grade of decline, with fewer and fewer species recorded over the coming sampling periods (Table 4).

Ecoregions

Ecoregions are conceptually bounded areas which share ecosystem characteristics (Omernik, 2004). In this instance fish community transitions in response to hydrology and climate are used to define an ecoregion. Ecoregions are not defined by drainage and so reaches from different catchments may be grouped together if they meet the criteria. The current approach has not considered ecoregions across reaches; however, there is scope for this in the future. The upper Cooper ecoregion was defined based on its prevalence of Disco-like fish communities (with the exception of Darr Waterhole) and appears to remain in a constant state of transition throughout the term of the study, indicating that the environmental factors within these reaches may tend to favor fish species that prefer ephemeral habitats despite these waterholes appearing to remain wet from year to year, suggesting that the hydro-climatic factors and associated habitat availability may be similar in nature to those found downstream during a supra-seasonal flood event; the difference being that fish responses in the Upper Cooper appear to be on a seasonal basis. The Upper-mid Cooper is characterized by highly stable Ark-like communities, with some slight variability in lower sites during periods of increased flooding. This zone contains communities of intermediate resilience, with a species assemblage structure that is rarely seen elsewhere within the catchment, except during initial dispersal periods. The Lower-Mid Cooper is defined by a number of transient communities (particularly those dominated by Gambusia) mixed with Disco communities and the Lower Cooper by many Disco communities mixed with stable resistant ephemeral communities towards the latter drying period. These zones are, for the moment, isolated to fish assemblage patterns, however functional zone definitions for each catchment should eventually integrate multidisciplinary datasets, whereby functional zones are derived using both biotic and abiotic patterns, such as fish, turtles, macro-invertebrates, hydrology and geomorphology, to improve condition assessment accuracy in the future.

Implications for Condition Assessment

The designation of community types, temporal cycles and spatial zones using the state/transition modelling analyses has effectively broken down the highly variable Cooper Creek system into spatio-temporal groupings with hypothesised behavioural patterns. These behavioural patterns are underpinned by four years of biannual data collection (from spring 2010 to autumn 2014) from across the geographic range of the catchment and over a range of hydroclimatic extremes. If these data are assumed to represent a near-natural baseline for this system then the observed states and transitions may be integrated into condition assessment methodologies, along with the predefined species groups based on the fish trait analyses, reducing the "noise" generated by such a diverse and unstable system.

The Cooper Creek model represents a proof of concept which has the potential to be applied to each catchment in the basin. Preliminary examination of state/transition models in other catchments suggest an idiosyncratic set of ecoregions and responses for each catchment. Developing condition assessments across the basin would be strongly supported by a fully developed state transition model for each catchment. Preliminary state/transition models created for the Diamantina, Finke and Neales catchments indicate they can underpin reliable modelling and contribute to condition assessment but require additional time to be fully developed.

Chapter 4: Hydrological Assessments

Authors: Travis Howson, Rupert Mathwin and David Schmarr

Hydrological metrics and fish communities in LEB catchments

As antecedent hydrological conditions of up to 10 years prior to the time of sampling were found to shape fish assemblage patterns (Chapter 2), it was deemed necessary to further explore relationships between hydrology patterns (wetting and drying) and fish assemblage structure. Both wetting (water supply) and drying (water retention and loss) influenced changes in the states of fish assemblage composition, thus, measures of both water supply (discharge) and water retention (water level or height) are key to understanding patterns of fish assemblage transition across the LEB. There are currently several limitations to accurately describing fish assemblage structure patterns in response to changes in river hydrology, particularly, across large regions of the LEB. The limited number of stream gauging stations, the highly variable nature of the hydrology (spatial and temporal), and that fish were collected from a diversity of locations, often located some distance away from gauging stations, creates considerable uncertainty around antecedent hydrological patterns for much of the dataset. Obtaining data at several sites and years in a single catchment is useful to understanding links between fish assemblage patterns and hydrology. The Neales River and Peake Creek catchment was the most suitable for investigating relationships between fish assemblage patterns and hydrology, primarily because a large proportion of fish sampling sites contained hydrological information. This gave the Neales River and Peake Creek catchment the best resolution of fish-hydrological information (both height and discharge) along a LEB river channel, for a period greater than the period of correlation (10 years).

Methods

Analysis of fish patterns

For the Neales River and Peake Creek catchment (hereafter referred to as the Neales catchment), an analysis that characterises individual wetting and drying events was chosen. Discharge data were used to characterise wetting events and water height data was used to characterise drying events. To quantify and describe variation in each type of event within each semester (semester 1 is the six months preceding autumn sampling, semester 2 is the six months preceding spring sampling), 26 metrics were developed for each time step (1, 2 and 5 years) *e.g.* average ML/day, date of first flow, average flow days. Collinearity between individual metrics and over the differing temporal scales were examined using a scatterplot matrix (Draftsman plots). Strong collinearity ($r > 0.95$) among metrics was identified and treated by removal of one metric (i.e. redundant in analysis) in order to gain explanatory power. All remaining variables were checked for skew and heteroscedasticity and, where required, a suitable transformation was undertaken (*e.g.* $Log_e(x+1)$, Fourth root or, 1/(0.1+x)). A 'final-cut' consisting of 60 variables (metrics over 1, 2 and 5 years) were selected for the analysis. Distance-based Linear Modelling (DstLm) was used to estimate the proportion of hydrological variation relating to the observed variability in fish assemblage state across sites and times. Distance-based Redundancy Analysis plots were used to describe patterns in fish assemblage composition. All analyses were undertaken in PRIMER-E V7.

Fish data

State/transition modelling outputs (generated but not reported in Chapter 3) identified one steady state, one provisional state, two common transitions and four transitional phases for fish communities in the Neales catchment. The species which drove these states were:

- SS1 –bony herring (54%), desert rainbowfish (25%) and spangled grunter (13%),
- PS2 –Lake Eyre hardyhead (33%), bony herring (23%) and desert rainbowfish (15%),
- CT1 – spangled grunter (72%) and bony herring (28%),
- CT2 –eastern gambusia (82%) and desert goby (12%),
- TP1 - desert goby (100%),
- TP2 – spangled grunter (92%),
- TP3 – bony herring (100%) and
- TP4 – Lake Eyre hardyhead (57%) and desert goby (41%).

Hydrological metrics and fish communities in the LEB

Using the statistical methods described above, flow metric vectors (frequency of flow events in ML/d separated by order of magnitude) were aligned against the community states and ecoregions established for other LEB catchments (generated but not reported, in chapter 3).

Results

Neales

The first two dbRDA axes accounting for 61.1% of the total variability with the first axis accounting for most (44.8%) of the variability in fish assemblage structure (Figure 8.). Redundancy analysis revealed clear separation among the assemblage transition states: SS1 and CT1, and for sites that were observed to be dry. Hydrological metrics that corresponded the strongest with fish assemblage groups were: *starting day of the last flow event* (SDLF) in the previous 1, 2 and 5 years with SS1. *Average number of days before pool refilling* (ANDBR)/*starting day of the last flow event across all years* (SDLFY) with CT1 (Figure 8). Sites which were dry at the time of sampling (X) corresponded with the average size of maximum flow (2AMF, 5AMF) over the previous 2 and 5 years and the average of Flow Frequency (5FF) over 5 years. Sites that previously contained fish but lost them, corresponded with older patterns of flow (2 and 5 years), and as expected, did not correspond with more recent flow events (1 year).

In contrast to dry sites, the position of SS1 communities on the opposite side of dbRDA axis 1 represented these states corresponding with years of higher flow or flood (Figure 8 and Figure 9). Hydrological metrics that best corresponded with SS1 was the *starting date of the last flow event* either in the last 1, 2 or 5 years. It appears the strong correspondence with *starting date of the last flow event* likely representing an increasing degree of hydrological stability and security, and it was clear these types of assemblages became more prevalent during flood years.

CT1 states differed to both Dry and SS1 positions in ordination space and largely corresponded to the *average number of days before refilling* – a measure of the length of the dry event (Figure 8 and Figure 9). The position of CT1 assemblages between Dry and SS1 assemblages in ordination space represents an intermediate community. It appears CT1 assemblages were characteristic of less stable locations where dry conditions persisted for longer and locations that started to become increasingly wet after a period of drying.

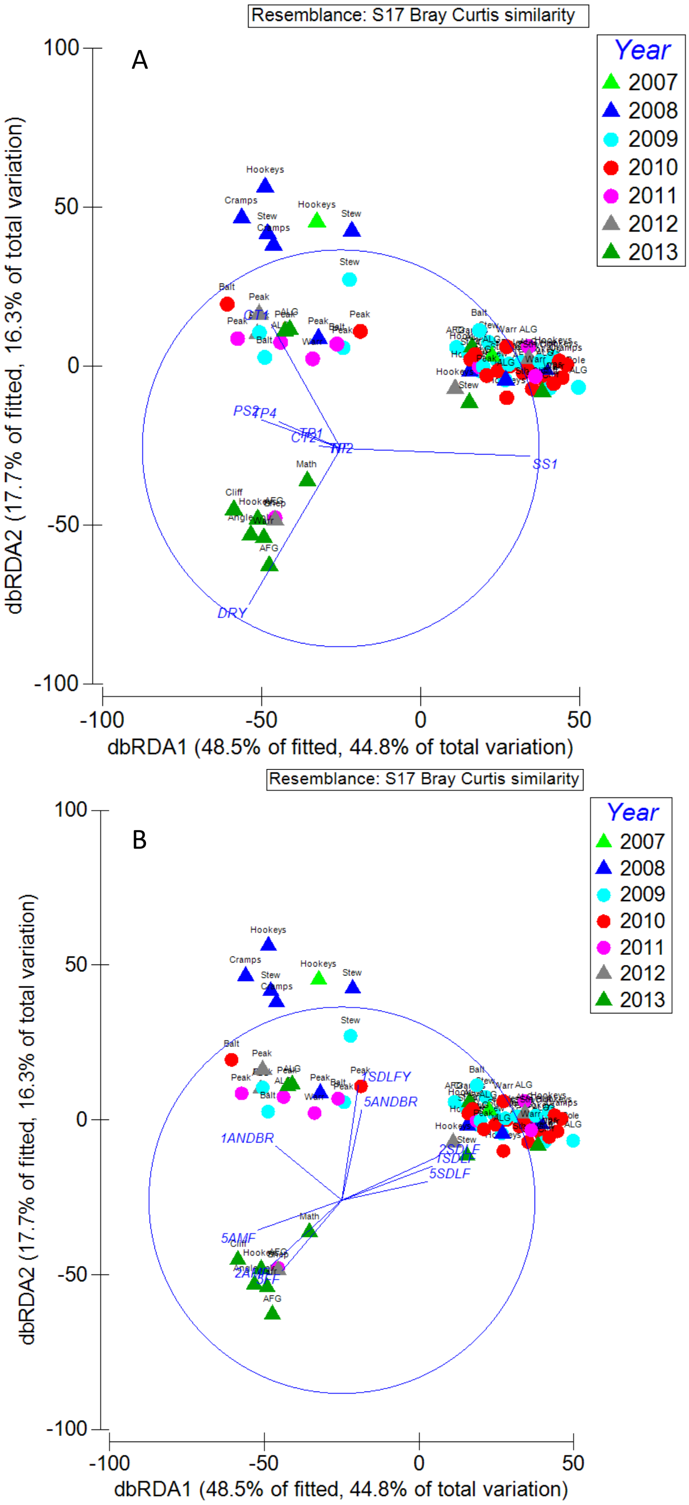

Figure 8. (A) Distance-based Redundancy Analysis plot describing the first two axes with vectors displaying fish community states (generated in chapter 3) correlating with fish communities observed during semester 1. (B) Distance-based Redundancy Analysis plot describing the first two axes with vectors representing hydrology metrics correlating with fish communities observed during semester 1 (Pearson correlation coefficient, r > 0.45).

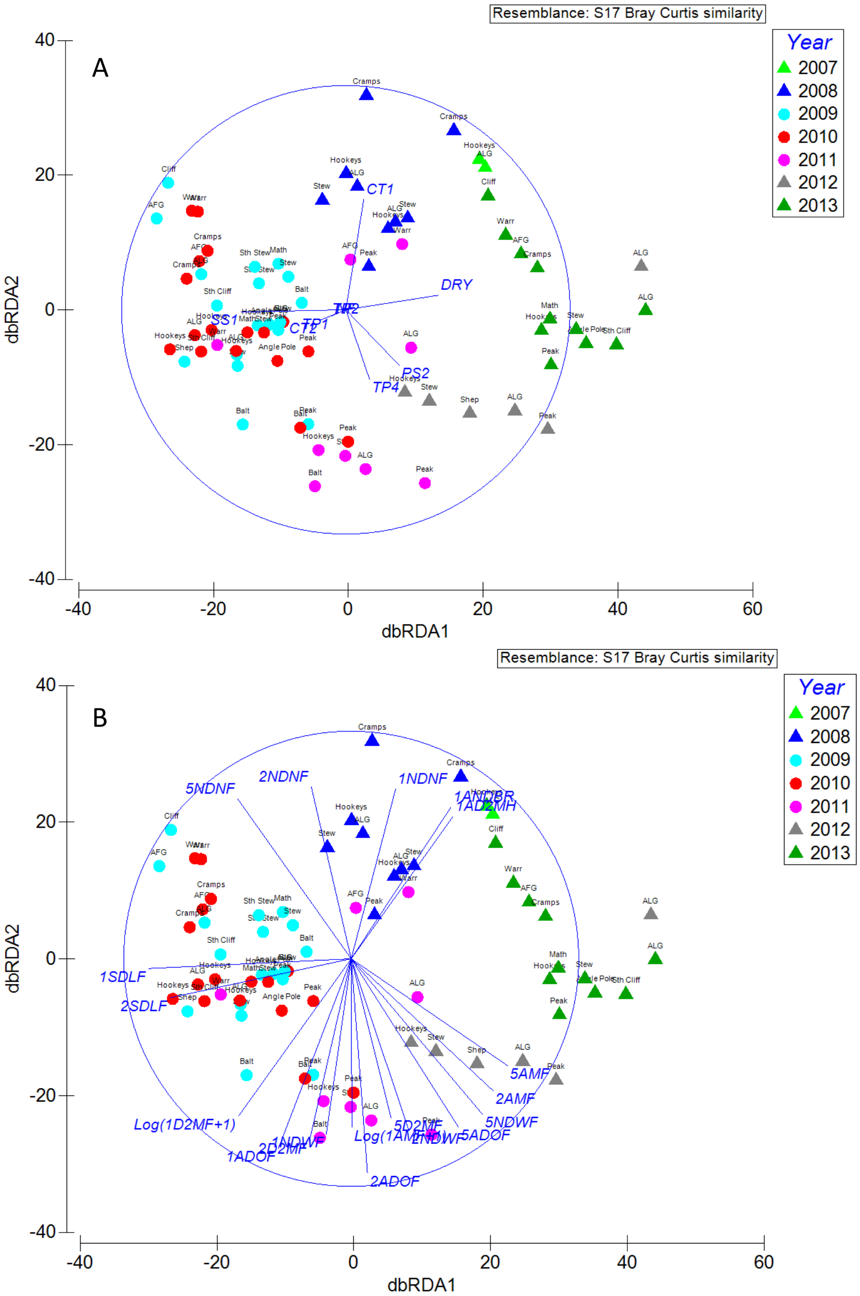

Figure 9 (A) Distance-based Redundancy Analysis plot describing the first two axes with vectors displaying fish community states (generated in chapter 3) correlating with fish communities observed during semester 2. (B) Distance-based Redundancy Analysis plot describing the first two axes with vectors representing hydrology metrics correlating with fish communities observed during semester 2 (Pearson correlation coefficient, r > 0.45).

LEB

The ecoregions generated during state transition analysis (Chapter 3) tended to separate out in ordination space confirming a relationship between flow and community behavior (Figure 10). The larger catchments (the Diamantina and Cooper) were positioned along a linear ordination trajectory with the upper reaches displaying the highest coefficient of variation (*CV Ml/day*) and the lower-mid reaches associate with the highest flow volumes (e.g. *P(time) 100,000 – 1,000,000 Ml/day*). The Neales catchment aligned most strongly with the Finke and Todd river fish states and with vectors representing frequent low flows (*e.g. Number of flow days (> 1 Ml/day)* and *P(time) 100 – 1000 Ml/day*).

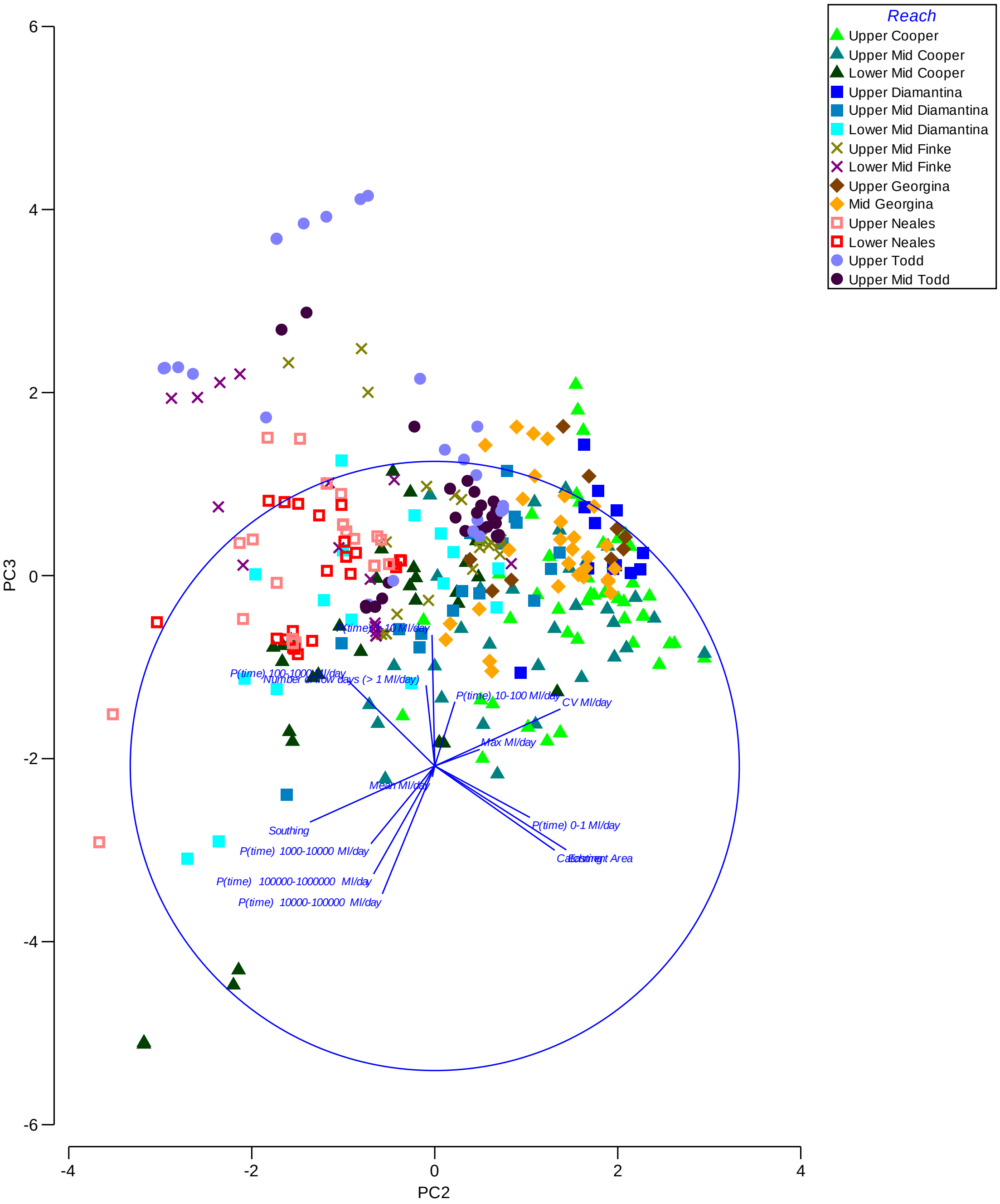

Figure 10. Principle components analysis of fish community displaying the second and third axes with vectors representing hydrology metrics correlating with fish communities. Larger catchments in the east of the LEB display an increase in daily flow. Upper reaches of the Cooper Creek have greater daily flow variability than the lower mid Reaches

Discussion

Neales

A range of hydrological characteristics correlated with fish community dynamics in the Neales catchment. These metrics reflect not just the degree of wetness but specific aspects of hydrological regime relating to timing and rate of change of flow. The most stable fish communities (SS1) were most closely associated with *starting day of the last flow event* (SDLF). An increase in the average of *starting day of flow events over all years* possibly reflects increasing hydrological stability, particularly over the summer. This effect was mirrored in CT1 communities which were most strongly connected to *Average number of days before pool refilling* and *starting day of the last flow event across all years*. Both are metrics that reflect less frequent inputs and longer periods without flow. Timing of flow may also be a factor with both waterbody permanence and community stability in this catchment benefitted by not receiving flow over summer.

Although a stable fish community in an arid setting would seem to require regular inputs to maintain water volume this is not the case as *average flow frequency* did not correspond with SS1 or CT1 communities but instead corresponded most strongly with sites which were dry at the time of sampling. This means that sites which receive frequent flow due to localized runoff events are also more likely to dry completely than sites corresponding to SS1 and CT1 communities. In these instances, geomorphological context plays an important role in predicting the permanence of the waterhole.

Variation in assemblage state corresponded to hydrological history- a combination of flow and dry events over the past 1, 2 and 5 years. Changes in hydrology appeared to be driving successional changes in the Neales fish assemblage composition and antecedent measures of both flow and dry events may be able to predict present semester assemblage types. It is expected that changes in assemblage states across time in other LEB rivers is likely to reflect a response due to hydrological changes. To further examine the role that hydrology plays as a driver of fish assemblage in catchments across the LEB, exploratory analyses were undertaken using a more spatially dispersed dataset containing sites where fish and flow data correspond for every gauging station across the LEB.

LEB

Different ecoregions did not associate uniformly to flow vectors. The larger catchments (the Cooper and Diamantina displayed similar trends with their upper reaches being most strongly associated with highly variable flow patterns (*CV Ml/day*) In contrast the lower-mid reaches of these catchments which were most strongly associated very high flow conditions. This reflects the ephemeral nature of these ecoregions which may receive flow only during flooding events and only during the wettest periods of the hydrological cycle. A lack of gauged flow data in the lowest reaches of these catchments does not allow these data to be incorporated in the current analysis, however it is anticipated that the lowest reaches of each catchment would occur further along the same trajectory. The similar trajectories of these two rivers, and the overlay of similarly responding ecoregions from different catchments in general, supports the future revision of ecoregions to incorporate functionally similar reaches from different catchments. Reconsidering the ecoregions generated through the state transition analysis would be best undertaken following completion of monitoring through a full hydroclimatic cycle.

It is clear that hydrological metrics which describe wetting and drying timing and pattern (rather than just volume) relate strongly to the observed changes in community dynamics in the Neales catchment. The Neales catchment contained the most comprehensive hydrological dataset (with associated fish monitoring data) of the LEB catchments which allowed a level of detailed examination of the Neales catchment which is not currently possible for other catchments. Given the varied flow volumes received by different ecoregions (Figure 10) and the adaptations of the fish communities therein it is not anticipated that the relationships between flow pattern (incorporating antecedent wetting and drying metrics) and fish community states generated for the Neales catchment hold true for other LEB catchments.

Chapter 5: Condition Assessment Approaches

Authors: David Cheshire, Rupert Mathwin and David Schmarr.

Biological Condition Gradient Model

The Biological Condition Gradient (BCG) was originally developed by the United States Environmental Protection Agency (USEPA) (Davies and Jackson, 2006), to use a combination of monitoring data and expert opinion to grade the condition of a site or reach. The BCG is designed to accept data from relevant taxa (*e.g.* fish, vegetation or macroinvertebrates) and different taxa may be scored concurrently for the same site using a range of inputs. This condition assessment methodology has been adopted by the South Australian Environmental Protection Authority (EPA) for use with macroinvertebrate data (e.g. Goonan et al. (2012) and has been adapted by SARDI (Mathwin et al., 2014) to score fish metrics in the coastal drainages of South Australia (e.g. (Schmarr et al., 2014)).

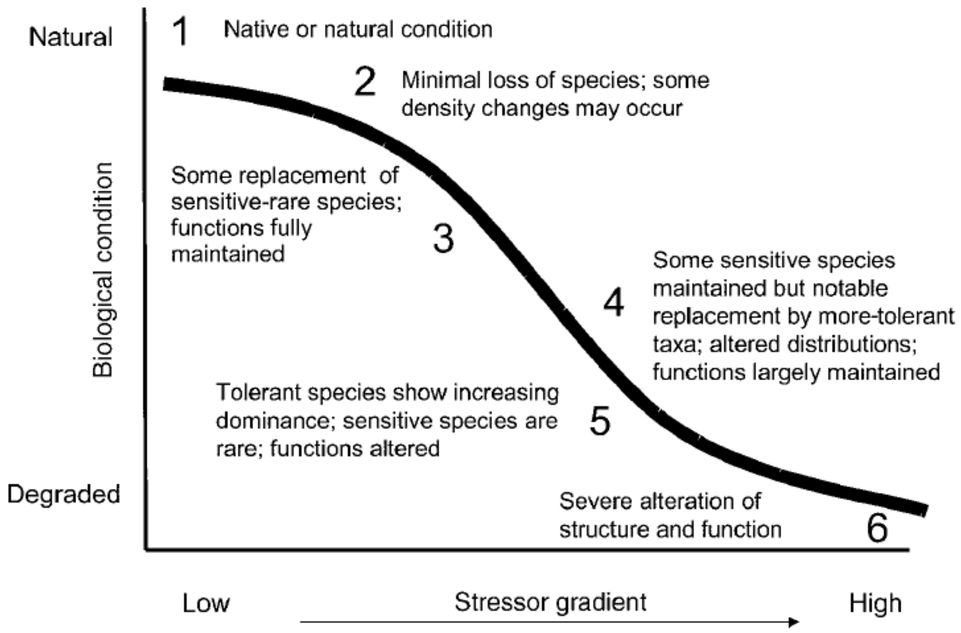

Figure 11. Conceptual Biological Condition Gradient Tier definitions

The approach scores ten biotic and abiotic attributes (representing different aspects of the ecosystem) along six conceptual tiers which sit on a gradient of environmental degradation (Figure 11). The combined average of each of the ten attribute scores determines the site BCG score for that site and site scores may be combined to create scores for a reach. This report recognises the key role that location and hydrology play in fish community dynamics and creates an ecoregion and hydroclimatic phase specific BCG template against which to assess ecosystem condition using appropriately collected fish data. The current adaptation also removes much of the 'expert opinion' that characterises the BCG and has replaced qualitative descriptors with quantitative thresholds wherever possible. It is hoped that in doing so the developed methodology with result in a more consistent condition assessment.

Sampling requirements

The condition assessment methodologies outlined in this report have been designed to match sampling outputs generated in the LEBRA (Mathwin et al., 2015, McNeil and Cockayne, 2010). This fish sampling methodology is also shared by several other monitoring programs in the region (Schmarr et al., 2013, McNeil et al., 2011b, McNeil and Schmarr, 2009) primarily using passive fishing techniques (fyke nets of varying sizes), set overnight, across a range of microhabitats within a single pool, with sampling repeated in spring and autumn. Future sampling to inform condition assessment will need to meet the methodological and seasonal precedents of baseline data in order to provide a comparable snapshot to the trends generated herein. For example fish data collected during the AridFlo project used similar nets to the LEBRA methodology but varied insofar as nets were set for only three hours and only during daylight hours. This variation in sampling regime resulted in a bias towards lowered species richness, with higher CPUE figures and disproportionately higher numbers of bony herring. To use the Aridflo (Costelloe et al., 2004) methodology to generate data to inform the current condition assessment would almost certainly provide a misleading representation of waterhole health when compared to the baseline trends generated in this report.

It strongly suggested that assessments using the BCG models developed in this report maintain minimum standards of spatial and temporal replication. Spatial replication of no fewer than three sites spread across an ecoregion provides spatial coverage and replication within the ecoregion and should allow sufficient variability to make generalised comment on the condition of the ecoregion as a whole. Proximate antecedent sampling data provides a temporal context for inference and will provide added confidence to the scoring of sites and also a basis for examining worrying changes in site condition. Spatial and temporal replication will also feed back into the review process greatly enhancing the accuracy of future revisions and adaptations.

BCG Adaptation

The Cooper Creek was chosen as the model catchment for this approach because of its robust spatial and temporal dataset. To examine how the BCG approach could be applicable in varied situations models were created for two contrasting ecoregions within the catchment, the highly stable upper-mid Cooper and the highly unstable lower Cooper.

In order to account for the effect that hydroclimatic phase has as a driver of fish dynamics within an ecoregion, the approach must first identify during which phase sampling took place and then adjust the scoring accordingly. For the upper Cooper, the flow gauge at Cullyamurra was used as a proxy to determine hydroclimatic phase. By answering a simple key the user is able to decide which column to consider when scoring attributes, allowing three BGCs (one each for boom, bust and dispersal phases) to be combined into a single document (Appendix D). For the lower Cooper a simple key was developed equating hydoclimatic phase to fresh flows at Lake Hope (Appendix E).

In the BCG attributes I – XII score different functional group within the target taxa. The original BCG uses rarity and sensitivity of species to create divisions within the taxa. As fish in the LEB response to flow depended on species traits (Chapter 2, Figure 12) it was determined that traits would be a more appropriate distinction in this system than rarity (Figure 13).

Tier scores were generated based on a mixture of data driven (using ecoregion data fish collected since 2008) and expert opinion, and were based on the assumption that the majority of fish patterns observed from spring 2010 to autumn 2014 represented a near natural state (tier 1 – 2). Temporal fish species patterns within each functional zone were assessed individually, with relative abundance (as CPUE) categories of Low, Moderate and High allocated to each species within each ecoregion. Expected species richness and relative abundance categories for different hydroclimatic phases within each zone were assigned a tier (with tier 1 pristine condition and tier 6 being the worst possible condition). These allocations accounted for expected variation within the ecoregion during the relevant hydroclimatic phase meaning that in the lower Cooper, during the bust phase observing a waterhole that was in trophic collapse may be typical, however in the upper-mid Cooper this was never typical. The finalised BCG for the upper-mid Cooper Creek is presented in Appendix D and the BCG for the Lower Cooper is presented in Appendix E.

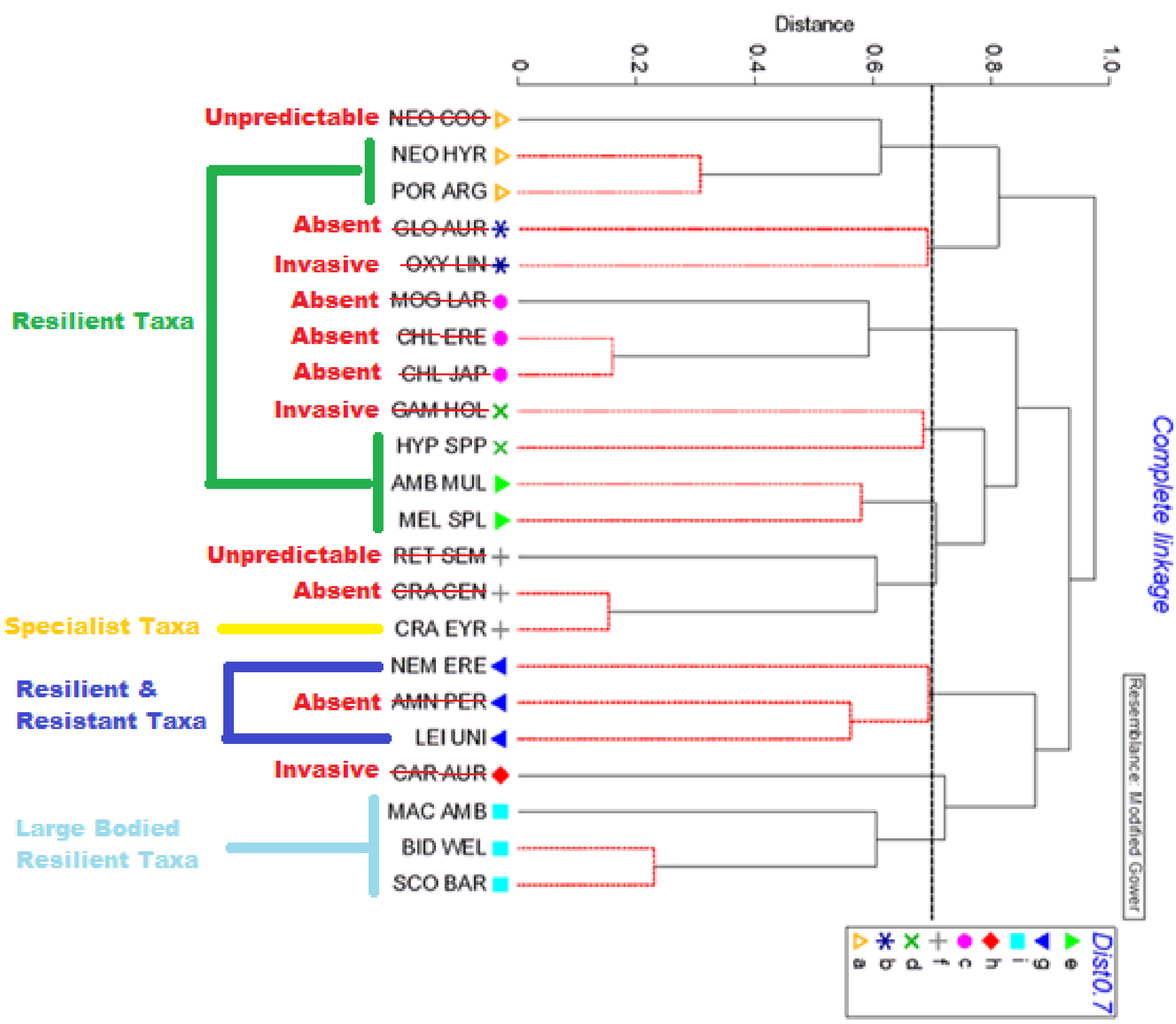

Figure 12. Methods for grouping fish species based on ecological response traits in the Cooper Creek, species absent from the catchment, or those that have been separated based on exotic status or prevalence are excluded.

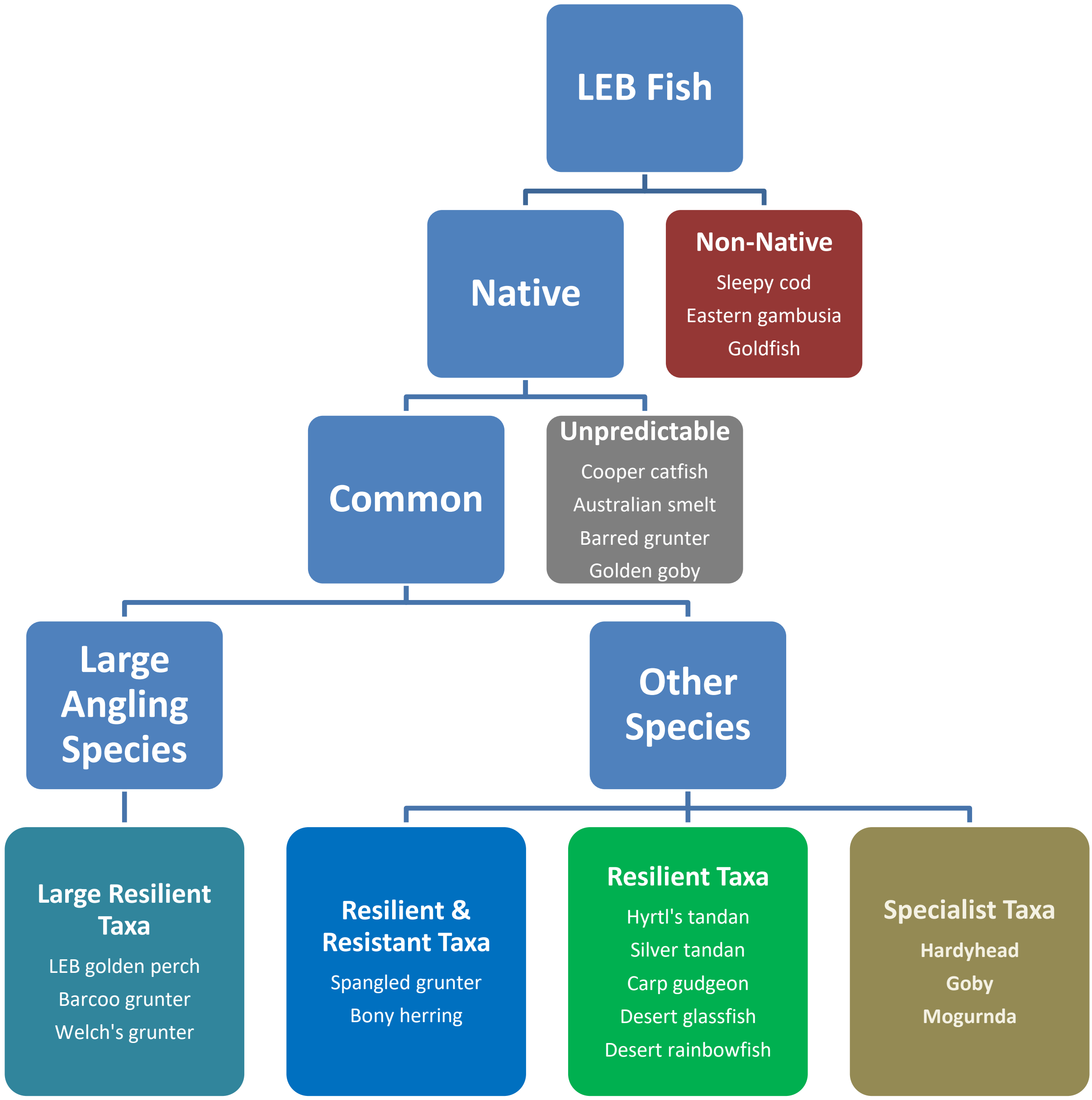

Figure 13. Diagram of BCG fish species classifications for LEB fishes based on their ethnicity, frequency of capture, indicator status and ecological response traits. Note: "Non-native" fish species here includes both translocated native and true exotics.

Default TPC Development

Fully developed, data-driven TPCs have not been developed for the LEB but have the potential to guide condition assessment. An example approach has been included showing how site BCG scores could act as TPCs and a potential approach to risk management could be implemented (Table 6). These are only presented as examples of how the current approach could be used to act as a TPC and are not intended to replace a more formal, iterative process of development. The approach uses outputs from the BCG assessment process to trigger appropriate responses at different spatial scales and with different levels of urgency. A nominal threshold score of 3 has been applied in this example however this could be adjusted quite easily to dictate what is an 'acceptable' level of degradation and at what scale. For example, site level impacts may be less severe than those observed at a whole of catchment scale, therefore an average BCG score of 3-4 may not be particularly concerning at a site whereas the same average score at a catchment scale will indicate widespread detrimental effects. The same consideration should be given to temporal extent as a site observed in poor condition a single occasions may be of less consequence than a site which is consistently observed to be in poor condition.

Table 6. An example of a risk assessment type approach using the BCG approach to trigger TPCs. Potential monitoring responses are presented which consider the spatial extent of observed impact and the severity of the impact.

		Level of Condition				
	Monitoring Response to TPCs	Good condition BCG score 1-2	Acceptable condition BCG Score 2-3	Poor condition BCG Score 3-4 **(TPC)**	Very poor condition BCG Score 4-5 **(TPC)**	Dire condition BCG Score 5-6 **(TPC)**
Spatial scale	**Site** Impacts at site level	Continue Current Monitoring	Continue Current Monitoring,	Examine other sites to see if effect is mirrored elsewhere. Generate an ecoregion score to explore extent of issue.	Examine other sites to see if effect is mirrored elsewhere. Generate an ecoregion score to explore extent of issue. Consider immediate additional monitoring.	Examine other sites to see if effect is mirrored elsewhere. Generate an ecoregion score to explore extent of issue. Consider investigating anthropogenic and other pressures at the site and ecoregion. Consider immediate additional monitoring.
	Ecoregion Impacts confined to a zone		Monitor scores through time. Consistently low scores may require re-definition of the assessment methodology thresholds.	Examine other ecoregions to see if effect is mirrored elsewhere. Consider immediate additional monitoring.	Examine other ecoregions to see if effect is mirrored elsewhere. Investigate anthropogenic and other pressures in the ecoregion. Consider immediate additional monitoring.	Examine other ecoregions to see if effect is mirrored elsewhere. Investigate anthropogenic and other pressures in the ecoregion. Consider immediate ecoregion or catchment-wide monitoring.
	Catchment Impacts confined to a catchment		Identify key factors influencing lower scores and assess their potential implications.	Examine other catchments to see if the effect is mirrored elsewhere. Consider increase in catchment-wide monitoring. Consider investigating anthropogenic and other pressures in the catchment.	Immediate expert evaluation. Consider immediate catchment-wide monitoring. Explore potential stressors. Detrimental effects need immediate investigation.	Immediate expert evaluation. Immediate intensive catchment-wide monitoring. Explore all potential stressors. Detrimental effects need immediate investigation.

Application of the BCG

To ensure that the final BCG generated was suitable a subset of three sites representing the greatest diversity of habitat types and spatial divergence were selected for testing in worked examples. The upper-mid Cooper worked examples are presented in Appendix F, the lower Cooper results are presented in Appendix G.

Hypothetical worst case scenarios were also generated using mock sites for each of the ecological phases encountered; whereby the worst possible states were devised in-order to generate a relative estimate of what extreme site level detriment would look like during each phase. Note that these scenarios took into account the actual status of the zone at the time where concurrent clauses were considered and therefore would not simply result in a score of 6 as the presence of missing species at other sites would influence the final condition score.

Upper-mid Cooper BCG example

The three sites chosen for this assessment were Cullyamurra, Windorah Bridge and Stonehenge (Figure 14), each of which provides a representative sample from the lower, middle and upper portions of the Upper-mid Cooper and all were fairly consistently sampled on consecutive intervals over the course of the 2010-2014 sampling period. Cullyamurra waterhole provides an example of a large channelized waterhole, Windorah Bridge an on channel flood out area and Stonehenge an upstream on-channel refuge, all of which are near permanent with varying levels of anthropogenic disturbance due to land use, tourism and water extraction.

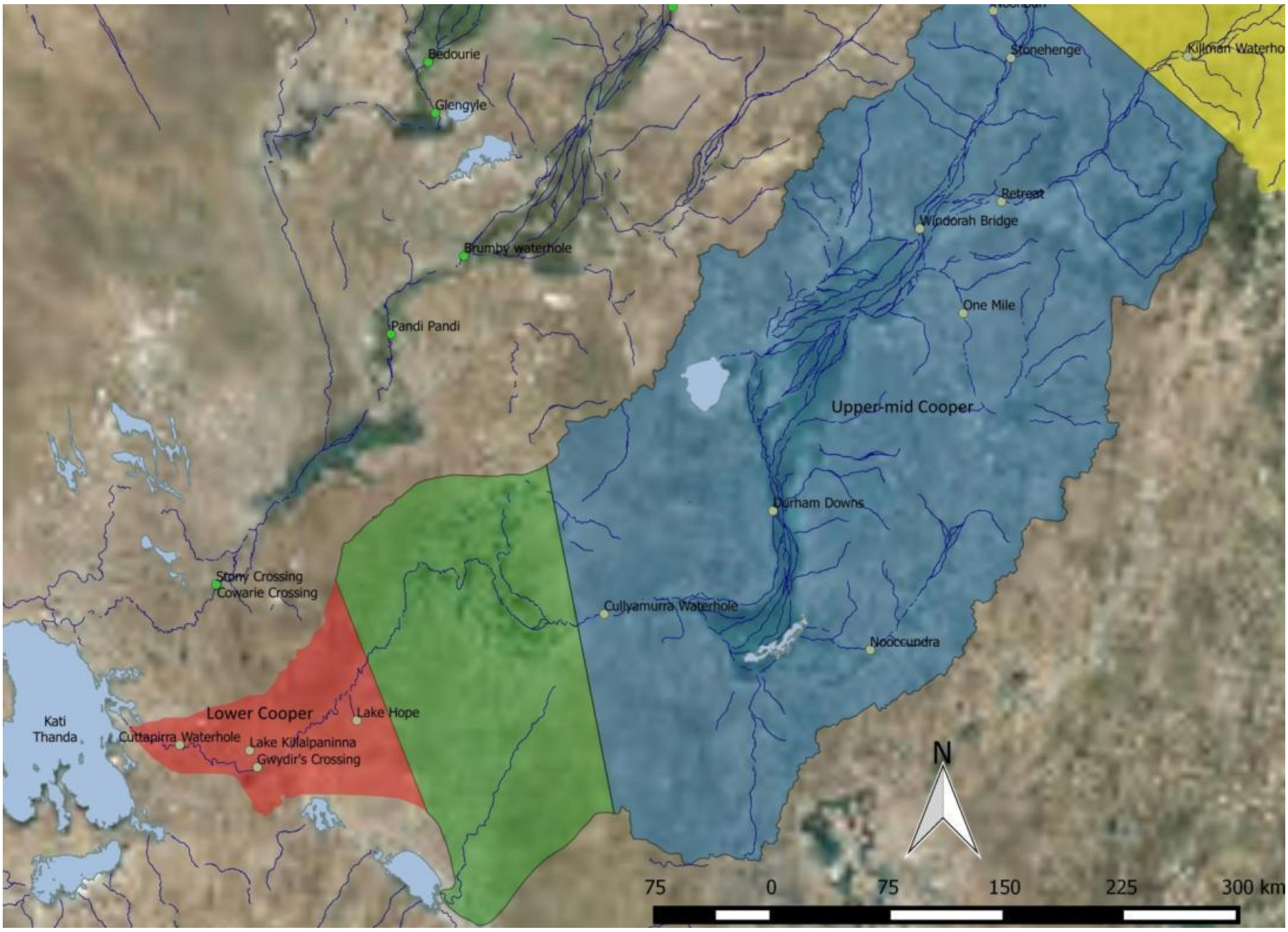

Figure 14. Map of Lower Cooper (red) and Upper-mid Cooper (blue) ecoregions and sites used in the BCG worked examples.

Dispersal Phase Assessment:- Only Cullyamurra was sampled within the Upper-mid Cooper during this initial period, achieving an acceptable condition BCG score of 2, most of which was influenced by a lack of species with unpredictable occurrence in addition to the presence of two exotic fish species. Overall this condition was expected during the dispersal phase as much of the fish assemblage appears to be inherently unpredictable at this time.

Boom Phase Assessment:- This phase recorded largely acceptable condition (2-3) results, with the exception of Cullyamurra and Windorah Bridge in spring 2011. Both of these sites received a score of 3-4, which was driven by different factors at each site. Cullyamurra received poor scores for the majority of attributes as it was lacking each unpredictable species (at a zone level) and large bodied (long lived) species, in addition to the lack of common resilient species, which were expected to be abundant at this time. It also featured two exotic species in moderate abundances. All of which contributed to the lower condition score. Windorah was also lacking unpredictable species, but contained more resilient and long lived taxa, the difference being that this site was missing an extremely common species in bony herring (caught on more than 95% of all sampling occasions in the Cooper), potentially as a result of an extreme lack of diversity caused by an explosion in the numbers of silver tandan at this site. Whilst both of these sites may have triggered the preliminary threshold applied to TPCs for the LEB, they provide a perfect example for spatial and temporal investigations following a TPC being triggered. This example is discussed in detail in the following section, which compares direct trend assessments with BCG model results.

Bust Phase Assessment:- The reach from Stonehenge to Cullyamurra is the only reach with data collected before and after flood events during relatively dry bust periods. Condition scores for both periods averaged around a BCG score of 2, with a similar temporal trend to that of the Lower Cooper assessment observed, whereby the scores slightly deteriorated over time as the transitional hangover from boom to bust dampened condition scores.

Overall observations:- Each phase appeared to account for the degree of natural variation within the data, with invasive species appearing to contribute to the majority of detrimental effects within the zone. The worst case scenario for each phase ultimately scored at a level of 4-5 (bad condition), which was predictable given that the spatial extent of detrimental effects within the zone was quite minimal over the course of each phase.

Lower Cooper BCG

The three sites chosen for this assessment were Cuttapirra Waterhole, Gwydirs Crossing and Lake Hope (Figure 14), each of which provides a representative sample from the lower, middle and upper portions of the Lower Cooper and all were fairly consistently sampled on consecutive intervals over the course of the 2010-2014 sampling period. Cuttapirra waterhole provides an example of a channelised waterhole, Gwydirs Crossing an on channel flood out area and Lake Hope an off-channel terminal lake, all of which are ephemeral with minimal direct anthropogenic disturbance, other than surrounding pastoral activity.

Dispersal Phase Assessment:- All sites scored at a level of good condition (1-2), with minimal detrimental disturbance recorded. Although presence/absence figures for attribute3 were somewhat lower than expected for most sites, this was absorbed by expected outcomes for all other attributes. Scores were particularly high due to a complete lack of invasive species throughout the zone at this time.

Boom Phase Assessment:- This was a successful test of the BCG models ability to absorb change and account for natural variation, as this period in particular contained a great degree of both temporal and spatial variability. The majority of scores during this period averaged around 2-3, which is considered acceptable condition, with most of the detriment appearing to have been caused by the prevalence of invasive species throughout the zone during this time.

Bust Phase Assessment:- This was a notable example of the models ability to account for expected conditions, as these sites were known to deteriorate into a state where only a few more resistant taxa remained, before disappearing completely; however within this ephemeral reach this process is considered completely natural and is always expected to occur eventually after flows recede, the difference being that the rate of decline is dependent on a number of factors, particularly the amount of water held in each habitat.

Overall observations:- A notable observation over the course of each period is slight reduction in average condition over time, where phases contain more than one seasonal sampling event. Both the boom and bust phases saw a pristine score at the beginning of each phase, which was no longer present towards the end. This appears to be an element of natural variation influencing scores as the phase's transition between one another, which is to be expected as these transitions are not likely to be as abruptly black and white as the classifications are. Overall the scores that resulted from this test were all within the realms of acceptable condition, despite the dramatic levels of variation observed within this zone throughout the study. The worst case scenario for each phase ultimately scored at a level of 4-5 (poor condition), which was predictable given that the spatial extent of detrimental effects within the zone was very minimal over the course of each phase.

Limitations

Cooper Creek data have the most comprehensive spatial coverage of any of the other LEB rivers sampled between 2008 and 2014. The greatest extent of sampling was between 2010 and 2012 during the concurrent Cooper Creek Aquatic Assessment project (funded through the South Australian Arid Lands NRM board) and LEBRA, which obtained an important snapshot of fish response during a large flood event. Sampling was very limited prior to 2010, with Cullyamurra the only site sampled on two consecutive occasions during this period. Sampling was reduced at the end of the 2012 flood period, particularly in South Australia, which limited the spatial coverage during the resistance phase and into a drier period. Ultimately the lack of sampling before and after the 2010-2012 floods resulted in a deficiency of data that could be used to establish a typical dry-wet-dry semiarid flow event. Ideally downstream sites should have been sampled more frequently as they dried up and degraded, in order to obtain a thorough comprehensive snapshot of decaying waterholes.

Future BCG Development

The BCG approach has proven to be an effective tool for establishing baseline condition in the reaches that it has been applied. The adaptive nature of this approach will enable it to be implemented in other reaches. The BCG response to variable hydroclimatic and ecoregion effects within the Cooper indicate that the method is sufficiently robust to natural variation in this system. It remains to be seen how the BCG responds to a broader range of environmental conditions and whether it is sensitive enough to detect detrimental effects as a result of anthropogenic impacts. It is anticipated that further development and refinement of the BCG will require an adaptive and iterative approach to incorporate new data within the expected range of natural variability.

Conclusions

In the first phase of this project McNeil et al (2015) presented a range of conceptual models describing the LEB ecosystem. In the second phase of this project we picked up on three key themes of those models and found:

1. Fish species responded to antecedent flow according to their relative resistance and resilience traits.
2. Catchments could be spatially divided into ecoregions that reflect the dynamics of fish populations in space over time.
3. Hydrologiocal metrics which related to timing, rate of change, duration and not just amount of water related to patterns in fish community.

Having established spatial and hydrological patterns in fish communities, we modified the BCG condition assessment methodology for use within a spatial and temporal context which allowed predictable responses despite the unpredictability of the basin as a whole.

In addition to the modelling and condition assessment outputs presented in this project there were a number of key findings that should provide direction for future work:

- Modelling approaches used here have benefited significantly from the data collected by LEBRA and associated projects
- Long-term data was pivotal in the accurate development of these models
- Data collected through LEBRA should be used to inform a benchmark state for which condition state will be applied
- The present long-term dataset has not closed the hydroclimatic cycle and as such does not provide a complete benchmark
- Further data collection and model development is required to incorporate a complete hydroclimatic cycle

- The modified BCG condition assessment methods developed here are suitable for application to all major rivers in the LEB
- This BCG methodology has the potential to inform bioregional assessments
- This BCG methodology should be used in combination with other assessment tools to inform the LEBRA State of the Basin reporting to be conducted in 2017/18.

Interpretation of the state/transition model identified some gaps and inconsistencies in sampling effort throughout the Cooper Catchment. These monitoring gaps are apparent for other catchments modelled using the state/transition approach. Based on these monitoring gaps, several recommendations can be made:

- Improving spatial sampling in the lower reaches of the Basin during dry/drought periods
- Recognising the importance of observing and recording dry sites
- Maintaining spatial coverage in the upper reaches of the Basin
- Improved spatial sampling to map extent of permanent refuge habitats.
- Including monitoring at Tirrawarra, Embarka, Cuttapirrie Corner and Deparannie waterholes to fill specific gaps in spatial and temporal coverage in Cooper Creek
- Identify similar waterholes elsewhere in the Basin to fill specific gaps in spatial and temporal coverage
- Continuing LEBRA monitoring to capture a full range of hydroclimatic conditions from boom to bust and back.

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Appendix A

The fish fauna of the Lake Eyre Basin includes endemic species (^), translocated species (†) and exotic species (¥).

Field Code	Common name	*Genus*	Species	Cooper	Diamantina	Finke	Frome	Georgina	Macumba	Neales
AMB MUL	Desert Glassfish^	*Ambassis*	*mulleri*	●	●	●	-	●	●	-
CRA CEN	Finke River Hardyhead^	*Craterocephalus*	*centralis*	-	-	●	-	-	-	-
CRA EYR	Lake Eyre Hardyhead^	*Craterocephalus*	*eyresii*	●	●	-	●	●	●	●
NEM ERE	Bony Herring	*Nematalosa*	*erebi*	●	●	●	●	●	●	●
CAR AUR	Goldfish¥	*Carassius*	*auratus*	●	-	-	-	-	-	-
HYP SPP	Carp Gudgeon	*Hypseleotris*	spp. (3 species)	●	-	-	●	-	-	-
MOG CLI	Flinders Ranges Mogurnda^	*Mogurnda*	*clivicola*	●	-	-	-	-	-	-
MOG LAR	Finke Mogurnda^	*Mogurnda*	*larapintae*	-	-	●	-	-	-	-
MOG SP.	Frew Mogurnda^	*Mogurnda*	sp.	-	-	-	-	●	-	-
OXY LIN	Sleepy Cod†	*Oxyeleotris*	*lineolatus*	●	-	-	-	-	-	-
CHL ERE	Desert Goby^	*Chlamydogobius*	*eremius*	-	●	-	●	-	-	●
CHL JAP	Finke Goby^	*Chlamydogobius*	*japalpa*	-	-	●	-	-	-	-
GLO AUR	Golden Goby^	*Glossogobius*	*aureus*	-	●	-	-	●	-	-
MEL SPL	Desert Rainbow Fish^	*Melanotaenia*	*splendida tatei*	●	●	●	-	●	●	●
MAC AMB	Lake Eyre golden perch^	*Macquaria*	*ambigua*	-	-	-	-	●	-	-
MAC PEE	Murray cod†	*Maccullochella*	*peelii peelii*	●	-	-	-	-	-	-
NEO COO	Cooper Catfish^	*Neosiluroides*	*cooperensis*	●	-	-	-	-	-	-
NEO HYR	Hyrtl's Catfish	*Neosilurus*	*hyrtlii*	●	●	●	-	●	●	●
POR ARG	Silver Tandan	*Porochilus*	*argenteus*	●	●	-	-	●	●	●
GAM HOL	Eastern Gambusia¥	*Gambusia*	*holbrooki*	●	●	-	●	●	-	●
RET SEM	Australian Smelt	*Retropinna*	*semoni*	●	-	-	-	-	-	-
AMN PER	Barred Grunter	*Amniataba*	*percoides*	-	●	●	-	●	●	●
BID BID	Silver Perch†	*Bidyanus*	*bidyanus*	-	-	-	-	●	-	-
BID WEL	Welch's Grunter	*Bidyanus*	*welchi*	●	●	-	-	●	●	●
LEI UNI	Spangled Grunter	*Leiopotherapon*	*unicolor*	●	●	●	●	●	●	●
SCO BAR	Barcoo Grunter	*Scortum*	*barcoo*	●	●	-	-	●	-	-

Appendix B

Ten of the 24 traits used to inform Trait analysis are presented for key Lake Eyre Basin fish species.

Species	Max Length	Shape Category	Vertical Position	Trophic Guild	Longevity	Age at Maturity
Desert glassfish^	Small	Deep	Pelagic	Insectivore	Short	Fast
Barred grunter	Medium	Deep	Bentho-pelagic	Insectivore/ Piscivore	Medium	Fast
Welch's grunter^	Large	Moderate	Bentho-pelagic	Insectivore/ Piscivore	Long	Moderate
Goldfish†	Large	Deep	Bentho-pelagic	Omnivore	Long	Fast
Desert goby^	Small	Slender	Benthic	Omnivore	Short	Fast
Finke goby^	Small	Slender	Benthic	Omnivore	Short	Fast
Finke River hardyhead^	Small	Slender	Pelagic	Insectivore	Short	Fast
Lake Eyre hardyhead^	Small	Slender	Pelagic	Insectivore	Short	Fast
Gambusia†	Small	Moderate	Pelagic	Insectivore	Short	Fast
Golden goby^	Medium	Slender	Benthic	Insectivore	Short	Fast
Carp gudgeon	Small	Moderate	Bentho-pelagic	Insectivore	Short	Fast
Spangled perch	Medium	Moderate	Bentho-pelagic	Insectivore/ Piscivore	Medium	Fast
Lake Eyre golden perch^	Large	Deep	Bentho-pelagic	Insectivore/ Piscivore	Long	Slow
Desert rainbowfish^	Small	Deep	Pelagic	Omnivore	Short	Fast
Finke mogurnda^	Small	Slender	Benthic	Insectivore	Medium	Fast
Bony Herring	Medium	Deep	Pelagic	Herbivore or Detritivore	Medium	Fast
Cooper catfish^	Large	Slender	Benthic	Insectivore	Long	Slow
Hyrtl's catfish	Medium	Slender	Benthic	Insectivore	Medium	Moderate
Sleepy cod†	Medium	Slender	Benthic	Insectivore/ Piscivore	Medium	Moderate
Silver tandan	Medium	Slender	Benthic	Insectivore	Medium	Moderate
Australian smelt	Small	Slender	Pelagic	Insectivore	Short	Fast
Barcoo grunter	Large	Moderate	Bentho-pelagic	Omnivore	Long	Moderate

Appendix C

Site Name	Watercourse	Location
Ag College waterhole	Thompson River	55 K 226939 7415075
Avington Rd	Barcoo River	55 J 329096 7310989
Beach Bridge	SA Cooper Creek	54J 339088 6906657
Blackall	Barcoo River	55 J 343615 7297752
Bowen Downs	Cornish Creek	55 K 296654 7516094
Burke's Waterhole	SA Cooper Creek	54 J 478059 6933518
Coongie Inflow	SA Cooper Creek	54 J 415859 6993267
Cullyamurra	SA Cooper Creek	54 J 484321 6935885
Cuttapirra Waterhole	SA Cooper Creek	54 J 214410 6838367
Cuttapirrie Corner	SA Cooper Creek	54 J 390410 6947133
Darr	Darr River	55 K 201142 7429702
Durham Downs	QLD Cooper Creek	54 J 589702 7007448
Eaglehawk	SA Cooper Creek	54 J 343166 6908968
Embarka Outflow	SA Cooper Creek	54 J 412315 6950487
Embarka WH	SA Cooper Creek	54 J 420814 6938207
Gidgealpa	SA Cooper Creek	54 J 416449 6921896
Gwydir's Crossing	SA Cooper Creek	54 J 274056 6832509
Innaminka Causeway	SA Cooper Creek	54 J 473806 6931375
Killalpaninna Mission	SA Cooper Creek	54 J 260382 6836650
Killman Waterhole	Barcoo River	55 J 232756 7312679
Kudriemitchie	SA Cooper Creek	54 J 420831 6974481
Lake Daer Inlet	SA Cooper Creek	54 J 410544 699091
Lake Hope	SA Cooper Creek	54 J 328455 6859435
Lake Hope Inlet	SA Cooper Creek	54 J 322984 6875519
Lake Kopperamanna	SA Cooper Creek	54 J 272635 6836589
Lammermoor	Towerhill Creek	55 K 256016 7638055
Minkie Waterhole	SA Cooper Creek	54 J 464472 6927297
Nappapethera	SA Cooper Creek	54 J 511916 6947760
Narie	SA Cooper Creek	54 J 408456 6962930
Noccundra	Wilson River	54 J 656334 6921236
Noonbah	Vergemont Creek	54 J 716389 7334791
One Mile	Kyabra Ck	54 J 705652 7140029
Pandruannie	SA Cooper Creek	54 J 307411 6854620
Red Lake	SA Cooper Creek	54 J 323079 6860269
Retreat	Barcoo River	54 J 726955 7212656
Stonehenge	Thompson River	54 J 728904 7305092
Tenham	Kyabra Ck	54 J 700818 7155694
Tilla Tilla Track Crossing	SA Cooper Creek	54 J 228649 6836010
Tirrawarra	SA Cooper Creek	54 J 415958 6965261
Toontoowarannie	SA Cooper Creek	54 J 416769 7004424
Windorah bridge	QLD Cooper Creek	54 J 675467 7192915
Yaningurie	Strzelecki Creek	54 J 414063 6795579

Appendix D

<u>At the time of sampling had Cullyamurra received at least an average of 5000 ML/d of flows over the last 12 months? (No-1, Yes - 2)</u>

1 – Flows have receded or have returned to seasonal flow patterns. When calculating BCG Tiers consider the 'Bust phase' column.

2 –Is this the first flow event to exceed 5000 ML/d within the last few years? (Yes -**3**, No – **4**)

3 – When calculating BCG Tier scores consider the 'Dispersal phase' column.

4 – This is a subsequent flow comprising a part of a supra-seasonal flood event. When calculating BCG Tier scores consider the 'Boom phase' column.

<u>Concurrent clauses only apply where at least three sites have been sampled concurrently within zone.</u>

<u>When considering "Low", "Moderate" or "High" abundances in the Upper-mid Cooper, refer to this table.</u>

Upper-Mid Cooper CPUE			
Attribute	**Species**	**Low (<=)**	**High (>=)**
I	**NEO COO**	0.04	0.08
	RET SEM	0.04	0.15
II	**BID WEL**	0.08	0.15
	SCO BAR	0.04	0.08
	NEO HYR	0.40	0.80
III	**POR ARG**	0.40	0.80
	MAC AMB	0.25	0.40
	HYP SPP	0.04	0.15
	AMB MUL	0.15	0.40
	MEL SPL	0.15	0.40
IV	**NEM ERE**	0.80	1.60
	LEI UNI	0.15	0.80
V	**CRA EYR**	0.00	0.01
VI	**CAR AUR**	0.08	0.15
	OXY LIN	0.04	0.05
	GAM HOL	0.08	0.25

BCG Tier	Description
Attribute I	**Rare taxa and species with unpredictable occurrence. (Cooper catfish and Australian smelt) Species with unpredictable occurrence are only scored if a historical record exists for locality.**
Tier 1	Both species present or one species present in high abundance
Tier 2	One species present in low abundance.
Tier 3	Both species absent but both captured concurrently elsewhere in zone OR less than three samples taken.
Tier 4	Both species absent, one species captured concurrently elsewhere in zone.
Tier 5	Both species absent but both captured elsewhere in zone within last 5 years
Tier 6	At least one species absent from zone over last 5 years
Attribute II	**Large bodied resilient taxa (Golden perch, Barcoo and Welch's Grunter), species are only scored if a historical record exist for locality.**
Tier 1	At least two species present or one species present with high abundance.
Tier 2	One species present with low abundance.
Tier 3	Group absent but all captured concurrently elsewhere in zone or less than three sites sampled.
Tier 4	Group absent but all captured elsewhere in catchment.
Tier 5	Group absent but all captured anywhere within catchment in last 2 years.
Tier 6	Any species absent due to regional extripation or global extinction.
Attribute III	**Resilient taxa (Hyrtl's and silver tandans, carp gudgeon, glassfish, rainbowfish).**
Tier 1	At least three species present, one with high abundances during boom phase, any abundance during dispersal and bust phases.
Tier 2	Two species present, low abundance during dispersal and bust phase, one with high abundance during boom period. All other species must have been recorded concurrently within zone.
Tier 3	At least two species present during the boom phase, with low abundance OR not all species have been recorded concurrently within zone with less than three sites sampled.
Tier 4	Less than two species present OR not all species have been recorded concurrently within zone with more than three sites sampled.
Tier 5	All species absent but captured concurrently in catchment.
Tier 6	Absent due to regional extirpation.

BCG Tier	Description
Attribute IV	**Resilient and resistant taxa (spangled grunter and bony herring).**
Tier 1	Both species present, both with moderate abundances or one with high abundance during boom phase. Both species present in low abundances during dispersal and bust phases.
Tier 2	Both species present in low abundance during boom phase.
Tier 3	Only bony herring present, spangled grunter captured concurrently within zone, or less than three samples taken.
Tier 4	Only bony herring present, no spangled grunter captured in zone during bust phase.
Tier 5	Only bony herring present, no spangled grunter captured in zone during boom phase.
Tier 6	No bony herring present (anytime).
Attribute V	**Specialist taxa (Lake Eyre hardyhead), *attribute is only scored if species are present as it is not historically documented in Upper-mid Cooper.***
Tier 1	
Tier 2	
Tier 3	
Tier 4	
Tier 5	
Tier 6	Present
Attribute VI	**Non-native or intentionally introduced taxa (gambusia and goldfish).**
Tier 1	**Non-native** taxa not present and not historically recorded in zone.
Tier 2	**Non-native** taxa not present and not concurrently captured in zone.
Tier 3	**Non-native** taxa not present but concurrently captured in zone, or less than three samples within zone.
Tier 4	One non-native species present but in low to moderate abundance.
Tier 5	More than one non-native species present or one species in high abundance (not dominant).
Tier 6	Non-native fish dominate assemblage and/or abundances.

Attribute VII	**Organism and population condition.** ***This Attribute is scored for native fish only.*** **(***Disease & congenital abnormalities to be included with improved data.*)**
Tier 1	Multiple age classes apparent for long-lived species at site, recruits present.
Tier 2	Multiple age classes apparent for long-lived species within zone.
Tier 3	Multiple age classes apparent for long-lived species within catchment, recruits present.
Tier 4	Multiple age classes apparent for long-lived species within catchment, recruits not present.
Tier 5	No multiple age classes apparent for long-lived species within catchment.
Tier 6	No multiple age classes apparent for long-lived species within catchment over last 5 years.
Attribute VIII	**Ecosystem functions**
	This attribute is not utilised in the current approach. It has been retained to allow future integration of limnological data.
Tier 1	All are maintained within a range of natural variability
Tier 2	All are maintained within a range of natural variability
Tier 3	Virtually all are maintained through functionally redundant system Attributes; minimal increase in export except in high storm flows
Tier 4	Virtually all are maintained through functionally redundant system Attributes, although there is evidence of loss of efficiency (eg increased export or increased import)
Tier 5	Apparent loss of some ecosystem functions manifested as increased export or increased import of some resources and, changes in energy exchange rates (eg P/R, decomposition)
Tier 6	Most functions show extensive and persistent interruption
Attribute IX	**Spatial and temporal extent of detrimental effects.**
	This attribute is not utilised in the current approach. It has been retained to allow future integration of atypical disturbance data.
Tier 1	Not applicable. Natural disturbance regime is maintained
Tier 2	Limited to small pockets and short durations
Tier 3	Limited to reach scale and/or limited to within a season
Tier 4	Mild detrimental effects may be detectable beyond the reach scale and may include more than one season
Tier 5	Detrimental effects extend far beyond reach scale leaving only a few islands of adequate conditions; effect extends across multiple seasons.
Tier 6	Detrimental effects may eliminate all refugia and colonisation sources within the catchment and affect multiple seasons.

Attribute X	**Anthropogenic Impacts and Site Connectance *This attribute is not utilised in the current approach. To be informed upon by threat mapping assessments and CAC/SAP TPC weighting values.***
Tier 1	No alteration to natural state.
Tier 2	Minor impacts (fishing, external grazing pressures).
Tier 3	Moderate impacts (Tourism, feral species (terrestrial), small scale water extraction, causeways and bunds)
Tier 4	Significant impacts (Direct impacts from livestock such as pugging, nutrification, aquatic vegetation clearance as well as intrusion on natural habitats by artifical water sources)
Tier 5	Major impacts (Large scale erosion, artificially created habitats such as bore drains)
Tier 6	Severe impacts (Large scale water extraction, severe water pollution).

Appendix E

At the time of sampling had Lake Hope received flow within the last 12 months?

(No-1, Yes - 2)

1 – Lake Hope has not been connected to the main channel within the last 12 months. When calculating BCG Tiers consider this the 'Bust phase'.

2 – Was the flow event that connected Lake Hope to the main channel the first flow event that had reached Lake Hope since drying? (Yes -**3**, No – **4**)

3 – Lake Hope has recently received a first flow event. When calculating BCG Tier scores consider this the 'Dispersal phase'.

4 – Lake Hope has contained water for a period of time but not through novel flows. When calculating BCG Tier scores consider this the 'Boom phase'.

Concurrent clauses only apply where at least three sites have been sampled concurrently within zone.

When considering "Low", "Moderate" or "High" abundances in the Upper-mid Cooper, refer to this table.

Lower Cooper CPUE Thresholds			
Attribute	**Species**	**Low (<=)**	**High (>=)**
I	NEO COO	0.00	0.01
	RET SEM	0.04	0.08
II	MAC AMB	0.08	0.17
	BID WEL	0.03	0.04
	SCO BAR	0.02	0.03
III	NEO HYR	0.00	0.01
	POR ARG	0.00	0.01
	HYP SPP	0.42	0.83
	AMB MUL	0.17	0.42
	MEL SPL	0.25	0.83
IV	NEM ERE	0.83	1.67
	LEI UNI	0.08	0.42
V	CRA EYR	2.50	8.33
VI	CAR AUR	0.04	0.08
	OXY LIN	0.00	0.01
	GAM HOL	0.42	1.67

BCG Tier	Description
Attribute I	**Rare taxa and species with unpredictable occurrence (Cooper catfish and Australian smelt) species are only scored if a historical record exist for locality.**
Tier 1	At least one species present.
Tier 6	Absent due to catchment extirpation or global extinction.
Attribute II	**Large bodied resilient taxa (Golden Perch, Barcoo and Welch's Grunter). Attribute only scored during "bust" phase if taxa are present.**
Tier 1	Two or more species present during "boom" or "dispersal" phases. One or more species present during bust phase.
Tier 2	One species present with high abundance during "boom", low abundance during "dispersal" phases.
Tier 3	One species present with a moderate abundance during "boom" phase, group absent during "dispersal" phases.
Tier 4	Group absent during "boom" phase but at least two species captured concurrently elsewhere in zone.
Tier 5	Group absent during "boom" phase but known in the zone within the last year.
Tier 6	Group absent during boom phase and not observed within zone for at least one year prior.
Attribute III	**Resilient taxa (Hyrtl's and silver tandans, carp gudgeon, glassfish, rainbowfish). Attribute only scored during "bust" phase if taxa are present.**
Tier 1	More than two species present OR more than one species present with at least one species in: high abundance during "boom" phase, more than one species present during "dispersal" or "bust" phases.
Tier 2	More than one species during "boom" or "dispersal" phase, one species during "bust" phases.
Tier 3	One species with moderate abundance during "boom" phase, one species present during "dispersal" phase.
Tier 4	One species with low abundance during "boom" phase, group absent during dispersal phase but captured concurrently within the zone.
Tier 5	Group absent during the boom or dispersal phases but captured in the catchment within the last 5 years.
Tier 6	Group absent due to regional extirpation (not bust phase)

Attribute IV	**Resilient and resistant taxa (spangled grunter and bony herring). Attribute only scored during "bust" phase if taxa are present.**
Tier 1	Both species present with at least one species in high abundance during "boom" period, low abundance during "dispersal" and "bust" phases.
Tier 2	Both species present during "boom" and "dispersal" phase, bony herring present in during "bust" phase.
Tier 3	Only bony herring present during dispersal & boom phase.
Tier 4	Bony herring absent during boom and dispersal phase but captured concurrently at all other sites within zone.
Tier 5	Both species absent during boom or dispersal phase, both captured concurrently in zone.
Tier 6	Both absent during boom or dispersal phase, spangled grunter not captured concurrently within zone, OR bony herring absent during boom or dispersal phase and not captured concurrently at all sites within zone.

Attribute V	**Specialist taxa (Lake Eyre hardyhead).**
Tier 1	Absent during "dispersal" or "boom" phase OR present with *low* abundance during "dispersal" or "boom" phase, present in moderate to high abundance during "bust" phases
Tier 2	Present with *high* abundance during "boom" phase, low abundance during "bust" phases
Tier 3	Present with high abundance during "dispersal" phase, absent during "bust" period, but captured elsewhere in catchment within last 5 years.
Tier 4	Absent during "bust" period, not captured elsewhere in catchment within last 5 years.
Tier 5	Absent during "bust" period, not captured elsewhere in catchment within last 10 years.
Tier 6	Absent due to apparent long term regional extirpation

Attribute VI	**Non-native or intentionally introduced taxa (Gambusia, sleepy cod and goldfish).**
Tier 1	Non-native taxa not present and not historically recorded in zone.
Tier 2	Non-native taxa not present and not concurrently captured in zone.
Tier 3	Non-native taxa not present but concurrently captured in zone or this was unknown due to less than three samples taken.
Tier 4	One non-native species present in low-moderate abundance.
Tier 5	More than one non-native species present or one species in high abundance (does not dominate the sum of all natives).
Tier 6	Non-native fish dominate all other taxa in abundance OR are the only fish present OR apparent range extension of non-native taxa (eg. Sleepy cod observed for the first time at this site).

Attribute VII **Organism and population condition (reproduction). This attribute is only scored for native fish during the dispersal and boom phases and only if the species group is present. ***Disease & congenital abnormalities to be included with improved data sets.***

Tier 1 Multiple age classes apparent for long-lived species at site OR recruits present.

Tier 2 Multiple age classes apparent for long-lived species concurrently within zone.

Tier 3 Multiple age classes apparent for long-lived species concurrently within catchment, recruits present.

Tier 4 Multiple age classes apparent for long-lived species concurrently within catchment, recruits not present.

Tier 5 No multiple age classes apparent for long-lived species concurrently within catchment.

Tier 6 No multiple age classes apparent for long-lived species within catchment over last 5 years.

Attribute VIII **Ecosystem functions**

This Tier is not utilised in the current approach. It has been retained to allow future integration of limnological data.

Tier 1 All are maintained within a range of natural variability

Tier 2 All are maintained within a range of natural variability

Tier 3 Virtually all are maintained through functionally redundant system Attributes; minimal increase in export except in high storm flows

Tier 4 Virtually all are maintained through functionally redundant system Attributes, although there is evidence of loss of efficiency (eg increased export or increased import)

Tier 5 Apparent loss of some ecosystem functions manifested as increased export or increased import of some resources and, changes in energy exchange rates (eg P/R, decomposition)

Tier 6 Most functions show extensive and persistent interruption

Attribute IX **Spatial and temporal extent of detrimental effects**

This attribute is not utilised in the current approach. It has been retained to allow future integration of limnological data.

Tier 1 Not applicable. Natural disturbance regime is maintained

Tier 2 Limited to small pockets and short durations

Tier 3 Limited to reach scale and/or limited to within a season

Tier 4 Mild detrimental effects may be detectable beyond the reach scale and may include more than one season

Tier 5 Detrimental effects extend far beyond reach scale leaving only a few islands of adequate conditions; effect extends across multiple seasons.

Tier 6 Detrimental effects may eliminate all refugia and colonisation sources within the catchment and affect multiple seasons.

Attribute X	**Ecosystem Connectance**
	This attribute is not utilised in the current approach. To be informed upon by threat mapping assessments and CAC/SAP TPC weighting values.
Tier 1	No alteration to natural state.
Tier 2	Minor impacts (fishing, external grazing pressures).
Tier 3	Moderate impacts (Tourism, feral species (terrestrial), small scale water extraction, causeways and bunds)
Tier 4	Significant impacts (Direct impacts from livestock such as pugging, nutrification, aquatic vegetation clearance as well as intrusion on natural habitats by artifical water sources)
Tier 5	Major impacts (Large scale erosion, artificially created habitats such as bore drains)
Tier 6	Severe impacts (Large scale water extraction, severe water pollution).

Appendix F

Upper-Mid Cooper BCG Assessment Example Scores

			Attribute I			Attribute II				Attribute III						Attribute IV			Attribute V		Attribute VI				Attribute VII	
Phase	Season/Year	Site	NEO COO	RET SEM	*Tier Score*	MAC AMB	BID WEL	SCO BAR	*Tier Score*	NEO HYR	POR ARG	HYP SPP	AMB MUL	MEL SPL	*Tier Score*	NEM ERE	LEI UNI	*Tier Score*	CRA EYR	*Tier Score*	CAR AUR	OXY LIN	GAM HOL	*Tier Score*	*Tier Score*	Site Score
Bust	Autumn 2008	*Cullyamurra*	.22	2.775	1	.78	.21	.15	1	9.49	.11	.72	.04	.451	1	.598	.365	1		x			.462	5	1	**1-2**
	Winter 2009	*Cullyamurra*		.116	2	.77	.63	.09	1	.91			.08	.609	1	.162	.066	1		x				3	1	**1-2**
Dispersal	Summer 2010	*Cullyamurra*			3	.11	.29		1	.85	.68	.06			1	.317	.329	1		x	.13		.313	5	1	**2**
	Worst Case Scenario (with concurrent clauses)				3				3						4			6	500	6	500	500	500	6	2	**4-5**
Boom	Autumn 2011	*Cullyamurra*			3	.63	.07	.05	1	1.31	.07	.05	1.74	1.255	1	.219	3.426	1		x	1.1		8.437	6	1	**2-3**
		Stonehenge	.03		2	.25	.09	.22	1	6.18	.85				2	.16	.528	2		x				3	1	**1-2**
		Noonbah			-	.11		.08	-	.5	1.01		.05	.15	-	.186	.204	-		-				-	-	**-**
		Retreat			-	.08	.18	.2	-	1.06	2.86	.06			-	.818	1	-		-				-	-	**-**
		Tenham			-	.75	.3	1.42	-	34.5	4.3		1.43	2.572	-	9.544	23.32	-		-	1.81			-	-	**-**
	Spring 2011	*Cullyamurra*			4				3	.18		.24			2	1.637		3		x	.04		.586	5	2	**3-4**
		Windorah bridge			4	.3		.25	1	.95	232			.197	1		1.816	6		x	2.23			4	2	**3**
		Durham Downs	1.36		2	2.53	6.04	.17	1	17.6	225				2	.773	3.389	1		x	5.08			4	1	**1-2**
		Nappapethera			x	.12	.06		1	.05	.09	.19			3	3.541	.143	1		x	.07		.114	5	2	**2-3**
		Noccundra			x			.06	2	.42	7.3	.06	1.83	2.872	1	.192	2.562	1		x	2.04		.118	5	2	**2-3**
	Autumn 2012	*Cullyamurra Rpt1*			3	.49	.45		1	.12		.63	.84	.061	1	.261		3		x	.08			4	1	**2-3**
		Cullyamurra Rpt2			3	.53	.34		1	.25		.44	3.85	.595	1	.731	.052	2		x	.04		.349	5	1	**2-3**
		Cullyamurra Rpt3			3	.14	.17		1	.08		.46	2.58	.403	1	.835		3		x	.09			4	1	**2-3**
		Cullyamurra Rpt4			3	.16	.11		1	.11		.51	.9	.054	1	.263	.147	2		x	.06			4	1	**2**
		Cullyamurra Rpt5			3	.22	.28		1	.08		.74	2.64		1	.822		3		x	.05			4	1	**2-3**
		Stonehenge	.1		2	.65	.06	.8	1	.68	.6		.03		3	1.968	.181	1		x	.03	.56		4	1	**2**
		Windorah bridge		.055	2	.2	.09	.05	1	.56	.38		.11	.207	3	.726	.162	2		x	.06			4	1	**2-3**
		Durham Downs			-	.21	.11		-	2.39	.4	.31	4.35	1.204	-	.333	1.146	-		-	.06		1.265	-		**-**
		Noccundra		.0635	-				-	1.75	6.04		.55	.187	-	.092	1.236	-		-	.1			-		**-**
		Noonbah			-	.06		.06	-	.18	.15		.19		-	.096	.063	-		-				-		**-**
		One Mile			-	.04	.03		-	.1	1.39		.3	.137	-	.214	.474	-		-	.13			-		**-**
		Retreat			-	.05		.05	-	.1					-	.046		-		-				-		**-**
	Spring 2012	*Cullyamurra*			3	.19	.06		1	.62		.33			2	.101		3		x	.06			4	1	**2-3**
		Windorah bridge		.053	2	.2	.15		1	.18	1.36		.14	.147	1	.86	.105	2		x	.03			4	1	**2**
		Retreat		.113	-	.08			-	.12	.09	.03	.06	.111	-	.259	.229	-		-				-	-	**-**
	Worst Case Scenario (with concurrent clauses)		0		4				3						4			6	500	6.00	500	500	500	6	2	**4-5**

Upper-Mid Cooper BCG Assessment Example Cont.

Phase	Season/Year	Site	Attribute I: NEO COO	Attribute I: RET SEM	Attribute I: ***Tier Score***	Attribute II: MAC AMB	Attribute II: BID WEL	Attribute II: SCO BAR	Attribute II: ***Tier Score***	Attribute III: NEO HYR	Attribute III: POR ARG	Attribute III: HYP SPP	Attribute III: AMB MUL	Attribute III: MEL SPL	Attribute III: ***Tier Score***	Attribute IV: NEM ERE	Attribute IV: LEI UNI	Attribute IV: ***Tier Score***	Attribute V: CRA EYR	Attribute V: ***Tier Score***	Attribute VI: CAR AUR	Attribute VI: OXY LIN	Attribute VI: GAM HOL	Attribute VI: ***Tier Score***	Attribute VII: ***Tier Score***	**Site Score**
Bust	Autumn 2013	*Cullyamurra*		.026	2	.15	.05		1	.03		.17			2	.074	.054	1		x				3	1	**1-2**
		Stonehenge	.06	.166	1	.21	.06		1	.26	.36		.16		3	.125	.062	2		x		.06		4	1	**2-3**
		Windorah bridge		.093	2	.57	.1		1	.84	.44				2	.495	.15	2		x				3	1	**1-2**
		Durham Downs			-	.21	.05		-	.05	.07	.07	.06	.034	-	.355		-		-	.02			-	-	-
		Noccundra			-				-	.13	.86	.14	.23	.092	-	.523	.18	-		-	.05			-	-	-
		Noonbah			-	.16		.06	-	.71	.23				-	.727		-		-				-	-	-
		One Mile			-			.23	-	1	1.82		.15	.231	-	.064	.456	-		-	.19			-	-	-
		Retreat		.26231	-	.26	.07		-	.32	.06	.06	.07		-	.085		-		-	.06			-	-	-
	Spring 2013	*Cullyamurra*		.462	1	.1	.05		1	.08		.16			2	.187		3		x				3	1	**1-2**
		Windorah bridge	.03	.276	1	.26	.08	.06	1	.76	.78		.09	.136	1	4.515	.113	1		x	.03	.1		5	1	**1-2**
		Retreat		.45196		.19	.07			.35	.14	.17				.611	.143									-
	Autumn 2014	*Cullyamurra*		.557	1	.25			2	.1		.11			2	.193	.055	1		x	.1		.067	5	1	**2**
		Stonehenge		.042	2	.15	.17	.06	1	.15	.11			.057	1	.656		3		x		.07		4	1	**2**
		Windorah bridge	.05	1.079	1	.15	.06	.06	1	.11	.06				2	.274		3		x		.1		4	1	**2**
		Durham Downs	.04		-	.17	.15	.14	-	.86	.08				-	.394		-		-				-	-	-
		Noccundra			-	.19	.03		-	.29	.16		.07		-	.535	.033	-		-				-	-	-
		Noonbah			-	.08			-	.38	.08				-	.045		-		-				-	-	-
		One Mile			-	.6		.11	-	.17	.61		.67	.252	-	.57	.062	-		-				-	-	-
		Retreat	.03	.1905	-	.09	.06		-	.16	.15	.11	.03		-	.273		-		-				-	-	-
	Spring 2014	*Cullyamurra*		.158	2	.17	.07		1	.97	.04	.16			1	.573	.075	2		x	.07		.075	5	1	**2-3**
	Worst Case Scenario (with concurrent clauses)				3				3						4			6	500	6.00	500	500	500	6	2	**4-5**

Appendix G

Lower Cooper BCG Assessment Example Attribute Scores			Attribute I			Attribute II				Attribute III						Attribute IV			Attribute V		Attribute VI				Attribute VII	
Phase	Season/Year	Site	NEO COO	RET SEM	*Tier Score*	MAC AMB	BID WEL	SCO BAR	*Tier Score*	NEO HYR	POR ARG	HYP SPP	AMB MUL	MEL SPL	*Tier Score*	NEM ERE	LEI UNI	*Tier Score*	CRA EYR	*Tier Score*	CAR AUR	OXY LIN	GAM HOL	*Tier Score*	*Tier Score*	Site Score
Dispersal	Summer 2010	*Cuttapirra Waterhole*			x	.059		.041	1					.050	2	2.224	.044	1	.098	1				2	2	1-2
		Gwydir's Crossing		.051	1	.153			2					.123	3	1.607	.088	1		1				2	1	1-2
		Lake Hope			x	.225	.132		1				.054	.197	1	.274	.239	1		1				2	2	1-2
		Killalpaninna Mission			-	.228	.231	.050	-					1.222	-	.209	.090	-		-				-	-	-
		Tilla Tilla Track Crossing			-	.466	.056	.063	-					.061	-	4.945	.130	-		-				-	-	-
		Lake Kopperamanna		.045	-	.388		.045	-					.123	-	.462	.093	-		-				-	-	-
	Worst Case Scenario (with concurrent clauses)				x				3						4			4	50	3	50	50	50	6	x	4-5
Boom	Autumn 2011	*Cuttapirra Waterhole*		.103	1	.299			2					.204	4	.267	.083	2	31.353	2			.051	4	2	2-3
		Gwydir's Crossing			x				4				.054	11.145	1	14.536	22.326	1		1			.133	4	x	2-3
		Lake Hope			1	.144	.160	.051	1	.027		.033	.097	.371	1	2.465	.117	1		1			3.309	5	2	1-2
		Killalpaninna Mission			-	.181	.071		-			.082		1.478	-	1.892	.078	-	.129	-			.129	-	-	-
		Lake Hope Inlet		.048	-	.757	.227		-			.549	2.381	31.257	-	6.336	.414	-		-			63.663	-	-	-
	Spring 2011	*Cuttapirra Waterhole*			x	.033		.067	1			.156		.267	2	2.904	.067	1	2.520	2			.200	4	2	2-3
		Gwydir's Crossing			x	.058		.059	1			.118		1.082	2	.205	.234	2	.118	1	1.517		.216	5	2	2-3
		Lake Hope			x	.024	.047		1			.206		1.214	1	.515	.048	2		1	.095		.381	5	2	2-3
		Killalpaninna Mission			-	.059			-	.035		1.083		2.100	-	1.116	.064	-	.250	-				-	-	-
		Pandruannie			-	.076			-			1.561	.087	.161	-	1.314	.220	-		-	.088		.165	-	-	-
	Autumn 2012	*Cuttapirra Waterhole*			x				4			7.144		.076	1	4.056	.057	1	19.408	2			3.578	4	x	2-3
		Gwydir's Crossing			x				4			.090	.054	.108	1	.081	.252	2	1.278	1	.324		1.351	5	x	2-3
		Lake Hope			x	.023	.082		1	.077		.801	.186	.171	1	8.669		3	.149	1			.804	4	2	2-3
		Killalpaninna Mission			-	.135	.027		-			9.785	.054	.216	-	6.812		-	9.641	-			2.852	-	-	-
		Lake Hope Inlet			-				-			.936	.851	.353	-	37.607		-	.049	-			1.253	-	-	-
		Red Lake		.098	-	.029			-			9.711	.121		-	1.621		-	.754	-	.058		.135	-	-	-
		Lake Kopperamanna			-	.029			-			.686		.058	-	3.133		-	.754	-			4.812	-	-	-
	Spring 2012	Lake Hope			x	1.113	.111	.074	1			.171			4	.114	.012	2	.033	1				3	2	2-3
	Worst Case Scenario (with concurrent clauses)				x				5						4			4	50	2	50	50	50	6	x	4-5
Bust	Autumn 2013	*Lake Hope*		.078	1				x			.206	.059		1	.912	.235	1	3.046	1				3	x	1-2
		Killalpaninna Mission			-				-			.452	.071		-	.719		-	1.053	-				-	-	-
	Spring 2013	*Killalpaninna Mission*		.350	-	.087			-			1.017				2.081			3.608				.050	-	-	-
	Autumn 2014	*Lake Hope*			x			.069	1						x	9.607		2	165.531	1	.069			4	x	2-3
		Killalpaninna Mission			-	.046			-			2.795			-	12.093		-	7.029	-			.062	-	-	-
	Spring 2014	*Lake Hope*			x				x						x	.942		2	69.022	1				3	x	2-3
		Killalpaninna Mission			-	.194			-			.281			-	.376		-	.466	-				-	-	-
	Worst Case Scenario (with concurrent clauses)				x				x						x			3		3	50	50	50	6	x	4-5

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