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COMMONWEALTH ENVIRONMENTAL WATER OFFICE LONG TERM INTERVENTION MONITORING PROJECT: LOWER LACHLAN RIVER SYSTEM 2016-17 ANNUAL REPORT

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Commonwealth Environmental Water Office
Long Term Intervention Monitoring Project
Lower Lachlan River system 2017 Annual Report

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Front cover photos: Booligal ibis colony Photo by Mitchell Lyons, UNSW.

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ACRONYMS AND ABBREVIATIONS

Accepted Acronym	Standard Term (capitalisation as specified)
ANAE	Australian National Aquatic Ecosystem
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CPUE	Catch per unit effort
ER	Ecosystem Respiration
EWA	Environmental water allowance
GS	General Security
GPP	Gross Primary Production
HS	High Security
IMEF	Integrated Monitoring of Environmental Flows
LLS	Local Land Services
LTIM Project	Long Term Intervention Monitoring Project
MDBA	Murray-Darling Basin Authority
M&E	Monitoring and Evaluation
MDMS	Monitoring Data Management System
SOP	Standard Operating Procedure
QA/QC	Quality assurance / quality control
WQA	Water quality allowance

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Two environmental watering actions comprising a total of 38 313 ML of Commonwealth (29 492 ML) and NSW (8 821 ML) water were delivered to the Lachlan River system in the 2016-17 water year. The Commonwealth contribution to the watering actions consisted of:

1) 28 168 ML to the mid Lachlan River targeting improvements in dissolved oxygen levels and provision of in-channel refuge. This action targeted the mid Lachlan between Wyangala Dam and Lake Cargelligo and was not expected to produce significant water quality benefits in the in the lower Lachlan river system.
2) 1324 ML to Merrimajeel Creek targeting the Booligal Wetlands to support water levels at the second bird breeding colony.

An additional 15 000 ML of water from the Water Quality Allowance was contributed to the first watering action and 350 000 ML of translucent flows were contributed to the Lower Lachlan river system under the Lachlan Regulated River Water Sharing Plan.

This was the third of a five year program established to answer specific questions about ecological responses to environmental watering in the Lower Lachlan river system. The three years of monitoring have seen vastly different climate conditions and environmental water delivery. In the first year of monitoring (2014-15) conditions were dry and a small watering action was delivered to achieve modest environmental outcomes. Data collected from 2014-15 essentially forms the baseline for the monitoring program. In 2015-16, a greater availability of water enabled the delivery of three watering actions designed to achieve a broad suite of environmental outcomes. These were accompanied by translucent flows which raised water levels in the main channel and inundated a number of wetlands. In 2016-17, widespread flooding across the Lachlan river system meant that Commonwealth environmental water use was limited and focussed on the protection of vulnerable populations.

Stream flow (hydrology), stream metabolism and water quality (temperature, pH, dissolved oxygen, turbidity, conductivity, concentrations of nitrogen and phosphorus), fish (including larval fish), waterbirds and the condition and diversity of vegetation were monitored to evaluate the outcomes of Commonwealth environmental watering actions. Monitoring effort was largely focussed on the reach between Lake Brewster and Hillston. The exceptions were the monitoring of vegetation which occurred at sites across the Lower Lachlan river system and monitoring of waterbirds which occurred in the Booligal wetlands. The green text in **bold** in this section of the report are recommendations for consideration in future years of water use in the Lachlan river system.

The two watering actions delivered in 2016-17 were designed to modify aspects of the flow regime to support vulnerable populations. The first action aimed to improve dissolved oxygen concentrations and provide in-channel refuge from poor water quality in the mid – Lachlan (between Wyangala Dam and Lake Cargelligo). Under natural conditions, the flood in the Lachlan River would have receded slowly with water from upstream of Wyangala Dam maintaining or improving dissolved oxygen levels in the river. The capture of water in Wyangala Dam following flood operations disconnected the upstream sections of the river posing a risk for downstream water quality. The first watering action sought to mitigate this risk. The volumes of environmental water contributed to the first watering action were small, but they provided a significant contribution to flow in the river at the time. The mid-Lachlan is not monitored as part of the LTIM program but monitoring by NSW OEH indicates a positive outcome for water quality in the mid-Lachlan from Watering Action 1.

Significant improvements in water quality in the Lower Lachlan river system were not expected from Watering Action 1. The arrival of this watering action at the LTIM monitoring sites in early December coincided with a slight increase in dissolved oxygen concentrations, but this was not accompanied by a response in any other monitored water quality parameters. It also coincided with the natural recovery in dissolved oxygen concentrations in the river following the flood. While it is possible that the increase in dissolved oxygen concentrations was the result of Commonwealth environmental water, the evidence is not strong and the main benefit from this watering action was the mid Lachlan (the target reach).

The widespread flooding in 2016-17 had a significant effect on the riverine fish community. There was a substantial increase in the number of carp caught in 2017 compared with the previous years of monitoring and a reduction in the numbers of large bodied native fish species such as Murray cod and golden perch. The increase in carp was not surprising; carp are known to respond favourably to flooding as the inundation of floodplains provides them with good spawning opportunities. Murray cod and golden perch are known to be susceptible to poor water quality and the very low dissolved oxygen concentrations that were observed in the river are likely to have resulted in the loss of significant numbers of fish, particularly Murray cod. The provision of Commonwealth environmental water is unlikely to have made much difference to these fish in the Lower Lachlan river system. At the time of delivery dissolved oxygen concentrations had been dangerously low for several weeks which is sufficient time to have killed fish. The presence of some Murray cod and golden perch in the river in early 2017 indicates that some water quality refuges must have been available during the flood event.

Native carp gudgeon are the only native species that appears to have responded favourably to the flooding with a large increase in numbers observed in the monitoring. Carp gudgeons are a small bodied opportunistic species that respond well to flooding.

Carp were the only larval fish captured in the monitoring program this year and in contrast to previous years, no native fish larvae were captured between October and December. The low dissolved oxygen is considered to the main reason for this. Larval fish are particularly susceptible to low dissolved oxygen concentrations. There was evidence of spawning of some small bodied native fish, with young of year of Australian smelt, bony herring, carp gudgeon and flatheaded gudgeon captured in the adult fish monitoring. These will provide the food resources that will support the large bodied native fish recovery following the flood.

The overall condition of the fish community, calculated using three indices (Nativeness, Expectedness and Recruitment) remains ‘very poor’ in 2017 with slight improvements in the Recruitment index, a significant drop in the Nativeness index and no change to the Expectedness Index.

The second watering action involved a combination of infrastructure management, the re-routing of water from the first watering action as well as the delivery of water to keep water levels stable within a late bird breeding colony (the Blockbank colony) in Booligal wetlands.

This bird breeding colony had established at the end of the flood when water levels in the wetlands were beginning to drop, tributary inflows had slowed and releases from Wyangala Dam had ceased. In the absence of the provision of environmental water and the management of the infrastructure, it is expected that water levels in the bird breeding colony at the Blockbank would have dropped quite rapidly from mid-January causing widespread abandonment of nests and providing opportunities for predation of nests. The management of water at the Blockbank colony ensured that water levels in the colony remained stable at an optimal depth (0.6 – 0.7 m) for waterbird breeding. Thus Commonwealth environmental water was a major contributor to the success of the breeding event in the Blockbank colony.

Commonwealth environmental water was not used to achieve outcomes for vegetation in 2016-17, with widespread flooding providing a natural event that inundated wetlands, effluent creeks and floodplains. Flooding provided a unique opportunity to document the response of the vegetation and contributes to our understanding of floodplain and wetland vegetation dynamics in the region. The flooding produced a distinct response in the vegetation as it peaked and receded. Water depth (and duration) defined the response of the vegetation during flooding and helps to explain the vegetation characteristics at some sites. Where water depths were greater than 0.4 m for long periods of time (such as the low lying areas in the middle of wetlands and in the channel sections of channel mound wetlands) no vegetation persisted. These are the locations where few species have been observed in the past. Where water depths were less than 0.4 m (such as the top of banks, mounds and wetland margins), there was a substantial response in the vegetation community with a large number of water dependent species observed. These are the locations that have been dominated by terrestrial vegetation in the past but retain a seedbank of water dependent species.

In the Lower Lachlan river system, the three years of monitoring (2014-15 to 2016-17) have seen vastly different climate conditions and environmental water delivery. In 2016-17, greater resource availability enabled the delivery of three watering actions designed to achieve a broader suite of outcomes. 2016-17 also saw the release of translucent flows which contributed significant volumes of water to the catchment, but made the attribution of responses to Commonwealth environmental water difficult. In 2016-17, widespread flooding meant that environmental water was used to achieve benefit by modifying the existing flow regime to protect vulnerable populations. In combination, these three years indicate the value of a long term monitoring program and start to build an understanding of the way in which this system responds to different flow conditions.

The 2016-17 monitoring and evaluation provides information that can be used to guide the future management of environmental water in the Lower Lachlan river system. The key findings were:

- In 2016-17 the Lower Lachlan river system was in flood. This meant that the approach to delivering Commonwealth environmental water changed from the traditional approach of adding missing elements of the hydrological regime to achieve environmental outcomes. Instead the management of Commonwealth water was in response to conditions in the river and the ecological responses observed. The aim was to capitalise on the natural flood event and protect vulnerable ecosystem attributes from the effects of a flood under highly managed conditions. This meant that environmental water was used to modify the outcome of the operation of Wyangala Dam once flood operations ceased. The positive outcomes achieved with the management of environmental water in 2016-17 provide evidence of the success of this approach when the system is in flood.

- While the benefits of the first watering action for dissolved oxygen concentrations in the monitored reach are not clear, the improvements in the target reach (mid Lachlan) mean that the provision of environmental water to manage dissolved oxygen on the receding limb of natural flow events, particularly where they occur in summer, is a valid management option with potential benefits.
- The provision of water to support the Blockbank waterbird colony was successful in achieving the goals of supporting a breeding event. Commonwealth environmental water contributed to the completion of nesting (prevented abandonment due to falling water levels), and provided suitable habitat in which chicks could be raised and successfully fledged. This 'event' demonstrates the value of cleverly managing water within the constraints of the system with a long lead time for delivering water. The combination of managing infrastructure, redirecting environmental water and delivering water generated successful outcomes.
- **The management of environmental water for the Blockbank waterbird colony demonstrated the value of tailoring observations to the conditions within the catchment.** The establishment of the second colony was observed during a reconnaissance plane flight taken to gain an understanding of the extent of the flooding. Without this flight, the colony may have remained undetected for sufficient time that the water levels would have dropped and the colony put at risk.
- There are logistical challenges to the responsive style of environmental water management that affect the capacity for closing the adaptive management loop and institutional learning. These include:
    - The standard processes for documenting objectives for the watering actions (Water Use minutes) does not fit the rapid and responsive style of water management. While the approach adopted is agile and effective, **better documentation of the actions, rationale and water use would facilitate future evaluation and learning**.
    - Watering actions that are targeted to one reach and then 'reused' in other parts of the river means that traditional accounting approaches to recording water use do not accurately reflect the outcomes. **The use of a single parcel of water for multiple benefits is an efficient and effective use of environmental water. Mechanisms for better documenting the water use would contribute to future evaluation and learning.**
- One of the challenges with delivering water to improve dissolved oxygen concentrations is that typically by the time dissolved oxygen concentrations drop below 4 mg/L, it is too late to respond to achieve a benefit for fish. In the mid Lachlan, early warning of the poor water quality was hampered by a paucity of data (and particularly a paucity of continuous data) that could be used to trigger a response. In the lower Lachlan, the LTIM loggers were collecting the relevant data, but were inaccessible because of the floodwaters**. It would be valuable to have water quality monitoring equipment in the reach from Wyangala Dam to Lake Brewster to inform water management decisions. Ideally this would use existing**

gauging infrastructure in the Lachlan catchment. Gauges should be fitted with dissolved oxygen loggers, as they are in other New South Wales catchments such as the Edward-Wakool and Murrumbidgee systems, accessible in real time.

- The current LTIM program for the Lower Lachlan river system only monitors the river system below Lake Brewster. This means we do not have data to evaluate watering actions upstream. The fish community between Wyangala Dam and Lake Brewster is in much better condition and has a greater probability of responding to environmental water than the reach downstream of Lake Brewster (Sam Davis, DPI Fisheries pers comm.). Thus the response observed downstream of Lake Brewster is unlikely to be representative of the upstream reaches. The watering action delivered was targeted at the mid-Lachlan River system below Wyangala Dam. Past watering actions have also targeted this reach. **Future monitoring programs should consider monitoring the target reach (Wyangala to Lake Brewster) so that the outcomes might better be evaluated**.
- The monitoring of the vegetation response to the flooding combined with the previous years of monitoring provides information about what might be expected at sites in response to the provision of environmental water. Vegetation at sites that are periodically inundated to more than 0.4 m have not responded to flooding nor to environmental water other than to grow floating plants such as azolla or duck week. **This indicates that perhaps these sites should not be expected to produce a groundcover vegetation response with the provision of environmental water. These sites include Moon swamp, the channel sections within Lake Bullogal, Lake Tarwong, The Ville and Hazelwood Billabong. These open water sites without vegetation may be functionally important in the landscape and the objectives for environmental water at these sites need to be considered in the context of a range of wetland habitats.**
- There was a marked response in groundcover vegetation at sites that are periodically inundated to <0.4 m. Some of these sites require large volumes of water to inundate and will only ever receive water from natural flooding. This includes the black box communities at Lake Tarwong and Lake Ita, the redgum floodplain woodland at The Ville, Whealbah Billabong and Lake Marrool, and the mounds in Lake Bullogal and Lake Tarwong. The volume of environmental water available is not sufficient to get water over these sites, which means that environmental water cannot be used to generate a response by the groundcover vegetation. **It is possible to get environmental water *near* to these sites which is likely to result in a response from the floodplain and riparian trees.**
- A few of the sites that are periodically inundated to <0.4 m and showed a marked response in groundcover vegetation to flooding are able to be watered with environmental water. These include sites within the Booligal wetlands in Booligal National Park and Tom's Lake. **The challenge at these sites is to identify the duration of flooding and frequency of flooding required to support the vegetation community. Ongoing data collection as part of the monitoring program will start to address this challenge but it would also benefit from some modelling of natural flows within these systems to better understand the frequency and duration of inundation.**

- Hypoxic floodwater looks to have prevented reproduction of large bodied native species in the selected area in 2016, particularly Murray cod, which have been the most numerically dominant larval fish species present in previous years. **The lack of spawning of large bodied native fish in 2016 and the drop in numbers of large bodied native fish in 2017 means that the recovery of these species should be a priority for upcoming watering actions.**
- No larval or young of year golden perch were detected in the Lachlan River again this year. Thus there is a need to develop a greater understanding of the golden perch populations that exist in the Lachlan. **It is important to understand the role of stocking and the relative contribution to the population from wild fish. Until such site specific understanding is gained, watering actions should be informed by the conditions under which spawning did not occur.**
- If the Lachlan catchment has the potential for an increase in Murray Cod recruitment in the year following a flood (as has been previously observed in other catchments – see King et al. (2007) and Thiem et al. (2017)), **the planned use of environmental water in the Lachlan catchment during 2017-18 may want to target flows that support Murray cod spawning and recruitment to the best extent possible.**
- In contrast to the outcomes for native fish, the widespread watering of all floodplain and wetland sites in 2016-17 has had benefits for vegetation within the catchment. **The long duration of flooding in some locations (the wetlands of the lower part of the Selected Area still held significant amounts of water in June 2017) has started to stress some of the lower lying vegetation and a drying phase is required before environmental water should be delivered to these locations. This means that the vegetation in the catchment should not be a primary target for watering in 2017-18.**
- **To try avoid adding to further increases in local carp populations, the planned use of environmental water in the Lachlan catchment during 2017-18 may, depending other environmental needs identified, want to target:**
    - **in-channel habitat rather than floodplain, wetland and lake habitats (preferred spawning habitat for carp)**
    - **delivery to floodplain and wetland habitats during winter when temperatures are less than 16°C and less likely to contribute to carp recruitment** (following Koehn et al. 2016a, b).
- Natural flow variability is the dominant driver of patterns of water quality and stream metabolism in the Lachlan River, but environmental water can generate smaller, but ecologically meaningful responses. **The effects of environmental water are likely to be more important in dryer years (e.g. 2014-15), where carbon has accumulated on banks and in flood runners.** In relatively wet years, such as occurred in 2016-17, metabolism responses to environmental flows are likely to be small relative to natural variability.
- The experiences of waterbird breeding in the Lachlan catchment in 2015-16 and 2016-17 highlight the importance of regional weather patterns, and the value of extensive flooding to provide foraging areas and habitat for food resources to thrive in a successful breeding event. **The strategy of using Commonwealth environmental water to support breeding events once they have established (rather than trying to trigger a breeding event) is therefore sound.** The management of the Blockbank

water levels in 2016-17 demonstrates the value of this approach and the successful outcome can be attributed to the use of Commonwealth (and NSW) environmental water.

- The observations of vegetation response provide information about the vegetation community during wet periods in the Lower Lachlan river system. Watering history did not appear to be a significant determinant of the response of the vegetation, suggesting that the flood response is not something that can be influenced by watering actions. However, this conclusion is limited by a lack of replication for some of the watering histories. **It is recommended that future monitoring of vegetation in the region should aim to include more sites, and particularly sites that are likely to be more frequently watered.** Recent data sets, such as the OEH inundation data and the data collected as part of this program, provides a stronger platform for the selection of future monitoring sites.

1 INTRODUCTION

The floods that occurred in 2016-17 completely dominated the Lower Lachlan river system during the 2016-17 watering season. Widespread flooding resulted in the inundation of most of the wetlands across the catchment, many of which were filled for extended periods of time. This meant that the approach to delivering Commonwealth environmental water changed from the traditional approach of adding missing elements of the hydrological regime to achieve environmental outcomes. Instead the management of Commonwealth water was in response to conditions in the river and the natural ecological responses observed within the catchment. The aim was to firstly capitalise on the natural flood event to augment ecological outcomes and secondly to protect vulnerable ecosystem attributes from the adverse effects of a flood.

Two environmental watering actions comprising a total of 38 313 ML of Commonwealth (29 492 ML) and NSW (8,821 ML) water were delivered to the Lachlan River system in the 2016-17 water year. The Commonwealth environmental watering actions included:

3) 28 168 ML to the mid Lachlan River targeting improvements in dissolved oxygen levels and provision of in-channel refuge. This action targeted the mid Lachlan between Wyangala Dam and Lake Cargelligo and was not expected to produce significant water quality benefits in the in the lower Lachlan river system.
4) 1,324 ML to Merrimajeel Creek targeting the Booligal Wetlands to support water levels at the second bird breeding colony.

The first watering action was augmented by 5,250 ML of NSW held water and a further 15 000 ML of water from the Water Quality Allowance (WQA). The WQA is defined within the Water Sharing Plan for the Lachlan Regulated River (see Water Management Act 2000 2016) and is an annual volume of water set aside to manage poor water quality[1].

The second watering action was augmented by a redirection of 1,064 ML of water from the first watering action and 3,571 ML of water from Environmental Water Allowance (EWA) The EWA is defined within the Water Sharing Plan for the Lachlan Regulated River (Water Management Act 2000 2016) and is an annual volume of water set aside to support waterbird breeding, fish breeding and passage, wetland watering or to increase flow variability.

The Long-Term Intervention Monitoring Project (LTIM Project) is the primary means by which the Commonwealth Environmental Water Office (CEWO) undertakes monitoring and evaluation of the ecological outcomes of Commonwealth environmental watering. Monitoring activities implemented within the LTIM Project to evaluate the outcomes of Commonwealth environmental watering actions in the Lower Lachlan river system in 2016-17 included the monitoring of stream flows (hydrology), stream metabolism and water quality (dissolved oxygen, temperature, pH, electrical conductivity, turbidity and nutrients), fish (including larval fish), waterbirds and vegetation condition and diversity.

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[1] For more details on the WQA see part 6, Division 1 Clause 28 of the Water Sharing Plan: (https://www.legislation.nsw.gov.au/#/view/regulation/2016/365/part6/div1/sec28)

This is the third year of a five year monitoring program with 2016-17 watering actions completely overwhelmed by a natural event which flooded a large proportion of the Lower Lachlan river system. This report documents the monitoring and evaluation of the ecological responses observed within the Lower Lachlan river system. It describes the context in which water was delivered, the environmental objectives of the watering actions, the monitoring activities undertaken and evaluates the outcomes of the watering actions. These are presented in separate sections (Sections 3 to 6) of the report. The results of the monitoring and evaluation are used to inform future management of watering actions (Section 7). Technical reports covering each of the monitoring activities are provided as appendices (Sections 8 to 14). The analysis and interpretation of indicator data draws on data from the three years of monitoring as well as field observations.

2 LOWER LACHLAN RIVER SYSTEM – SELECTED AREA

The area of the Lower Lachlan river system (referred to as the Selected Area) identified as the focus for the LTIM Project is the western end of the Lachlan River, and extends from the outlet of Lake Brewster to the Great Cumbung Swamp (Figure 1). It encompasses anabranches, flood runners, billabongs and terminal wetlands, such as Merrowie Creek, Booligal Wetlands and Lachlan Swamp but excludes Middle Creek and other creeks to the north. The river system is complex, with a diversity of in-channel and floodplain features that provide a variety of habitats for the species in the region. Flows and water levels are naturally variable and unpredictable providing temporally complex habitats.

The Lachlan River catchment supports many flora and fauna listed as vulnerable or endangered under federal or NSW state legislation, including the Sloane's froglet, Australian painted snipe, osprey, blue-billed duck and the fishing bat. The Selected Area comprises the majority of the Lachlan River endangered ecological community. In addition, the Great Cumbung Swamp is one of the most important waterbird breeding areas in eastern Australia, and supports one of the largest remaining stands of river red gums in NSW.

Like many rivers of the Murray Darling basin, flow regulation in the Lachlan river catchment has had a significant effect on the average annual flow as well as inter-annual and seasonal variability (Driver et al. 2004). This is believed to have been a key driver in a deterioration of the freshwater ecosystems within the catchment. The Lower Lachlan river system has previously been assessed as being in poor ecosystem health as part of the Murray-Darling Basin Authority's Sustainable Rivers Audit (SRA) (Murray-Darling Basin Authority 2012) (Davies et al. 2008). This assessment was primarily due to having an extremely poor native fish community (with low native species richness and poor recruitment) and poor hydrological condition. Macroinvertebrate communities were assessed as being in moderate condition whereas the physical form of the river and the vegetation were assessed as being in poor to moderate condition, respectively.

The millennium drought (2001-2009) resulted in large areas of river red gums becoming stressed, and in wetlands, vegetation became dominated by terrestrial, drought tolerant species (Thurtell et al. 2011). Some recovery of the wetlands and rivers has been observed since 2010, attributed to natural flow events and environmental watering actions.

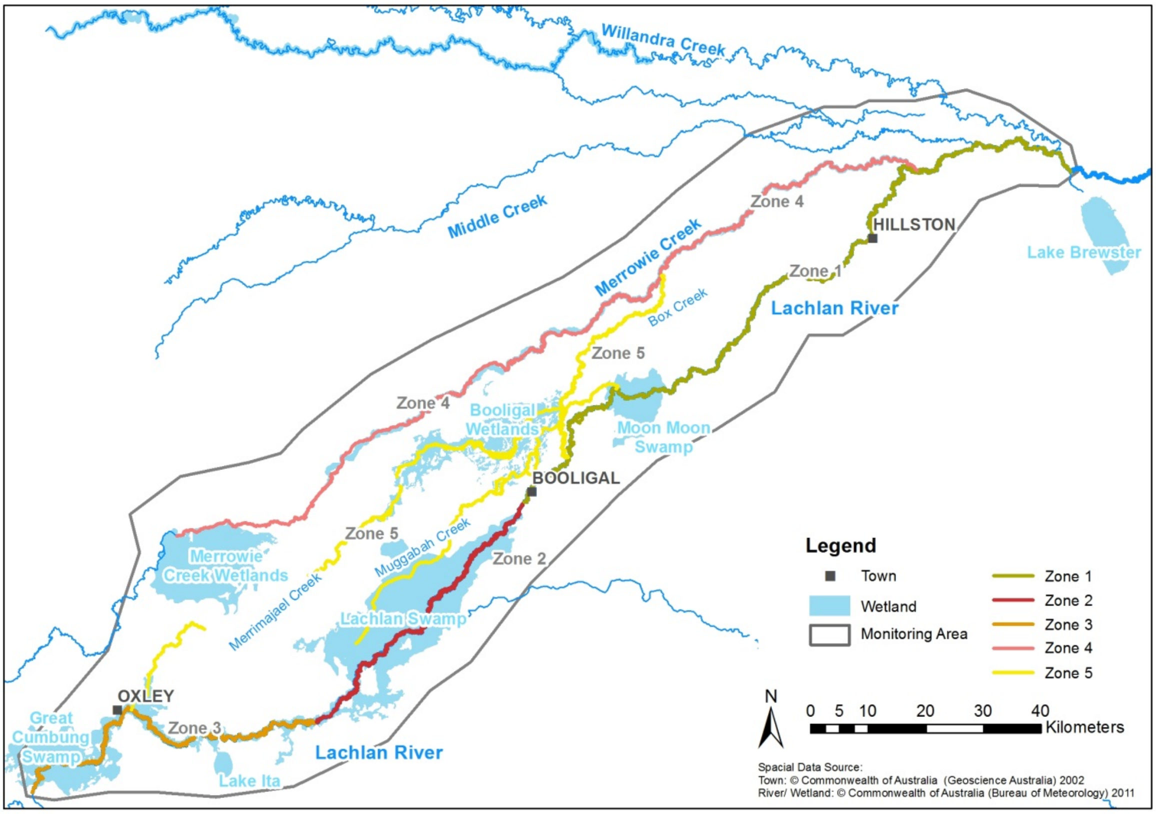

Figure 1. The Lower Lachlan river system showing the region for the LTIM Project.

3 COMMONWEALTH ENVIRONMENTAL WATERING ACTIONS 2016-17

3.1 CLIMATE AND WATER CONTEXT

Environmental watering actions are determined by a combination of catchment and climate conditions as well as the volume of water holdings. The condition of the catchment also provides context for evaluating ecosystem responses to watering.

3.1.1 CATCHMENT AND CLIMATE CONDITIONS

The Lower Lachlan river system experiences alternating periods of wet and dry conditions (Figure 2) and the influence of upland catchment conditions on river flows and inundation extent are time-lagged and complex. The ending of the Millennium Drought was associated with a series of short, sharp flood peaks in 2010 and were followed by floods in 2012 and 2016 that were progressively more prolonged with greater peak discharge (Figure 2).

In 2012 there were multiple peaks in the Lachlan River over a period of 8 months, starting with significant catchment-wide rainfall which resulted in localised flooding and filling of floodplain wetlands and depressions. This was followed by whole of system flooding, dam spills, translucent releases following floods, and overbank flows. The Lachlan Catchment then entered a relatively drier phase with cumulative inflows into Wyangala Dam from July 2014 to June 2016 tracking close to the assessed total inflows under 'dry' (80% inflow exceedance) conditions (Figure 3). The exception was in mid-2015 when reasonable rainfall across the catchment resulted in higher river flows and an increase in Wyangala Dam storage level in September 2015, but led to little in the way of floodplain inundation and wetland filling.

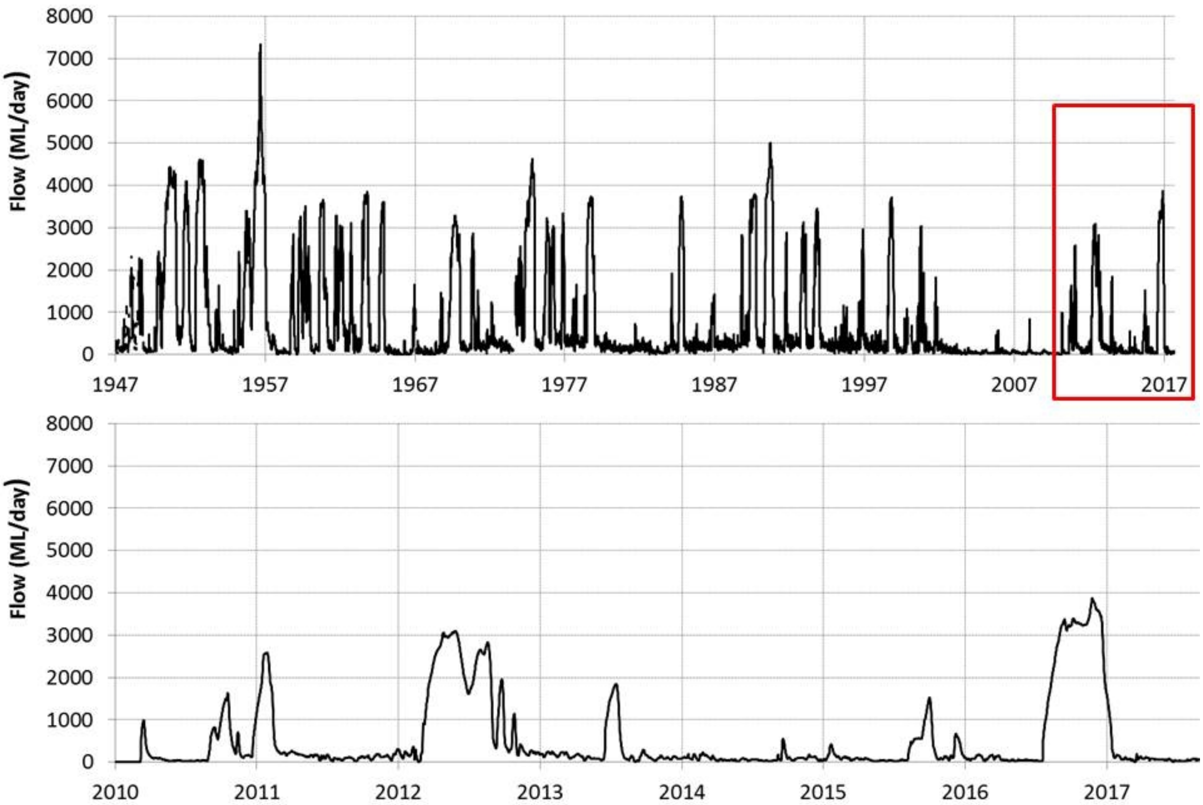

Figure 2. Hydrographs for the Lachlan River at Booligal illustrating the variability in flow in the river the characteristics of the last three floods which started with heavy rainfall in the Upper Lachlan Catchment in December 2012, March 2012 and June 2016.
The long term continuous flow record is shown at the top, the period from 2000 to present is shown in the bottom left and the period from 2011 to present is show in the bottom right. Note that the delivery of Commonwealth environmental water past Booligal is constrained to 800 ML/day by the CEWO's good neighbour policy.

The start of 2016 was very dry across the Murray Darling Basin which lead to Basin wide watering priorities being established for a dry to very dry resource availability scenario (Murray Darling Basin Authority 2016) (BWS 2016-17). The start of 2016 in the Lachlan river system matched this pattern with average to below average rainfall between February and April (Figure 4). This dry period was followed by record breaking winter/spring rainfall across the catchments. Large rainfall events in the upper Lachlan catchment lead to rapid filling of Wyangala Dam between June and September 2016.

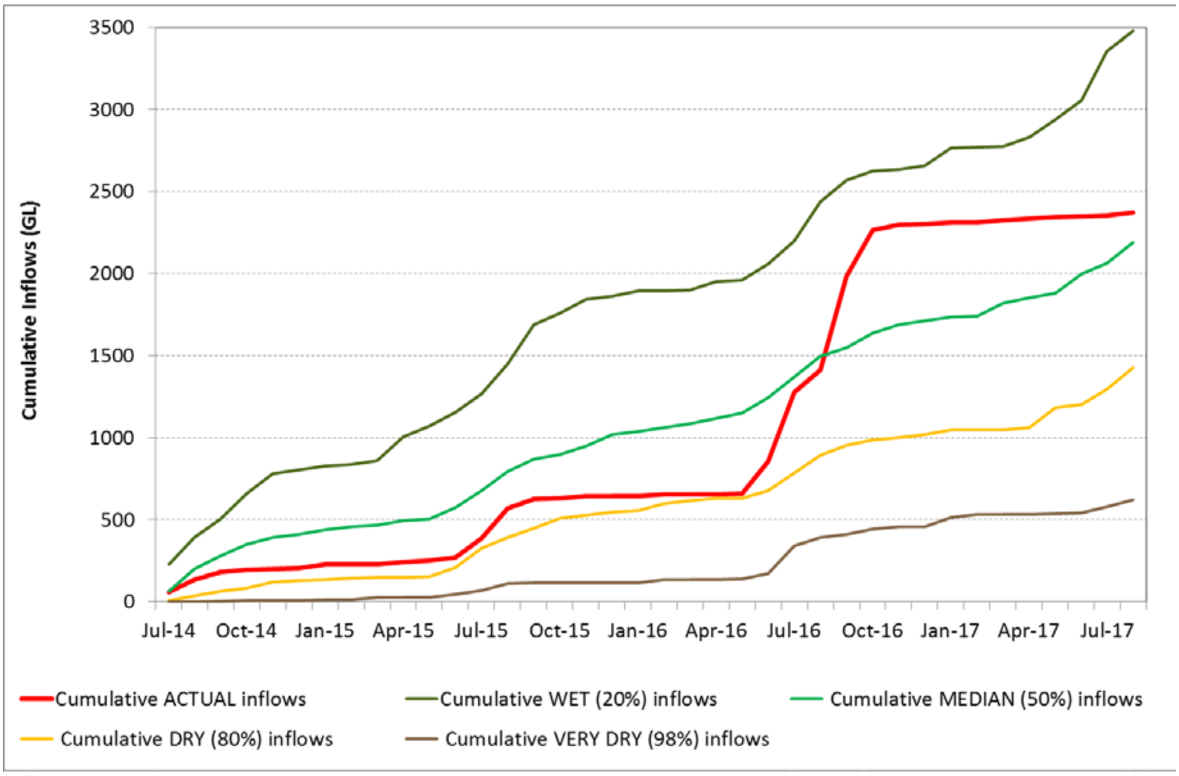

Figure 3 Inflow statistics for Wyangala Dam from July 2014 to June 2017. Data provided by Water NSW.

Rainfall and subsequent inflows into Wyangala Dam triggered the translucency rule at the dam in early July, and airspace operations started 2 August when the dam was at 90%. Airspace releases occurred concurrently with translucency throughout most of August, keeping Wyangala Dam levels between 90 and 95%. Translucent releases ceased at Wyangala Dam by the end of August after reaching the Water Sharing Plan (WSP) limit of 350 000 ML at Willandra Weir.

A series of significant rain events in September and October on top of a very wet catchment resulted in airspace management and flood operations through much of September and October. The subsequent total surplus past Willandra Weir was 1 796 096 ML in addition to above average localised rainfall. These conditions contributed to rarely encountered areas of floodplain inundation and wetland filling, and the running of ephemeral creeks and flood runners for extraordinarily long periods of time (3 to 6 months). For example, 192 000 ML ran through the Merrowie Creek system filling Lake Tarwong and then interconnecting with Box Creek to reach Chillichil Swamp. Box Creek also connected laterally and longitudinally to contribute to flows in Merrimajeel Creek. In 2012, flows past Booligal were greater than the commence to fill/flow (CTF) for the Lower Lachlan Swamps for 120 days and ‘wet’ Lake Waljeers, Peppermint Swamp, Lake Bullogal, Ryans Lake, Lake Ita and Baconian Swamp. In 2016, those Lower Lachlan Swamp wetlands filled and spilled, and flooding extent is likely to differ somewhat due to the longer duration of 171 days of flows greater than CTF for Lower Lachlan Swamps. Cabbage Garden Creek, which starts to run around minor flood level at Hillston, reached the Cobb Highway and Mirrool Creek provided significant, but ungauged, flows into the Lower Lachlan Swamps. The Lachlan and Murrumbidgee rivers were also effectively connected for around 6 months (July 2016 to January 2017) as the Murrumbidgee was also in flood.

Flood peaks and floodplain return persisted into late November and early December in the Lower Lachlan (below Lake Brewster to Oxley) as flood waters progressed downstream and rainfall continued (particularly during December).Rainfall in the Lower Lachlan River catchment was below average over summer, and reflected a return to dry conditions. However, wetland areas did not dry out and in some areas, retained significant inundation through summer into Winter 2017.

Figure 4. Monthly rainfall at Hillston Airport (075032, top) and Booligal (075007, bottom) during 2016 compared with the mean and median rainfall for the entire period of record.
Graphs sourced from Climate Data Online, Bureau of Meteorology.

Temperatures followed normal seasonal patterns (Figure 5), but were below average during the very wet Spring 2016 (September and October). Average temperatures going into summer (November and December 2016) along with the extended inundation (4–6 months) and rainfall in December prevented the catchment from 'browning-off' or drying out too quickly over summer. However, below average rainfall over January to March and above average temperatures saw a sharp return to dry resource scenario for the first half of 2017.

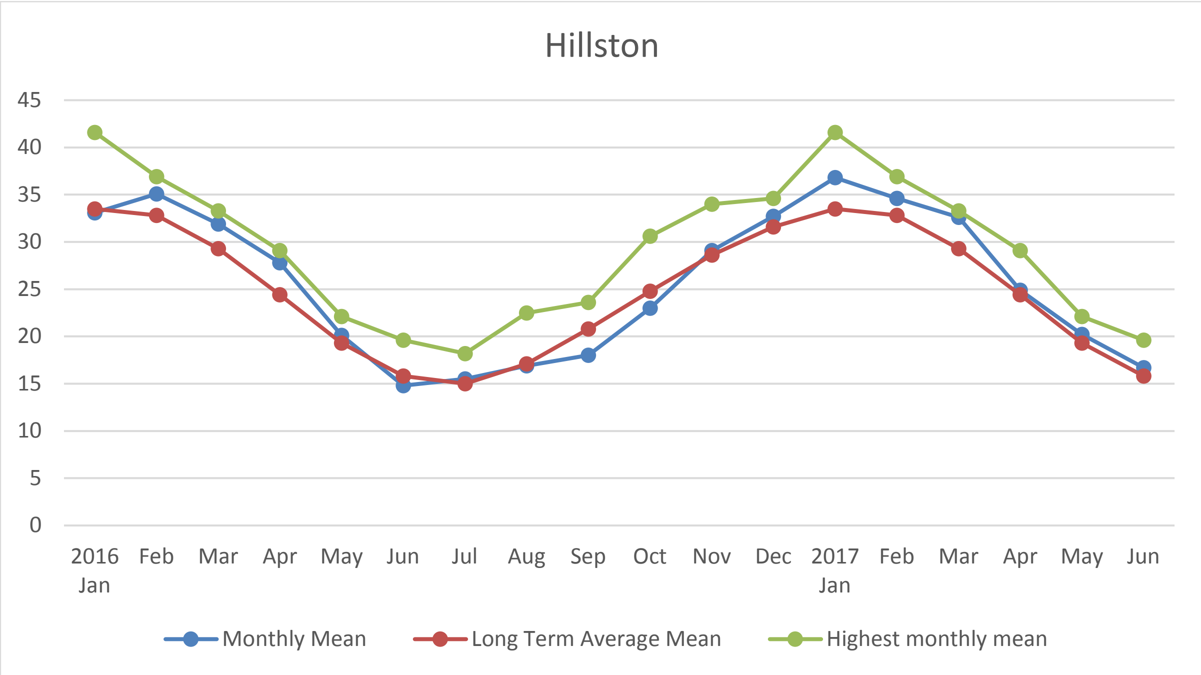

Figure 5 Monthly mean for Hillston compared to the long term average and highest monthly temperature on record.

3.1.2 ENVIRONMENTAL WATER HOLDINGS

Environmental water has been allocated to the Lachlan River since 1992 (from NSW) and more recently the river system has received Commonwealth environmental water. Thus, environmental water for the Lachlan River comprises both Commonwealth government holdings of water entitlements (Commonwealth environmental water) and NSW government-held licensed environmental water (NSW environmental water holdings). At the beginning of the 2016-17 water year, the Commonwealth government held a total of almost 40 400 ML (Table 1).

Table 1. Environmental water holdings in the Lachlan River Valley as at 1 July 2016.

	WATER HOLDINGS (ML) BY ENTITLEMENT TYPE		
WATER HOLDER	HIGH SECURITY	GENERAL SECURITY	TOTAL
CEWH	933	39 462	**40 395**
NSW	1,795	36 569	**38 364**
TOTAL	**2,728**	**76 031**	**78 759**

3.2 WATERING ACTIONS AND THEIR OBJECTIVES

3.2.1 PLANNED WATER USE

Basin-wide planning for 2016-17 watering (BWS 2016) was conducted in anticipation of dry conditions and priorities were established for low to moderate resource availability. Thus environmental watering was prioritised to ensure environmental assets maintain their basic functions and resilience by:

- supporting the survival and viability of threatened species and communities
- maintaining environmental assets and ecosystem functions, including by allowing drying to occur consistent with natural wetting-drying cycles
- maintaining refuges.

The context in which the 2016-17 environmental watering actions were delivered was one in which the river system was in flood. Consequently, the planning for watering actions evolved to focus on 1) augmenting the natural flood outcomes and 2) protecting vulnerable populations by modifying the existing flow regimes. Actions planned would therefore support broader objectives of maintaining ecological health and resilience by capitalising on natural events.

3.2.2 IMPLEMENTED WATERING ACTIONS

The total environmental water delivery to the Lower Lachlan river system in 2016-17 was 38 313 ML and was made up of 29 492 ML of Commonwealth environmental water and 8 821 ML of NSW held water. Commonwealth and NSW environmental water was delivered in two watering actions:

1) 28 168 ML of Commonwealth environmental water and 5,250 ML of NSW held water to the mid Lachlan River targeting improvements in dissolved oxygen levels and provision of in-channel refuge. This action targeted the mid Lachlan between Wyangala Dam and Lake Cargelligo and was not expected to produce significant water quality benefits in the in the lower Lachlan river system.
2) 1,324 ML of Commonwealth environmental water to Merrimajeel Creek targeting the Booligal Wetlands to support water levels at for colonial nesting waterbirds. This action was supported by 1,064 ML of water redirected from Watering Action 1.

The watering actions were delivered to the Lachlan river system between the 4th November 2016 and the 17th March 2017 and involved a combination of releases from Wyangala Dam (Watering Action 1) and the management of water levels in the Booligal wetlands by redirecting flow and managing infrastructure (Watering Action 2). Details of the actions are provided in Section 8.3.

3.2.3 OTHER ENVIRONMENTAL WATER IN THE LOWER LACHLAN RIVER SYSTEM

The first watering action was augmented 15 000 ML of water from the Water Quality Allowance (WQA). The WQA is defined within the Water Sharing Plan for the Lachlan Regulated River (Water Management Act 2000 2016) and is an annual volume of water set aside to manage poor water quality[2].

The second watering action was augmented by 3,571 ML of water from Environmental Water Allowance (EWA) The EWA is defined within the Water Sharing Plan for the Lachlan Regulated River (Water Management Act 2000 2016) and is an annual volume of water set aside to support waterbird breeding, fish breeding and passage, wetland watering or to increase flow variability.

The high inflows to Wyangala Dam in June and July triggered the delivery of translucent releases from the dam in early July, as required under the Lachlan Regulated River Water Sharing Plan. The continuing high inflows meant that translucent releases continued until the end of August when the maximum translucent release (350 000 ML at Willandra Weir) allowed under the Water Sharing Plan was reached. The translucent release was delivered concurrently with airspace operation.

[2] For more details on the WQA see part 6, Division 1 Clause 28 of the Water Sharing Plan: (https://www.legislation.nsw.gov.au/#/view/regulation/2016/365/part6/div1/sec28)

Table 2. The 2016-17 Commonwealth environmental watering actions.

DESCRIPTION	DETAILS	
Action	1	3
Target Asset	Mid Lachlan River, main channel	Booligal Wetlands
Reference	WUM10053	WUM10053
Accounting Location	Lachlan River at Forbes (Cotton's Weir)	Merrimajeel
Flow component	Fresh flow	Fresh flow
Volume (CEW)	28 168	1,324
Volume (NSW)	5,250	
EWA[1]		3,571
WQA[2]	15 000	
Total Volume (ML)	48 418	4,895
Re-use (CEW)		1,064 (re-used from Watering Action 1)
Primary Objective	Provide improvements in dissolved oxygen levels and in-channel refuge.	Support habitat requirements for waterbirds, native fish and other water-dependent vertebrates.
Secondary Objective	Water quality is improved; native fish and other aquatic animals have opportunities to move from the floodplain to the river channel minimising stranding; and in-channel refuges are maintained.	Waterbird breeding in Booligal Wetlands is maintained through a suitable flow regime.
Basin Annual watering priorities 2016-17	Not linked to any 2016-17 Basin-wide Annual watering priorities as none were applicable.	Under moderate water availability, capitalise on opportunities to support waterbird breeding.

[1] Environmental Water Allowance [2]Water Quality Allowance

4 EVALUATION OF WATERING ACTIONS

The 2016-17 watering actions targeted the main channel of the mid-Lachlan River and the Booligal wetlands. The aims (Table 2) were to provide improvements in dissolved oxygen levels and in-channel refuge, and support habitat requirements for waterbirds, native fish and other water dependent vertebrates.

4.1 EVALUATION APPROACH

The LTIM Project has two levels of evaluation:

1) Basin evaluation which is conducted across seven catchments (known as Selected Areas) in the Murray Darling Basin. This evaluates the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's Environmental Watering Plan (MDBA EWP); and
2) Selected Area which evaluates ecological outcomes of Commonwealth environmental watering at each of seven Selected Areas individually.

Basin evaluation is being led by Monitoring and Evaluation (M&E) Advisors and is designed to address a set of specific evaluation questions which are described in Gawne et al. (2014). Selected Area evaluation is being led by M&E Providers. Evaluating outcomes at both scales involves monitoring a set of ecosystem attributes (e.g. vegetation condition), the response of which demonstrates the achievement (or otherwise) of an outcome. These attributes are known as indicators. While monitoring programs (and the indicators used) should be designed to be specific to each evaluation scale, in the Lower Lachlan river system, Basin evaluation needs have been prioritised and define the majority of the monitoring effort. To avoid designing parallel monitoring programs, the majority of the indicators used to evaluate ecological outcomes within the Selected Area of the Lower Lachlan river system are the same as used in the Basin evaluation.

The indicators that are monitored to inform both Basin and Selected Area evaluation for the Lower Lachlan river system Selected Area are:

- Fish (river).
- Fish (larvae).
- Stream metabolism.
- Vegetation condition and diversity.
- Hydrology (river).

Decapods and turtles (which are likely to be by-catch from riverine fish monitoring) are reported specifically for the Selected Area. In 2016-17 optional monitoring of waterbird breeding was implemented at the request of the CEWO.

This evaluation assesses the achievements of Commonwealth environmental watering in relation to outcomes expected for the lower Lachlan river system Selected Area. The evaluation is in two parts. The first addresses the specific objectives of the watering actions (primary and secondary objectives Table 2) and the second addresses specific evaluation questions defined in (Dyer et al. 2014) and summarised in Table 3.

One challenge for the evaluation arises in 2016-17: the target reach (the mid-Lachlan) for the first watering action is upstream of the Selected Area in which monitoring activities are undertaken. This means there are limited data to evaluate the outcomes of this watering action and it is outside the scope of the contracted monitoring and evaluation activities to address this watering action. However, where possible, some comments are provided around the outcomes of this watering action and it is tracked through the river system to investigate responses within the Selected Area.

Table 3. Lower Lachlan river system Selected Area evaluation question and indicators. Questions have been defined as short or long term evaluation questions.

THEME	EVALUATION QUESTIONS	SHORT- /LONG-TERM	INDICATORS
Vegetation	What did Commonwealth environmental water contribute to vegetation community diversity?	Short / Long	Vegetation diversity Hydrology (river and wetland)
	What did Commonwealth environmental water contribute to vegetation species diversity?	Short / Long	
	What did Commonwealth environmental water contribute to populations of long-lived organisms?	Long	Tree community and extent Hydrology (river)
	What did Commonwealth environmental water contribute to condition of floodplain and riparian trees?	Short	
	What did Commonwealth environmental water contribute to vegetation condition and reproduction?	Short	
Fish	What did Commonwealth environmental water contribute to fish community resilience and condition?	Long	Fish (species, abundance and size frequency in rivers) Hydrology (river) Water quality (temperature and dissolved oxygen)
	What did Commonwealth environmental water contribute to native fish abundance and diversity?	Long	
	What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan River catchment?	Long	
	What did Commonwealth environmental water contribute to native fish survival?	Short	
	What did Commonwealth environmental water contribute to native fish reproduction?	Short	
	What did Commonwealth environmental water contribute to native fish abundance?	Short	
	What did Commonwealth environmental water contribute to native fish recruitment?	Short	
	What did Commonwealth environmental water contribute to maintenance of drought refugia for native fish?	Short	
	What did Commonwealth environmental water contribute to native larval fish growth and survival?	Short	
	What did Commonwealth environmental water contribute to fish community resilience?	Short	
Waterbirds (Option)	What did Commonwealth environmental water contribute to waterbird populations?	Long	Waterbirds – breeding (colonial nesting species) Hydrology (wetlands) Vegetation type and condition
	What did Commonwealth environmental water contribute to waterbird chick fledging?	Short	
	What did Commonwealth environmental water contribute to waterbird survival?	Short	
	What did Commonwealth environmental water contribute to waterbird breeding?	Short	
Stream Metabolism	What did Commonwealth environmental water contribute to patterns and rates of primary productivity?	Short / Long	Stream metabolism Hydrology (river)
	What did Commonwealth environmental water contribute to patterns and rates of decomposition?	Short Long	
Other Vertebrates (Option)	What did Commonwealth environmental water contribute to other vertebrate populations?	Long	Frogs Turtles (species and abundance) Decapods (species and abundance) Hydrology (river)
	What did Commonwealth environmental water contribute to other vertebrate species diversity?	Long	
	What did Commonwealth environmental water contribute to other vertebrate reproduction and recruitment?	Short	
	What did Commonwealth environmental water contribute to other vertebrate survival?	Short	
	What did Commonwealth environmental water contribute to refuges?	Short / Long	
Hydrology	What did Commonwealth environmental water contribute to hydrological connectivity?	Short / Long	Hydrology (river)
	What did Commonwealth environmental water contribute to sediment transport?	Long	
	What did Commonwealth environmental water contribute to biotic dispersal?	Long	

4.2 MONITORING SITES & 2016-17 MONITORING ACTIVITIES

The Lower Lachlan river system is partitioned into five zones on the basis of geomorphic and hydrologic characteristics (Table 4). These zones are used to define the monitoring of outcomes for fish, stream metabolism and water quality. These indicators are only monitored in Zone 1. Zone 1 is chosen as it is the zone most likely to receive Commonwealth environmental water during the LTIM Project, and is most likely to produce a detectable response.

The vegetation communities are not clearly delineated on the basis of the zones in the Lower Lachlan river system, and the vegetation monitoring occurs across the entire Selected Area and not just a single zone.

The breeding of birds in 2016-17 triggered the need to monitor waterbirds in Zone 5. The monitoring sites (Figure 7) and timing of monitoring were specific to the indicators being monitored. Details of sites and timing of sampling are given in Dyer et al., 2014.

Table 4. Zones for the Lower Lachlan river system Selected Area relevant to fish and stream metabolism indicators.

ZONE	LOCATION	CHARACTER
Zone 1	Lachlan River channel between Brewster Weir and Booligal	This zone contains relatively high abundances of the required target species of fish (with potentially limited numbers of freshwater catfish). Situated in the upper reaches of the Selected Area, this zone is likely to receive Commonwealth environmental water every year of the LTIM Project.
Zone 2	Lachlan River channel between Booligal and Corrong	Located downstream of Booligal Weir. Similar to Zone 1 in geomorphology. This zone differs hydrologically because of water diversion and extraction above Booligal Weir.
Zone 3	Lachlan River channel between Corrong and its terminus in the Great Cumbung Swamp	This zone starts at the point at which the mid-Lachlan wetland system re-enters (drains into) the main Lachlan channel, providing an increase in riverine productivity, stimulating food webs. The fish assemblages are currently dominated by alien species.
Zone 4	Merrowie Creek	A distributary creek that receives intermittent regulated stock and domestic flows as well as targeted environmental flows at Tarwong Lake and Cuba Dam. No data exist on the fish assemblage present within Merrowie Creek.
Zone 5	Torriganny, Box, Merrimajeel and Muggabah Creek system	The largely ephemeral, effluent streams of the Merrimajeel and Muggabah system north of the Lachlan main channel and Merrowie creek. This complex system is fundamentally different to main channel zones acting more like linear wetlands that are likely to only retain water for limited periods, during and following environmental flow deliveries or deliveries for stock and domestic purposes.

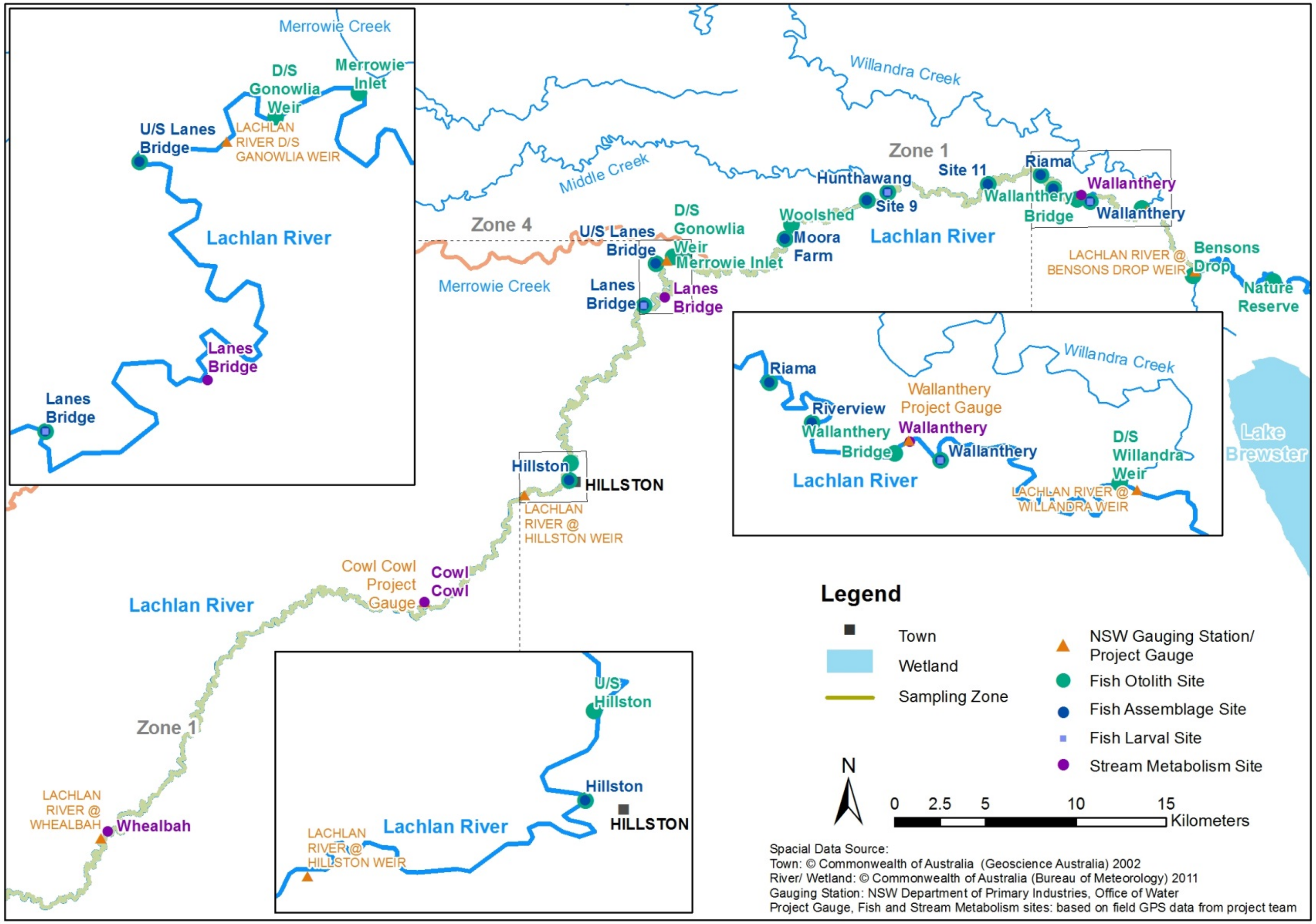

Figure 6. Map of monitoring sites for fish and stream metabolism in Zone 1.

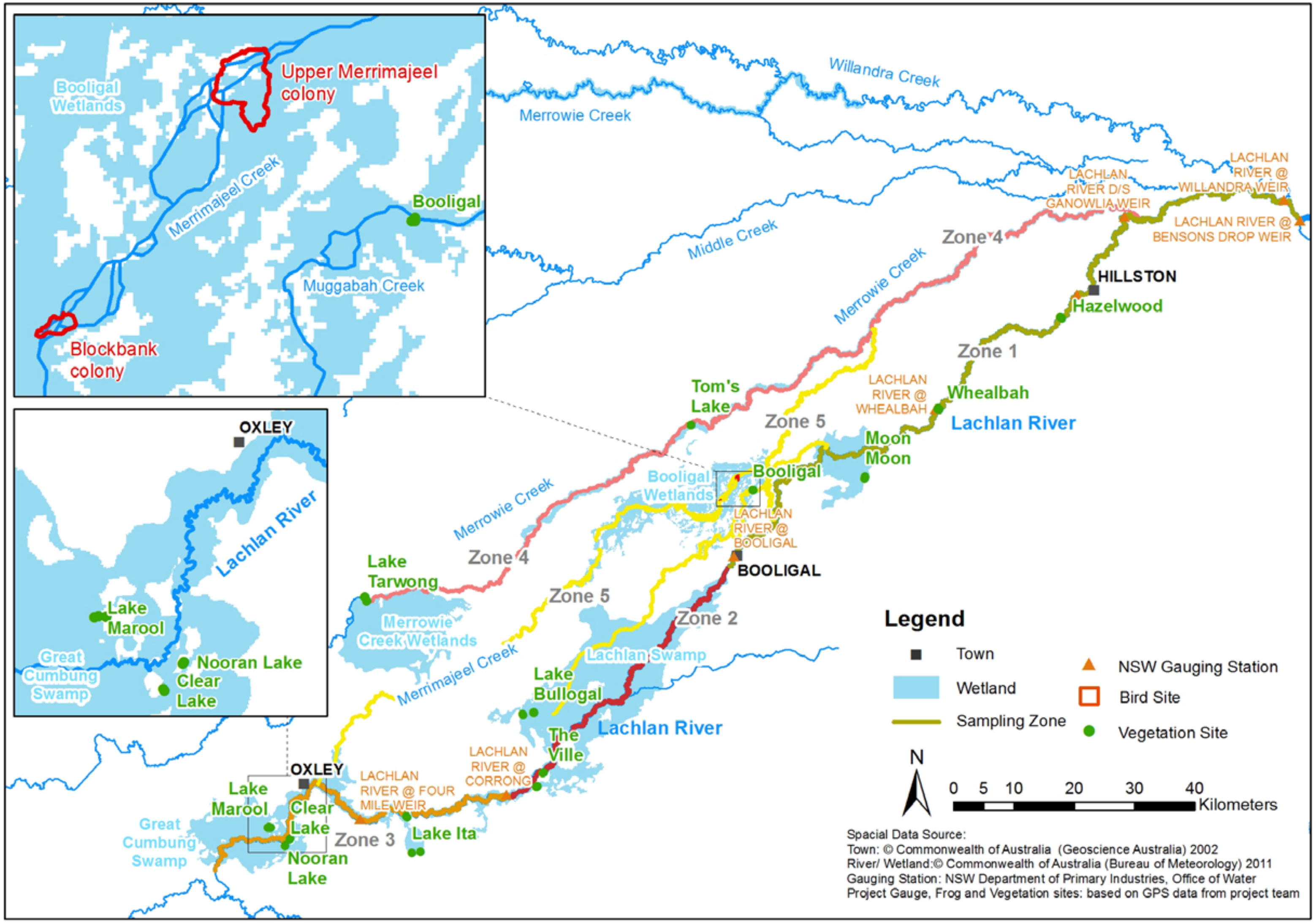

Figure 7. Map of monitoring sites for vegetation and waterbirds in the Selected Area.

4.3 HYDROLOGY

The environmental water delivery to the Lower Lachlan river system in 2016-17 was made up of 29 492 ML of Commonwealth environmental water, 5,250 ML of NSW held water, 3,571 of Environmental Water Allowance (EWA) and 15 000 ML of Water Quality Allowance (WQA). A further 350 000 ML of translucent flows were delivered under the Lachlan Regulated River Water Sharing Plan making a total of 403 313 ML of environmental water delivered to the Lower Lachlan river system. Commonwealth environmental water contributed approximately 2% of the flow in the river in 2016-17 (based on the flow at Willandra Weir which was 1 659 486 ML for the period 1 July 2016 to 30 June 2017). While the volume of Commonwealth environmental water was a very small proportion of the annual flow in the river, it was strategically delivered to modify the flow regime and at the time of delivery, comprised a significant proportion of the flow in the river.

A combination of flow data, river height data, wetland inundation information and observations were used to determine the contribution of Commonwealth environmental water to waterbird habitat and hydrological connectivity. In doing so, two evaluation questions were addressed.

What did Commonwealth environmental water contribute to habitat for native fish, waterbirds, and other water dependent vertebrate species? (Action specific question)

The second watering action delivered in 2016-17 aimed to maintain water levels (thus providing good quality breeding habitat) for the bird breeding colony which had established in late December adjacent the Blockbank in Booligal wetlands. This watering action delivered water to the wetlands and, in combination with the operation of the Blockbank, extended the duration that water levels were above 0.7 m by around 4 months (Figure 8). Without the delivery of environmental water and active management of regulating structures, water levels would have dropped below 0.7 m in mid-January. This would have reduced the suitable habitat for the birds, increased the vulnerability of the colony to predation and caused abandonment of the nests.

What did Commonwealth environmental water contribute to hydrological connectivity? (Selected area question)

The natural flood which dominated the Lower Lachlan river system in 2016-17 resulted in widespread lateral and longitudinal connectivity producing significant inundation of wetlands, anabranches and effluent channels. Thus at an annual scale, the two watering actions delivered in 2016-17 were volumetrically insignificant, but at the time of delivery they provided an important contribution to water at the target sites. Both actions provided small freshes of water for water quality (Watering Action 1) and bird breeding outcomes (Watering Action 2). The first watering action was used to attenuate the adverse effects of a flood passing through Lake Cowal and delivering low dissolved oxygen water to the river. Under natural conditions, the flood in the Lower Lachlan system would have receded slowly with water from upstream of Wyangala Dam maintaining or improving dissolved oxygen levels in the river. The capture of water in Wyangala Dam following flood operations essentially shut off the upstream sections of the river posing a risk for downstream water quality. The volumes of environmental water contributed to modifying the first watering action were small, but they were a significant contribution to flow in the river at the time and delivered positive outcomes for water quality. The second watering action which combined the active management the Blockbank as well as the delivery of water, maintained water levels within the bird breeding colony in Booligal wetlands for 4 months, thus providing the lateral connectivity needed to support bird breeding outcomes (see Section 4.6).

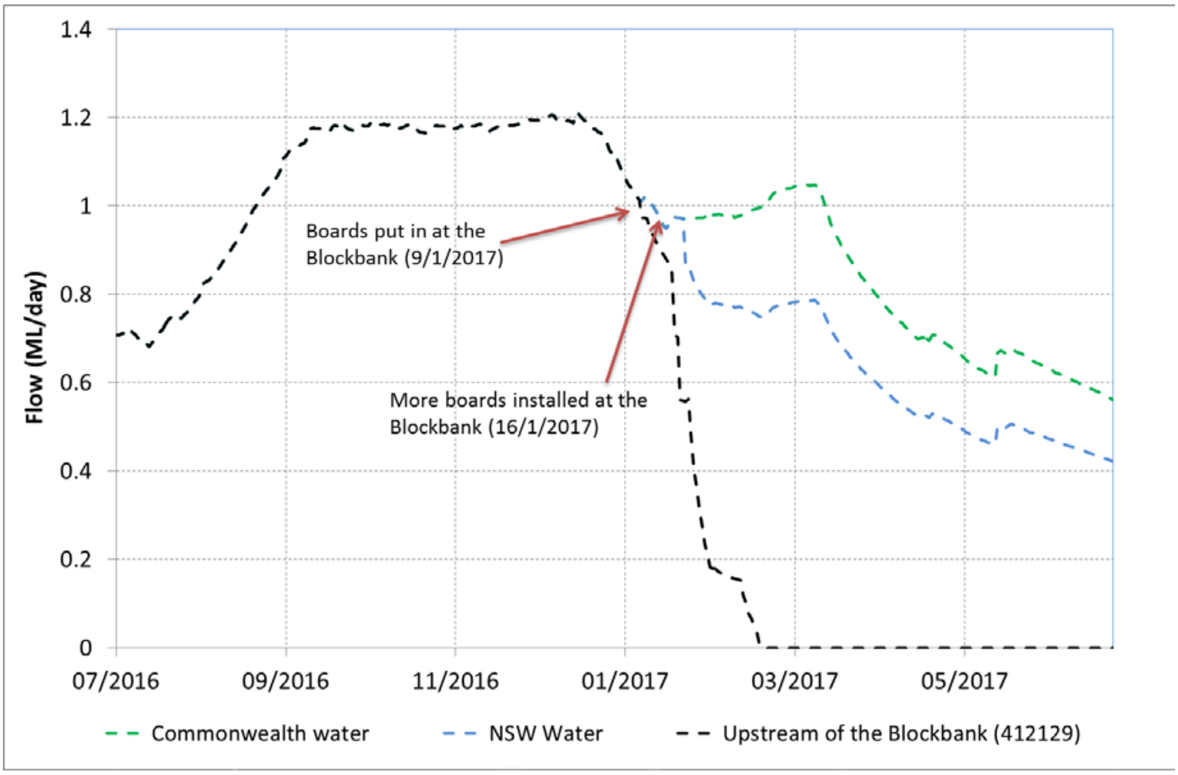

Figure 8. Water level data from the gauge upstream of the Blockbank (412129) showing estimated contributions to water levels from Commonwealth (green) and NSW (blue) environmental water. Estimated water level without environmental water is shown in black. Operational notes are also provided.

4.4 STREAM METABOLISM AND WATER QUALITY

The energetic base of food webs in freshwater systems is provided either by primary production (the energy fixed by photosynthesis occurring in plants and algae) or by breakdown of organic matter such as leaves, wood and organic carbon dissolved in the water. Those processes are both influenced by the availability of key nutrients, particularly nitrogen and phosphorus, and water temperature and light. Primary production (referred to as gross primary production, GPP) and organic matter processing or decomposition (known as ecosystem respiration, ER) can be measured through continuous monitoring of changes in the concentration of oxygen in the water (described as measurements of open channel stream metabolism).

The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream. Natural flooding, which is most often larger in spatial scale than environmental flows can also mobilise excess carbon and nutrients through floodplain inundation, and in situations where water temperatures are high, can generate hypoxic blackwater. Hypoxic black water events typically occur when the breakdown of high concentrations of dissolved organic carbon in the water column causes low dissolved oxygen concentrations. Blackwater can have substantive negative effects on aquatic fauna and may require use of environmental flows to dilute low oxygen water and protect biota.

In 2016-17, the widespread flooding in the Lachlan river system resulted in concerns about the possibility of a hypoxic blackwater event. Observations of very low concentrations of dissolved oxygen (<2mg/L) being contributed to the river from Lake Cowal and the cessation of flood operations from Wyangala Dam resulted in Watering Action 1 being delivered to provide water quality refuges in the mid Lachlan river. It was not expected to produce significant water quality benefits in the Lower Lachlan river system.

The second watering action delivered to the Booligal Wetlands to support habitat requirements for waterbirds did not have an explicit stream metabolism or water quality targets. However, increased GPP in the main stem of the river system could conceivably increase secondary production and support waterbirds foraging from the Booligal Wetland.

Water quality parameters (dissolved oxygen, temperature, pH, turbidity, conductivity, concentrations of nitrogen and phosphorus) were recorded using a combination of automatic loggers and manual point measurements at four riverine sites (Figure 6) between May 2016 and May 2017. The flooding resulted in the loss of data and/or equipment from three of these sites, but sufficient data were available to address three evaluation questions.

What did Commonwealth environmental water contribute to water quality refuge? (Action specific question)

Unfortunately, there are no LTIM monitoring activities in the mid-Lachlan and Watering Action 1 was only monitored by the LTIM program as it reached the Selected Area.

There was a notable drop in dissolved oxygen concentrations in the river as the flood event passed the monitoring sites with concentrations dropping below 4 mg/L in October 2016 and remaining low into December 2016 (Figure 9). Concentrations below 4mg/L are known to be stressful for fish and below 2 mg/L is known to cause fish kills. The arrival of water from Watering Action 1 is expected to have occurred at the LTIM monitoring sites in early December. This coincided with an increase in dissolved oxygen concentrations, so it is possible that there was some beneficial effect of the watering action for dissolved oxygen. There was a drop in dissolved oxygen concentrations around the time when the watering actions is likely to have stopped, and this was also correlated with an increase in water temperatures. There were no obvious effects of this watering action on other water quality parameters (see Section). It appears that there was a slight improvement in the dissolved oxygen concentrations with the arrival of the environmental water, but the lack of response in other water quality parameters (including GPP and ER) combined with the 30 days travel time between Wyangala Dam and the monitoring sites which is likely to have mixed the water well, means that the evidence is not strong.

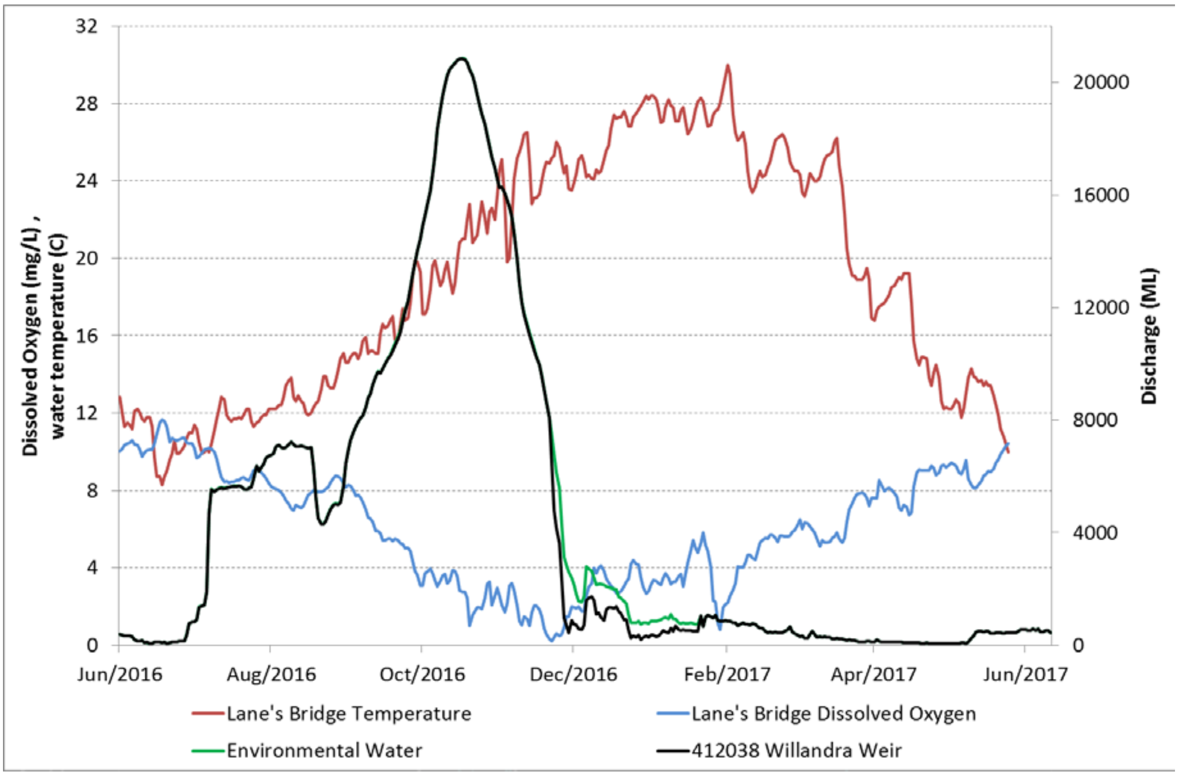

Figure 9. Dissolved oxygen and temperature recorded at Lane's Bridge and flow at the gauge upstream of Willandra Weir (412038).
The combination of Commonwealth and NSW environmental water is shown in green along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in black.

While the water quality outcomes of Watering Action 1 for the Selected Area are not clear, monitoring from other programs showed significant improvements in dissolved oxygen concentrations in the mid-Lachlan (NSW OEH unpublished data). Thus the watering action can be considered to have been an effective use of Commonwealth environmental water.

What did Commonwealth environmental water contribute to patterns and rates of decomposition (ER) and primary productivity (GPP)?

The flood event was associated with increased primary production, with rates higher than in previous years. Ecosystem respiration seems to be more responsive to flow than gross primary production, and this appears likely to be associated with organic matter mobilisation and processing. There was little evidence of any effect of either watering action on GPP or ER which is not surprising given the magnitude of the flood event which will have dominated the movement and processing of carbon in the system.

4.5 FISH

Watering Action 1 aimed to provide improvements in dissolved oxygen levels and in channel refuge for fish in the mid Lachlan, as well as provide opportunities for native fish to move from the floodplain to the river channel minimising stranding (Table 2). The primary objective of providing in-channel water quality refuge for native fish as the flood receded was targeted at the reach immediately downstream of Wyangala Dam which is not monitored as part of this program.

4.5.1 FISH COMMUNITY

Fish community data were collected from 10 in-channel sites in Zone 1 (Figure 6) during March 2017 using a combination of electrofishing, trapping and netting techniques. A total of 9,216 fish comprising seven native and three alien species were captured across all of the sampling sites. The most abundant species were common carp (*Cyprinus carpio*), bony herring (*Nematolosa erebi*), eastern gambusia (*Gambusia holbrooki*), carp gudgeon (*Hypseleotris* spp.), golden perch (*Macquaria ambigua*) and goldfish (*Carassius auratus*) (Figure 10). The fish species making the greatest contribution to total biomass (total weight of fish) in 2017 were common carp, golden perch, Murray cod (*Macullochella peelii*) and bony herring.

The fish community data provides information about the effect of the floods on the fish community and enables three evaluation questions to be addressed.

The same seven native species of fish were captured in 2016-17 and 2015-16 (Figure 10), suggesting a consistency of the native fish community. Freshwater catfish (*Tandanus tandanus*) were again not captured in 2017 despite sampling for this species. Neither Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) or silver perch (*Bidyanus bidyanus*), presumed to have been historically common in lowland sections of the Lachlan Basin, were detected. Consistent with previous results, four native fish species (flathead galaxias - *Galaxias rostratus*, olive perchlet - *Ambassis agassizii*, southern purple spotted gudgeon - *Mogurnda adspersa* and southern pygmy perch - *Nannocarpa australis)* which were historically present, were not detected in 2017. Of these, olive perchlet is the only species to have been recently detected near Lake Brewster. Despite the absence of a number of native species, the native species richness in the sampled reach of the Lachlan Selected Area is generally higher than in other parts of the Lower Lachlan River system.

There was a substantial increase in the abundance and biomass of carp caught in 2017 compared with 2016 and 2015 (3970% increase in abundance in 2017, 498% increase in biomass in 2017). This increase was not surprising as carp are known to respond positively to flooding and the widespread flooding will have provided good conditions for carp. In contrast, there was a reduction in the abundance and biomass of large long-lived species such as golden perch and Murray cod. These native species are particularly susceptible to poor water quality conditions. Dissolved oxygen concentrations in the river were sufficiently low during the peak and recession of the flood to be of significant concern for native fish (Figure 9). While widespread fish kills were not reported, it is likely that the low oxygen concentrations are the reasons for the low numbers of Murray cod in particular. The small remnant population of Murray cod are likely to provide the basis for the recovery of this species in the Lower Lachlan river system over the coming years.

One native species appears to have responded positively to the flooding, with native carp gudgeon numbers increasing notably. Native carp gudgeon are a small bodied opportunistic species likely to respond well to flooding.

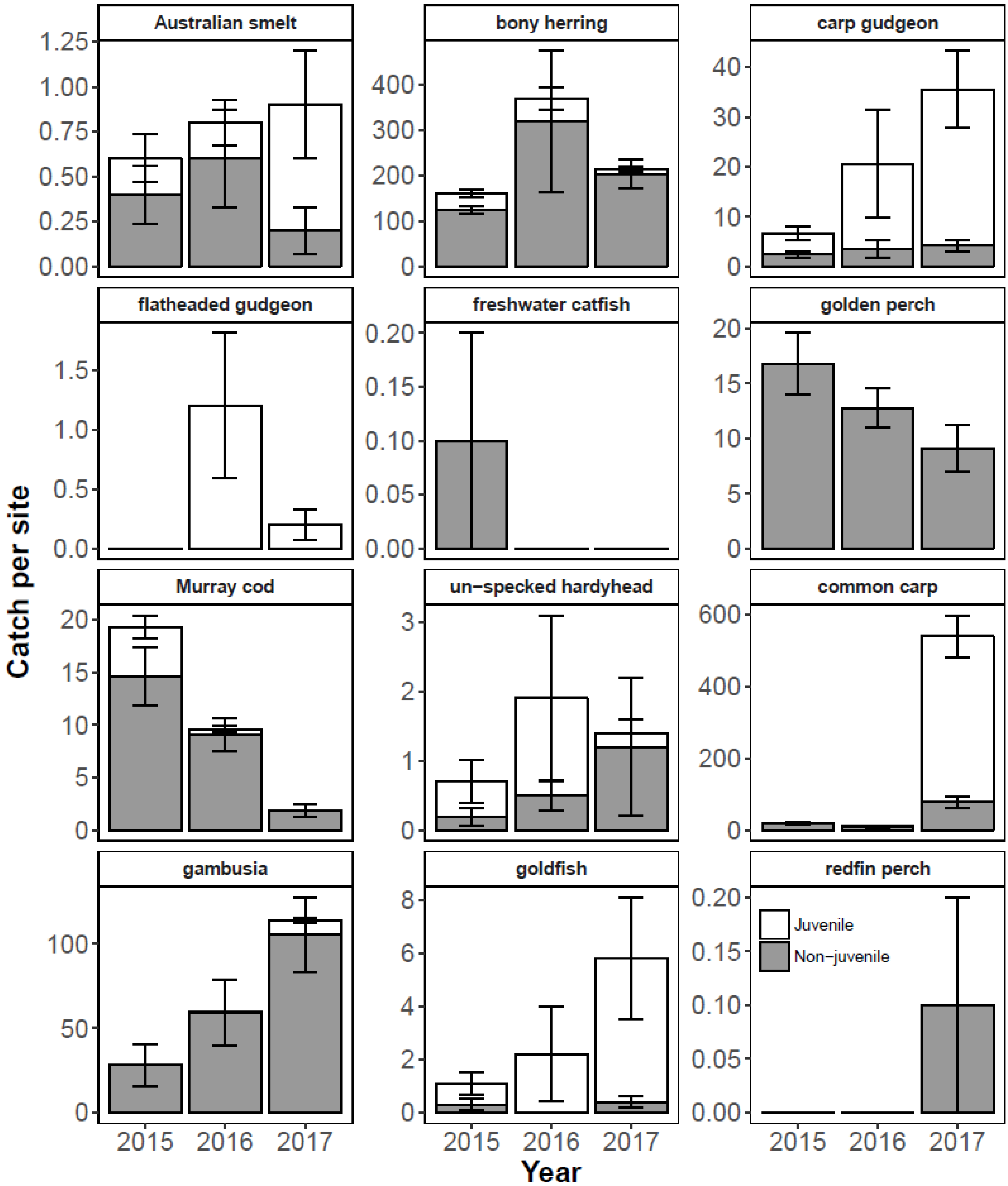

Figure 10. Catch per site (number of fish; mean ± SE) of each fish species within the Lower Lachlan river system target reach sampled in 2015, 2016 and 2017.

What did Commonwealth environmental water contribute to native fish survival? (Selected Area question and Action specific question)

The decline in numbers of large-bodied native fish occurred in the river following low concentrations of dissolved oxygen. Whilst it is likely that some fish deaths occurred as a result of the hypoxic conditions, the study design cannot rule out other possibilities such as dispersal to other reaches. The presence of a remnant population (and not a complete loss of fish) indicated there were some water quality refuges in the river that were accessible to the fish community. The role of environmental water in providing refuges is not clear. Environmental water was used in 2016-17 to mitigate the effects of hypoxic blackwater in the mid Lachlan and provide localised refuge for fish. An improvement in dissolved oxygen concentrations was observed immediately downstream of Wyangala Dam, but the contribution of this action within the monitoring zone (some 30 days travel time later) is not obvious. Even if the improvement in dissolved oxygen from < 2mg/L (lethal range) to just under 4mg/L in the monitoring reach was the result of environmental water, it would have only provided small (if any) refuge for the large bodied species and it is likely that by the time it arrived the damage had been done. An earlier release was not possible, because the floodwaters were still high and environmental water was unable to be added to them. The release may have, however, provided some refuge for smaller bodied species such as carp gudgeon which recorded significant increase in abundance in 2016/2017.

What did Commonwealth environmental water contribute to native fish populations? (Selected Area question and Action specific question)

New recruits (juveniles) of only one native longer-lived species (bony herring) at multiple sites and three native short-lived species (Australian smelt, carp gudgeon and flatheaded gudgeon) were detected at multiple sites. New recruits of all three alien species, common carp, goldfish and eastern gambusia, were also captured. No golden perch or Murray cod new recruits were captured and it is likely that the low dissolved oxygen concentrations were responsible for the lack of Murray cod recruits observed this year (see Section 4.5.2). Golden perch recruits have not been detected in the three years of monitoring in the Lower Lachlan and while the absence of golden perch recruits is not definitive evidence of a lack of spawning, it does suggest that they may not be recruiting in the river.

What did Commonwealth environmental water contribute to native fish community resilience? (Selected Area question and Action specific question)

The fish conditions sub-indices of Expectedness, Nativeness and Recruitment used across the Murray Darling Basin provide an indication of the condition and resilience of the fish community (Table 5). In 2017, there was no change in the Expectedness score, a slight improvement in the Recruitment score (as a result of good recruitment of some small bodied natives) and a significant reduction in the Nativeness score (with the increase in carp numbers and reduction in the numbers of large bodied native fish). Thus the Overall Condition of the fish community in the Lower Lachlan river system is considered to remain 'very poor' in the monitored zone.

Table 5. Summary of SRA fish indices over the three LTIM sampling years in the Lachlan River.

	Nativeness	Expectedness	Recruitment	Overall Condition
2015	Good	Very poor	Extremely poor	Very poor
2016	Good	Poor	Very poor	Very poor
2017	Very poor	Poor	Poor	Very poor

4.5.2 SPAWNING AND LARVAL FISH

The 2016-17 watering actions did not target spawning of native fish. The objectives for native fish targeted water quality improvements as well as opportunities for native fish and other aquatic animals to move from the floodplain to the river channel minimising stranding. These were targeted at the mid-Lachlan and as such results from the larval fish monitoring are not able to inform whether these objectives have been met. Thus the monitoring and evaluation conducted in 2016-17 provides an understanding of the larval fish responses to flooding in the Lower Lachlan river system which is useful context within the five year monitoring program.

Larval fish were sampled fortnightly from mid-October to mid-December 2016 using drift nets set at three sites in Zone 1: Wallanthery, Hunthawang and Lane's Bridge (Figure 6). Sampling was designed to coincide with the known spawning window of six target native fish species which also coincided with the peak of the flooding and a period of low dissolved oxygen concentrations in the river. Despite logistical difficulties, larval sampling was still undertaken, albeit with the revised methods of not employing light traps, as the river channel trap locations were not able to be sampled because of high water velocities.

Only common carp larvae were captured in the five sampling trips in 2016 and of those the majority were captured at one site (Wallanthery) in the first sampling trip in mid October. No native fish larvae were caught and no other alien species were caught. The absence of Murray cod is especially telling as this species has been the most abundant over the first two years of the monitoring program. Juvenile Murray cod are not expected to survive when dissolved oxygen concentrations are less than 2 mg L^{-1}, and concentrations were well below 2 mg L^{-1} at Lane's Bridge from mid-October until mid-December 2016 (Figure 9). This coincides with the likely presence of larvae and early juvenile Murray cod in the system (based on previous years sampling). It is likely that the low dissolved oxygen concentrations are responsible for either prevention of spawning or mortality of eggs and / or larvae and earlier juveniles of this species. This conclusion is supported by the sampling conducted in autumn 2017 where no young-of-year Murray cod were detected (see Section 4.5.1).

There was no evidence again this year of golden perch eggs or larvae and there were not young-of-year golden perch detected in the autumn sampling either. The reasons for the lack of recruitment are not clear, but it is likely that the low dissolved oxygen concentrations would have either deterred spawning or resulted in the death of eggs and/or larvae.

There was no evidence of spawning of small bodied native species in the drift nets in 2016. However, Australian smelt, carp gudgeon, bony herring and flatheaded gudgeon recruits were detected in the fish community monitoring (see Section 4.5.1). Flooding (the inundation of floodplains and wetlands) is known to benefit the recruitment of at least two of these species, carp gudgeon and Australian smelt. These results indicate that spawning and recruitment of these species still occurred, though the recruitment was undetected as it did not overlap spatially with the sampling method employed during the flooding. The results of the community monitoring indicate that even though the area experienced a period of low dissolved oxygen during spawning and early development, recruitment of these species was able to occur.

The substantial increase in the abundance of common carp larvae caught on 2016 indicates that the flood event provided favourable conditions for reproduction and early development of carp. The onset of spawning at Wallanthery is estimated to coincide with overbank flows in the catchment and it is well known that carp respond favourable to flooding. The numbers of adult carp caught (see fish community section) indicates that a good proportion of the larval carp survived at least through until Autumn 2017.

4.6 VEGETATION

Most of the wetlands across the Lower Lachlan river system were inundated by floodwaters in 2016-17 and as a result, Commonwealth environmental water was not used to achieve vegetation outcomes in this year. While vegetation was not a target for environmental water, the flooding provided a unique opportunity to document the vegetation responses at the LTIM vegetation monitoring sites and investigate the influence of historical watering actions.

The condition and diversity of vegetation within tree communities and non-tree communities was surveyed at 13 sites across the selected area (Figure 7) around the peak of the flood event and in Autumn 2017. These data are used in combination with the data collected in 2014-15 and 2015-16 to address four evaluation questions.

All of the monitoring sites were inundated by flooding in 2016-17 with some sites inundated for an extended period of time. The flooding produced a distinct response in the vegetation as the flood peaked and then receded. The response was related to the depth of inundation at the peak of the flood and, as the flood receded, the time since inundation and waterlogging of the soils.

During inundation, water depth defined the response of the vegetation (Figure 10). Sites that were inundated to more than 0.4 m produced no emergent or submerged vegetation and only floating plants (such as Azolla, *Azolla filiculoides* or Duck weed, *Lemna minor*) seemed to be present. At sites that were inundated to less than 0.4 m a number of amphibious plants were observed during the inundation that had not been previously recorded. Common spike rush (*Eliocharis acuta*) was the most widespread and abundant but we also observed small flower umbrella sedge (*Cyperus difformis*) and marsh club-rush (*Bulboschoenus fluviatalis*). Water ribbons (Triglochin spp.), Star fruit (*Damasonium minus*) and Common blown grass (*Lachangrostis filiformis*) were also recorded and there was a significant increase in the abundance of nardoo (*Marsillea drummondii*).

As the flood waters receded, species adapted to mud flats appeared at sites, with Small club-rush (Isolepis, spp.) matted water starwort (*Callitriche sonderi*), Ferny buttercup (*Ranunculus pumilio*), Spreading nutheads (*Epaltes australis*) and Australian mudwort (*Limosella australis*) appearing (Figure 11). As the flood waters receded further, numerous terrestrial damp species appeared including bluish raspwort (*Haloragis glauca*), yellow twin-heads (*Eclipta platyglossa*), hyssop loosestrife (*Lythrum hyssopifolia*) and lesser joy weed (*Alternanthera denticulata*) followed by Sneeze weed (*Centipeda cunninghamii*), couch grass (C*ynodon dactylon*), dock (Rumex spp) and swamp daisy (*Brachyscome basaltica*).

Figure 11. Vegetation responses at the peak of the flood.
Left: flooding at Moon Moon swamp where water levels were >1.2 m. The patterns on the surface of the water are made by azolla and duck weed. Right: flooding at Whealbah lagoon where water levels were < 0.4 m. The vegetation includes nardoo, typha, common spike rush and swamp daisy.

Figure 12. Vegetation responses as the flood recedes.
Left: mudflats at Lake Bullogal as the floodwaters recede. The vegetation is a mix of small club-rush, Australian mudwort, matted water starwort and ferny buttercup. Right: sneeze weed at Lake Tarwong three months after the flood receded.

To determine if the watering history influenced the response of riparian and wetland vegetation to a significant flood event four evaluation questions were addressed.

Does the watering history of the sites influence the vegetation species diversity following flooding? (Action specific question)

Watering history did not appear to influence the vegetation diversity at the monitoring sites, with differences in site responses appearing to be more a function of the vegetation community and watering depth than historical watering. There are two possible reasons for this: 1) the frequency of watering of the monitored sites is less important for the seed bank than vegetation community and watering depth 2) the magnitude of the response was such that it overwhelmed any influence of watering history. It should be noted that there is limited replication of some watering histories (only 1 of our monitored sites was completely inundated in 2015) which makes it difficult to be confident in the apparent response. Ongoing monitoring will continue to develop our understanding of the drivers of vegetation response.

Does the watering history of the sites influence the vegetation community diversity following flooding? (Action specific question)

The monitored sites retained a high degree of nativeness, particularly within the tree community. More than 70% of the vegetation cover within the tree community comprised native species and 60% within the non-tree community. Typically more than 60% of the species present were native within both the tree and non-tree community, with only one site showing a marked increase in exotic plants in the Autumn following the flooding. The watering history of the sites does not appear to have influenced the nativeness of the groundcover vegetation. It was noticeable that the proportion of native vegetation cover has increased since monitoring commenced in 2014.

There was a notable increase in the cover and proportion of wetland specific species (classified as terrestrially damp or amphibious) in 2016-17 and a number of species that had not been recorded in previous surveys were observed. These included water ribbons (*Triglochin* spp.), small flower umbrella sedge (Cyperus difformis), star-fruit (*Damasonium minus*), buttercups (*Ranunculus spp*) and Common spike rush (*Eleocharis acuta*). Up to 50% of the species observed at sites were classified as amphibious or terrestrially damp species. This was observed across all sites, irrespective of watering history. The relative proportion of amphibious and terrestrially damp species appears to be greatest at sites that were inundated or partially inundated in 2015-16, although as previously mentioned the lack of replication for some watering histories limits our ability to infer that this is a widespread response.

Does the watering history of the sites influence the condition of floodplain and riparian trees following flooding? (Action specific question)

There was a slight improvement in tree condition in 2016-17 with an improvement in foliage cover. This follows the improvement observed with watering in 2015-16. The response was greatest at sites that had been dry for the longest (either last watered in 2013 and/or only received water nearby in 2015). Flooding maintained tree condition at the sites that had been completely, or partially, inundated in 2015-16. The improvement in foliage cover was not accompanied by a reduction in the proportion of dead canopy cover with almost no change observed in dead canopy cover between 2015-16 and 2016-17. This reflects the greater timeframes required to recover tree canopy that has been lost over multiple dry seasons.

Does the watering history of the sites influence populations of long lived organisms following flooding? (Action specific question)

Tree seedlings were observed at all sites in 2016-17, except those that were inundated at the time of sampling. This included black box, red gum and river cooba seedlings and these were observed at sites where we had not previously observed seedlings, such as Lake Bullogal and the Lake Tarwong black box. It is likely that the removal of sheep and cattle from these sites during the floods have contributed to the occurrence of seedlings and saplings. There was no noticeable influence of watering history on tree seedlings.

4.7 WATERBIRDS

The Booligal wetlands in the Lower Lachlan river system are one of the key sites for colonial waterbird breeding in the Murray Darling Basin, with straw-necked ibis recorded as breeding the wetlands every 2-3 years since 1984. The management of environmental water for waterbird habitat and breeding outcomes forms part of the strategic direction for the wetland. Two colonial nesting waterbird colonies established in the Booligal wetlands in 2016, the first at Upper Merrimajeel in September and the second at the Blockbank in late December (Figure 13 and Figure 14.

Waterbird breeding in the Upper Merrimajeel and Blockbank colonies was surveyed at fortnightly intervals between September and November 2016 and between January and March 2017 respectively. Surveys were timed to correspond with chick development stages. More than 40 wetland-dependent bird species were observed in the Upper Merrimajeel and Blockbank colonies including 12 species observed to be breeding. The colonies were dominated by straw-necked ibis, but white and glossy ibis were also recorded.

The Upper Merrimajeel colony was the largest and most successful colony of straw-necked ibis in the Murray-Darling Basin in 2016-2017. It was also the largest recorded colony since 1984. At its peak, the Upper Merrimajeel colony contained more than 200,000 adults and covered a total area of 68 hectares. More than 100,000 nests were counted and the average clutch size was slightly more than 2 eggs per nest. Reproductive success rates from the Upper Merrimajeel colony were high (> 80%), reflecting the optimal breeding conditions including stable water levels, good availability of nesting habitat and widespread inundation for a long period of time. High fledgling rates associated with the colony indicate that the catchment conditions supported good food resources. The Upper Merrimajeel colony was not supported by Commonwealth environmental water because water levels were stable and sufficiently high from natural flooding. Widespread flooding was the result of unregulated flows in the Lachlan River following high rainfall.

The second watering action delivered in 2016-17 aimed to support the Blockbank waterbird breeding colony. This colony had established in late December when tributary inflows to the Lower Lachlan river system had slowed and releases from Wyangala Dam had ceased. This meant that water levels within the wetlands were beginning to drop rapidly and without the active management of water levels, the breeding event was at risk of failure caused by nest abandonment and predation.

To determine the contribution of Commonwealth environmental water to the provision of habitat for waterbird breeding, the following question was addressed:

What did Commonwealth environmental water contribute to waterbird breeding, fledging and survival? (Action specific question)

The Blockbank colony was much smaller than the Upper Merrimajeel colony and at its peak it was estimated to contain more than 16 000 birds. The reproductive success rate for the Blockbank colony was lower (>60%) than the Upper Merrimajeel colony but was still good given that it had established late in the season. Water levels in the colony were managed by the operation of infrastructure, re-routing water from Watering Action 1 to the Merrimajeel system and the delivery of additional amounts of Commonwealth and NSW environmental water. Water levels were stable throughout the breeding period, which was critical to the success of this colony. Without the active management of water in the wetlands, the water level would have dropped rapidly and it is likely that the colony wold have been far less successful than observed. The provision of Commonwealth and NSW environmental water to support this breeding colony resulted in the successful fledging of several thousand juvenile straw-necked ibis, and provided foraging habitats, particularly for species that feed in the wetland e.g. spoonbills. In addition this water also watered flood dependent vegetation that provides nesting and roosting habitats e.g. lignum, wetland trees and provided opportunities for fish and frog spawning and the emergence of macro and micro aquatic invertebrates.

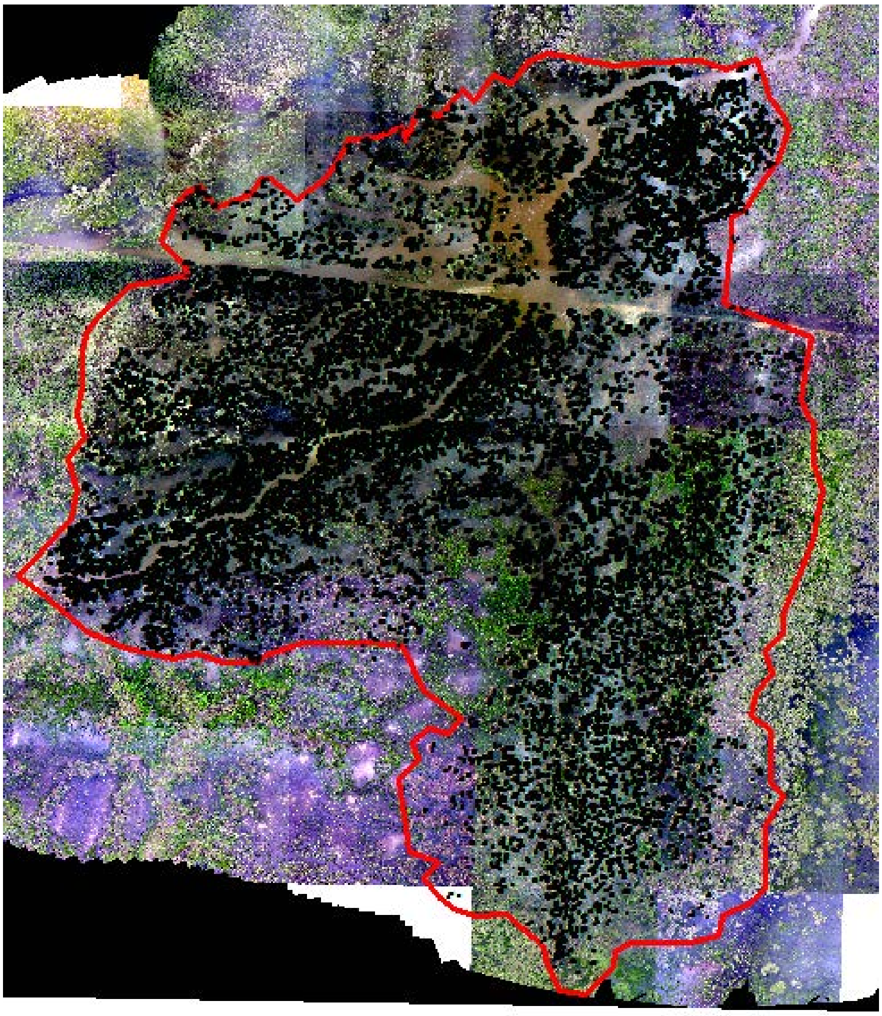

Figure 13. Upper Merrimajeel colony orthomosaic compiled from UAV imagery (12th October, 2016) (background) with colony boundary (red) and nests (black dots) marked. Image M. Lyons, UNSW.

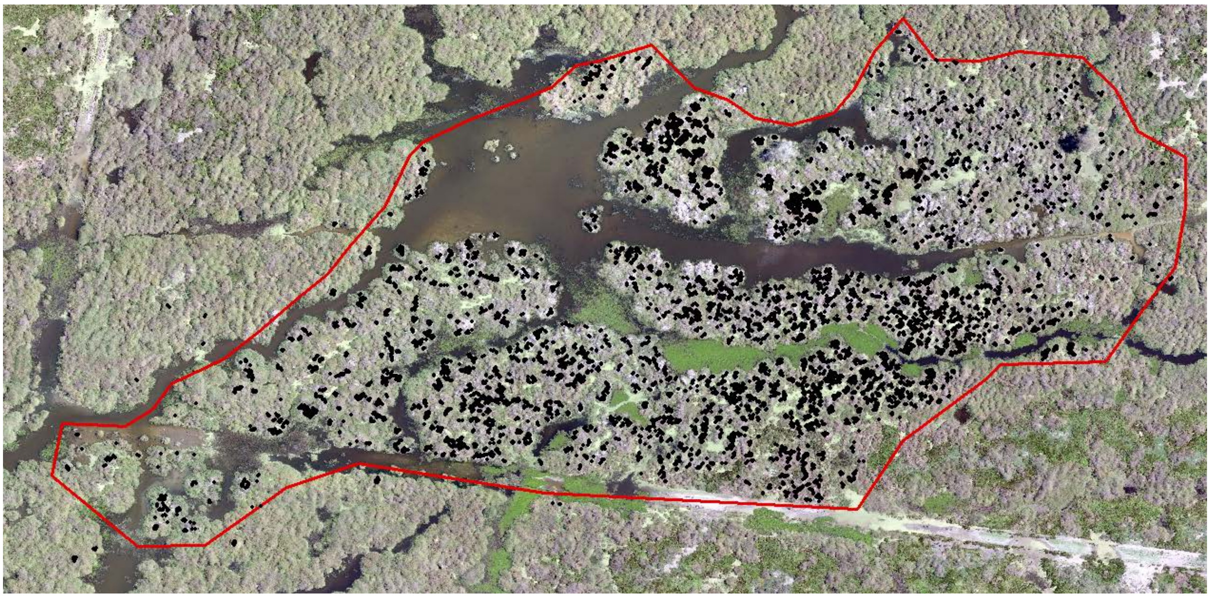

Figure 14. Blockbank colony orthomosaic compiled from UAV imagery, (26th January 2017) with colony boundary (red line) and nests (black dots) marked. Image M. Lyons UNSW

5 OTHER RELEVANT RESEARCH

The use of Drones to monitor the waterbird colonies provided an opportunity to collect broad scale data on the condition and complexity of vegetation within the wetlands. These data could be compared with measures of structure and condition from the LTIM vegetation survey data. The aim was to provide baseline vegetation data against which to compare future measurements but also to enable a pilot comparison of Drone captured vegetation data with field measurements. This was a very small pilot study and was conducted to contribute to a discussion about the potential to use Drones for future monitoring of environmental watering responses.

Vegetation condition and structure data were collected from the Upper Merrimajeel colony using Drones and field surveys during the colony development. These data were used to compare the outputs from the drone and field surveys to give an indication of the utility of drones for measuring vegetation responses to environmental watering. The data from the field surveys was also used to compare the vegetation community at the bird breeding site with the existing LTIM vegetation monitoring sites to determine if it possible to extrapolate the vegetation responses from 2014-15 and 2015-16 to the bird breeding site.

There was reasonable agreement between the drone survey data and the field surveys for estimates of vegetation cover and the cover of lignum. More detailed vegetation information is difficult to obtain from the drone imagery, with structurally similar vegetation difficult to distinguish. This suggests that there may be value in broad scale metrics of cover from drone imagery, but detailed floristic survey is still better achieved with ground survey.

Unfortunately, the vegetation within the waterbird breeding colony is not analogous to any of the current monitoring sites and it was not possible to use the data collected to infer the contribution of past use of Commonwealth environmental water to the condition, structure and health of nesting and foraging habitats.

6 EVALUATION

There are two components to the Selected Area evaluation of the ecological outcomes of Commonwealth environmental watering in the Lower Lachlan river system in 2016-17. The first is an evaluation of the ecological outcomes in relation to the specific objectives of the watering actions and the second is evaluation of the watering outcomes framed in the context of specific (pre-defined) evaluation questions (Table 3).

6.1.1 EVALUATION OF SPECIFIC OBJECTIVES

The two watering actions delivered in 2016-17 were designed to modify the flow regime to support vulnerable populations. The first action aimed to improve dissolved oxygen concentrations and provide in-channel refuge from poor water quality in the mid –Lachlan (between Wyangala Dam and Lake Cargelligo). The second action aimed to support the breeding of colonial nesting waterbirds in the Booligal wetlands. In combination 53 313 ML of environmental water was delivered to achieve these outcomes.

The mid-Lachlan is not monitored as part of the LTIM program which means that the outcomes of the first watering action are unable to be evaluated here. However, monitoring by NSW OEH suggests a positive response for water quality. Under natural conditions (in the absence of regulation), the flood in the Lower Lachlan system would have receded slowly with water from upstream of Wyangala Dam maintaining or improving dissolved oxygen levels in the river. The capture of water in Wyangala Dam following flood operations essentially shut off the upstream sections of the river posing a risk for downstream water quality. The volumes of environmental water contributed to modifying the first watering action were small, but they were a significant contribution to flow in the river at the time and delivered positive outcomes for water quality.

The second watering action addressed the drop in water levels that would have occurred in the Booligal wetlands to improve the success rate of a late bird breeding colony (the Blockbank colony). The water provided to the Blockbank colony ensured that water levels in the colony remained stable at a sufficient depth (50-70 cm) to prevent nest abandonment and limit the access of ground based predators into the colony site. The management of Commonwealth (and NSW) environmental water was the major contribution to the success of the breeding event in the Blockbank colony.

6.1.2 EVALUATION QUESTIONS

This was the third of a five year program established to answer specific questions about ecological responses to environmental watering in the Lower Lachlan river system. Stream flow (hydrology), stream metabolism and water quality (temperature, pH, dissolved oxygen, turbidity, conductivity, concentrations of nitrogen and phosphorus), fish (including larval fish) waterbirds and the condition and diversity of vegetation were monitored to evaluate the outcomes of Commonwealth watering actions. In 2016-17 the Commonwealth watering actions were completely overwhelmed by a natural event which flooded a large proportion of the Lower Lachlan river system. Thus much of the monitoring activity provides information about the response of the system to flooding.

Responses for a number of indicators are summarised in Table 6.

Table 6. Evaluation questions and responses for the Lower Lachlan river system Selected Area. Bold text represents a response to Commonwealth environmental water, whereas normal text represents a response to the floods.

INDICATOR	EVALUATION QUESTION What did Commonwealth environmental water contribute	RESPONSE
Hydrology	**to habitat for native fish, waterbirds and other water dependent vertebrate species**	**Watering Action 2 extended the duration that water levels at the Blockbank bird breeding colony in the Booligal wetlands by 4 months. Without the delivery of environmental water and the management of regulating structures, water levels would have dropped well below critical levels, substantially reducing the success of the nesting event.**
	to hydrological connectivity.	**Watering Action 2 provided the lateral connectivity requited to support bird breeding outcomes.**
Water Quality and Stream Metabolism	**to patterns and rates of decomposition?**	**There was some evidence that Watering Action 1 may have resulted in an increase in dissolved oxygen and possibly ecosystem respiration but the evidence is not strong.**
	to patterns and rates of primary productivity?	**There was no clear response of stream respiration to Watering Action 1**
Fish - community	*Short-term (one year)*	
	to native fish community resilience?	The native fish community was adversely affected by the flooding, with a drop in numbers of large bodied native fish and an increase in carp numbers. A positive response to the flooding was observed in some of the small-bodied native fish.
	to native fish survival?	Recent recruits of small bodied native and carp were captured suggesting that the flood events were positive for these species.
	Long-term (five years)	
	to native fish populations?	Indeterminate – data contributes to the longer term data set and Basin evaluation.
	to native fish diversity?	
Fish - reproduction	*Short-term (one year)*	
	to native fish reproduction in the Lower Lachlan river system?	No spawning of native species was detected, but the numbers of small bodied fish detected indicated that these species had reproduced in 2016.
	to native larval fish growth in the Lower Lachlan river system?	The presence of 0+ individuals in the fish community provides an indication that growth and survival did occur for small bodied native fish and one medium bodied native fish as well as large numbers of carp, goldfish and gambusia..
	Long-term (five years)	
	to native fish populations in the Lower Lachlan river system?	No native fish larvae was detected in monitoring in 2016.
	to native fish species diversity in the Lower Lachlan river system?	No detectable change in fish diversity
Waterbirds	**To waterbird breeding, fledging and survival**	**Watering Action 2 resulted in a 64% reproductive success rate in the Blockbank breeding colony in the Booligal wetlands. Without the management of environmental water it is likely that the success rate would have been very low.**
Vegetation	*Short-term (one year) and long-term (five years)*	
	to vegetation species diversity?	

INDICATOR	EVALUATION QUESTION What did Commonwealth environmental water contribute	RESPONSE
	to vegetation community diversity?	There was an increase in the proportion of species classified as amphibious or terrestrially damp in response to flooding and this appears to be greatest in sites that are regularly watered. Watering history did not appear to affect species diversity.
	Short-term (one year)	
	to condition of floodplain and riparian trees?	There was a slight improvement in the condition of riparian and floodplain trees with an improvement in foliage cover.
	Long-term (five years)	
	to populations of long-lived organisms?	Seedlings of all long lived species were observed, including at sites where they had not been observed in the past. Future monitoring will enable the success of this recruitment event to be determined.

7 ADAPTIVE MANAGEMENT

The 2016-17 monitoring and evaluation provides information that can be used to guide the future management of environmental water in the Lower Lachlan river system. The key findings are described in the following sections.

7.1 DELIVERING ENVIRONMENTAL WATER DURING A FLOOD YEAR

In 2016-17 the Lower Lachlan river system was in flood. This meant that the approach to delivering Commonwealth environmental water changed from the traditional approach of adding missing elements of the hydrological regime to achieve environmental outcomes. Instead the management of Commonwealth water was in response to conditions in the river and the ecological responses observed. The aim was to capitalise on the natural flood event and protect vulnerable ecosystem attributes from the effects of a flood under highly managed conditions. This meant that environmental water was used to modify the outcome of the operation of Wyangala Dam once flood operations ceased. The positive outcomes achieved with the management of environmental water in 2016-17 provide evidence of the success of this approach when the system is in flood.

While the benefits of the first watering action for dissolved oxygen concentrations in the monitored reach are not clear, the improvements in the target reach (mid Lachlan) mean that the provision of environmental water to manage dissolved oxygen on the receding limb of natural flow events, particularly where they occur in summer, is a valid management option with potential benefits.

The provision of water to support the Blockbank waterbird colony was successful in achieving the goals of supporting a breeding event. Commonwealth environmental water contributed to the completion of nesting (prevented abandonment due to falling water levels), and provided suitable habitat in which chicks could be raised and successfully fledged. This ‘event’ demonstrates the value of cleverly managing water within the constraints of the system with a long lead time for delivering water. The combination of managing infrastructure, redirecting environmental water and delivering water generated successful outcomes.

The management of environmental water for the Blockbank waterbird colony also demonstrated the value of tailoring observations to the conditions within the catchment. The establishment of the second colony was observed during a reconnaissance plane flight taken to gain an understanding of the extent of the flooding. Without this flight, the colony may have remained undetected for sufficient time that the water levels would have dropped and the colony put at risk.

There are logistical challenges to the responsive style of environmental water management that affect the capacity for closing the adaptive management loop and institutional learning. These include:

- The standard processes for documenting objectives for the watering actions (Water Use minutes) does not fit the rapid and responsive style of water management. While the approach adopted is agile and effective, better documentation of the actions, rationale and water use would facilitate future evaluation and learning.
- Watering actions that are targeted to one reach and then ‘reused’ in other parts of the river means that traditional accounting approaches to recording water use do not accurately reflect the outcomes. This use of a single parcel of water for multiple benefits is an efficient and effective use of environmental water. Mechanisms for better documenting the water use would facilitate future evaluation and learning.

7.2 INFORMING FUTURE MONITORING

One of the challenges with delivering water to improve dissolved oxygen concentrations is that typically by the time dissolved oxygen concentrations drop below 4 mg/L, it is too late to respond to achieve a benefit for fish. In the mid Lachlan, early warning of the poor water quality was hampered by a paucity of data (and particularly a paucity of continuous data) that could be used to trigger a response. It would be valuable to have water quality monitoring equipment in the reach from Wyangala Dam to Lake Brewster to inform water management decisions. Ideally this would use existing gauging infrastructure in the Lachlan catchment. Gauges should be fitted with dissolved oxygen loggers, as they are in other New South Wales catchments such as the Edward-Wakool and Murrumbidgee systems, accessible in real time.

The current LTIM program for the Lower Lachlan river system only monitors the river system below Lake Brewster. This means we do not have data to evaluate watering actions upstream. The fish community between Wyangala Dam and Lake Brewster is in much better condition and has a greater probability of responding to environmental water than the reach downstream of Lake Brewster (Sam Davis, DPI Fisheries pers comm.). Thus the response observed downstream of Lake Brewster is unlikely to be representative of the upstream reaches. The watering action delivered was targeted at the mid-Lachlan River system below Wyangala Dam. Past watering actions have also targeted this reach. Future monitoring programs should consider monitoring the target reach (Wyangala to Lake Brewster) so that the outcomes might better be evaluated.

The monitoring of the vegetation response to the flooding combined with the previous years of monitoring provides information about what might be expected at sites in response to the provision of environmental water. Vegetation at sites that are periodically inundated to more than 0.4 m have not responded to flooding nor to environmental water other than to grow floating plants such as Azolla or duck week. This indicates that perhaps these sites should not be expected to produce a groundcover vegetation response with the provision of environmental water. These sites include Moon Moon swamp, the channel sections within Lake Bullogal, Lake Tarwong, The Ville and Hazelwood Billabong. These open water sites without vegetation may be functionally important in the landscape and the objectives for environmental water at these sites need to be considered in the context of a range of wetland habitats. Current seedbank studies by PhD student Will Higgisson will inform future decisions for watering of these sites.

There was a marked response in groundcover vegetation at sites that are periodically inundated to <0.4 m. Some of these sites require large volumes of water to inundate and will only ever receive water from natural flooding. This includes the black box communities at Lake Tarwong and Lake Ita, the redgum floodplain woodland at The Ville, Whealbah Billabong and Lake Marrool, and the mounds in Lake Bullogal and Lake Tarwong. The volume of environmental water available is not sufficient to get water over these sites, which means that environmental water cannot be used to generate a response by the groundcover vegetation. It is possible to get environmental water *near* to these sites which is likely to result in a response from the floodplain and riparian trees.

A few of the sites that are periodically inundated to <0.4 m and showed a marked response in groundcover vegetation to flooding are able to be watered with environmental water. These include sites within the Booligal wetlands in Booligal National Park and Tom's Lake. The challenge at these sites is to identify the duration of flooding and frequency of flooding required to support the vegetation community. Ongoing data collection as part of the monitoring program will start to address this challenge but it would also benefit from some modelling of natural flows within these systems.

7.3 EMERGING PRIORITIES

Hypoxic floodwater looks to have prevented reproduction of large bodied native species in the selected area in 2016, particularly Murray cod, which have been the most numerically dominant larval fish species present in previous years. The lack of spawning of large bodied native fish in 2016 and the drop in numbers of large bodied native fish in 2017 means that the recovery of these species should be a priority for upcoming watering actions.

No larval or young of year golden perch were detected in the Lachlan River again this year. Thus there is a need to develop a greater understanding of the golden perch populations that exist in the Lachlan. It is important to understand the role of stocking and the relative contribution to the population from wild fish. Until such site specific understanding is gained, watering actions should be informed by the conditions under which spawning did not occur.

If the Lachlan catchment has the potential for an increase in Murray Cod recruitment in the year following a flood (as has been previously observed in other catchments – see King et al. (2007) and Thiem et al. (2017)), the planned use of environmental water in the Lachlan catchment during 2017-18 may want to target flows that support Murray cod spawning and recruitment to the best extent possible.

In contrast to the outcomes for fish, the widespread watering of all floodplain and wetland sites in 2016-17 has had benefits for vegetation within the catchment. The long duration of flooding in some locations (the wetlands of the lower part of the Selected Area still held significant amounts of water in June 2017) has started to stress some of the lower lying vegetation and a drying phase is required before environmental water should be delivered to these locations. This means that the vegetation in the catchment should not be a primary target for watering in 2017-18.

7.4 THE DESIGN OF WATERING ACTIONS

To try to avoid adding to further increases in local carp populations, the planned use of environmental water in the Lachlan catchment during 2017-18 may, depending other environmental needs identified, want to target:

- in-channel habitat rather than floodplain, wetland and lake habitats (preferred spawning habitat for carp)
- delivery to floodplain and wetland habitats during winter when temperatures are less than 16°C and less likely to contribute to carp recruitment (following Koehn et al. 2016a, b).

Natural flow variability is the dominant driver of patterns of water quality and stream metabolism in the Lachlan River, but environmental water can generate smaller, but ecologically meaningful responses. The effects of environmental water are likely to be more important in dryer years (e.g. 2014-15), where carbon has accumulated on banks and in flood runners. In relatively wet years, such as occurred in 2016-17, metabolism responses to environmental flows are likely to be small relative to natural variability.

The experiences of waterbird breeding in the Lachlan catchment in 2015-16 and 2016-17 highlight the importance of regional weather patterns, and the value of extensive flooding to provide foraging areas and habitat for food resources to thrive in a successful breeding event. The strategy of using Commonwealth environmental water to support breeding events once they have established (rather than trying to trigger a breeding event) is therefore a sound strategy. The management of the Blockbank water levels in 2016-17 demonstrates the value of this approach and the successful outcome can be attributed to the use of Commonwealth (and NSW) environmental water.

The observations of vegetation response provide information about the vegetation community during wet periods in the Lower Lachlan river system. Watering history did not appear to be a significant determinant of the response of the vegetation, suggesting that the flood response is not something that can be influenced by watering actions. However, this conclusion is limited by a lack of replication for some of the watering histories. It is recommended that future monitoring of vegetation in the region should aim to include more sites, and particularly sites that are likely to be more frequently watered. Recent data sets, such as the OEH inundation data and the data collected as part of this program, provides a stronger platform for the selection of future monitoring sites.

8 HYDROLOGY

8.1 INTRODUCTION

The provision of water to maintain and restore riverine environments is based on the premise that the hydrological regime is one of the fundamental drivers of the structure and function of riverine and floodplain ecosystems (Nilsson and Berggren 2000, Bunn and Arthington 2002). Flow drives physical processes, providing longitudinal and lateral connectivity, moving sediments and nutrients and providing a diversity of hydraulic conditions for aquatic biota (Bunn and Arthington 2002). Altering flow regimes, through various water resource development activities, markedly affects the health of freshwater ecosystems (Walker and Thoms 1993, Gehrke et al. 1995, Kingsford 2000) and thus returning elements of the natural flow regime is an important part of managing and restoring river health.

In this chapter we evaluate the hydrological outcomes of providing Commonwealth environmental water to the Lower Lachlan river system. There are two components to the evaluation. The first is an evaluation of the hydrological outcomes in relation to the defined hydrological objectives of the watering actions and the second is an evaluation of the watering outcomes framed in the context of evaluation questions defined in the Long Term Intervention Monitoring and Evaluation Plan for the Lachlan river system (Dyer et al. 2014). The hydrological outcomes are tied to ecological outcomes and this chapter provides the analysis of the managed flow and water levels that will underpin the interpretation of the outcomes presented in later chapters.

The context in which the 2016-17 environmental watering actions were delivered was one in which the river system was in flood. Consequently, the approach to delivering environmental water differs from the more traditional approach of adding missing elements of the hydrological regime and instead focuses on the protection of vulnerable populations by modifying the existing flow regimes. Two watering actions involving Commonwealth environmental water were delivered to the Lower Lachlan river system in 2016-17 (Table 7). The first action targeted water quality improvements in the main channel of the Lachlan River and the second action targeted ecological outcomes in Booligal Wetlands. The first watering action did not have specific hydrological objectives whereas the second watering action aimed to maintain water levels in Booligal Wetlands and provide habitat for native fish, waterbirds and other water dependent vertebrates. The outcomes for both riverine and wetland hydrology are examined in this technical report and the following questions addressed:

8.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to habitat for native fish, waterbirds, and other water dependent vertebrate species?

8.1.2 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

2) What did Commonwealth environmental water contribute to hydrological connectivity?

Table 7. The 2016-17 Commonwealth environmental watering actions in the Lower Lachlan river system and their hydrological objectives.

Action	Target	Flow components	Volumes delivered (combined CEW, WQA and NSW Water)	Hydrology objectives
1	Mid Lachlan River, main channel	Fresh flow	48 418 ML to the mid Lachlan River.	None defined[1].
2	Booligal Wetlands	Fresh flow	5,959 ML to Merrimajeel Creek to support waterbird habitat at the Blockbank. This includes 4,895 ML of 'ordered' water and 1,064 ML of water redirected from Watering Action 1	Support habitat requirements for waterbirds, native fish and other water dependent vertebrates.

[1] The watering action was designed to provide a water quality benefit. There were no documented hydrological objectives although the water managers advise that there was an objective to provide a more natural, slower recession to the flood that would have occurred with the cessation of flow from Wyangala Dam. Additionally, the flow regime was modified to achieve the improvements in dissolved oxygen concentration and thus the in-channel refuge desired. Achieving these goals cannot be evaluated through defined hydrological metrics.

8.2 METHODS

The evaluation of the hydrological outcomes used a combination of flow data, river height data, wetland inundation information and observations.

Mean daily discharge (ML/day) and daily mean 'stage' (as relative water level in metres) data were obtained from the NSW WaterInfo site (http://waterinfo.nsw.gov.au/) for gauging sites within the Selected Area (Figure 15). The selected gauging sites were those relevant to the locations at which monitoring activities were occurring as well as sites that could be used to evaluate the hydrological outcomes of Commonwealth environmental water.

Data apportioning the daily contribution of Commonwealth and NSW environmental water (ML/day) to the flow in the river was provided by the Commonwealth Environmental Water Office and the NSW Office of Environment and Heritage. These contributions were subtracted from the flow at the relevant water accounting locations to produce hydrographs illustrating the relative contribution to the flow.

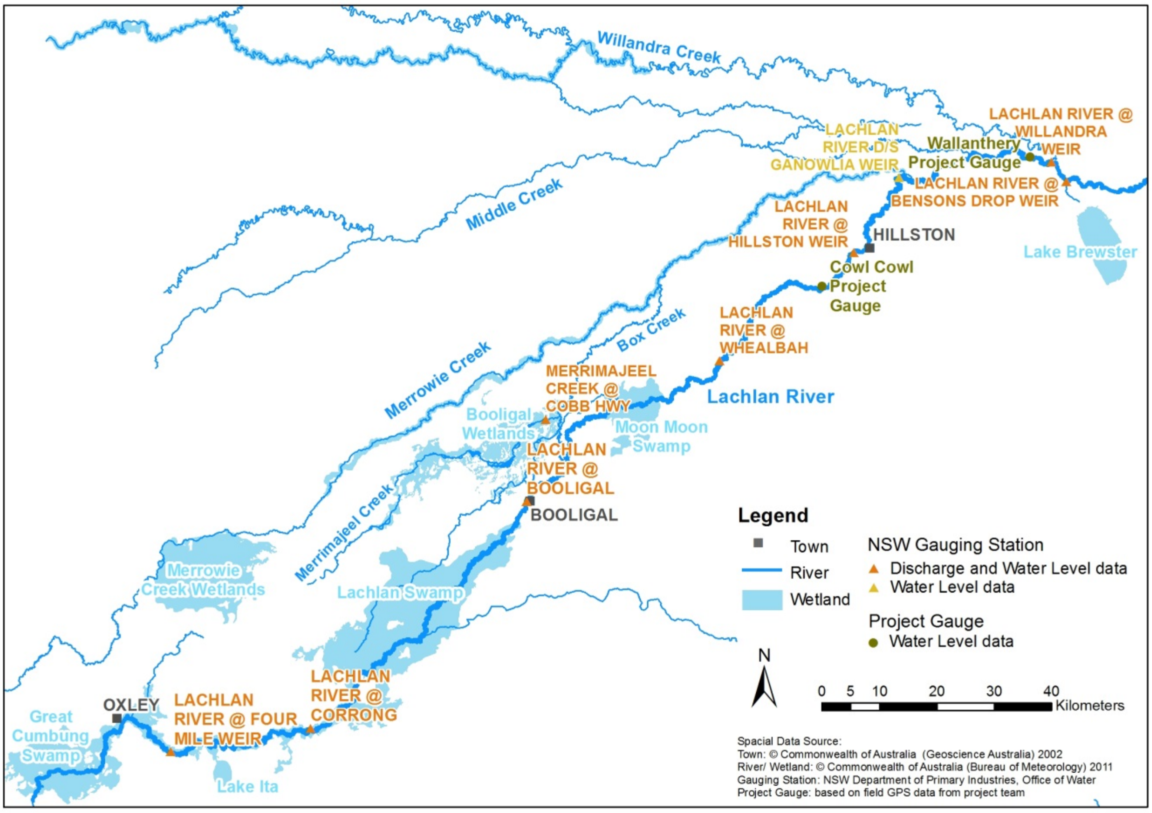

Figure 15. The location of relevant gauging stations in the Lower Lachlan river system.

8.3 RESULTS

The total environmental water delivery to the Lower Lachlan river system in 2016-2017 was 58 313 ML and was made up of 29 492 ML of Commonwealth environmental water, 6,250 ML of NSW water, 7,571 of Environmental water Allowance (EWA) and 15 000 ML of Water Quality Allowance (WQA). A further 350 000 ML of translucent flows were delivered under the Lachlan Regulated River Water Sharing Plan making a total of 408 313 ML of environmental water delivered to the Lower Lachlan river system. Commonwealth environmental water contributed approximately 2% of the flow in the river in 2016-17 (based on the flow at Willandra Weir which was 1 659 486 ML for the period 1 July 2016 to 30 June 2017).

While the volume of Commonwealth environmental water was a very small proportion of the annual flow in the river, it was strategically delivered to modify the flow regime and at the time of delivery, comprised a significant proportion of the flow in the river. The details of this are described for each of the watering actions in the following sections.

8.3.1 WATERING ACTION 1: WATER QUALITY IMPROVEMENTS

The first watering action was delivered in response to:

1. Advice from Water NSW that releases from Wyangala Dam would be reduced to minimum base flows in early November following a reduction in inflows to the dam and cessation of flood operation of the dam. This would result in a rapid drop in flow downstream of Wyangala Dam.

2. A reduction in tributary inflows to the Lachlan River
3. Observations of very low dissolved oxygen concentrations (<2 mg/L) in the river coming primarily from Lake Cowal. Lake Cowal was expected to continue to contribute water of very low oxygen concentrations for many months to the Lachlan River.

In combination, these factors were considered to pose a significant risk to aquatic biota. Water from Wyangala Dam and tributaries would no longer be diluting the water from Lake Cowal and dissolved oxygen concentrations were expected to remain low or decline further as the flows in the river channel became dominated by floodplain return flows. The watering action was therefore designed to attenuate the recession of the hydrograph and promote mixing and the creation of microhabitat (water quality) refuges.

Delivery of this first watering action from Wyangala Weir commenced on the 4th November 2016 and finished on the 2nd January 2017 (Figure 16 A). This action targeted the mid-Lachlan River at Forbes and Commonwealth environmental water contributed between 15 and 64% of the flow in the river at Cotton's weir (Forbes) during the watering action.

The first watering action flowed past the gauge upstream of Willandra weir between early December 2016 and the end of January 2017 but it was still having a notable effect on the flow (Figure 16 B). Commonwealth environmental water contributed between 10 and 68% of the water in the river at Willandra weir during the watering action. Downstream of Willandra weir, it becomes impossible to distinguish the watering action from the flood.

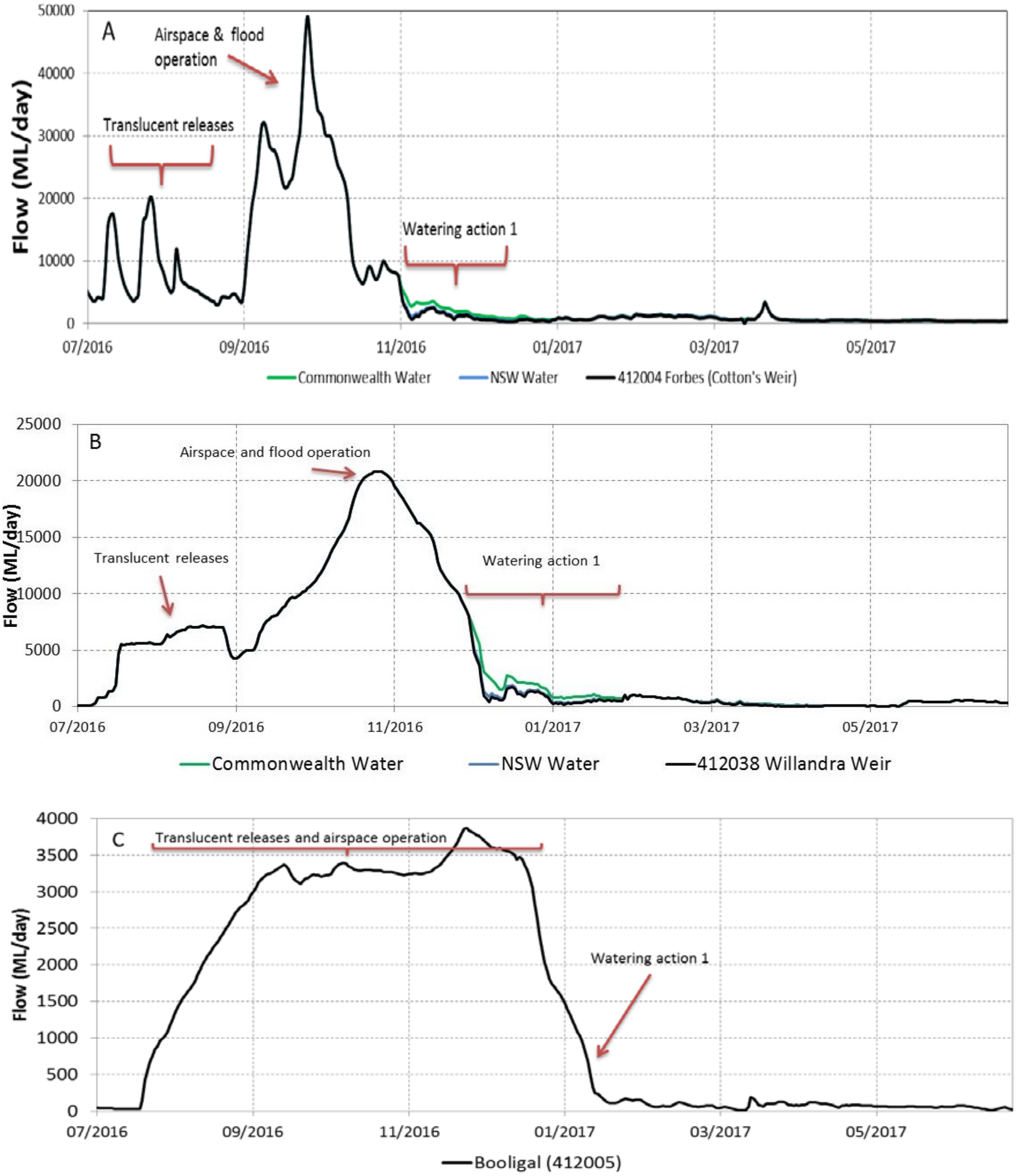

Figure 16. Passage of Watering Action 1 through the Lower Lachlan River System from the gauge at Cotton's Weir (Forbes) to Booligal for the period 1 July 2016 to 30 June 2017. Commonwealth (green) and NSW (blue) environmental water are shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in black. A) Data from the gauge at Cotton's Weir (412005); B) data from the gauge upstream of Willandra Weir (412038); C) data from the gauge at Booligal (412005). Watering Action1 is not shown at the Booligal gauge because it has become absorbed by the flood. Refer to Figure 15 for gauge locations.

8.3.2 WATERING ACTION 2: BOOLIGAL WETLANDS

The second watering action was delivered in response to the observation on the 19th December that ibis were commencing to breed at the Blockbank in the Booligal wetlands. Water levels were beginning to drop at that time as tributary flows had slowed and releases from Wyangala Dam had ceased. The management of water in the colony involved multiple activities:

1) Installation of boards at the Blockbank (9/1/2017 and then subsequently an additional board on 16/1/17) to slow the post flood recession
2) Redirection of 1,064 ML of flow from the tail of Watering Action 1 to Merrimajeel Creek instead of allowing it to pass down the Lachlan River towards the Great Cumbung Swamp.
3) The provision of environmental water to the Merrimajeel Creek to maintain water levels.
4) The installation of additional boards at the Blockbank (6/3/2017) to increase the pooling of environmental water behind the Blockbank. These were left in place on cessation of the environmental water to Merrimajeel Creek to slow the recession.

Thus the delivery of water was only one component of managing water levels in the waterbird colony.

The delivery of water for watering Action 2 commenced at Merrimajeel Creek on the 25th January 2017 and continued until the 17th March 2017 (Figure 17). Environmental water provided all of the flow in the creek during this watering action.

The combination of activities undertaken as part of this watering action maintained water levels upstream of the Blockbank above 0.9 m until the 25th March and above 0.7 m until the 28th April after which water levels slowly dropped to below 0.6 m at the end June (Figure 18). In the absence of the provision of environmental water and the management of the infrastructure, it is expected that water levels in the bird breeding colony at the Blockbank would have dropped quite rapidly from mid-January.

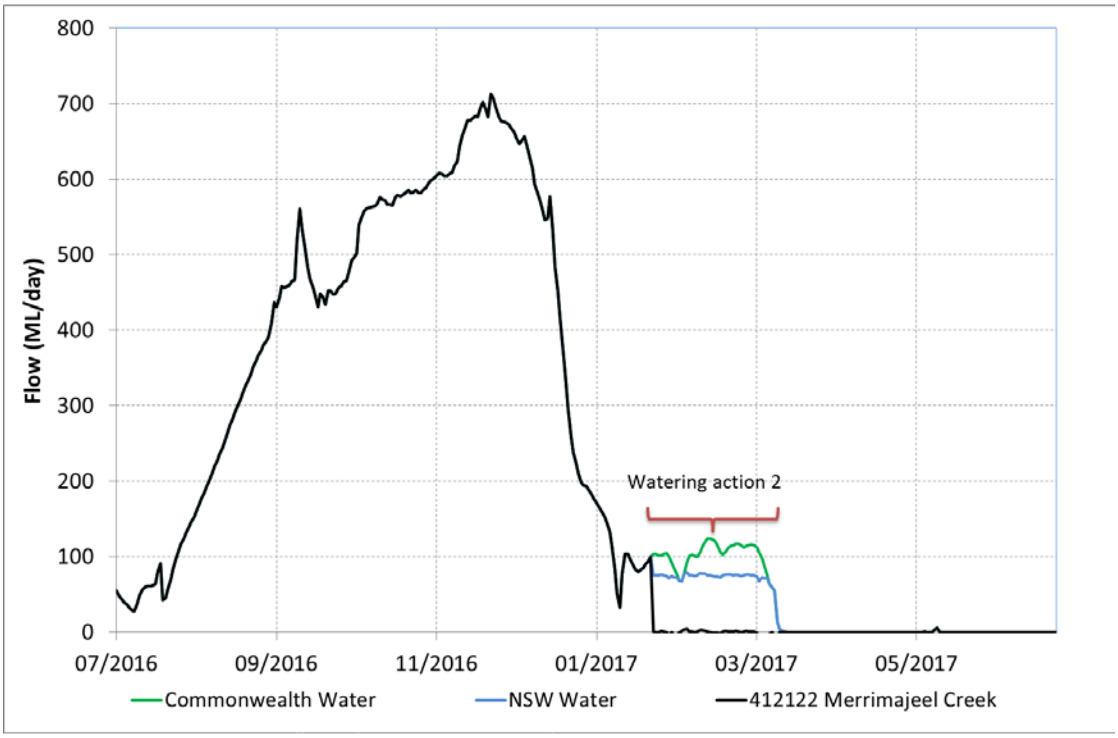

Figure 17. Flow at gauge Merrimajeel Creek (412122) combined showing the delivery of Commonwealth (green) and NSW (blue) environmental water
Creek flow without environmental water (including the licensed delivery of water) is shown in black. Operational notes are also provided.

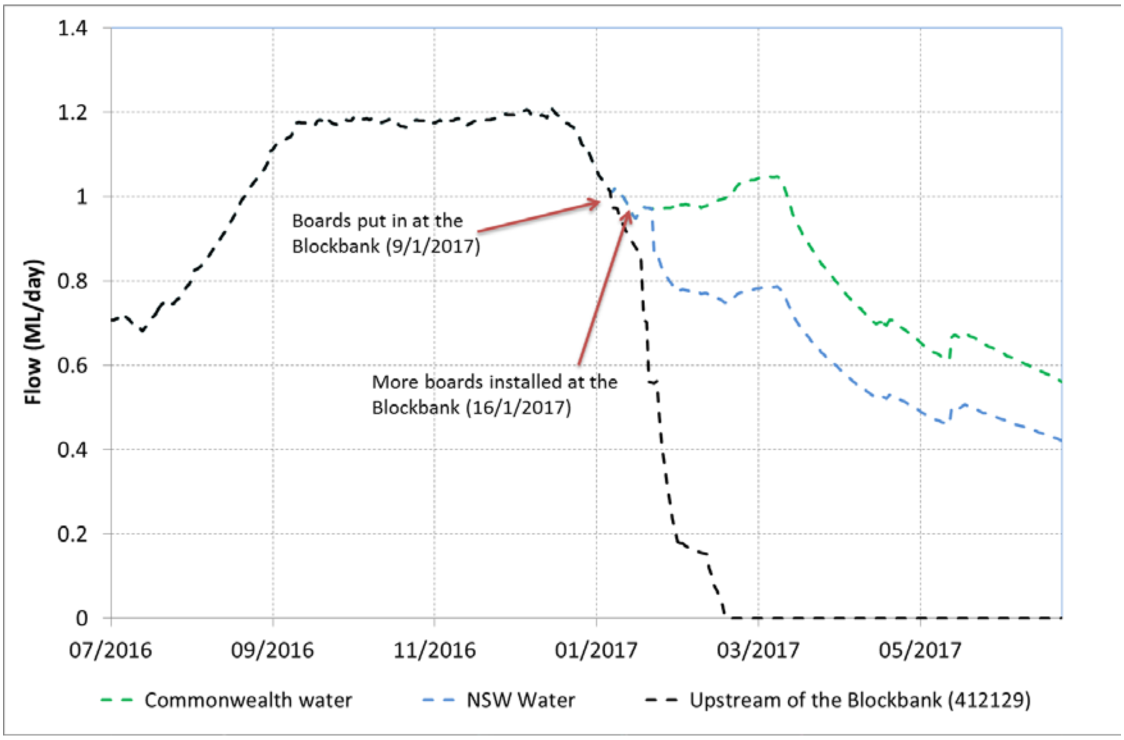

Figure 18. Water level data from the gauge upstream of the Blockbank (412129) showing estimated contributions to water levels from (green) and NSW (blue) environmental water
Estimated water level without environmental water is shown in black. Operational notes are also provided.

8.3.3 FLOOD INUNDATION

Flood mapping was not available at the time of reporting and it is hoped that it will be available for the final version of the report.

All of the monitored sites were inundated, some for extended periods of time and some remain inundated at the end of June 2017. Water extended beyond the extent of the black box. Images taken around the peak of the flooding (December 2017) are provided in Figure 16 and Figure 17

Figure 19. Photos of the flooded Lower Lachlan Selected Area from a flight on the 19th December 2016.
Top left: Whealbah Billabong Top right: Moon Moon Swamp; Middle: Ibis breeding colony at the Blockbank in Booligal wetlands; Bottom left: flooded distributary channels near Booligal; Bottom right: Lake Tarwong. Photos: Fiona Dyer

Figure 20. Photos of the flooded Lower Lachlan Selected Area from a flight on the 19th December 2016. Top: Lake Ita; Middle left: Lake Bullogal; Middle right: flooded channel wetlands near Lake Bullogal; Bottom: Cumbung Swamp. Photos: Fiona Dyer

8.4 EVALUATION

The floods that occurred in 2016-17 completely dominated the Lower Lachlan river system during the 2016-17 watering season. Widespread flooding resulted in the inundation of most of the wetlands across the catchment, many of which were filled for extended periods of time.

In relation to the effects of Commonwealth environmental water, the evaluation questions are addressed as follows:

1) What did Commonwealth environmental water contribute to habitat for native fish, waterbirds, and other water dependent vertebrate species?

Watering Action 2 delivered water to the Booligal wetlands and, in combination with the operation of the Blockbank, extended the duration that water levels were above 0.7 m by around 4 months. The objective was to maintain water levels for the bird breeding colony which had established in late December adjacent the Blockbank. Without the delivery of environmental water and active management of regulating structures, water levels would have dropped below 0.7 m in mid-January, which would have reduced the suitable habitat for the birds, increased the vulnerability of the colony to predation and likely cause abandonment of the nests.

2) What did Commonwealth environmental water contribute to hydrological connectivity?

A natural flood dominated the Lower Lachlan river System in 2016-17 resulting in widespread lateral and longitudinal connectivity. While at an annual scale, the two watering actions delivered in 2016-17 were volumetrically insignificant, at the time of delivery they provided an important contribution to water at the target sites. Both actions provided small freshes of water for water quality (Watering Action 1) and bird breeding outcomes (Watering Action 2). Watering Action 2, which combined the active management the Blockbank as well as the delivery of water, maintained water levels within the bird breeding colony in Booligal wetlands for 4 months, thus providing the lateral connectivity needed to support bird breeding outcomes.

8.4.1 FINAL COMMENTS AND RECOMMENDATIONS

In 2016-17 the Lower Lachlan river system was in flood. This meant that the approach to delivering Commonwealth environmental water changed from the traditional approach of adding missing elements of the hydrological regime to achieve environmental outcomes. Instead the management of Commonwealth water was in response to conditions in the river and the ecological responses observed. The aim was to capitalise on the natural flood event and protect vulnerable ecosystem attributes from the effects of a flood under highly managed conditions. This meant that environmental water was used to modify the outcome of the operation of Wyangala Dam once flood operations ceased.

The first watering action was used to attenuate the adverse effects of a flood passing through Lake Cowal and delivering low dissolved oxygen water to the river. Under natural conditions, the flood in the Lower Lachlan system would have receded slowly with water from upstream of Wyangala Dam maintaining or improving dissolved oxygen levels in the river. The capture of water in Wyangala Dam following flood operations essentially shut off the upstream sections of the river posing a risk for downstream water quality. The volumes of environmental water contributed to modifying the first watering action were small, but they were a significant contribution to flow in the river at the time and delivered positive outcomes for water quality. The outcomes for water quality are explained in more detail in Section 9.

The second watering action addressed the drop in water levels that would have occurred in the Merrimajeel Creek and Booligal wetlands to support a late bird breeding colony. This action maintained water levels in the Booligal wetlands for around 4 months, thus providing the habitat conditions to support bird breeding outcomes. The outcomes for bird breeding are addressed in more details in Section 13.

9 STREAM METABOLISM AND WATER QUALITY

9.1 INTRODUCTION

The energetic base of food webs in freshwater systems is provided either by primary production (the energy fixed by photosynthesis occurring in plants and algae) or by breakdown of organic matter such as leaves, wood and organic carbon dissolved in the water (Bunn et al. 2006). Those processes are both influenced by the availability of key nutrients, particularly nitrogen and phosphorus, and water temperature and light. Primary production (referred to as gross primary production, GPP) and organic matter processing or decomposition (known as ecosystem respiration, ER) can be measured through continuous monitoring of changes in the concentration of oxygen in the water (described as measurements of open channel stream metabolism).

The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (Boulton and Lake 1992, MDFRC 2013, Stewardson et al. 2013).

In this section we evaluate the outcomes of providing Commonwealth environmental water to the Lower Lachlan river system in terms of measured changes in GPP, ER and water nutrients. The 2016-17 watering actions involving Commonwealth environmental water in the Lower Lachlan river system are described in Table 2, page 30.

The first watering action targeted improvements in water quality and delivered 28 168 ML to the Lachlan River targeting improvements in dissolved oxygen levels and provision of in-channel refuge. A further 15 000 ML of water from the Water Quality Allowance (see footnote 1, page 2121) was used to augment this flow. This action targeted the mid Lachlan and was not expected to produce significant water quality benefits in the in the Lower Lachlan river system.

The second watering action delivered 1,324 ML to Merrimajeel Creek targeting the Booligal Wetlands to support habitat requirements for waterbirds, native fish and other water dependent vertebrates. While this action did not have an explicit stream metabolism or water quality target, increased GPP in the main stem of the river system could conceivably increase secondary production and support waterbirds foraging from the Booligal Wetland.

The evaluation in this chapter is focussed on the evaluation questions defined in the Long Term Intervention Monitoring and Evaluation Plan for the Lachlan river system (Dyer et al. 2014).

9.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to patterns and rates of decomposition (ER)?
2) What did Commonwealth environmental contribute to patterns and rates of primary productivity (GPP)?

9.2 METHODS

The evaluation of the stream metabolism and water quality outcomes used a combination of river height data, water quality data and stream metabolism data (dissolved oxygen measurements modelled to calculate GPP and ER).

Sampling occurred at four sites (Wallanthery, Whealbah, Cowl Cowl and Lanes Bridge) (Figure 6) between May 2016 and May 2017. Water quality parameters (dissolved oxygen, temperature, pH, turbidity, conductivity, concentrations of nitrogen and phosphorus) were recorded using a combination of automatic loggers and manual point measures. Dissolved oxygen and temperature were measured using the stream metabolism loggers (see below). Conductivity, pH and turbidity were recorded using a handheld water quality meter. For nitrogen and phosphorus, duplicate water samples were taken 2 m from the water's edge at 1 m depth. These were placed on ice and returned to University of Canberra for analysis for total nitrogen, nitrate/ nitrite, total phosphorus, dissolved reactive phosphorus and ammonia.

Stream metabolism was measured applying the standard methods for the LTIM project. An oxygen logger was installed at each site in the middle of the water column. Dissolved oxygen (DO) and water temperature were logged at 10-min intervals using D-Opto dissolved oxygen sensors (Zebra-Tech, Nelson, New Zealand) and MiniDOT sensors (Precision Measurement Engineering Inc., Vista, USA). Before and after placement, the loggers were put in an O_2 saturated solution and then together in the stream for 1 hr to account for probe drift, and if required, linear corrections were applied prior to metabolism calculations. Photosynthetic active radiation (PAR) was measured in an adjacent unshaded location at 10-min intervals using photosynthetic irradiance loggers (Odyssey, Christchurch, New Zealand). Barometric pressure was logged with a Silva Atmospheric Data Centre Pro (Silva, Sollentuna, Sweden).

Curve fitting was applied using the BASE model (Grace et al. 2015) to estimate primary production and respiration on a daily basis. The version of the model used incorporated a series of updates which have been applied across the LTIM project, and was current at the 1st August 2017.

Curve fits were examined by eye for the influence of any outliers. Where a single outlier was resulting in poor curve fit that data point was removed and replaced by the average of the two adjoining data points. After this process estimates derived from curve fits with $R^2 < 0.6$, and/or R-hats >1.1 and/or CV for GPP of > 50% were discarded.

Because the acceptance criteria above removed large amounts of data, particularly those data associated with high flow events, additional estimates were also reported on with $R^2 > 0.20$, R-hats < 1.5 and CV of GPP < 100%. These are referred to as 'high uncertainty' estimates.

9.3 RESULTS

9.3.1 OVERALL RESULTS

Water temperature showed a typical seasonal pattern, ranging from 10 degrees Celsius in winter, to 30 degrees Celsius in summer, with no clear association with flow events (Figure 21 and Figure 24).

Both pH and turbidity (Figure 21) showed patterns that were indicative of initial dilution of ions and fine sediment associated with the major natural flow event, with somewhat higher levels in December. This may suggest that material is entering the main channel from the floodplain or flood-runners on the declining limb of the hydrograph.

Patterns of salinity show that the system was generally fresh, with no clear association between salinity levels and flow events or actions (Figure 21).

The was clear evidence of increasing concentrations of nitrogen, phosphorus, ammonium and dissolved organic carbon associated with the high natural flow event in the lower Lachlan River in October 2016 (Figure 22).

There was strong evidence for organic carbon entering the channel associated with the natural high flow event (Figure 22), and these levels persisted for at least two months after the high flows receded.

Chlorophyll levels were low but detectable during the natural high flow event, and increased on the receding limb (Figure 22). This flow could reflect algal growth in channel or concentration of algal cells from the floodplain and flood runners into the channel. High levels in-channel in January are likely to reflect in channel algal productivity.

It is possible that high levels of nutrients, carbon and chlorophyll were prolonged by the watering actions, but it is not possible to differentiate the lag effects of the natural flow from the impacts of the watering actions.

Dissolved oxygen was highest in winter, but declined rapidly during the major flood in late 2016, reaching near zero in December 2016 (Figure 23). An increase in oxygen levels from that time was associated both with the reduction in flood volumes and provision of the first watering action. A second low oxygen event occurred in late January.

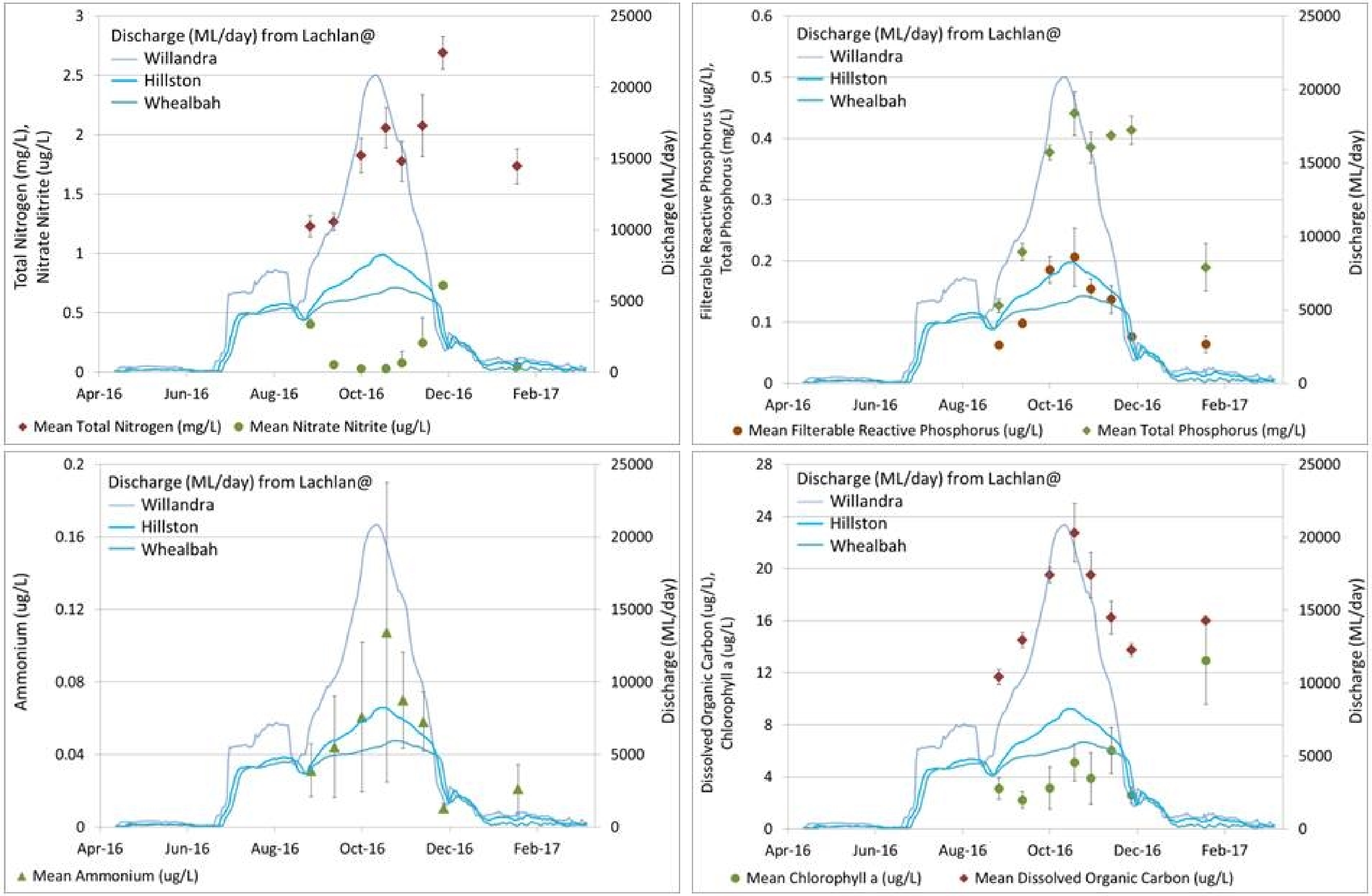

Figure 21. Mean water quality measurements (± standard error) for four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period: physico chemical attributes.

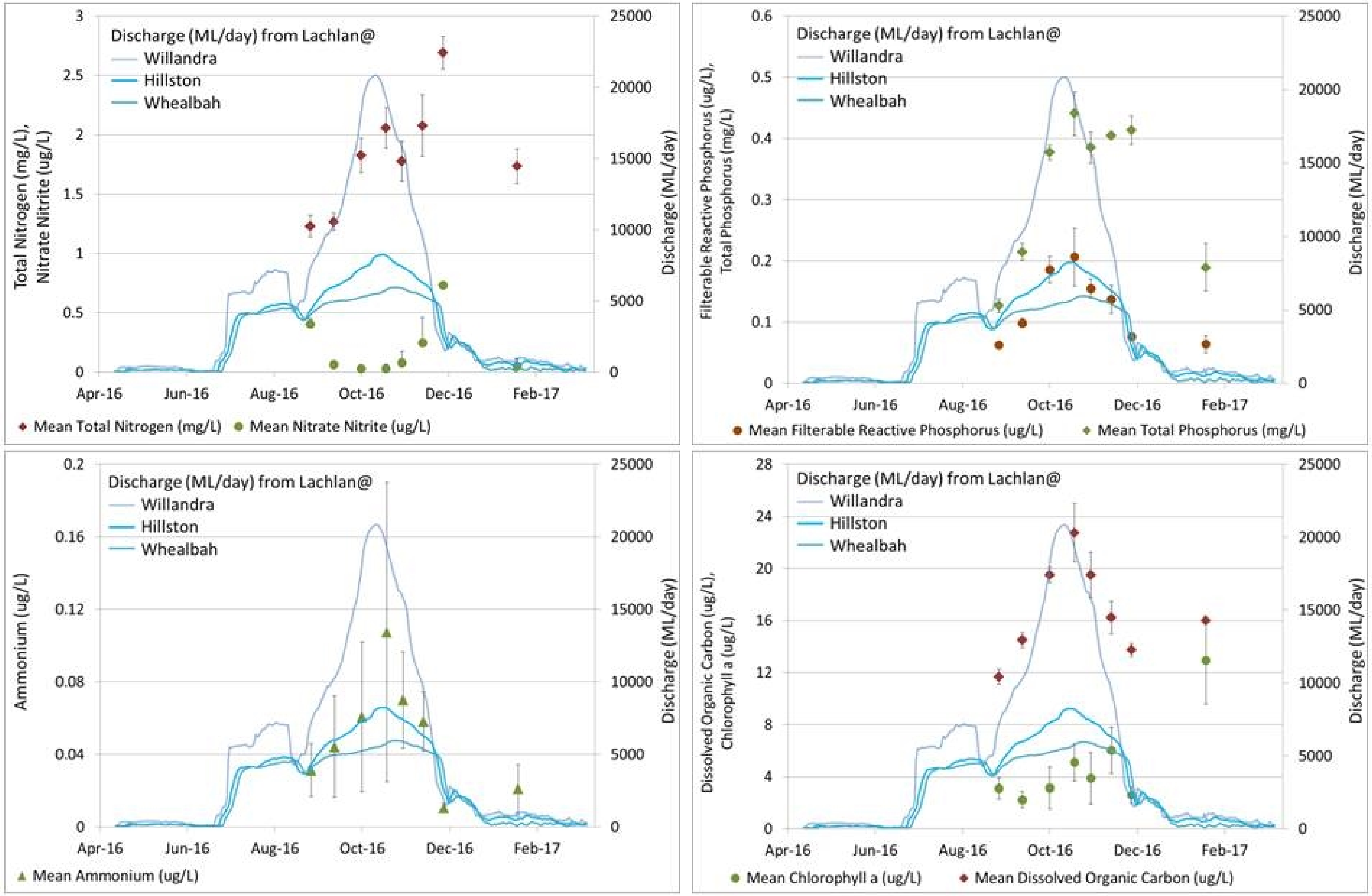

Figure 22. Mean water quality measurements (± standard error) for four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period: nutrients and chlorophyll a.

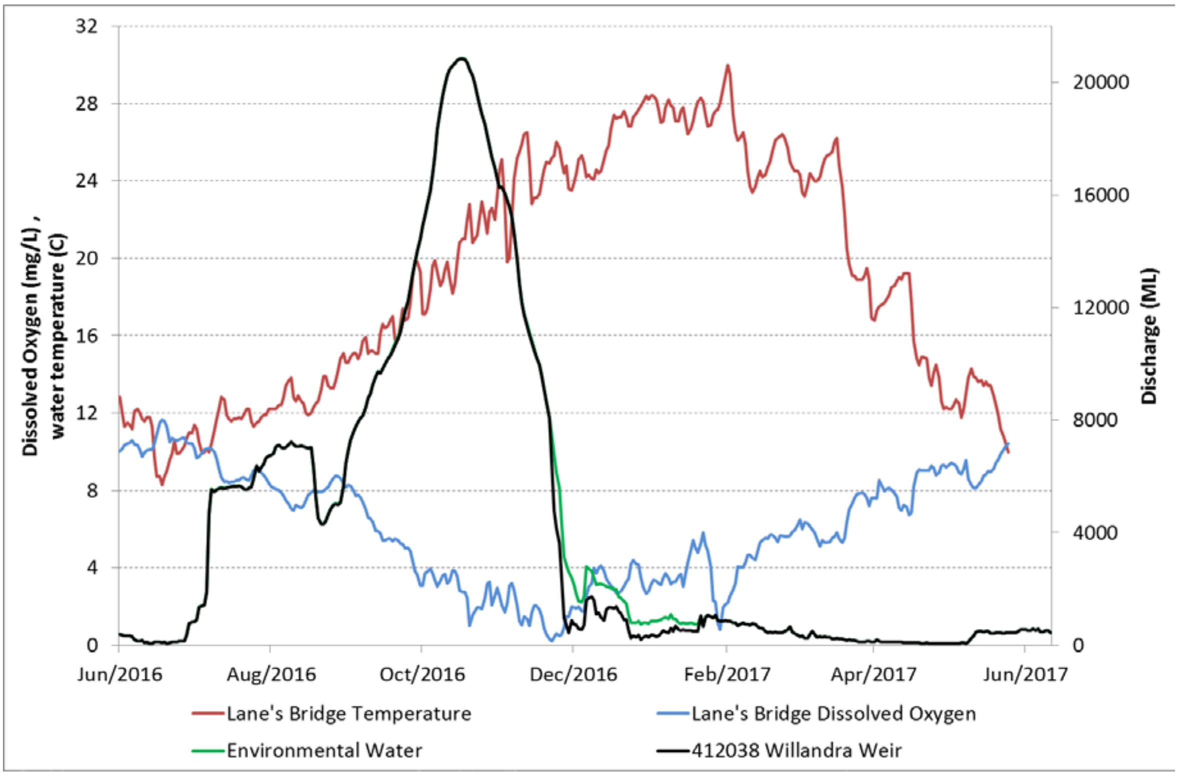

Figure 23. Dissolved oxygen and temperature recorded at Lane's Bridge and flow at the gauge upstream of Willandra Weir (412038).
The combination of Commonwealth and NSW environmental water is shown in green along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in black.

Table 8. Stream metabolism data obtained from the four sites on the Lower Lachlan river system May 2016 to May 2017. Shown is the number of logged days of oxygen data for each site (data days) and data days for which a GPP/ER estimate could be modelled under the standard acceptance criteria and under the 'high uncertainty' criteria,

	Wallanthery	Cowl Cowl*	Whealbah*	Lanes Bridge	sum
Data days collected	No data	73	249	358	680
Estimate obtained (standard criteria)	No data	51%	29%	37%	
Estimate obtained (high uncertainty)	No data	74%	43%	45%	
Data obtained (standard criteria)	No data	37	73	131	241
Data obtained (high uncertainty)	No data	54	160	109	323

* no data available from Cowl Cowl after August 2016 and Whealbah after January 2017

Very high flows occurred over the sampling period and all data from the Wallanthery site was lost as a consequence of loggers being dislodged. Loggers were also lost or inaccessible from the Cowl Cowl site from August 2016 and Whealbah from January 2017. A full set of data was only obtained from the Lanes Bridge logger we got a full set of data. From the three sites (Whealbah, Cowl Cowl and Lanes Bridge), there were 680 days of data collected. Of those, 241 estimates of GPP/ER were possible using the standard acceptance criteria, with an additional 82 days added when the ‘high uncertainty’ criteria were applied (Table 8).

Time series plots of GPP and ER are shown in Figure 24 and Figure 25. Because of the scale of the large flood event, results are also shown on a logarithmic scale. The large flood event, particularly the rising limb of the flood was strongly associated with the failure of the model to obtain estimates of GPP and ER. The high uncertainty estimates available do suggest that GPP increased with the rising limb of the flood, and that ER declined, although the values obtained are exceptionally high and must be treated with caution. There was a general trend towards higher rates of GPP and ER moving into summer, likely as a consequence of increased water temperatures.

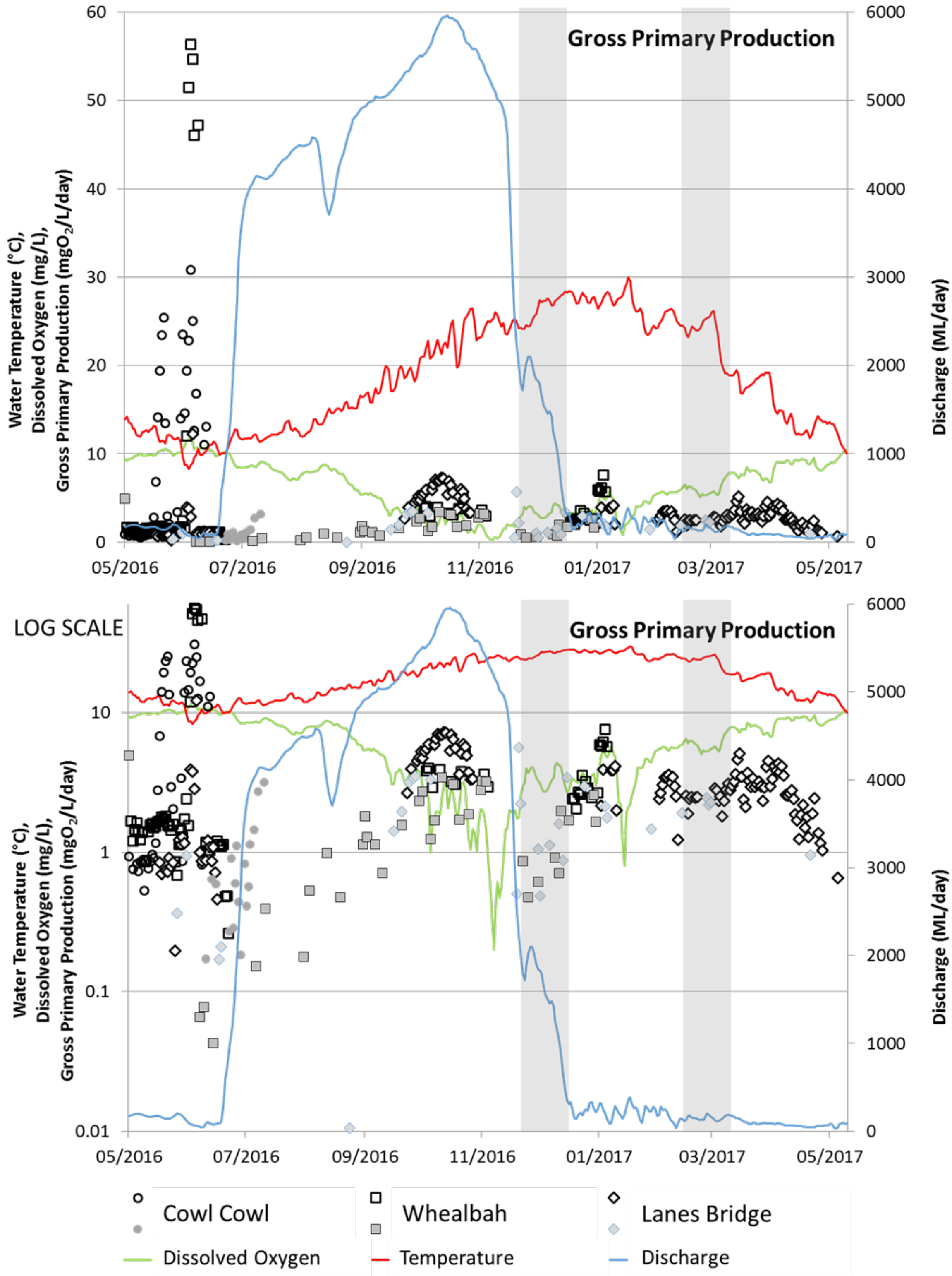

Figure 24. Gross primary production from three sites in the Lower Lachlan river system, May 2016-May 2017.
The top panel has dissolved oxygen, temperature and gross primary production on a normal scale, in the lower panel those parameters are on a log scale. Grey shaded vertical bars indicate watering actions. Symbols for each site are modelled gross primary production values using standard (open symbols) and high uncertainty (grey symbols) criteria.

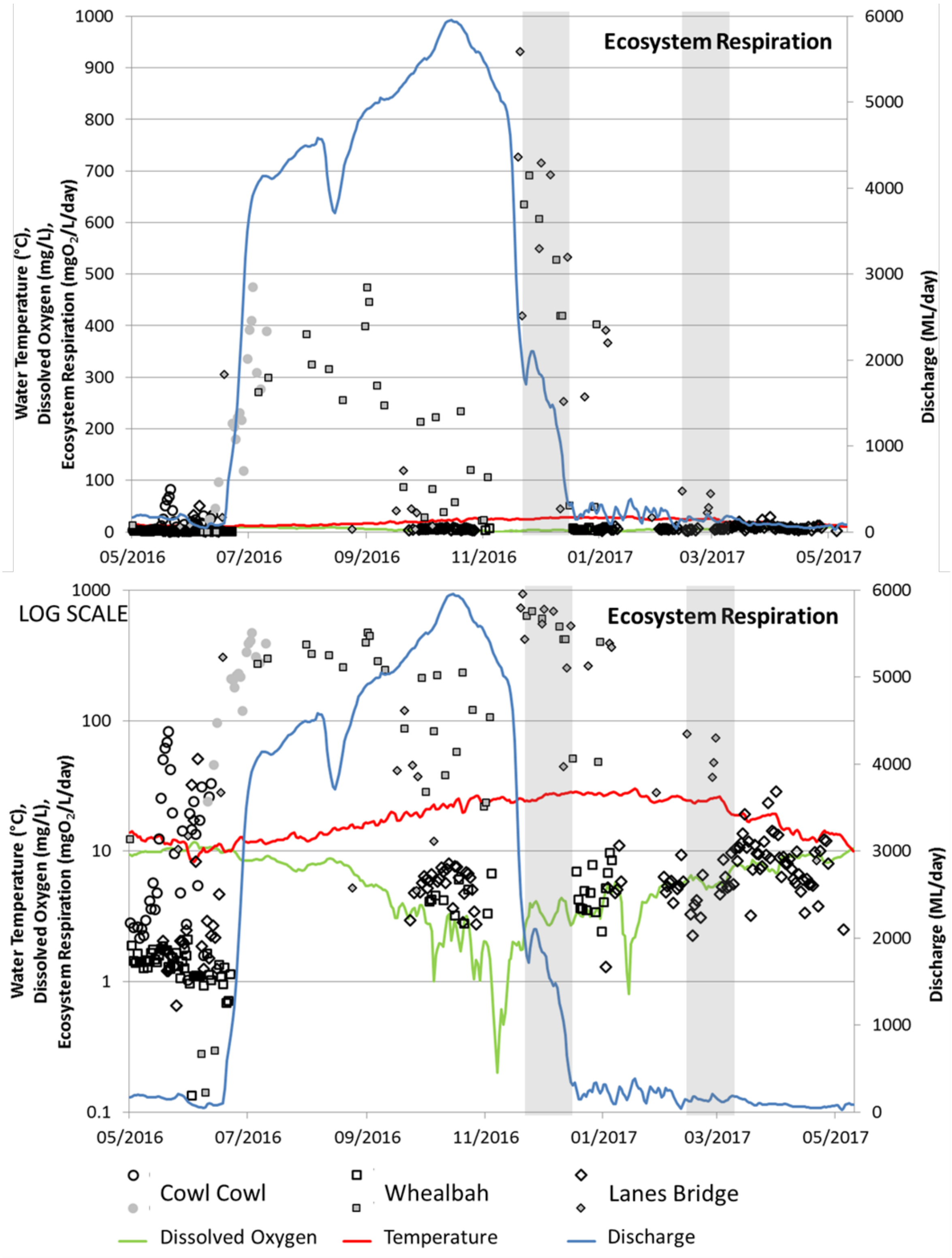

Figure 25. Ecosystem respiration from three sites in the Lower Lachlan river system, May 2016-May 2017.

The top panel has dissolved oxygen, temperature and ecosystem respiration on a normal scale, in the lower panel those parameters are on a log scale. Grey shaded vertical bars indicate watering actions. Symbols for each site are modelled gross primary production values using standard (open symbols) and high uncertainty (grey symbols) criteria.

9.3.2 WATERING ACTION 1

Watering action 1 was released from Wyangala Dam on the 4th November and is expected to have arrived at Willandra Weir and Lane's Bridge in early December. This is coincident with an increase in DO at those sites (Figure 23). It then appears that the cessation of environmental water coincides with a drop in DO concentrations. During the same period water temperatures reaching 30 degrees, which is also likely to have influenced DO levels.

Other fluctuations in water delivery are not well matched to the patterns in the dissolved oxygen concentrations. By the time it reaches Willandra Weir and Lane's Bridge, the environmental water had been resident in the river for 30 days and had been mixed with very low DO water from Lake Cowal and return flows from the floodplain. Thus while it would seem that there may be a slight improvement in DO concentrations with the arrival of the environmental water, the evidence is not strong. There was no discernible effect of this watering action on other measures of water quality (Figure 21 and Figure 22) gross primary production (Figure 24) or ecosystem respiration (Figure 25).

9.3.3 WATERING ACTION 2

Watering Action 2 commenced at Merrimajeel Creek on the 25th January 2017 and continued until the 17th March 2017. Environmental water provided the majority of the flow in the creek at this time. This watering action maintained water levels upstream of the Blockbank above 0.9 m until the 25th March and above 0.7 m until the 28th April after which water levels slowly dropped to below 0.6 m at the end June.

There was some evidence for a minor increase in ecosystem respiration (Figure 25) associated with this watering event, which may reflect mobilisation and processing of organic matter from the river margins or from upstream. There was no discernible effect of this watering action on measures of water quality (Figure 21 and Figure 22), oxygen concentrations (Figure 23) or gross primary production (Figure 24).

9.3.4 COMPARISONS WITH PREVIOUS YEARS

Figure 26 and Figure 27 compare the relationships between gross primary production and ecosystem respiration with flow for the three years sampled to date. The much larger magnitude of the 2016/2017 natural flows events is clearly evident, and it appears that higher natural flows are related to higher overall channel productivity. Ecosystem respiration in particular (Figure 25) was considerably higher in the most recent year of sampling, and this appears likely to be associated with organic matter mobilised and processed as a consequence of high natural flows.

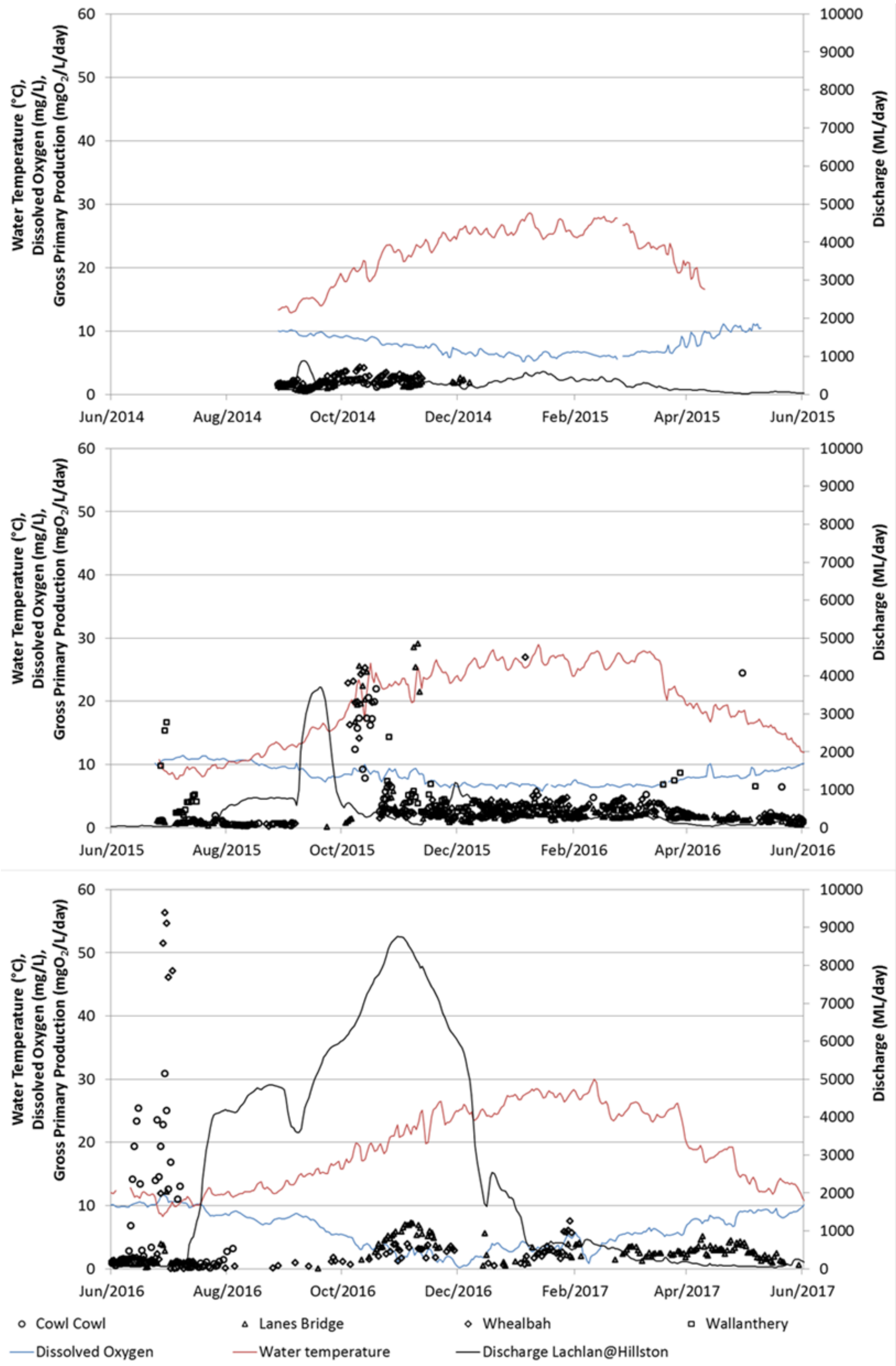

Figure 26. Gross primary production from four (2014/15 and 2015/16) and three (2016/17) sites across three years in the Lower Lachlan river system, relative to water temperature, dissolved oxygen and river discharge.
Symbols for each site are modelled gross primary production values using standard.

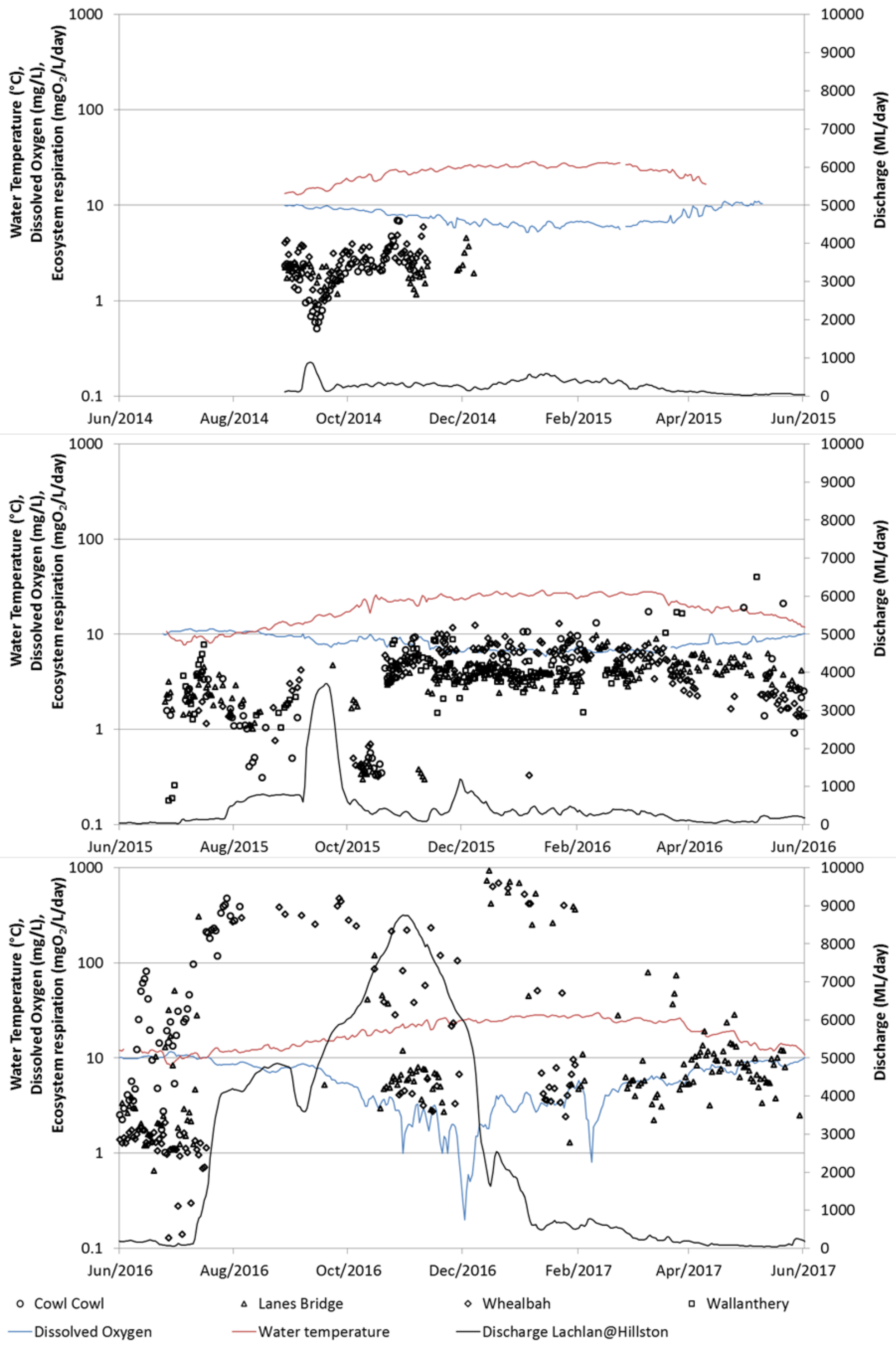

Figure 27. Ecosystem respiration (on a log scale) from four (2014/15 and 2015/16) and three (2016/17) sites across three years in the Lower Lachlan river system, relative to water temperature, dissolved oxygen and river discharge.
Symbols for each site are modelled ecosystem respiration values.

9.4 DISCUSSION

The sampling period was dominated by an extremely large flow event which is likely to have had substantial effects on movement and processing of carbon in the system. This is reflected by high levels of nutrients and carbon in the channel during and after this flow, indicative of inputs from the floodplain and flood runners. The exception to this is the relatively low nitrate/nitrite levels mid-flow, which may have limited algal productivity at the peak of the natural flow event. On the receding limb of the high flow event there were high levels of bio-available phosphorus and nitrogen, and in combination with water temperatures, this is likely to explain the high levels of chlorophyll post flow event.

The arrival of water from Watering action 1 is expected to have occurred at Willandra Weir and Lane's Bridge in early December and was coincident with an increase in DO at those sites. Between 30 and 60% of the water in the river at Willandra Weir between the 6th December and the 30th January was environmental water, so it is possible that there was some beneficial effect for dissolved oxygen. The cessation of environmental water coincided with a drop in DO concentrations in the river, but was also correlated with an increase in water temperatures. Thus while it would seem that there may be a slight improvement in DO concentrations with the arrival of the environmental water, the evidence is not strong.

The natural flow event resulted in the loss of metabolism data from two sampling locations. There was some evidence from the remaining sites that the large natural flood was associated with increased primary production, and rates were slightly higher than those recorded in previous years. As in previous years, a very large number of days were not able to be fitted for oxygen curves. This appears to be a consequence of high reaeration due to physical processes at anything above low flows, resulting in a failure of curve fits in the night time section of the curve.

As in previous years, curve fits for the BASE model were poorest when flow was highest, leading to a lack of estimates of metabolism during high flow events. Relaxing the acceptance criteria for the model did provide some additional data during these critical times, and suggested that primary production may have increased during the flood, and ecosystem respiration decreased. However many of the estimates generated for both GPP and ER were unrealistically high. This appears to be a consequence of very high values for K, suggesting that the dominant process is physical reaeration, effectively 'drowning out' the ecological signals. These data have been retained, but need to be viewed with extreme caution. Omitting these data removes any clear association between provision of flows and increases in GPP.

It is possible that high levels of carbon and chlorophyll were prolonged by the watering actions, but it is not possible to differentiate the impact of these actions from the lag effects of the natural flow. There was little evidence for any effect of the watering actions on GPP or ER.

The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (e.g. Baldwin et al. 2016, Wallace and Furst 2016). Natural flooding, which is most often larger in spatial scale than environmental flows can also mobilise excess carbon and nutrients through floodplain inundation, and in situations where water temperatures are high, can generate hypoxic blackwater (e.g King et al. 2016). Blackwater can have substantive negative effects on aquatic fauna (e.g. King et al. 2016, Thiem et al. 2017), and may require use of environmental flows to dilute low oxygen water and protect biota (Conallin et al. 2017, Watts et al. 2017, Wolfenden et al. 2017). In 2016, the major flood in the Lachlan resulted in observations of very low dissolved oxygen concentrations, and environmental flows were applied in order to manage these impacts.

10 FISH COMMUNITY

10.1 INTRODUCTION

Fish are an integral component of aquatic ecosystems and have been used as an indicator of aquatic ecosystem health in several large river health monitoring programs in south-east Australia The advantages of using fish as indicators of aquatic ecosystem condition include; i) fish are relatively long-lived and mobile, so reflect both short and longer-term and local to catchment scale processes, ii) they occupy higher trophic levels within aquatic ecosystems and, in turn, directly impact lower trophic level organisms, iii) they are relatively easily and rapidly collected and can be sampled non-destructively, iv) they are typically present in most waterbodies, and v) biological integrity of fish assemblages can be assessed easily and interpretation of indicators is relatively intuitive (Harris 1995). Further, as fish have a high public profile, with significant recreational, economic and social values, they foster substantial public interest (MDBC 2004)

Historically, 14 species of native fish are believed to have occurred in the Lower Lachlan river system (Dean Gilligan, NSW DPI, *unpublished data*). Recent monitoring indicates that 10 of these species are still present, leaving four species either locally extinct of extremely rare (NSW DPI, *unpublished data*). These four species include the flat-headed galaxias (*Galaxias rostratus*), southern pygmy perch (*Nannoperca australis*), southern purple spotted gudgeon (*Mogurnda adspersa*) and the Murray-Darling rainbowfish (*Melanotaenia fluviatilis*). Of the 10 extant species, olive perchlet (*Ambassis agassizii*), silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*) are at very low abundance and/or have a very restricted distribution. Only two species; carp-gudgeons (*Hypseleotris* spp.) and bony herring (*Nematalosa erebi*) could be considered widespread and abundant.

Flow plays an important role in the life-cycle of native fishes from larval through to adult life stages. Water may inundate habitat needed for reproduction, triggering a spawning response, create a boost in primary production that improves recruitment success, improve habitat condition through maintaining natural geomorphic processes or stimulate in-stream migration. River channel dependent species require flow triggers to initiate spawning (i.e. golden perch *Macquaria ambigua* and silver perch), and recruitment success may be heavily dependent on nutrient inputs to the river channel following overbank flows. The seasonality of these flow triggers is critically important. Further, sediment transport and scouring during high flow events is essential for the maintenance of deep pools and the input of large wood habitat. Freshes also provide movement triggers and facilitate longitudinal connectivity within the system. Persistence of these species is dependent on the provision of natural spawning triggers and subsequent boosts in primary production to facilitate successful recruitment as well as longitudinal connectivity within the river channel network. For all fish species, access to high quality refugia during drought is critically important for ecosystem resilience, as unlike vegetation, many species of invertebrates, waterbirds and turtles, fish have no mechanisms to cope with the loss of water for even very brief periods of time.

The objectives of the 2016-17 watering action relating to native fish were to:

- improve dissolved oxygen levels and maintain in-channel refuge
- provide opportunities for native fish and other aquatic animals to move from the floodplain to the river channel minimising stranding;

To assess the contribution of Commonwealth environmental water to the fish community, the relevant short term and long term questions to be evaluated are:

Short-term (one-year) questions:

- What did Commonwealth environmental water contribute to native fish community resilience?
- What did Commonwealth environmental water contribute to native fish survival?

Long-term (five-year) questions:

- What did Commonwealth environmental water contribute to native fish populations?
- What did Commonwealth environmental water contribute to native fish diversity?

In 2016-17, the aim of this component of the Lachlan LTIM Project was to assess changes in the fish community in terms of its abundance, biomass and community health in the Lower Lachlan river system Selected Area, and so provide a basis for determining changes in relation to environmental water. The current study reports on the third year of the five-year Long Term Intervention Monitoring Project.

10.2 METHODS

Fish community data was collected from 10 in-channel sites in the Lower Lachlan river system Selected Area, from Wallanthery to Hillston (Figure 23). All sites were randomly selected for this study, or had previously been randomly selected as part of another study (i.e. SRA; Davies et al. 2008, 2012). Sampling was undertaken in March 2017, and each site was sampled once using a suite of passive and active gears including boat-electrofishing (*n*=32 operations, each consisting of 90 seconds 'on-time'), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). Additionally, large fyke nets were used at each site to target freshwater catfish (n=4). Decapods (prawns, shrimps and yabbies) were also surveyed and these were sampled using baited opera house traps (n=5).

All captures (fish and other non-target taxa) were identified to species level and released onsite, with the exception of the periodic species bony herring which were retained for annual ageing (n=100) (Hale et al. 2014). Individuals were measured to the nearest mm and weighed to the nearest gram. Where large catches of particular species occurred, a sub-sample of individuals was measured and examined for each gear type. The sub-sampling procedure consisted of firstly measuring all individuals in each operation until at least 50 individuals had been measured in total. The remainder of individuals in that operation were also measured, although any individuals of that species from subsequent operations of that gear type were only counted. Fish that escaped capture, but could be positively identified were also counted and recorded as "observed".

Total catch was pooled for all sites and methods, with the exception of calculation of SRA metrics where the first 12 electrofishing shots and bait trap data were used by Davies et al. (2010). To determine differences between years (2015, 2016 and 2017) abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of (PERMANOVA, Anderson et al. 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between years.

Sustainable Rivers Audit (SRA) fish community condition indices (Expectedness, Nativeness, Recruitment) were calculated to quantify overall condition of the fish community assemblage. Data were first portioned into recruits and non-recruits. Large-bodied and generally longer lived species (maximum age >3 years) were considered recruits when length was less than that of a one year old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 9). Eight fish metrics were calculated using the methods described by Robinson (2012). These metrics were subsequently aggregated to produce three indicators (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition index. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) (Davies et al. 2010, Carter 2012)

Table 9. Size limits used to distinguish new recruits for each species.
Values represent the length at one year of age for longer-lived species or the age at sexual maturity for species that reach maturity within one year.

SPECIES	ESTIMATED SIZE AT 1 YEAR OLD OR AT SEXUAL MATURITY (FORK OR TOTAL LENGTH)
Native species	
Australian smelt	40 mm (Pusey et al. 2004)
bony herring	67 mm (Cadwallader 1977)
carp gudgeon	35 mm (Pusey et al. 2004)
flatheaded gudgeon	58 mm (Pusey et al. 2004, Llewellyn 2007)
freshwater catfish	83 mm (Davies 1977)
golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, *unpublished data*)
un-specked hardyhead	38 mm (Pusey et al. 2004)
Alien species	
common carp	155 mm (Vilizzi and Walker 1999)
eastern gambusia	20 mm (McDowall 1996)
Goldfish	127 mm(Lorenzoni et al. 2007)

The Expectedness index is the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. The index value is derived from two input metrics; the observed native species richness relative to the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). The Nativeness index is the proportion of native compared to alien fishes, and is derived from three input metrics; proportion of total biomass that is native, proportion of total abundance that is native and proportion of total species richness that is native (Robinson 2012). The Recruitment index represents the recent reproductive activity of the native fish community, and is derived from three input metrics; the proportion of native species showing evidence of recruitment, the average proportion of sites at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indicators are aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition is then partitioned into five equal categorical bands to rate the condition of the fish community as "Good" (80–100), "Moderate" (60–79), "Poor" (40–59), "Very Poor" (20–39), or "Extremely Poor" (0–19).

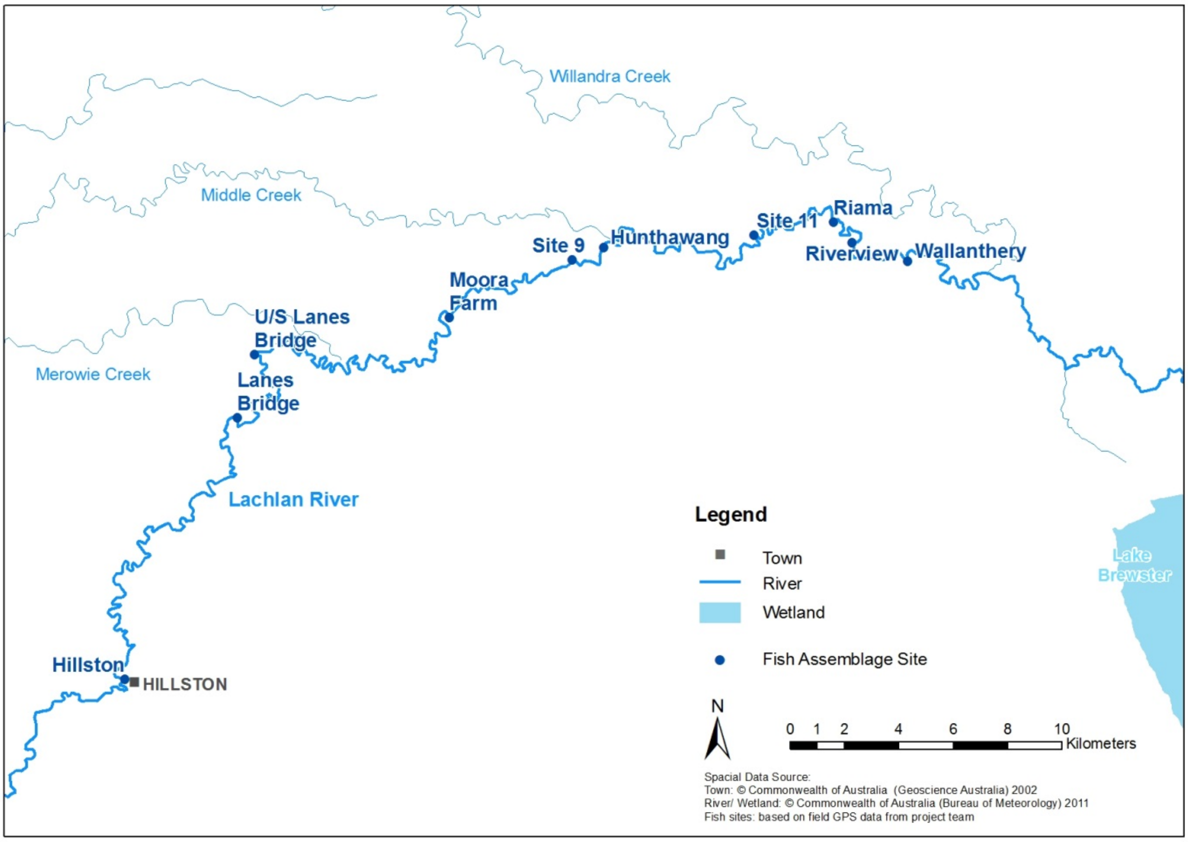

Figure 28. Location of riverine fish sampling sites on the Lachlan River.

10.3 RESULTS

A total of 9,216 fish comprising seven native and four alien species were captured across 10 in-channel sampling sites in 2017 (Table 10). In order, common carp (*Cyprinus carpio*), bony herring, eastern gambusia (*Gambusia holbrooki*), carp gudgeon (*Hypseleotris* spp.), golden perch and goldfish were the most abundant species, respectively (Table 10; Figure 24). In order, common carp, golden perch, Murray cod and bony herring contributed the greatest overall biomass in 2017, respectively (Figure 25).

New recruits (juveniles) were detected in one native longer-lived species at multiple sites (bony herring (at 9 of 10 sites); Figure 24; Figure 26), and three native short-lived species (Australian smelt (5 of 6 sites), carp gudgeon (10 of 10 sites) and flatheaded gudgeon (2 of 2 sites); Figure 24; Figure 26). No golden perch or Murray cod new recruits were captured (Figure 24; Figure 26). New recruits of three alien species were captured (common carp

(*Cyprinus carpio*) (10 of 10 sites), goldfish (*Carassius auratus*) (7 of 8 sites) and eastern gambusia (*Gambusia holbrooki*), (10 of 10 sites); Figure 24; Figure 26).

Sustainable Rivers Audit indices varied substantially in the target reach. Nativeness rated "Very Poor" (mean ± SE score: 35.5 ± 3.7), Expectedness was "Poor" (45.2 ± 3.2) and Recruitment was "Poor" (39.9; zone metric). The Overall Condition of the fish community is rated "Very Poor" (30.0 ± 2.3) (Table 11).

There were significant differences in the abundance ($Pseudo\text{-}F_{2, 27}$ = 10.050, P <0.001) of the fish community among years. Pair-wise comparisons indicated that the differences in abundance were between 2015 and 2017 (t=4.288, P<0.001) as well as 2016 and 2017 (t=3.496, P<0.001), but not between 2015 and 2016 (t=1.316, P=0.144). These differences were driven by higher abundances of native carp gudgeon in 2017 (73% increase in mean catch per site compared with 2016), alien common carp (3670% increase in mean catch per site), eastern gambusia (90% increase in mean catch per site) and goldfish in 2017 (164% increase in mean catch per site) and a lower abundance of Murray cod in 2017 (80% decrease in mean catch per site) (Table 12; Figure 29).

Similarly, differences in biomass occurred among years ($Pseudo\text{-}F_{2, 27}$ = 6.419, P <0.001), with these differences between 2015 and 2017 (t=2.939, P<0.001) as well as 2016 and 2017 (t=3.019, P<0.001), but no differences in biomass occurred between 2015 and 2016 (t=1.237, P=0.197). Differences in biomass were driven by reduced biomass of native Murray cod (70% decrease in mean biomass per site in 2017 compared with 2016) and golden perch (25% decrease in mean biomass per site in 2017 compared with 2016), and a higher biomass of common carp (498% increase in mean biomass per site in 2017 compared with 2016) and goldfish (346% increase in mean biomass per site in 2017 compared with 2016) (Table 12; Figure 30).

Table 10. Total (non-standardised) catch from the Lower Lachlan river system target reach. Sampling was undertaken in autumn 2017 using a combination of five sampling gear types.

	SAMPLING METHOD					
COMMON NAME	BOAT ELECTROFISHING	SMALL FYKE NET	LARGE FYKE NET	BAIT TRAP	OPERA HOUSE TRAP	TOTAL
Fish (*native species)*						
Australian smelt	8	1				**9**
bony herring	2,115	5	16			**2,136**
carp gudgeon complex	4	343		9		**356**
flatheaded gudgeon	1	1				**2**
freshwater catfish						
golden perch	77		14			**91**
Murray cod	19					**19**
un-specked hardyhead	14					**14**
Fish *(alien species*						
common carp	3,990	835	236	5	325	**5,391**
eastern gambusia	161	978				**1,139**
goldfish	55	1	2			**58**
redfin perch		1				**1**
Turtles						
long-necked turtle		1	1			**2**
Murray River turtle						
Decapods						
freshwater prawn		10 466	52	292	100	**10 910**
freshwater shrimp		69		5		**74**
freshwater yabby	2	188	37	11	136	**374**

Table 11. Summary of SRA fish indices over the three LTIM sampling years in the Lachlan River.

	Nativeness	Expectedness	Recruitment	Overall Condition
2015	Good	Very poor	Extremely poor	Very poor
2016	Good	Poor	Very poor	Very poor
2017	Very poor	Poor	Poor	Very poor

Table 12. Contributions of fish species abundance and biomass to variability among years in the Lachlan River, determined through SIMPER analysis.
Note that only species contributing ≥10% (dissimilarity) to changes in community composition are included. Comparisons between 2015 and 2016 are not included as there were no significant differences in abundance or biomass.

Indicator	Year comparison	Species	Contribution to difference (%)	Year with greater value
Abundance	2015-2017	common carp	28	2017
		eastern gambusia	13	2017
		Murray cod	13	2015
		carp gudgeon	11	2017
		goldfish	10	2017
	2016-2017	common carp	29	2017
		carp gudgeon	11	2017
		goldfish	11	2017
Biomass	2015-2017	Murray cod	34	2015
		common carp	20	2017
		golden perch	12	2015
		goldfish	11	2017
	2016-2017	Murray cod	28	2016
		common carp	27	2017
		goldfish	12	2017
		golden perch	10	2016

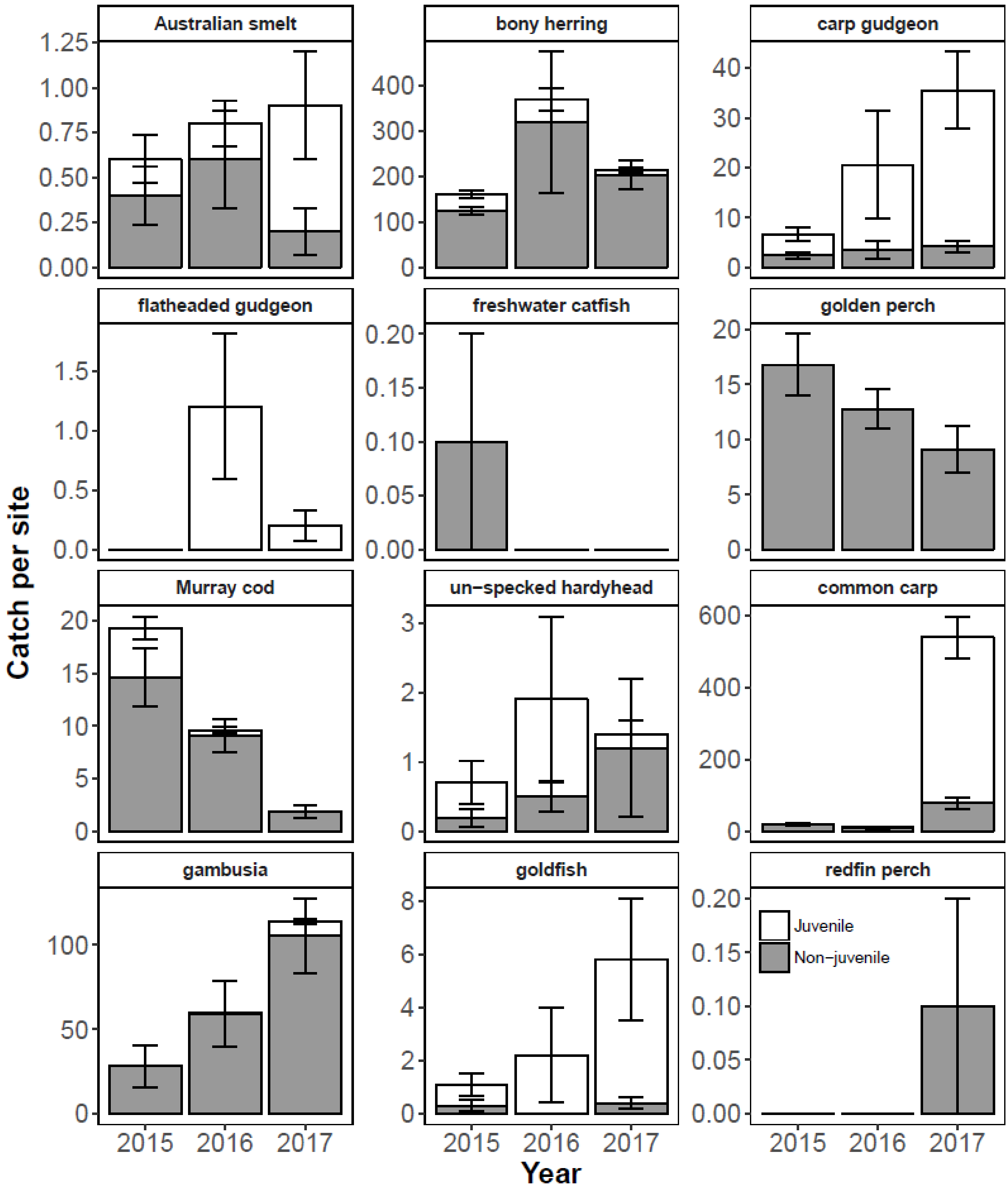

Figure 29. Catch per site (number of fish; mean ± SE) of each fish species within the Lower Lachlan river system target reach sampled in 2015, 2016 and 2017.

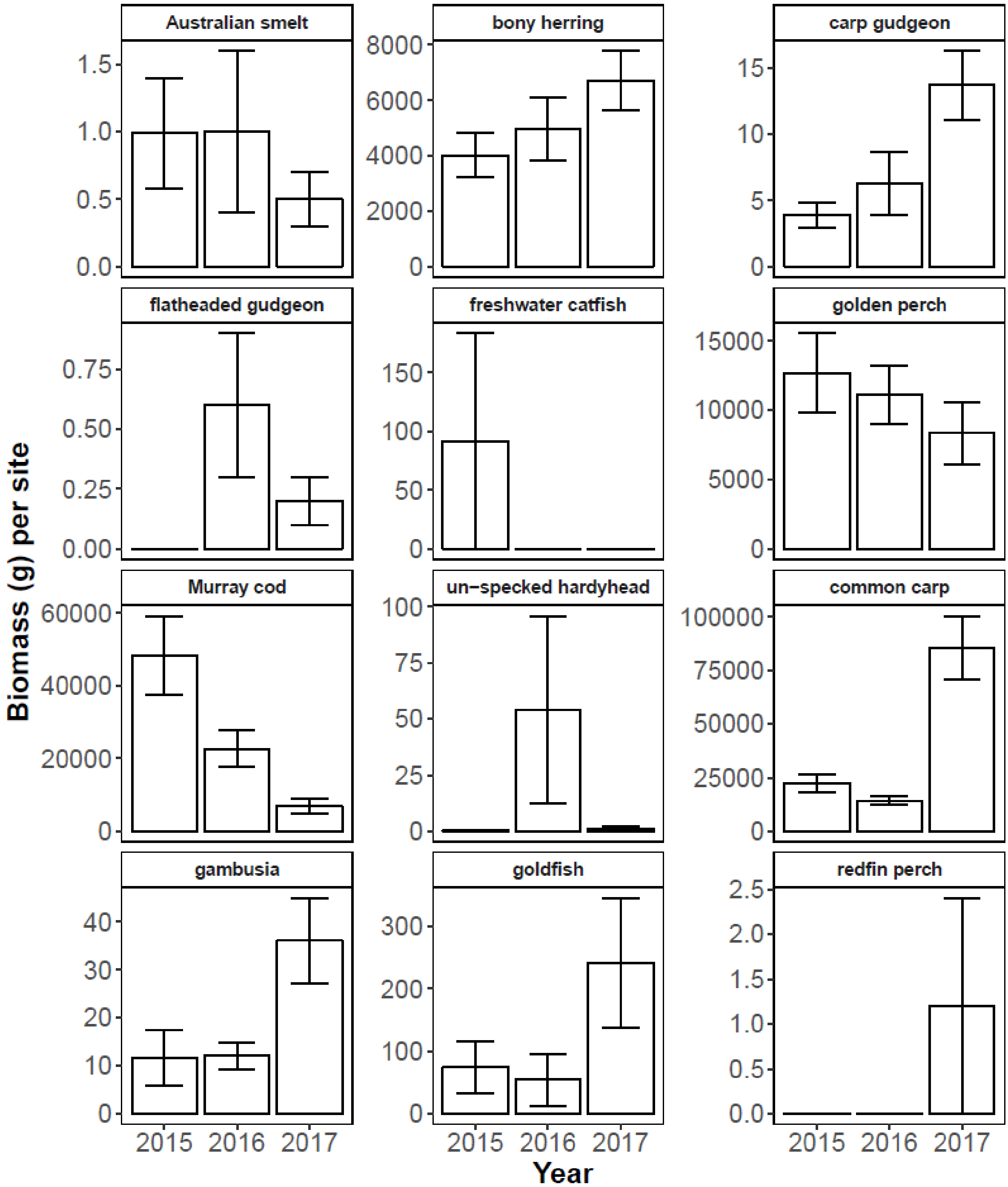

Figure 30. Biomass per site (g; mean ± SE) of each fish species within the Lower Lachlan river system target reach sampled in 2015, 2016 and 2017.

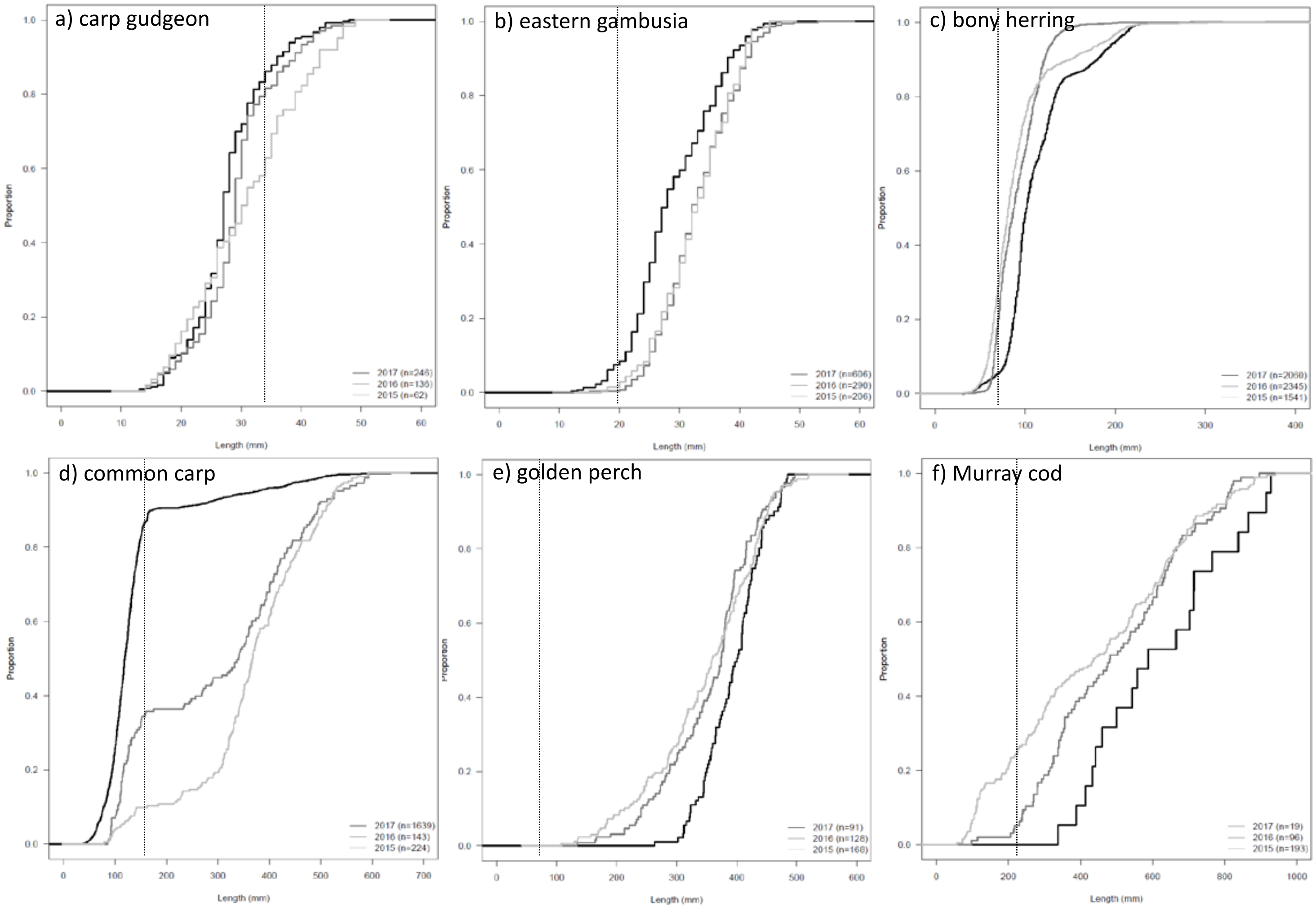

Figure 31. Proportionate length-frequencies of the six most abundant species captured in the Lachlan River in 2015 and 2016. The dashed line indicates approximate size limits used to distinguish new recruits for each species (see Table 9)

10.4 BY-CATCH

A total of two turtles were captured during fish community monitoring, both of these were long-necked turtles (Table 10). Freshwater shrimp and prawns were the most abundant taxa in small mesh fyke nets and bait traps (Table 10). Only a small number of Yabbies were captured across the 10 monitoring sites (Table 10).

10.5 DISCUSSION

The current study resulted in the capture of seven native species of freshwater fish in the Lachlan Selected Area in 2017. Freshwater catfish were not captured in 2017 despite additional targeted sampling for this species using large fyke nets. Two native species, Murray-Darling rainbowfish and silver perch, although presumed to have been historically common in lowland sections of the Lachlan Basin are now rarely encountered within the target reach and were not detected in the current study. Consistent with previous results, four native fish species (flathead galaxias, olive perchlet, southern purple spotted gudgeon and southern pygmy perch) which were historically present, were not detected in 2017. Of these, olive perchlet is the only species to have been recently detected (Wallace and Bindokas 2011, DPI Fisheries, *unpublished data*). Despite the absence of a number of native species, the native species richness in the Lachlan Selected Area is generally higher than in other parts of the catchment.

Based on the use of SRA metrics, the native fish community composition generally stayed in the same Overall Condition (very poor) compared with the previous years. New recruits of one longer-lived species (bony herring) and a number of smaller native species increased the Recruitment score from previous years. However, Nativeness, which reflects a key measure of the proportional abundance and biomass of native compared with alien species, declined from Good in 2015 and 2016 to Very poor in 2017. This result partially reflects a reduced abundance (and subsequent biomass) of large long-lived species such as golden perch and Murray cod. The result is also reflective of an increased abundance of alien common carp and the associated increased biomass. Native carp gudgeon, a small-bodied opportunistic species were the only native species to respond positively (in comparison to previous years) to the hydrological conditions in 2016-17. The positive response exhibited by common carp is unsurprising as previous positive responses by common carp to flooding in other parts of the Murray-Darling Basin have been well documented (e.g. Bice et al. 2014). A number of behavioural and physiological traits, including a wide range of environmental tolerances, ability to rapidly colonise habitats and high reproductive output, enable common carp to dominate freshwater fish communities in the Murray-Darling Basin (Koehn 2004).

Conversely, a number of native species such as Murray cod, golden perch and freshwater catfish are particularly susceptible to poor water quality. For example, the observed concentrations of dissolved oxygen in the Lachlan River during 2016-17, were at or above the levels required to induce mortality in a number of large-bodied native species (Small et al. 2014). Small et al. (2014) predicted that mortality in juvenile Murray cod would begin at dissolved oxygen concentrations of 3.1 mg L^{-1}, and concentrations lower than 2 mg L^{-1} would result in substantial fish kills. While widespread fish kills were not observed to be associated with the flooding event and associated dissolved oxygen crash in the Lachlan River in 2016-17, anecdotal reports from local landholders of suggest that fish kills resulting from hypoxia are the most likely explanation for the reduced abundance (and associated biomass) of Murray cod in the focal reach.

Substantial fish kills associated with widespread flooding occurred in other parts of the (southern) Murray Darling Basin in both 2010/ 2011 (Hladyz et al. 2011, King et al. 2012, Whitworth et al. 2012) and also in 2016/17 (DPI Fisheries, *unpublished data*). Encouragingly, recent evidence from the Edward-Wakool system indicates that recovery of the Murray cod population from the 2010/ 2011 fish kills was predominantly driven by localised spawning and recruitment originating from surviving remnant adults (Thiem et al. 2017). Given evidence in the Lachlan Selected Area of a remnant adult Murray cod population, as well as documented localised spawning in preceding monitoring years under this LTIM program, it is anticipated that natural processes are the most likely recovery pathway for this species.

Consistent with the results from 2015 and 2016, golden perch new recruits were not captured in 2017. This result alone does not provide definitive evidence of a lack of spawning within the lowland Lachlan River as other Selected Areas (e.g. the Murrumbidgee; Wassens et al. 2015) that have detected spawning in this species rarely encounter new recruits either as a result of 1) high larval mortality, 2) inappropriate sampling methods or locations, or a combination of both. Golden perch abundance was reduced in 2017 compared with other years, although not to the same extent as Murray cod. Stocking of golden perch has been undertaken in the Lachlan River since the 1970's, including on numerous occasions within the Selected Area in the past 10 years (http://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking and DPI Fisheries, *unpublished data*). It remains unknown whether the current adult population of golden perch is a result of stocking, wild-spawning, or a combination of the two. This represents an important knowledge gap when developing expected outcomes for future watering events. Recent published evidence suggests substantial variability in the contribution of stocking to riverine populations of golden perch (Crook et al. 2016, Forbes et al. 2016) and declines in stocking effectiveness have been observed with increasing riverine connectedness (e.g. Hunt et al. 2010).

10.6 FURTHER COMMENTS

Environmental water was used in 2016-17 to mitigate the effects of hypoxic blackwater in the mid Lachlan and provide localised refuge for fish. An improvement in dissolved oxygen concentrations was observed immediately downstream of Wyangala, but the outcomes of this action downstream of the immediate improvement (some 30 days travel time later) is not clear (see Section Stream Metabolism). One of the challenges with the water quality action for fish is that typically by the time dissolved oxygen concentrations drop below 4 mg/L, it is too late to respond to achieve a benefit for fish. Prior to the watering action designed to improve the water quality, high flows in the river and flood operation of the Dam prevented water from being used to increase the dissolved oxygen. Dissolved oxygen concentrations had reached well into the lethal range (<2 mg/L) before the environmental water was used. Monitoring of the fish community suggests that while there was a decline in fish numbers, there was not a complete loss of fish which means that there were some water quality refuges in the river.

10.7 SUPPLEMENT 1

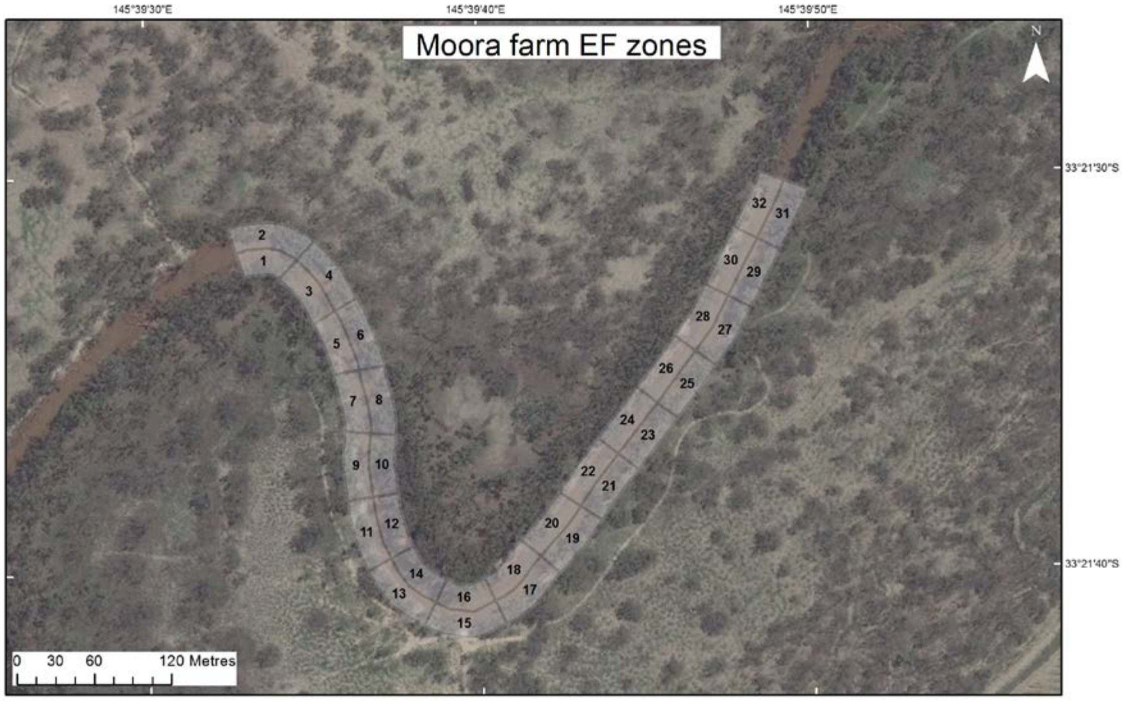

Figure 32. Example of mapped boat electrofishing units used for Category 1 fish community sampling in the Lachlan River. Each unit was sampled using 90 seconds of 'on-time'.

10.8 SUPPLEMENT 2

Table 13. Pre-European (PERCH) list of the expected native species present in the lowland Lachlan Basin, their associated rarity and subsequent detection during the LTIM 2016 census.

COMMON NAME	SCIENTIFIC NAME	OCCURRENCE[1]	2015 LTIM CENSUS	2016 LTIM CENSUS
Australian smelt	*Retropinna semoni*	common	Y	Y
bony herring	*Nematalosa erebi*	common	Y	Y
carp gudgeon	*Hypseleotris spp*	common	Y	Y
freshwater catfish	*Tandanus tandanus*	common	Y	
golden perch	*Macquaria ambigua*	common	Y	Y
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	common		
silver perch	*Bidyanus bidyanus*	common		
Murray cod	*Maccullochella peelii*	occasional	Y	Y
un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*	occasional	Y	Y
flathead galaxias	*Galaxias rostratus*	rare		
flat-headed gudgeon	*Philypnodon grandiceps*	rare		Y
olive perchlet	*Ambassis agassizii*	rare		
southern purple spotted gudgeon	*Mogurnda adspersa*	rare		
southern pygmy perch	*Nannoperca australis*	rare		

[1]Descriptions of predominance (occurrence) correspond to reference condition categories for the Murray-Darling Basin Sustainable Rivers Audit program and are used to generate fish condition metrics.

11 SPAWNING AND LARVAL FISH

11.1 INTRODUCTION

Environmental flow regimes commonly aim to maintain and enhance native fish community populations (King et al. 2010). The premise being that aspects of the flow regime are linked to key components of the life history of fish, including pre-spawning condition and maturation, movement cues, spawning cues and behaviour, and larval and juvenile survival (Junk et al. 1989, Humphries et al. 1999, King et al. 2003, Balcombe et al. 2006). Since the strength of recruitment to adulthood is largely driven by spawning success, and growth and survival of young, understanding how the flow regime influences the early life history of fishes is critical to managing fish populations (King et al. 2010).

To assess the contribution of Commonwealth environmental water to native fish spawning and recruitment, the relevant short term and long term questions to be evaluated are:

11.1.1 SHORT-TERM (ONE YEAR) EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to native fish reproduction in the Lower Lachlan river system?
2) What did Commonwealth environmental water contribute to native larval fish growth in the Lower Lachlan river system?

11.1.2 LONG-TERM (FIVE YEAR) EVALUATION QUESTIONS:

3) What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan river system?
4) What did Commonwealth environmental water contribute to native fish species diversity in the Lower Lachlan river system?

The larval fish monitoring implemented within the Lower Lachlan river system is directed at Basin scale evaluation and is confined to a single zone within the Lower Lachlan river system Selected Area. There are likely to be strong differences in the fish community and habitats between zones within the Selected Area resulting in the evaluation of outcomes for the Selected Area being confined to the target reach (i.e. Zone 1) (Dyer et al. 2014). There are two components to the evaluation provided in this report. The first evaluates the 2016-17 watering actions in relation to the specific objectives for fish, the second starts to address the short term evaluation questions.

11.2 METHODS

Larval fish were sampled at three sites (Dyer et al. 2014) on the Lower Lachlan river system Selected Area (Wallanthery, Hunthawang and Lane's Bridge). Five sampling events were undertaken at fortnightly intervals between 17th October 2016 and 14th December 2016. Sampling was timed to coincide with the known spawning windows of six target species:

- Equilibrium: Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*)
- Periodic: Golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)

- Opportunistic: Carp gudgeons (*Hypseleotris spp*) and un-specked hardyhead (*Craterocephalus stercusmuscarum*).

To capture larval fish, three drift nets were set overnight at each site (for more detail see Dyer et al. 2014). Catches of larval fish for drift nets was standardised as the number of individuals per cubic meter of water sampled. Due to flooding (and associated high water velocities) light traps were not able to be set in 2016.

11.3 RESULTS

A total of 985 larval fish were captured across the five sampling events of spring-summer 2016, all of which were common carp. Of the total number of common carp captured in 2016, 973 (99%) were captured on the first trip (17-18th October). No other species of fish were detected in the larval fish monitoring in 2016. Common carp were mainly captured from one sampling event (event 1) and from one site (Wallanthery – 96% of total catch). Larvae ranged in size from 7 – 24 mm SL.

Table 14. Capture summary of larval fish from sampling conducted between mid-October to mid December 2016 in the Lower Lachlan river system Selected Area. Note: light traps were not set in 2016.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	0	-	**0**
flat headed gudgeon	0	-	**0**
Australian smelt	0	-	**0**
carp gudgeon	0	-	**0**
freshwater catfish	0	-	**0**
golden perch	0	-	**0**
eastern gambusia	0	-	**0**
common carp	985	-	**985**
TOTAL	**985**	**-**	**985**

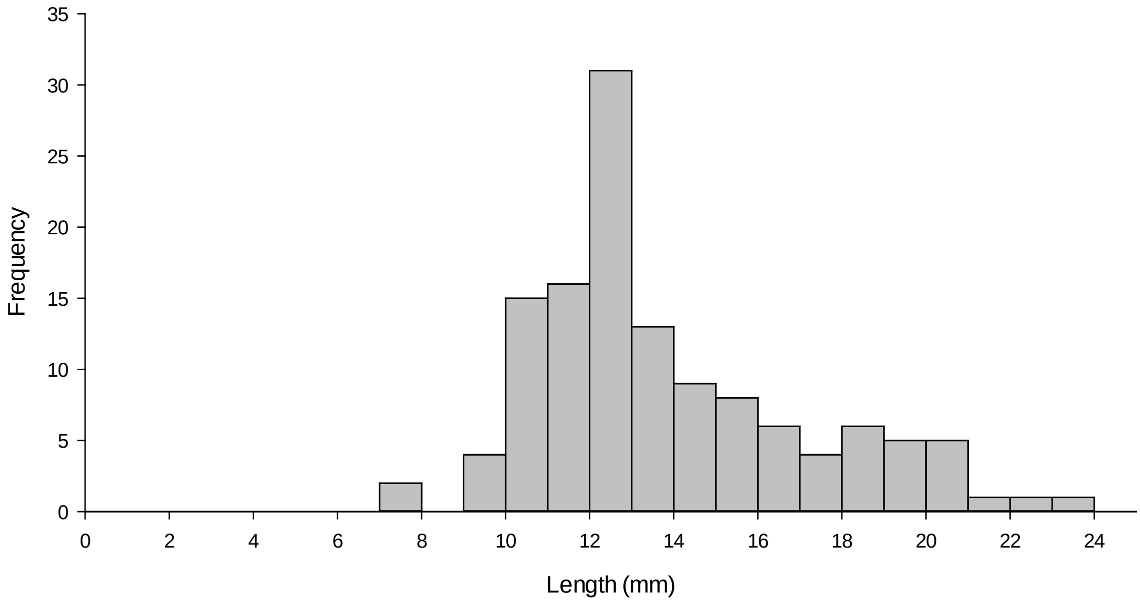

Figure 33. Length frequency histogram for larval carp captured during sampling event 1 (n = 127) in 2016.

11.3.1 BYCATCH IN DRIFT NETS

When retrieved, especially in trips 1 – 3, drift nets contained large amounts of organic matter, mostly microcustaceans (primarily Cladocera) and chironomidae (Figure 34).

Figure 34. Sample of the typical contents of a drift net from the 2016 larval fish sampling.

11.3.2 2016 VS PREVIOUS YEARS

No native fish larvae were captured in 2016, with the only species captured being common carp. Mean common carp relative abundance in drift nets was 712 times higher in 2016 than in 2015 (Figure 35).

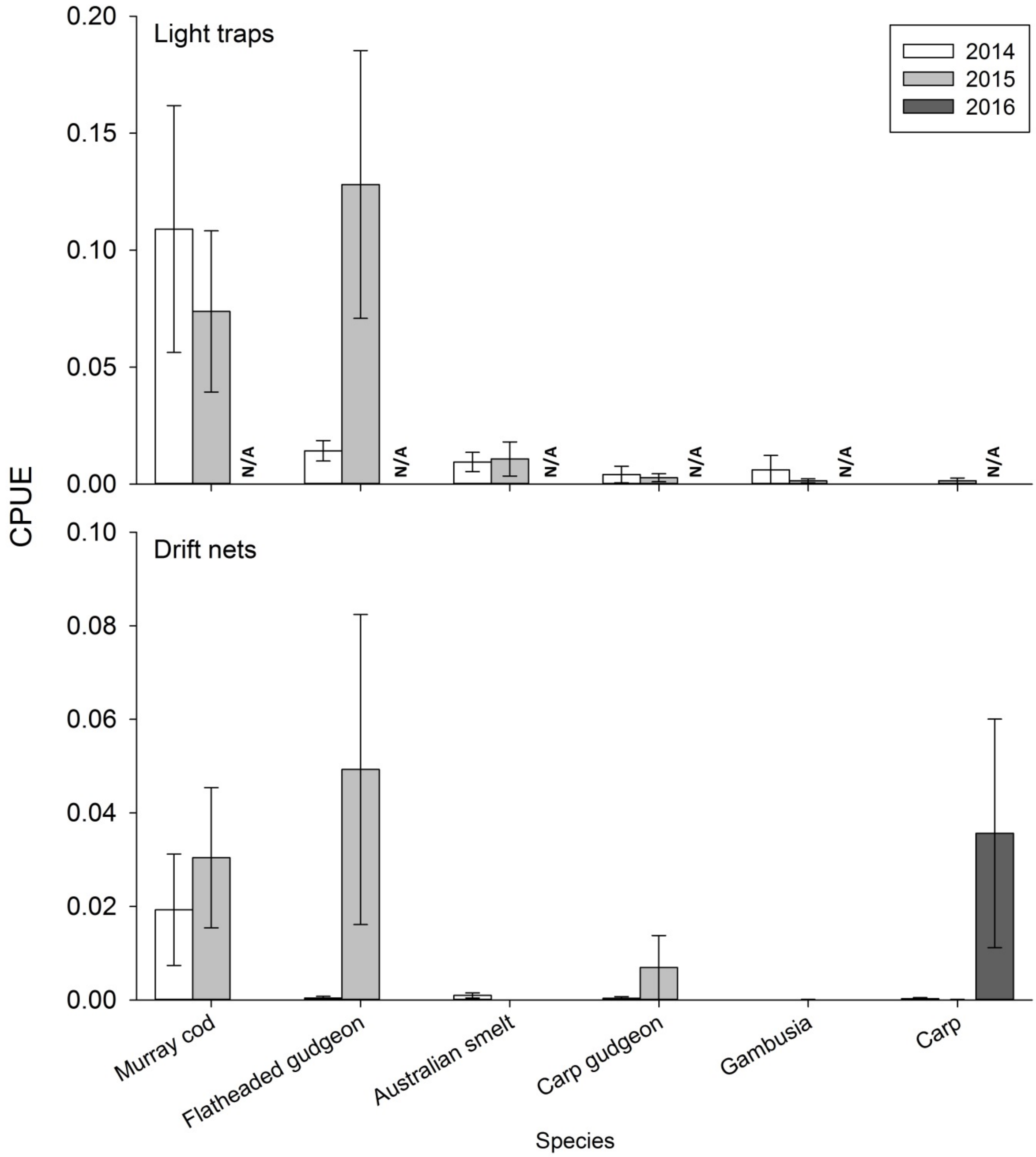

Figure 35. Mean catch per unit effort (± standard error) of larval fish species captured in light traps (CPUE = catch-per-hour, top) and drift nets (CPUE = individuals capture per m^3 of water sampled; bottom) from spring – summer 2014 – 2016.
Note: N/A indicates gear type was not used in that sampling year.

11.4 DISCUSSION

11.4.1 GENERAL DISCUSSION

The 2016 spawning season for native fish in the lower Lachlan Selected Area coincided with a large natural flooding event which was characterised by overbank flows, flooding and wetland inundation and a hypoxic period in the river channel. Despite logistical difficulties, larval sampling was still undertaken, albeit with the revised methods of not employing light traps, as the river channel trap locations were not able to be sampled because of high water velocities.

Based on drift net surveys, there was no evidence of native fish spawning or recruitment in 2016. The absence of Murray cod is especially telling as this species has been the most numerically dominant over the first two years of the monitoring program (Dyer et al. 2016). Mortality of Juvenile Murray cod is predicted to begin at dissolved oxygen concentrations of 3.1 mg L^{-1}, with concentrations lower than 2 mg L^{-1} resulting in substantial mortalities (Small et al. 2014). Indications from the logger at the lanes bridge site are that dissolved oxygen dropped below 2 mg L^{-1} in the lower Lachlan River Selected Area from mid-October until mid-December 2016 (Figure 23), coinciding with the likely presence of larvae and early juvenile Murray cod in the system (based on previous years sampling: Dyer et al. 2016). It is likely that the low dissolved oxygen concentrations are responsible for either prevention of spawning or mortality of eggs and / or larvae and earlier juveniles of this species. This conclusion is supported by the sampling conducted in autumn 2017 where no young-of-year Murray cod were detected.

As for the first two years of monitoring, there was no evidence of natural recruitment of golden perch in the selected area. The reasons for the lack of detection of eggs or larvae of golden perch in 2016 is not clear at this stage though is likely to be related to water quality, specifically dissolved oxygen. It is believed that the onset of golden perch spawning is related to rises in discharge when water temperatures are around 19 – 23 °C (e.g. King et al. 2005, Stuart and Jones 2006, Roberts et al. 2008). These conditions were present during late spring / early summer in the selected area, with discharge rising as the preferred water temperature was approached. As water temperatures rose, dissolved oxygen decreased, so much that it was largely below 4 mg L^{-1} in the lead up and dropped to below 2 mg L^{-1} as temperatures continued to rise (dropping to as low as 0.2 mg L^{-1} at the start of December) (Figure 23). Small et al. (2014) found that high mortality was observed in juvenile golden perch when dissolved oxygen levels were below 2 mg L^{-1}. It is not possible to determine if lack of recruitment is because of low dissolved oxygen deterring spawning or low dissolved oxygen resulting is high mortalities of eggs and larvae.

There was no evidence of spawning of small bodied native species in the drift nets in 2016. However, in the community fish monitoring undertaken in autumn, recruits were detected for three small bodied native species; Australian smelt, carp gudgeon and flatheaded gudgeon (see Section 10). Flatheaded gudgeon, Australian smelt and carp gudgeon have previously been relatively rare captures in drift nets in previous years of the monitoring program. Neither of these species has a drifting larval phase, with captures in drift nets likely because of displacement related to flow. The majority of individuals from these species have been captured in light traps set in slower flowing sections of the river. Flood water prevented setting of light traps at each of the monitoring sites in 2016. This is not surprising, as carp gudgeon were found to have enhanced recruitment during flooding (associated with wetland inundation) (Beesley et al. 2012) or used floodplain inundation for recruitment (King et al. 2003). Australian Smelt were also found to recruit in inundated floodplain habitats (King et al. 2003). These results indicate that spawning and recruitment of these species still occurred, though the recruitment was undetected as it did not overlap spatially with the sampling method employed during the flooding (or that the dramatic increase in discharge resulted in dilution of larvae to an undetectable level using the current monitoring techniques).. The results of the community monitoring indicate that even though the area experienced a period of low dissolved oxygen during spawning and early development, recruitment of these species was able to occur.

The 700 times increase in relative abundance of larval common carp in 2016 indicates that the flood event, including overbank conditions, provided favourable conditions for reproduction and early development of this species. Based on estimates of the timing of spawning of carp (see

Supplement 1: Estimating fish spawning dates 2016, p. 104) the onset of the spawning peak of carp in the Wallanthery area coincided with overbank flows. This was largely to be expected as increased carp recruitment with floodplain inundation is well documented in the Murray-Darling Basin (e.g. King et al. 2003, Crook and Gillanders 2006, Stoffels et al. 2013). The estimated onset of carp spawning in the Lachlan Selected Area in 2016 coincided with lower than expected in channel temperatures of around 12 – 14 °C. Carp are generally thought to require water temperatures of > 16 °C for oocyte maturation, ovulation, movement and spawning (Sivakumaran et al. 2003, Smith and Walker 2004, Conallin et al. 2012). It is likely that carp were spawning in off channel or floodplain habitats that would likely to have been several degrees warmer than the temperatures recorded at the same time by in channel temperature loggers.

11.4.2 EVALUATION

Watering action 1 had two objectives relating to native fish:

1. Provide improvements in dissolved oxygen levels and in-channel refuge
2. Native fish and other aquatic animals have opportunities to move from the floodplain to the river channel minimising stranding

Results from the larval fish monitoring are not able to inform whether these objectives have been met.

To assess the contribution of Commonwealth environmental water to native fish spawning and recruitment, the relevant short term and long term questions to be evaluated are:

Short-term (one year) evaluation questions:

1) What did Commonwealth environmental water contribute to native fish reproduction in the Lower Lachlan river system?

The 2016 – 2017 watering year was dominated by natural flood conditions characterised by overbank flow and low dissolved oxygen, especially from September to December inclusive. A flow was released from Wyangala in November to provide improvements is dissolved oxygen concentrations and provide in channel refuge, but the target area for this action was outside the selected area. Secondarily this release may have increased connectivity between the floodplain and the river channel minimising stranding of aquatic animals including native fish. Whilst this may have had some benefits to the selected area, specific benefits for native fish reproduction in the selected area in 2016 are not evident.

2) What did Commonwealth environmental water contribute to native larval fish growth in the Lower Lachlan river system?

Without knowledge of age (independent of estimates based on size) it is impossible to accurately determine growth of larval fish in response to Commonwealth environmental flow releases in the targeted area. The presence of 0+ individuals in the fish community monitoring (see Section 10) provides an indication that growth and survival did occur for small bodied native fish and one medium bodied native fish in the selected area.

Long-term (five year) evaluation questions:

3) What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan river system?
4) What did Commonwealth environmental water contribute to native fish species diversity in the Lower Lachlan river system?

This is the third year of a five year program (the last being a major flooding anomaly) and without baseline data, addressing long-term evaluation questions is not appropriate at this stage.

11.5 FINAL COMMENTS

- Hypoxic floodwater looks to have prevented reproduction of large bodied native species in the selected area in 2016, particularly Murray cod, which have been the most numerically dominant larval fish species present in previous years.
- Small bodied native fish reproduced in 2016 and survived through to autumn 2017 (see Fish community chapter), though none were collected in the 2016 larval fish monitoring.
- Common carp were the only species detected in the larval monitoring in 2016. It appears as though common carp utilised newly available off channel habitat to spawn resulting in a large recruitment event for this species in the selected area.

11.6 SUPPLEMENT 1: ESTIMATING FISH SPAWNING DATES 2016

The most accurate and precise method of estimating larval fish age and hence deriving a spawning date is by direct daily aging using otoliths of larval fish (Anderson et al. 1992, Campana and Thorrold 2001). Resource constraints meant direct aging was not currently feasible for this project (although larvae captured in 2014 – 2016 have been stored for potential otolith analysis should funds be available), and this forced the use of less accurate indirect methods of aging and spawning date estimation. Age of larval common carp was estimated using age vs growth relationships from Vilizzi (1998) and hatching time was taken from Lintermans (2007).

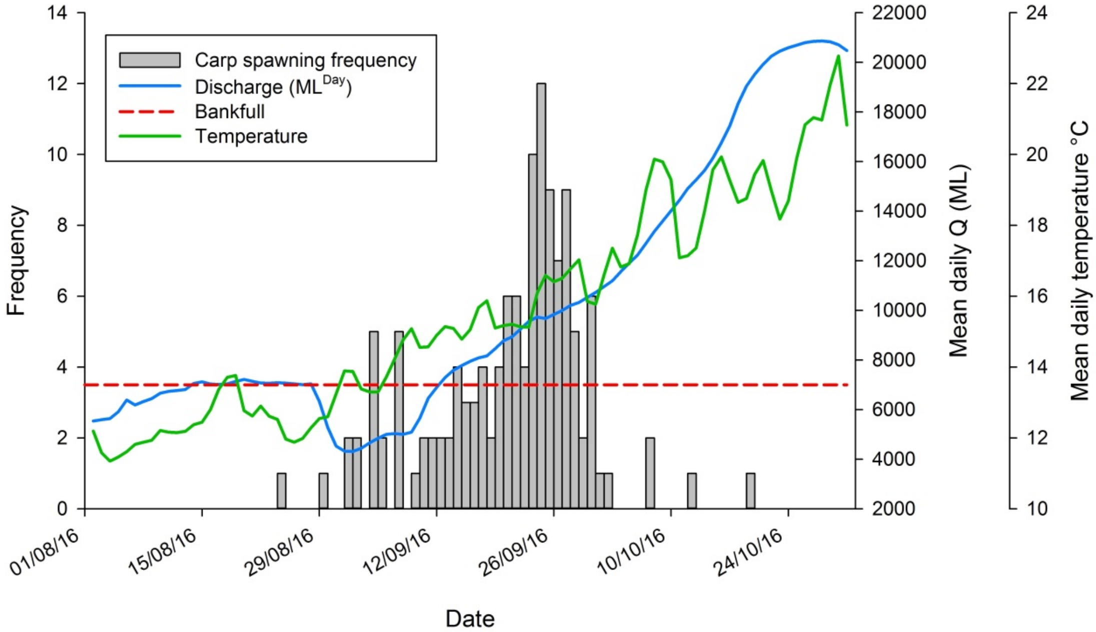

Figure 36. Estimated spawning date frequency (grey bars) and associated discharge and temperature for common carp captured at Wallanthery.
Discharge from Lachlan River at Willandra Weir (blue line) and temperature from Lachlan River at Willandra Weir (green line). Estimated discharge at bankfull at Wallanthery (red dashed line).

12 VEGETATION

12.1 INTRODUCTION

The Lower Lachlan river system contains many wetlands considered to be of national, regional and local importance. These are sites of high-value wetland plant communities including black box (*Eucalyptus largiflorens*), river cooba (*Acacia stenophylla*), extensive reed beds (*Phragmites australis*) and substantial areas of riparian fringing river red gum forest (*Eucalyptus camaldulensis*) and woodland. The Great Cumbung Swamp contains one of the largest stands of river red gum in NSW. These vegetation communities provide food and habitat for water birds, amphibians, fish, terrestrial vertebrates and a variety of other biota and support breeding events for tens of thousands of colonial nesting birds.

The condition, type and diversity of riparian and wetland vegetation communities are strongly influenced by the frequency and duration of inundation (Brock and Casanova 1997, Kingsford 2000). The floodplain and wetland vegetation communities of the Lower Lachlan river system display sequences of dry and wet phases depending on regional climatic conditions. During the Millenium drought (2001-2009), the health of the wetland vegetation declined rapidly (Armstrong et al. 2009). Observations and measurement made during the years immediately after the drought (2010-2012) suggested some degree of drought recovery was occurring within wetland vegetation communities, but by early 2012 aquatic vegetation, such as within the Great Cumbung Swamp, Lake Bullogal and Lake Merrimajeel was starting to show drought effects again (Driver et al. 2011, Driver et al. 2013a, Driver et al. 2013b).

In 2016-17 the Lower Lachlan river system experienced widespread flooding from July 2016 through to early 2017. Most of the wetlands in the lower catchment were inundated by the floodwaters and as a result, Commonwealth environmental water was not used to achieve vegetation outcomes. The two watering actions involving Commonwealth environmental water targeted water quality improvements in the main channel of the Lachlan River and the second action targeted ecological outcomes in Booligal Wetlands.

While vegetation in the Lower Lachlan river system was not a target for Commonwealth Water in 2016-17, the flooding provided a unique opportunity to document the vegetation responses at the LTIM vegetation monitoring sites. Consequently, this technical report describes how the vegetation responded to the flood event. In addition, we also evaluate the vegetation responses in relation to the watering history of the sites to determine if the watering history of the sites contributed to the response of the vegetation to flooding. Thus the following evaluation questions are addressed:

Does the watering history of the sites influence:

1. the vegetation species diversity following flooding?
2. the vegetation community diversity following flooding?
3. the condition of floodplain and riparian trees following flooding?
4. populations of long lived organisms following flooding?

These questions differ from the required evaluation questions (Dyer et al. 2014) but provide a useful framing for the presentation of the data in a flood year.

12.2 METHODS

Vegetation monitoring sites were selected to provide a sample from the different vegetation communities distributed across wetlands and riparian zones with different environmental watering probabilities (see Dyer et al. (2014), Figure 1, p. 23 and Table 15, p. 107). While the intent was to conduct vegetation surveys in both non-tree and tree communities during spring 2016 and autumn 2017, the flooding resulted in many sites being inaccessible for very long periods of time and as such the timing of the surveys were modified to try to capture the vegetation response just after the peak of the flood and then again in Autumn 2017.

Access at the flooded sites was carefully managed to ensure minimal damage of the site and safety of field staff. This involved an assessment of the consequences of both walking to the site and then conducting the survey at the site. General principles adopted were that staff did not travel through water >1.3 m deep, staff always worked in teams, and where the sites were muddy, (or under water) minimise movement at the site and use common pathways. Common sense and the precautionary principle were applied. This meant that at some sites with large numbers of trees (such as Moon Moon) the full suite of tree metrics were not recorded because the walking around the site was considered to create too much damage at the site.

The non-tree community survey was conducted along 2 replicate 100 m transects extending from the fringing woodland into the deeper section of the wetlands and billabongs at each of 10 sites (Table 15) using the methods of Driver et al. (2003) described in Dyer et al. (2014). Species abundance (and cover) was recorded in 1 m^2 quadrats placed at 10 m intervals along the 100 m transects (n=10 per transect).

Woodland tree communities were surveyed in a minimum of 2 replicate 0.1 ha plots at each of 12 sites (Table 15) using the methods of Bowen (2013) described in Dyer et al. (2014). An understory floristic survey was undertaken in a nested 0.04 ha plot inside the 0.1 ha plots. In each 0.1 ha plot, measures of stand and tree condition (basal area, canopy openness, canopy extent, live/dead limbs) were recorded as well as tree recruitment (trees >10 cm in diameter). In each 0.04 ha plot, the floristic survey recorded species abundance (of all species including trees) and cover.

All plants observed (including grasses) were identified to species either during field surveys or from field specimens which were preserved for later identification. Where plants were not able to be identified to species (because of a lack of suitable identifying features) they were recorded to the lowest taxonomic level possible and as distinct species based on morphological differences.

Table 15. Summary of vegetation monitoring sites.
The location of the sites within each Zone has been provided, however we do not consider the vegetation to be clearly separated according to zone.

SITE (CODE)	GEOMORPHIC DESCRIPTION	ANAE CLASSIFICATION	VEGETATION COMMUNITY	TREE COMMUNITY: RIPARIAN PLOTS	NON – TREE COMMUNITY: TRANSECTS
ZONE 1					
Hazelwood (HW)	Floodplain Billabong	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
Whealbah (WB)	Floodplain Billabong	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum/lignum	2	2
Moon Moon (MM)	Open lake fringed with red gum	Lt2.1: Temporary floodplain lakes Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
ZONE 2					
Lake Bullogal (LBU)	Channel mound wetland	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
The Ville (TV)	Floodplain Billabong	Pt1.2.1 Intermittent black box floodplain swamp	River red gum/Black box/river cooba/lignum	2	0
		Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum/river cooba/blackbox	2	2
ZONE 3					

SITE (CODE)	GEOMORPHIC DESCRIPTION	ANAE CLASSIFICATION	VEGETATION COMMUNITY	TREE COMMUNITY: RIPARIAN PLOTS	NON – TREE COMMUNITY: TRANSECTS
Lake Ita (LI)[3]	Open Lake fringed with black box and red gums	Lt2.1: Temporary floodplain lakes	Black box/river cooba	3	0
			River red gum	2	0
Clear Lake (CL)	Lake (with reed beds) fringed with red gum	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	0
Nooran Lake (NL)	Lake (with reed beds) fringed with red gum	Lt2.1: Temporary floodplain lakes	River red gum	2	2
Lake Marrool (LM)	Open lake fringed with red gum	Lt2.1: Temporary floodplain lakes	River red gum	2	2
ZONE 4					
Tom's Lake (TL)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	0
Lake Tarwong (LT)	Floodplain wetland Channel mound wetland	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	0
		Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
ZONE 5					
Booligal (BO)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	2

[33] Lake Ita had originally been established as an optional site for vegetation monitoring (Dyer et al., 2014). With the cessation of access to Murrumbidgil Swamp, Lake Ita is now being monitored each year. As this is likely to continue to the end of the monitoring, a new riparian plot was established at Lake Ita to provide replication for the red gum tree community plots.

Table 16. Wetland sampling dates and observations 2016-17. Watering categories correspond with the historical watering of the sites (see Table 17)

	OBSERVATION				NOTES		Watering history	
	Following flood peak[1]		May/June 2017					
SITE (CODE)	**Transect**	**Plot**	**Transect**	**Plot**	**Transect**	**Plot**	**Transect**	**Plot**
ZONE 1								
Hazelwood (HW)	100%	100%	dry	dry	For the sampling following flood peak, the observations were made from the flood margins as the site was inaccessible. The water was > 1.5 m deep		2015-PW	2013
Whealbah (WB)	100%	100%	20%	dry	May/June: both transects 20% flooded	For the sampling following flood peak, the survey data is from one plot only as the second plot was inaccessible.	2015-W	2015-W
Moon Moon (MM)	100%	100%	85%	3%	May/June: T2 100%, T1 70% flooded	For the sampling following the flood peak observations were made from the flood margins as the site was inaccessible. The water was > 1.5 m deep; May/June: survey was limited by ongoing flooding and tree metrics were not recorded because it would have caused too much damage of the site.	2015-W	2015-W
ZONE 2								
Lake Bullogal (LBU)	100%	100%	80%	6%	May/June: T2 100%, T1 60% flooded	For the sampling following the flood peak observations were made from the flood margins as the site was inaccessible. The water was > 1.5 m deep; May/June: sampling limited by ongoing flooding (P2 12% flooded, P1 dry)	2013	2013
The Ville (TV): Mixed		78%		dry		For the sampling following the flood peak the water depths were approx. 0.4 m		2013
The Ville (TV): RRG	100%	100%	dry	dry	For the sampling following the flood peak water depths were > 0.7 m		2015-PW	2015-PW
ZONE 3								
Lake Ita (LI): BBX		dry		dry		For the sampling following flood peak the plots had been completely inundated prior to the survey date but were dry at the time of survey		2012
Lake Ita (LI): RRG		100%		60%		For the sampling following the flood peak the water depths were 0.6 m; May/June: sampling limited by ongoing flooding (water depths 0.2)		2012

	OBSERVATION				NOTES		Watering history	
	Following flood peak[1]		May/June 2017					
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot	Transect	Plot
Clear Lake (CL)		dry		dry		For the sampling following flood peak the plots had been completely inundated prior to the survey date but were dry at the time of survey		2015-WN
Nooran Lake (NL)	dry	dry	dry	dry	For the sampling following the flood peak the transects had been completely inundated but were dry at the time of survey	For the sampling following flood peak the plots had been completely inundated prior to the survey date but were dry at the time of survey	2015-PW	2015-PW
Lake Marrool (LM)	4%	dry	dry	dry	Sampling following flood peak: transects had been completely inundated	For the sampling following the flood peak there was evidence of water on backend of the 0.1 ha plot but not over the whole plot.	2015-PW	2015-WN
ZONE 4								
Tom's Lake (TL)		100%		dry				2015-PW
Lake Tarwong (LT) – BBX		10%		dry		For the sampling following flood peak the plots had been completely inundated prior to the survey date but were dry at the time of survey	2013	2013
Lake Tarwong (LT)- RRG	100%	100%	100%	100%	Sampling following flood peak and May/June 2017 observations were made from the flood margins as the site was inaccessible. The water was > 1.5 m deep;		2013	2013
ZONE 5								
Booligal (BO)	100%	100%	dry	dry		For the sampling following the flood peak the water depths were approximately 0.5 m	2015-PW	2015-PW

[1] Sampling dates as follows: MM, WB, BO, HW, TL, T Oct/Nov 2016; LI, LM, LBU, LT Mid Feb 2017; CL, NL April 2017.

12.2.1 EVALUATION APPROACH

The flooding across the river system meant that all of the wetland sites were inundated with naturally occurring flood waters. Commonwealth environmental water was not used to target vegetation outcomes in 2016-17 and many of the sites were inaccessible for much of the year. The sampling and access constraints meant that the timing of the vegetation surveys in relation to the duration of the flood differed between sites. Some sites (such as Whealbah Billabong) were visited just prior to the peak of the flood whereas others were visited as the flood was receding. Differences in flood duration at each of the sites also meant that some of the Autumn sampling occurred when some sites had been dry for several months yet others were still under water. This makes our data analysis challenging. We therefore adopt two approaches to evaluating the outcomes from the flooding.

Firstly, we use our observations from different points within the flood to present descriptions of the vegetation responses to flooding. This illustrates the temporal response of the vegetation to flooding, identifying the species that respond to flood waters of varying depth and then the transient species that appear on the recession of the flood. This includes a number of short lived species that have not been observed in dryer times in the landscape.

The components of the inundation regime of wetlands that are most commonly investigated in relation to wetland vegetation communities are depth, duration and the frequency of wetting and drying. While depth on its own is considered to be a poor predictor of plant community composition in studies of wetland plants (e.g. Casanova and Brock (2000)) other studies have shown the importance of depth in structuring the vegetation community (van der Valk 2005, Raulings et al. 2010). Depth and duration are intrinsically linked within wetlands and it is difficult to separate the effects in a field based study. It is likely that plants respond to a combination of depth and duration. We use the depth of flooding to explain the response of the vegetation in the Lachlan river system because we have information about water depth (both maximum depths and the depth at the time of the surveys) for our survey sites and at the time of evaluation we did not have duration data. Additionally, field observations suggested a marked difference in the vegetation communities in differing depths of water.

Secondly, we analyse the responses observed at the sites in relation to their previous watering history. In the 2015 – 16 watering season, 9 of the 13 monitored sites received water from a combination of Commonwealth environmental water and translucent flow. Of these, 5 received a combination of Commonwealth water and translucent flow, and the remaining 4 received only translucent flow. Prior to the 2015-16 watering, the last watering of almost all of the sites occurred during the large scale watering action in 2012-13. At each site, transects and plots were assigned a watering history (Table 17) and these categories were used to structure the data analysis. The watering history classification has been applied to sites. This means that where the data are reported over multiple years the recent watering history is applied to data from 2014. This structures the comparison of sites across years.

Table 17. Watering history used to structure analysis of vegetation data

WATERING HISTORY	DESCRIPTION	SYMBOL
2015-W	Watering events inundated the monitoring site in 2015	■
2015-PW	Watering events partially inundated the monitoring site in 2015	▲
2015-WN	Watering events inundated areas adjacent[1] the monitoring site in 2015, previous inundation occurred in 2013.	◆
2013	Previous inundation occurred in 2012/2013	●

[1] Adjacent means that water had inundated areas of the broader wetland, but the monitoring plots and transects had not been inundated. For example at sites such as Lake Marrool, water had partially filled the open sections of the wetland, but had not reached the plots and transects which were on the margins of the wetland. It was expected that the trees on the margins of the wetlands would have been able to access water from within the wetland and respond in condition. This was demonstrated in the 2015-16 data.

To evaluate vegetation outcomes the following approach was applied:

- Vegetation species diversity is defined as the number of groundcover species and the evenness of their abundance. Simpson's Diversity Index has been calculated for each sampling unit and compared across years for each watering history.
- Vegetation community diversity is taken to mean the composition of the community in terms of species composition, functional type and nativeness. For the evaluation species have been classified according to the plant functional types (Table 18) of Brock and Casanova (1997) and Casanova (2011). Species were also classified as native/non-native using information provided on PlantNET (http://plantnet.rbgsyd.nsw.gov.au/).
- The condition of floodplain and riparian trees is defined as the canopy cover of the floodplain trees (red gums and black box). For the evaluation condition metrics (Table 18) are derived from Bowen (2013), Bowen and Simpson (2010) and Bowen et al. (2012) and are adapted from Cunningham et al. (2007).
- Long lived organisms refers to the floodplain and riparian trees (river red gum, black box and river cooba). The contributions to populations of long-lived organisms means ensuring that there are new cohorts in the population. The evaluation was based on the number of eucalypt seedlings following watering and their persistence over time.

Table 18. Plant functional group classifications of Brock and Casanova (1997) and Casanova (2011)

FUNCTIONAL TYPE	DESCRIPTION
Amphibious responders (AmR)	Plants which change their growth form in response to flooding and drying cycles.
Amphibious tolerators (AmT)	Plants which tolerate flooding patterns without changing their growth form.
Terrestrial damp plants (Tda)	Plants which are terrestrial species but tend to grow close to the water margin on damp soils.
Terrestrial dry plants (Tdr)	Plants which are terrestrial species which don't normally grow in wetlands but may be encroaching into the area due to prolonged drying.

12.2.2 DATA ANALYSIS

For the analysis presented in this report the survey data have been treated in the following way:

- Species richness was calculated from the combined survey data from the two sampling dates and an average of the data from multiple plots or transects at each site.
- Simpson's Diversity Index (D) is calculated as:
  $D = 1 - (\sum n(n-1)/N(N-1))$
  where n = the total number of organisms of a particular species
  N = the total number of organisms of all species.
- Measures of stand and tree condition at each site were calculated as the average of the plot data from each vegetation community at each site. This means that for sites with more than one vegetation community, there are two measures of stand and tree condition provided (e.g. Lake Tarwong black box and Lake Tarwong river red gums).

Table 19. Plant condition classification derived from Bowen (2013), Bowen and Simpson (2010) and Bowen et al (2012) and are adapted from Cunningham et al. (2007)

CONDITION	DESCRIPTION
Good	0-10% Dead Canopy
Intermediate	11-40% Dead Canopy
Intermediate/poor	41-80% Dead Canopy
Poor	> 81% Dead Canopy

The observations relating to landuse and other activities that may confound the interpretation of vegetation response to watering were recorded. The frequency and time since activity were recorded for grazing by livestock, firewood collection and site disturbance. The presence of feral animals was also noted.

12.3 RESULTS

12.3.1 VEGETATION RESPONSES TO FLOODING

During inundation, water depth defined the response of the vegetation. Sites that were inundated to more than 0.4 m produced no emergent or submerged vegetation and tended to have either only floating plants (such as Azolla, *Azolla filiculoides* or Duck weed, *Lemna minor*) or no vegetation present (other than the existing trees). At sites that were inundated to less than 0.4 m a number of amphibious plants were observed during the inundation that had not been previously recorded. Common spike rush (*Eliocharis acuta*) was the most widespread and abundant but we also observed small flower umbrella sedge (*Cyperus difformis*) and marsh club-rush (*Bulboschoenus fluviatalis*). Water ribbons (Triglochin spp.), star fruit (*Damasonium minus*) and common blown grass (*Lachangrostis filiformis*) were also recorded and there was a significant increase in the abundance of nardoo (*Marsillea drummondii*).

The autumn sampling meant that sites were visited in the drying phase of the flood. At some of the sites, the ground was still waterlogged and at others, the ground had been dry for several months. The response of the vegetation at 4 sites, Whealbah Billabong, Lake Bullogal, Lake Ita Inlet (Black Box) and Clear Lake, are shown in relation to inundation in Section 12.5, Table 21 to Table 24. These illustrate the different species that were present at different points in the wetting and drying phases of the flood.

There appeared to be a sequencing of species following the flooding. As the flood waters receded, species adapted to mud flats appeared at sites, with Small club-rush (Isolepis spp.) matted water starwort (*Callitriche sonderi*), ferny buttercup (*Ranunculus pumilio*), Spreading nutheads (*Epaltes australis*) and Australian mudwort (*Limosella australis*) appearing (see Table B for Lake Bullogal where we visited the site as the waters were receding and the ground was still waterlogged). As the flood waters receded further, numerous terrestrial damp species appeared including bluish raspwort (*Haloragis glauca*), yellow twin-heads (*Eclipta platyglossa*), hyssop loosestrife (*Lythrum hyssopifolia*) and lesser joy weed (*Alternanthera denticulata*) followed by sneeze weed (*Centipeda cunninghamii*), couch grass (C*ynodon dactylon*), dock (Rumex spp) and swamp daisy (*Brachyscome basaltica*).

12.3.2 VEGETATION SPECIES RICHNESS AND DIVERSITY

In 2016-17 approximately 6% of species could not be identified accurately. These were often small seedlings that were not sufficiently mature to allow identification.

12.3.2.1 Non-tree community

A total of 96 species were identified across the non-tree community sites during the 2016-17 watering season compared with 154 species identified during the 2015-16 watering season and 130 species identified during the 2014-15 watering season. Most sites were inaccessible around the flood peak and it was observed that once the water was more than 0.4 m deep, no ground cover species were present. This means that data from the peak of the flood are not shown. In 2016-17 the greatest number of species (32) was recorded from Booligal National Park.

In autumn 2017 the plant community was dominated by sedges (Cyperaceae spp. predominantly *Eleocharis acuta*) and aquatic ferns (Azollaceae spp. *Azolla filiculoides*) which are species that require flooding. Peas (Fabaceae spp. predominantly *Medicago polymorpha*) and grasses (Poaceae spp.) were also present in significant numbers and are species which respond well to wetter conditions.

The vegetation diversity (Simpson's diversity index) was only calculated for the Autumn 2017 data. The vegetation diversity continues to be variable, with the seasonal pattern less obvious when the Autumn 2017 data are included (Figure 37). The vegetation diversity in Autumn 2017 was broadly consistent with the diversity observed in Autumn 2015 and 2016 (Figure 37). Interestingly, the sites that had been inundated in Spring 2015 (2015-W) and displayed low diversity during 2015-16 had returned to previous levels of diversity in Autumn 2017. This may be a reflection of the different durations of the inundation that occurred over the two years.

In autumn 2016, inundated sites had been dominated by Ward's weed, burr medic and crumb-weed (*Carichtera annua, Medicago polymorpha* and *Chenopodium pumilio* respectively). Ward's weed and burr medic were notably absent from the same sites in autumn 2017 and most abundant species were instead sneeze weed (*Centipeda cunninghamii*) and nardoo (*Marsilea dummondii*).

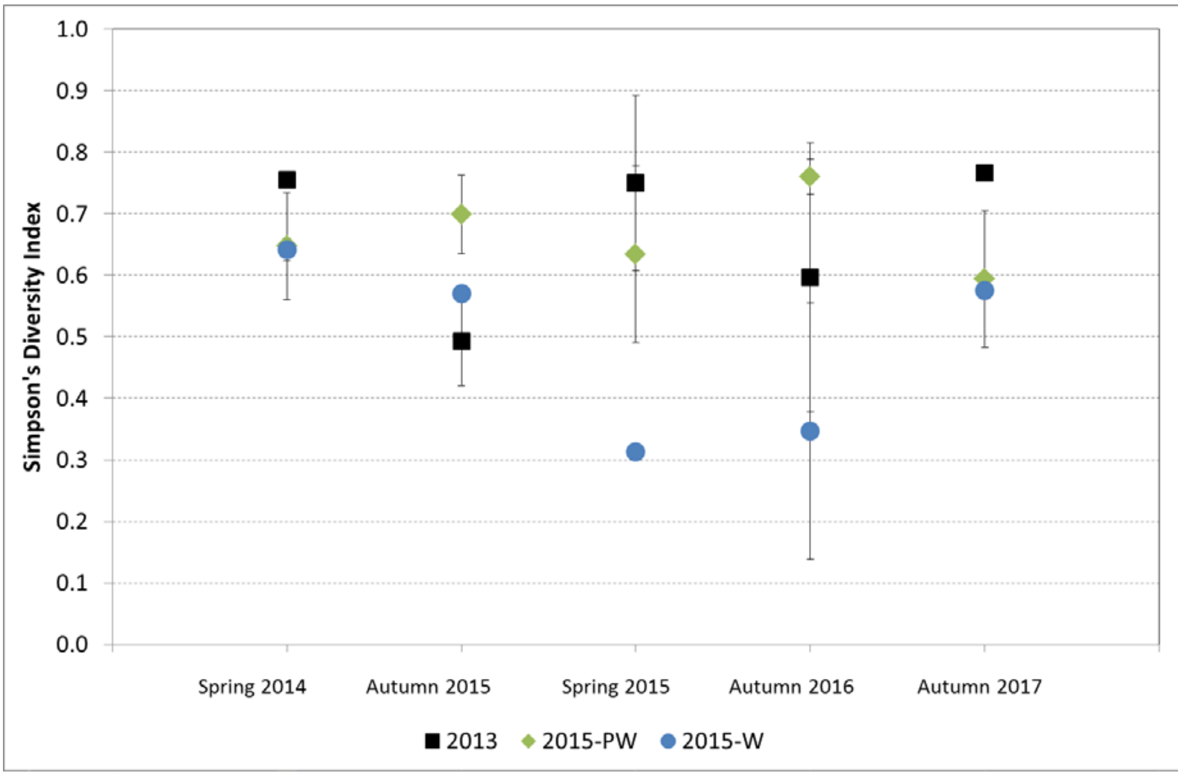

Figure 37. Comparison of groundcover vegetation diversity in the non-tree community between seasons and years using Simpson's diversity index.
The data points are the mean diversity index for each watering treatment (refer to Table 17, p. 112). Error bars represent ± the standard error. The absence of error bars either means they are smaller than the symbol size or there is only one data point. Note that data are not shown for the peak of the flood event. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

12.3.2.2 Tree community

A total of 181 species were identified across the tree community plots during the 2016-17 watering season compared with 166[4] species identified during the 2015-16 watering season and 137 species identified during the 2014-15 watering season. The greatest number of species (40) were recorded at Lake Ita Inlet in the Lachlan Valley National Park. Of note was the recording of Mossgiel daisy (*Brachyscome papillosa*) at Lake Ita Inlet which is a species listed as vulnerable in NSW.

In Autumn 2017 the plant community was dominated by brassicas (Brassicaceae spp, mainly smooth mustard *Sisymbrium erysimoides*), peas (Fabaceae spp. mainly burr medic *Medicago polymorpha*) and grasses (Poaceae spp.) which are terrestrial species that respond opportunistically to wet conditions. Significant numbers of asters (Asteraceae spp.) mainly old man weed *Centipeda cunninghamii* and yellow twin heads, *Eclipta platyglossa* were present. These species tend to grow on damp soils near to water. Large number of nardoo (Marsileaceae spp.) were also recorded. Nardoo respond well to flooding.

The vegetation diversity shows a variable response to inundation in 2016-17 that is not clearly related to watering history (Figure 38). The site that was completely inundated in the spring of 2015 and 2016 responds to flooding with low vegetation diversity in the Autumn following the flooding caused by a dominance of sneeze weed (*Centipeda Cunninghamii*).

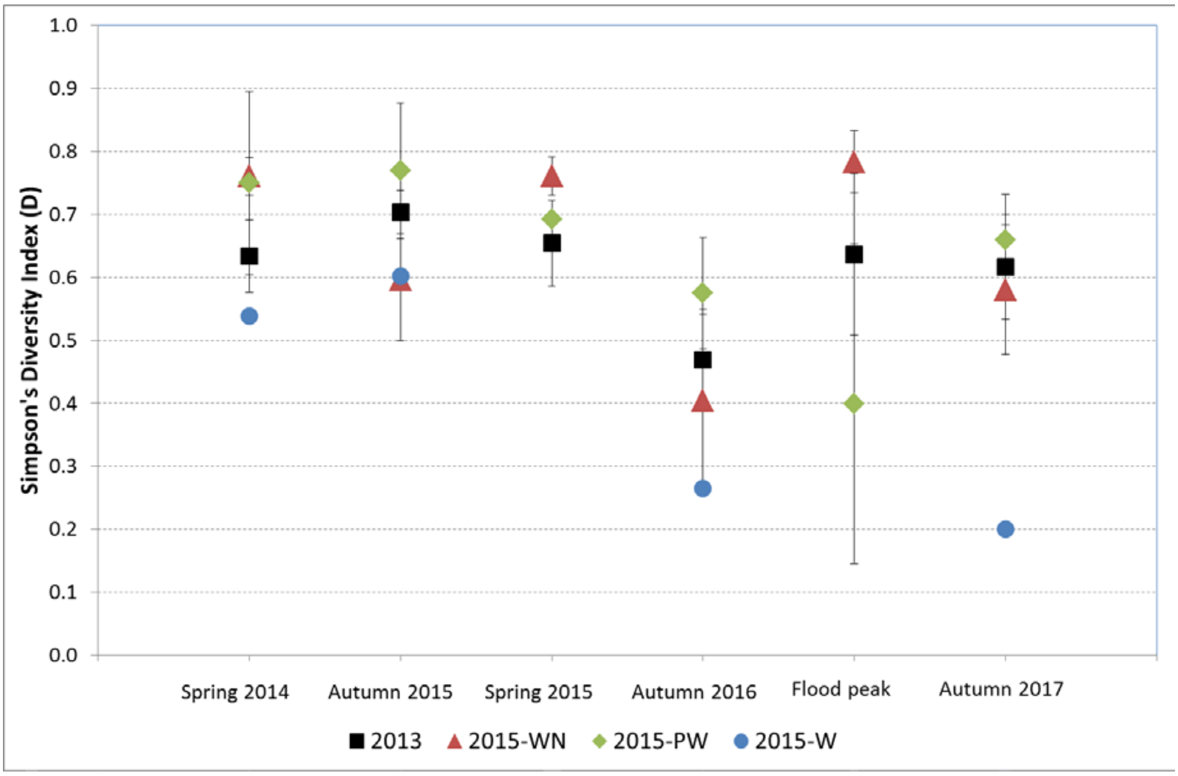

Figure 38. Comparison of groundcover vegetation diversity in the tree community between seasons and years using Simpson's diversity index. The data points are the mean diversity index for each watering treatment (refer to Table 17, p. 112). Error bars represent ± the standard error. The absence of error bars either means they are smaller than the symbol size or there is only one data point.

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[4] Four species previously not identified in 2015-16 have now been identified.

12.3.3 VEGETATION COMMUNITY DIVERSITY

12.3.3.1 Nativeness and functional types: non-tree community

It should be noted that no community data are presented for the peak of the flood for the non-tree community. Most of these sites were either inaccessible around the peak of the flood and it was observed that once the water was greater than about 0.4 m deep, no groundcover species were present and thus relative proportions become meaningless.

More than 60% of the vegetation cover at all of the monitored sites in 2016-17 was native, irrespective of watering history (Figure 39). Sites that have been watered less frequently appear to have had a consistently higher cover of native species over the years of monitoring, but watering history does not appear to have influenced the outcome for the cover of native vegetation in 2016-17.

Across all of the monitored sites, 60% of the species identified in the 2016-17 monitoring were native. The proportion of native species remained high in 2017 and there was slight (non-significant) drop in the proportion of exotic species present following the recent flooding. There was no observed influence of watering history on the proportion of native species present (Figure 40) and the proportion of native species present is generally consistent across monitoring years.

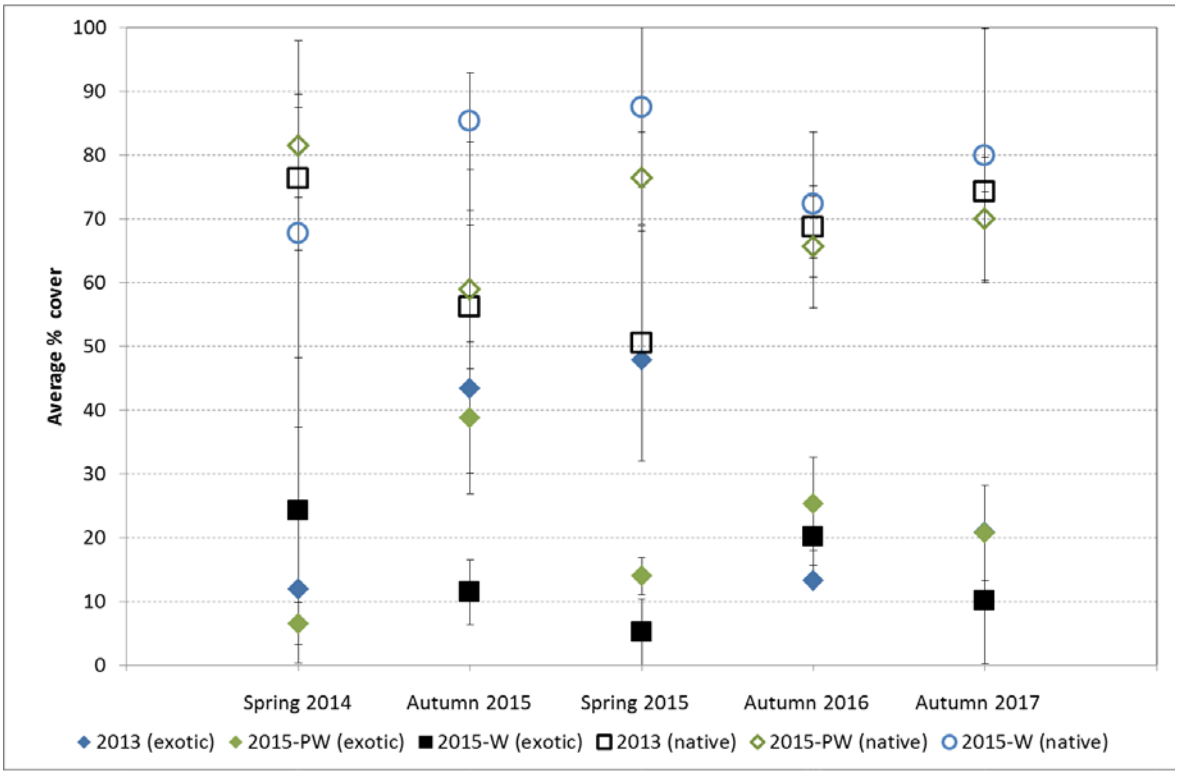

Figure 39. Average proportional cover of native and exotic species for the non-tree communities. The data points represent the mean for each watering treatment (refer to Table 17, p. 112) and the error bars represent ± the standard error. The proportion of native species is shown by open symbols and the proportion of exotic species is shown by closed symbols. Note that data are not shown for the peak of the flood event. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

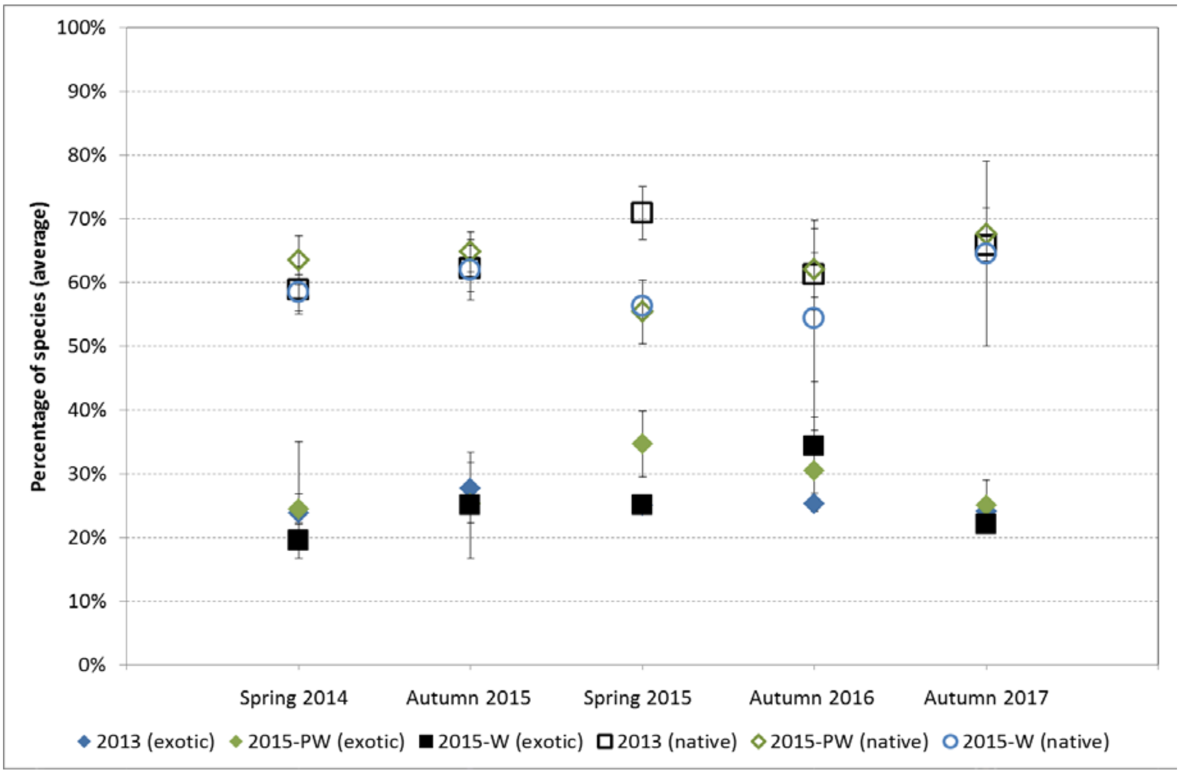

Figure 40. Average proportion of native and exotic species for the non-tree communities. The data points represent the mean for each watering treatment (refer to Table 17, p. 112) and the error bars represent ± the standard error. The proportion of native species is shown by open symbols and the proportion of exotic species is shown by closed symbols. Note that data are not shown for the peak of the flood event. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

There was a marked increase in the cover of amphibious and terrestrial-damp species in Autumn 2017 at sites that had been completely inundated in 2015 (2015-W) and sites where the last known watering was prior to 2013 (Figure 41). In contrast, sites that had been partially watered in 2015 (2015-PW) showed a decrease in the cover of amphibious and terrestrial-damp species. The response of amphibious and terrestrial-damp species at sites where the last known watering was prior to 2013 indicates that there is either a persistent seedbank of flood responding species at the sites, or that the spring floods brought in a seedbank.

There was a notable increase in the proportion of amphibious and terrestrial-damp species across all sites in Autumn 2017 compared with previous years (Figure 42). Species such as buttercups (Ranunculus spp.) and common spike rush (*Eleocharis acuta*) appeared for the first time following the flooding. Sites that had been completely inundated in 2015 (2015-W) had the greatest proportion of both amphibious (26%) and terrestrial damp (27%) species. There was a doubling of the relative proportion of amphibious and terrestrial-damp species at sites where the last known watering was prior to 2013. The response of the amphibious vegetation to flooding suggests that the sites that are more frequently watered have a greater number of amphibious and terrestrially damp species.

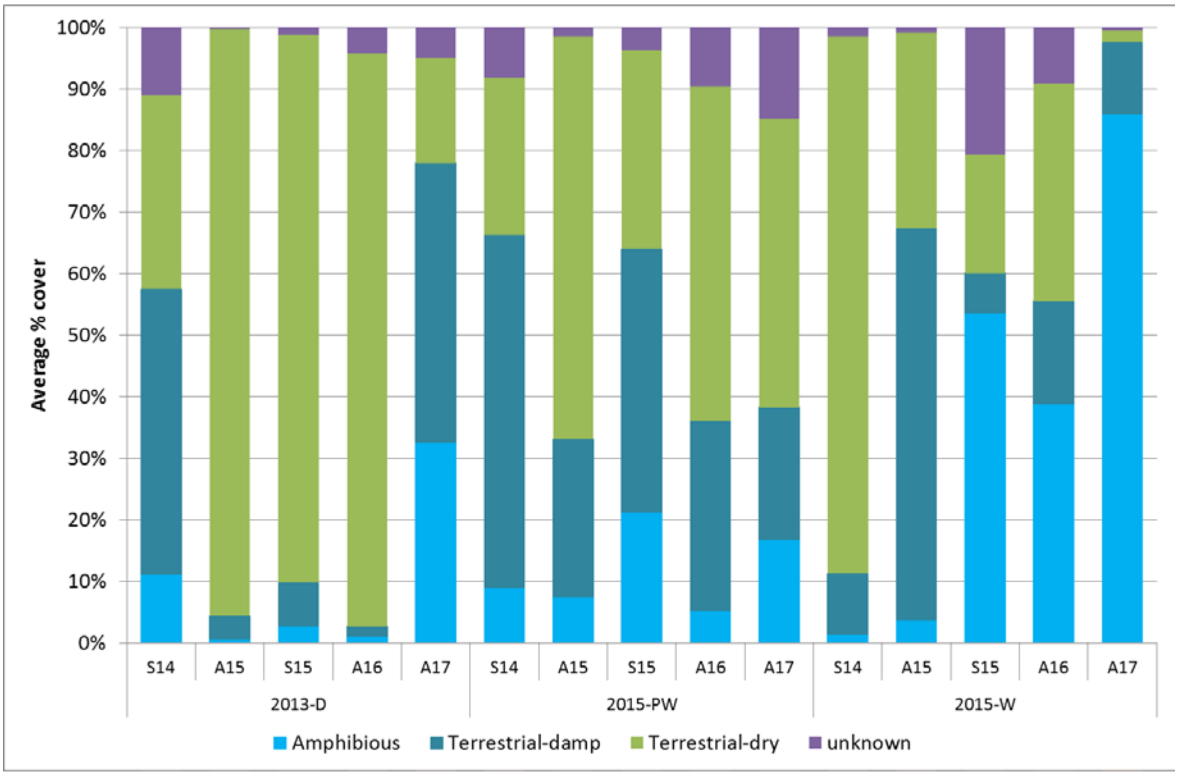

Figure 41. Average proportional cover of terrestrial and amphibious species within the non-tree community for sites from each watering history (refer to Table 17, p. 112) over the sampling period. (S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017) Unknown represents species that were unable to be identified to a suitable level for classification. Note that data are not shown for the peak of the flood event. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

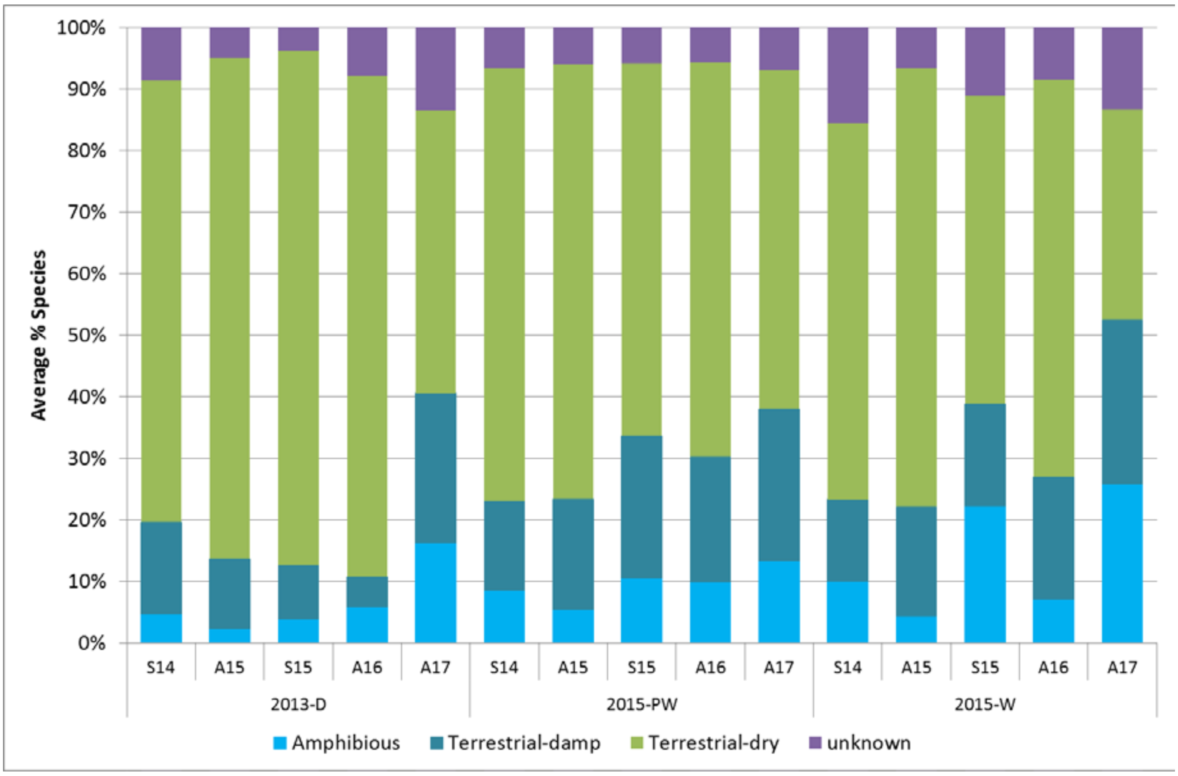

Figure 42. Average proportion of terrestrial and amphibious species within the non-tree community for sites from each watering history (refer to Table 17, p. 112) over the sampling period. (S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017) Unknown represents species that were unable to be identified to a suitable level for classification. Note that data are not shown for the peak of the flood event. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

12.3.3.2 Nativeness and functional types: tree community

More than 70% of the vegetation cover at the monitored sites in 2016-17 was native (Figure 43). The exception to this was sites that had been partially inundated in 2015 in which there was a more even distribution of native and exotic vegetation. There was no obvious effect of previous watering history on the proportion of native vegetation cover. It is noticeable that the proportion of native cover has increased since monitoring commenced in 2014.

Across all of the monitored sites, more than 65% of the groundcover vegetation species recorded in autumn 2017 were native species. The proportion of native species remained generally high during the floods (Figure 44) and dropped slightly after the flood waters had receded (Autumn 2017). The site that was completely inundated in 2015 (Moon Moon Swamp) again showed a marked reduction in the proportion of native species in the Autumn following the flooding. It is noted that this is the response of a single site which has had a lower proportion of native species throughout the monitoring program rather than a generalizable response to watering history. None of the other watering histories had a discernible effect on the proportion of native species present at the sites.

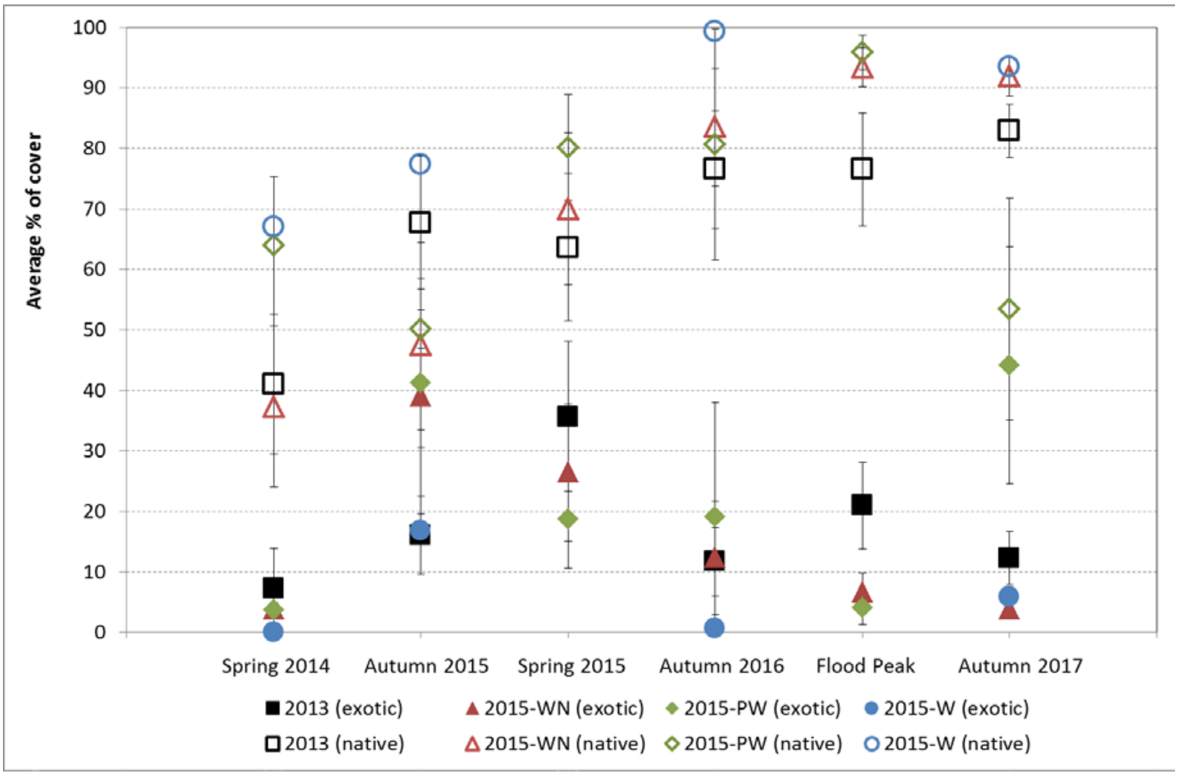

Figure 43. Average proportional cover of native and exotic species for the tree communities. The data points represent the mean for each watering treatment (refer to Table 17, p. 112) and the error bars represent ± the standard error. The proportion of native species is shown by open symbols and the proportion of exotic species are shown by closed symbols.

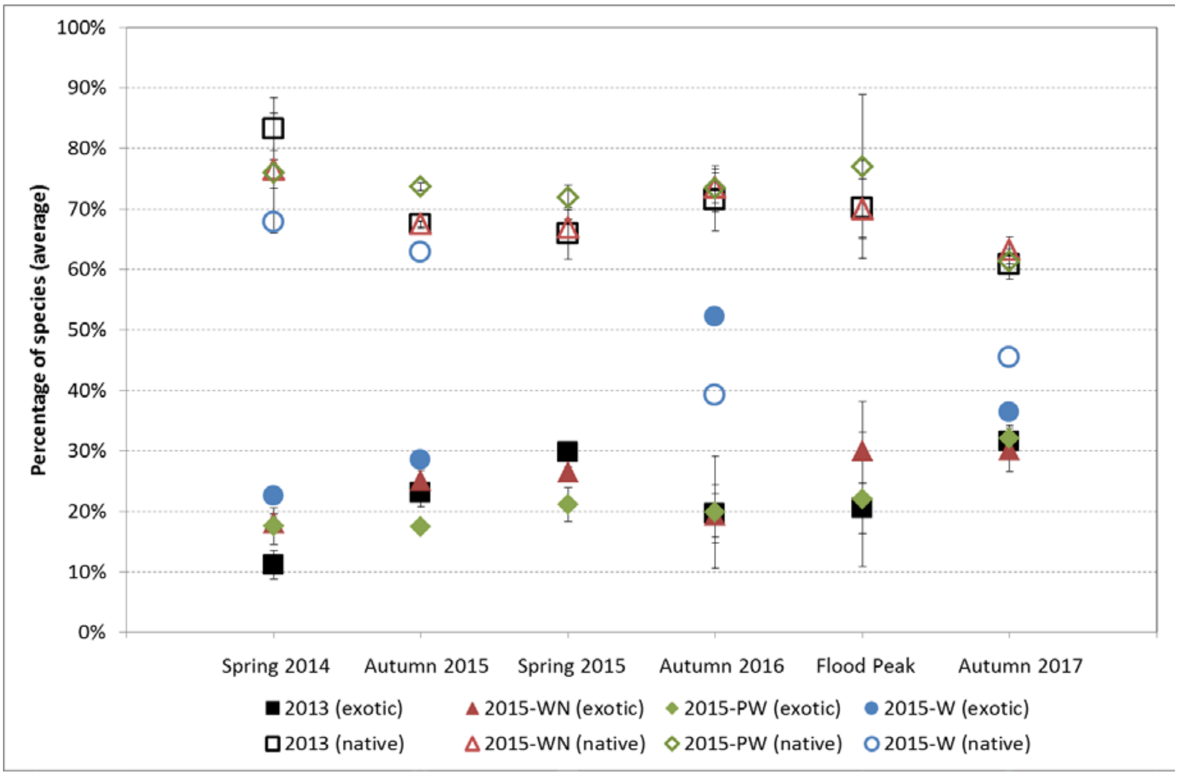

Figure 44. Average proportion of native and exotic species for the tree communities.

The data points represent the mean for each watering treatment (refer to Table 17, p. 112) and the error bars represent ± the standard error. The proportion of native species is shown by open symbols and the proportion of exotic species are shown by closed symbols.

There was an increase in the proportional cover of amphibious and terrestrial-damp species in 2016-17 compared with previous years (Figure 45). This was most notable in the proportion of amphibious species. Sites that were sampled at the peak of the flood typically had a significant cover of amphibious species which is a function of the sites being under water at the time of sampling. The response of amphibious and terrestrial-damp species at the peak of the flood in sites where the last known watering was prior to 2013 indicates the persistence of a seedbank at these sites and their capacity to respond to watering.

There was a notable increase in the proportion of amphibious and terrestrial-damp species across most sites in 2016-17 compared with previous years (Figure 44). Species such as water ribbons (Triglochin sp.), small flower umbrella sedge (*Cyperus difformis*), star-fruit (*Damasonium minus*), buttercups (Ranunculus spp.) and common spike rush (*Eleocharis acuta*) appeared for the first time following the flooding. Sites that had been partially watered in 2015 (2015-PW) showed an increase in amphibious plants at the peak of the 2016-17 flood with few terrestrial damp species present. This is a function of the sites being under water at the time of sampling.

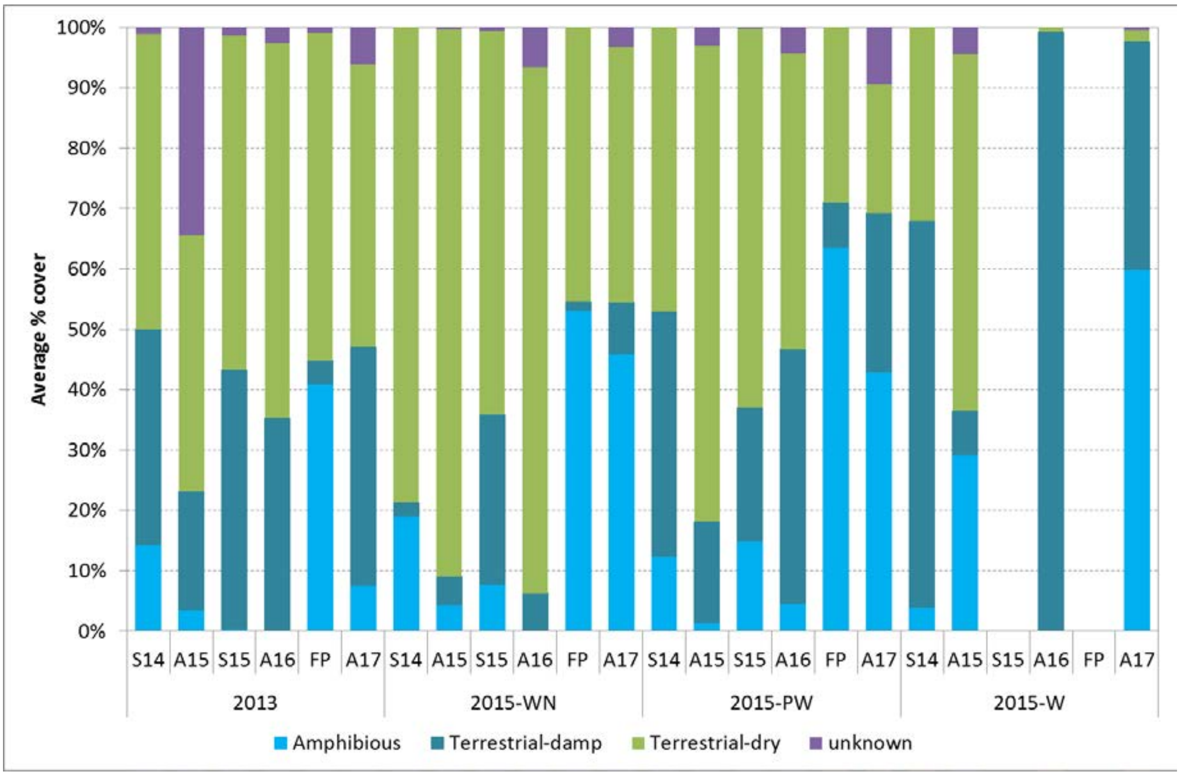

Figure 45. Average proportional cover of terrestrial and amphibious species within the tree community for sites from each watering history (refer to Table 17, p. 112) over the sampling period. (S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; FP: Flood Peak; A17: Autumn 2017) Unknown represents species that were unable to be identified to a suitable level for classification.

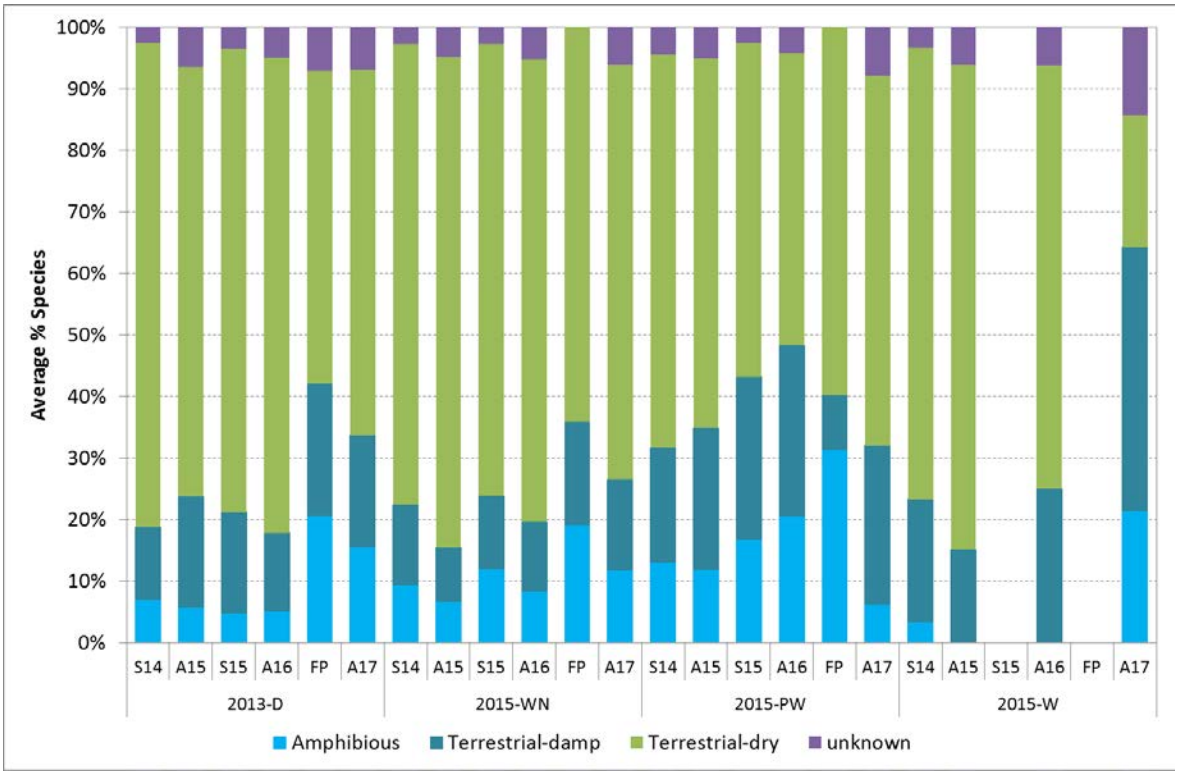

Figure 46. Average proportion of terrestrial and amphibious species within the tree community for sites from each watering history (refer to Table 17, p. 112) over the sampling period. (S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; FP: Flood Peak; A17: Autumn 2017) Unknown represents species that were unable to be identified to a suitable level for classification.

12.3.4 CONDITION OF FLOODPLAIN AND RIPARIAN TREES

Small increases (up to 10%) in the percent foliage cover of the river red gum in the catchment was observed in 2016-17, but little change or a decline was observed in black box (Figure 47). The greatest improvement in the percent foliage cover was recorded at sites which had not been inundated in 2015 (the categories 2013 and 2015-WN). The sites that had displayed significant increases in percent foliage cover in 2015-16 (sites that had been partially watered: 2015-PW and 2015-W) did not show a similar increase again in 2016-17.

There was little change in the proportion of dead canopy between 2015-16 and 2016-17 (Figure 48) except for one site which had been completely inundated in 2015, Moon Moon Swamp. This data for this site is from only one plot in 2016-17 because the second plot was still under water at the time of sampling.

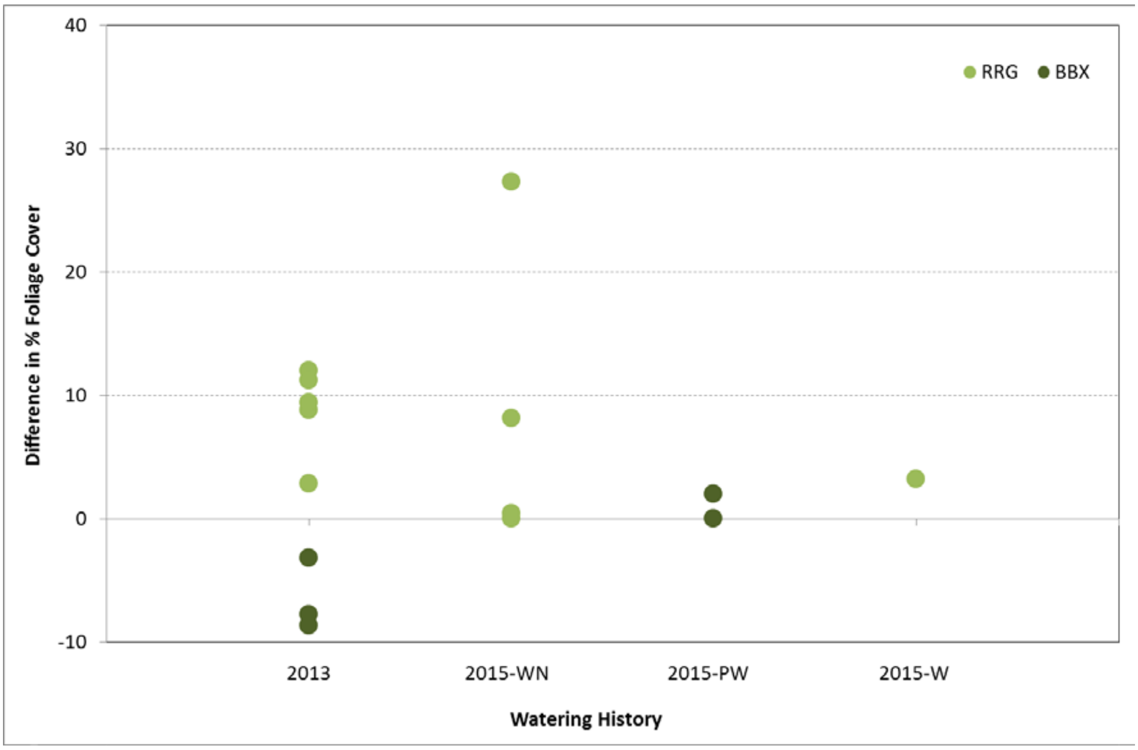

Figure 47. The difference in percent foliage cover between 2015-16 and 2016-17 for river red gum and black box in relation to watering history.

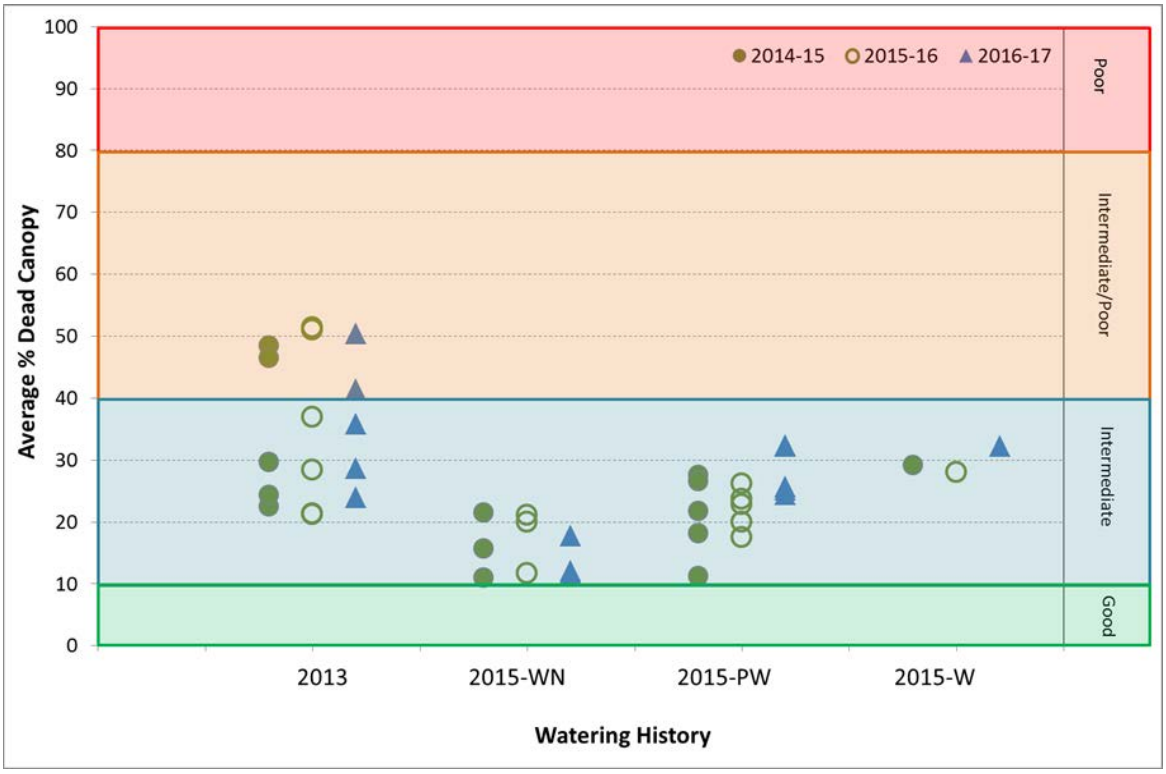

Figure 48. Change in the percent dead canopy over the three monitoring seasons for the woodland vegetation community of the Lower Lachlan river system.
Sites are grouped according to watering history (see Table 17, p. 112) and condition classification after Bowen (2010) is shown by coloured bands (see Table 18, p. 112).

12.3.5 CONTRIBUTIONS TO LONG LIVED ORGANISMS

The numbers of seedlings and saplings present in all plots per site were aggregated to give a combined count per time of sampling, and to facilitate comparison between monitoring dates (Table 20). There was a notable response to flooding with the germination of seedlings in all monitored plots in 2016-17. The greatest responses were in the black box communities of Booligal, Tom's Lake and Lake Tarwong with large numbers of black box seedlings appearing following the flood recession. Good numbers of seedling were also observed in the red gum communities of The Ville, Lake Ita and Whealbah.

Table 20. The total number of seedlings and saplings per site.

SITE	FLOODPLAIN/ WETLAND COMPLEX	LANDUSE	GRAZING INTENSITY	RECRUITMENT (<0.2 to >3.0 m)			
Trip				Autumn 2015	Spring 2015	Autumn 2016	Autumn 2017
Red gum community							
Hazelwood	Lachlan River Floodplain	Grazing (sheep)	Recent and frequent	35	35	41	29
Whealbah	Lachlan River Floodplain	Grazing (sheep)	Recent and occasional	740	315	926	134
Moon Moon Swamp	Booligal Wetlands	Grazing (cattle)	Recent and frequent	13	100% flooded	73	Partially inundated
Nooran Lake	Great Cumbung Swamp	Grazing (cattle)	Recent and frequent	14	40	38	9
Lake Marrool	Great Cumbung Swamp	Grazing	Recent and occasional	2	3	1	2
Lake Bullogal	Lachlan Swamp	Grazing (sheep large numbers)	Recent and frequent	0	0	0	67
Lake Tarwong-RRG	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	237	136	91	100% flooded
Clear Lake	Cumbung Swamp	Grazing (cattle)	Recent and frequent	61	29	23	40
Black box community							
Booligal wetland	Booligal Wetlands	Nature conservation	Low	44	75	43	112
Tom's Lake	Booligal Wetlands	Grazing (cattle)	Recent and frequent	1	16	41	220
Lake Tarwong-BBX	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	0	6	1	159
Mixed Red Gum, River Cooba and Black Box							
The Ville	Lachlan Swamp	Nature conservation	Low	42	45	157	230
Lake Ita	Lachlan River Floodplain	Nature conservation	Low	no visit		3	247
Lake Ita (Inlet)	Lachlan River Floodplain	Nature conservation	Low			3	4

12.4 DISCUSSION

Vegetation in the Lower Lachlan river system was not a target for Commonwealth environmental water in 2016-17, with all of the sites inundated by natural flooding. This provided a unique opportunity to document the inundation response of the vegetation at the LTIM vegetation monitoring sites and the data collected provides a useful comparison for future environmental watering events.

The flooding produced a distinct response in the vegetation as it peaked and receded. The response was related to the depth of inundation and, as the flood receded, the time since inundation and waterlogging of the soils. Water depth (and duration) defined the response of the vegetation during flooding and helps to explain the vegetation characteristics at some sites. Where water depths were greater than 0.4 m for long periods of time (such as the low lying areas in the middle of wetlands and in the channel sections of channel mound wetlands) no vegetation persisted. These are the locations where little other than annual species have been observed in the past. Where water depths were less than 0.4 m (such as the top of banks, mounds and wetland margins), there was a substantial response in the vegetation community with a large number of water dependent species observed. These are the locations that have been dominated by terrestrial vegetation in the past but the response to flooding indicates that these sites retain a seedbank of water dependent species.

These observations provide information about what might be expected at sites in response to the provision of environmental water. Vegetation at sites that are periodically inundated to more than 0.4 m have not responded to flooding nor to environmental water other than to grow floating plants such as azolla or duck week. This indicates that perhaps these sites should not be expected to produce a groundcover vegetation response with the provision of environmental water. These sites include Moon Moon swamp, the channel sections within Lake Bullogal, Lake Tarwong, The Ville and Hazelwood Billabong. These open water sites without vegetation may be functionally important in the landscape and the objectives for environmental water at these sites need to be considered in the context of a range of wetland habitats. Current seedbank studies by PhD student Will Higgisson will inform future decisions for watering of these sites.

There was a marked response in groundcover vegetation at sites that are periodically inundated to <0.4 m. Some of these sites require large volumes of water to inundate and will only ever receive water from natural flooding. This includes the black box communities at Lake Tarwong and Lake Ita, the redgum floodplain woodland at The Ville, Whealbah Billabong and Lake Marrool, and the mounds in Lake Bullogal and Lake Tarwong. The volume of environmental water available is not sufficient to get water over these sites, which means that environmental water cannot be used to generate a response by the groundcover vegetation. It is possible to get environmental water *near* to these sites which is likely to result in a response from the floodplain and riparian trees.

A few of the sites that are periodically inundated to <0.4 m and showed a marked response in groundcover vegetation to flooding are able to be watered with environmental water. These include sites within the Booligal wetlands in Booligal National Park and Tom's Lake. The challenge at these sites is to identify the duration of flooding and frequency of flooding required to support the vegetation community. Ongoing data collection as part of the monitoring program will inform this but it would also benefit from some modelling of natural flows within these systems.

12.4.1 ADDRESSING EVALUATION QUESTIONS

1) Does the watering history of the sites influence the vegetation species diversity following flooding?

There was a reduction in the number of groundcover plant species recorded in 2016-17 in the non-tree community compared with previous years. Conversely there was an increase in the number of groundcover plant species observed in the tree community. The non-tree community was typically inundated to greater depths than the tree community and it was observed that once water levels exceeded about 0.4 m, very few species were present and the vegetation community was dominated by floating aquatic species such as such as azolla, (*Azolla filiculoides)* or duck weed, (*Lemna minor)*. Within the tree community, inundation to less than 0.4 m resulted in a substantial vegetation response, with sedges and rushes covering large portions of the monitoring sites. The large numbers of plants such as common spike rush (*Eliocharis acuta*) meant that diversity[5] was low at some sites, in spite of an increase in the number of species recorded.

Watering history did not appear to influence the vegetation diversity at the monitoring sites, with differences in site responses appearing to be more a function of the vegetation community and watering depth than historical watering. However, it should be noted that there is limited replication of some watering histories (only 1 of our monitored sites was completely inundated in 2015) which makes it difficult to be confident in this apparent response.

2) Does the watering history of the sites influence the vegetation community diversity following flooding?

The monitored sites retained a high degree of nativeness, particularly within the tree community. More than 70% of the vegetation cover within the tree community comprised native species and 60% within the non-tree community. Typically more than 60% of the species present were native within both the tree and non-tree community, with only one site showing a marked increase in exotic plants in the Autumn following the flooding. Typically more than 60% of the identified groundcover species were native. Only one site again showed a drop in the proportion of native species in response to complete inundation. This is consistent with previous years observations and the proportion of native species was reasonably consistent across sites with different watering histories. This suggests that historical watering has not influenced the nativeness of the groundcover vegetation.

There was an increase in the cover and proportion of amphibious and terrestrially damp species in 2016-17 compared with previous years, with up to 50% of the species observed at sites classified as amphibious or terrestrially damp species. This increase was observed

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[5] Note that diversity is a measure of both species richness and species evenness. In this report, we calculate diversity using Simpson's diversity index.

across all sites, irrespective of watering history. The relative proportion of amphibious and terrestrially damp species appears to be greatest at sites that were inundated or partially inundated in 2015-16, although as previously mentioned the lack of replication for some watering histories limits our ability to infer that this is a widespread response.

The observations from 2016-17 support those of 2015-16 that the groundcover vegetation was able to respond to watering suggesting a persistent seedbank at the sites that is able to respond to watering.

3) Does the watering history of the sites influence the condition of floodplain and riparian trees following flooding?

There was a slight improvement in tree condition again in 2016-17 with an improvement in foliage cover. This follows the improvement noticed with watering in 2015-16. The response was greatest at sites that had either been last watered in 2013 or received water nearby in 2015. This was not accompanied by a reduction in the proportion of dead canopy cover with almost no change observed in dead canopy cover between 2015-16 and 2016-17. The one site watered most frequently (Moon Moon Swamp) displayed almost no change in foliage cover. This is in line with the greater timeframes required to recover tree canopy that has been lost over multiple dry seasons, one season is not enough to show a change.

4) Does the watering history of the sites influence populations of long lived organisms following flooding?

Tree seedlings were observed at all sites in 2016-17, except those that were inundated at the time of sampling. This included black box, red gum and river cooba seedlings and these were observed at sites where we had not previously observed seedlings, such as Lake Bullogal and the Lake Tarwong black box. It is likely that the removal of sheep and cattle from these sites during the floods have contributed to the occurrence of seedlings and saplings. The greatest response was observed within the Lake Ita red gums and at the Ville, however this response may also have been a function of the timing of our visit with tiny red gum seedlings just beginning to appear when we sampled.

12.5 SUPPLEMENT 1: SAMPLE VEGETATION RESPONSES TO WATERING

Table 21. Species abundance at Whealbah Billabong in relation to inundation

Whealbah	Oct-2014	Nov-2014	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	May-2016	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016[1]	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	Jun-2017
Amphibious																																	
Marsileaceae		98						72					1500							20					2000							2533	
Polygonaceae		23											4												5								
Cyperaceae																									1000							12000	
Poaceae													8							7													
Juncaceae																																1	
Juncaginaceae																																1	
Terrestrial-damp																																	
Asteraceae		27						30					41							5					5							74	
Haloragaceae		28						8					282							2					5							83	
Poaceae								61					141							175												674	

Whealbah	Oct-2014	Nov-2014	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	May-2016	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016[1]	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	Jun-2017
Fumariaceae								200					54							10000													
Polygonaceae								8												1													
Verbenaceae													111																			9	
Amaranthaceae																																13	
Asphodelaceae																									5								
Brassicaceae																				1100													
Rubiaceae													325																				
Terrestrial-dry																																	
Solanaceae								4																									
Asteraceae		3						2					23							7					5							4	
Oxalidaceae		22						9					18							3					5							5	
Chenopodiaceae		6						78					3							2												5	
Lobeliaceae								58					475							58					1000							164	
Brassicaceae		154						290					277																			11	
Solanaceae								1					1							1												23	
Boraginaceae								30					26												5								
Fabaceae (Faboideae)								80					8																			1	
Poaceae		138											31												500								
Rubiaceae								26					2																			3	
Apiaceae								1					1																				
Euphorbiaceae		3																														46	

Whealbah	Oct-2014	Nov-2014	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	May-2016	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016[1]	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	Jun-2017
Goodeniaceae		89											17																				
Zygophyllaceae		46						30																									
Aizoaceae																																111	

[1] only one plot had been inundated

Table 22. Species abundance at Lake Bullogal in relation to inundation

Lake Bullogal	Oct-2014	Nov-2014	**Dec-2014**	Jan-2015	Feb-2015	Mar-2015	Apr-2015	**May-2015**	Jun-2015	Jul-2015	Aug-2015	Sep-2015	**Oct-2015**	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	**Jun-2017**
Amphibious																																	
Polygonaceae			1										2							2													4
Callitrichaceae																																	2235
Cyperaceae																																	880
Ranunculaceae																																	218
Scrophulariaceae																																	1250
Terrestrial-damp																																	
Lamiaceae			79					175					113							238													362
Asteraceae								4					1							1													1505
Amaranthaceae								3																									3
Haloragaceae								13																									22
Polygonaceae																				1													349
Geraniaceae								6																									

Lake Bullogal	Oct-2014	Nov-2014	**Dec-2014**	Jan-2015	Feb-2015	Mar-2015	Apr-2015	**May-2015**	Jun-2015	Jul-2015	Aug-2015	Sep-2015	**Oct-2015**	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	Apr-2017	May-2017	**Jun-2017**
Lythraceae																																	3
Poaceae													12																				
Solanaceae																				14													
Terrestrial-dry																																	
Asteraceae			1					7					5							105													60
Brassicaceae			3					589					2475							20000													1956
Chenopodiaceae			22					26					42							86													16
Zygophyllaceae			18					120					47							9000													4
Fabaceae (Faboideae)								151					2							300													176
Lamiaceae								4					7							54													1
Malvaceae								7					2							3													18
Poaceae			4					5					3							107													
Verbenaceae								2					8							2													652
Aizoaceae													36							2700													110
Euphorbiaceae			1					2																									2
Solanaceae													1							1													3
Goodeniaceae													2																				1
Lobeliaceae								1																									
Urticaceae								3																									

Table 23. Species abundance at Lake Ita Inlet in relation to inundation

Lake Ita Inlet	Oct-2014	**Nov-2014**	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	**Feb-2017**	Mar-2017	Apr-2017	**May-2017**	Jun-2017
Amphibious																																	
Polygonaceae		7																		1									2				
Cyperaceae																													321			93	
Marsileaceae																													70			11	
Alismataceae																													61				
Juncaginaceae																													9				
Lythraceae																																20	
Typhaceae																													3				
Terrestrial-damp																																	
Amaranthaceae																													270			47	
Asteraceae																													76			271	
Poaceae																													31			50	
Polygonaceae																													2			12	
Brassicaceae																																2000	

Lake Ita Inlet	Oct-2014	**Nov-2014**	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	**Feb-2017**	Mar-2017	Apr-2017	**May-2017**	Jun-2017
Fabaceae (Faboideae)																																201	
Solanaceae																																7	
Plantaginaceae																													1				
Terrestrial-dry																																	
Chenopodiaceae		11																		50									44			98	
Aizoaceae																													29			5170	
Asteraceae																													9			21	
Brassicaceae																													123			5500	
Cucurbitaceae																													6			2	
Euphorbiaceae																													4			13	
Goodeniaceae																													18			15	
Poaceae																													5			1	
Solanaceae																													3			5	
Zygophyllaceae																													47			1050	
Boraginaceae																													2537				
Fabaceae (Faboideae)																																600	
Lamiaceae																																1	
Malvaceae																																1	
Phyllanthaceae																																37	
Rubiaceae																																1	
Verbenaceae																																12	

Table 24. Species abundance at Clear Lake in relation to inundation

Clear Lake	Oct-2014	**Nov-2014**	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	**May-2015**	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	**Nov-2015**	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	**Apr-2017**	May-2017	**Jun-2017**
Amphibious																																	
Marsileaceae		27						84						16						40											548		2405
Cyperaceae														57						13											86		7270
Juncaceae		9																															2
Ranunculaceae																															48		100
Alismataceae																																	2
Onagraceae																																	16
Poaceae																															16		
Terrestrial-damp																																	
Asteraceae		1						2						10						1											212		90
Amaranthaceae																				5											11		2
Lythraceae																															44		243
Poaceae																															4		10
Polygonaceae																															7		2

Clear Lake	Oct-2014	**Nov-2014**	Dec-2014	Jan-2015	Feb-2015	Mar-2015	Apr-2015	**May-2015**	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	**Nov-2015**	Dec-2015	Jan-2016	Feb-2016	Mar-2016	Apr-2016	**May-2016**	Jun-2016	Jul-2016	Aug-2016	Sep-2016	Oct-2016	Nov-2016	Dec-2016	Jan-2017	Feb-2017	Mar-2017	**Apr-2017**	May-2017	**Jun-2017**
Rubiaceae								6																							7		
Brassicaceae		275																															
Solanaceae																																	11
Terrestrial-dry																																	
Asteraceae		1						3						32						2											6		6
Chenopodiaceae		32						66						90						72											32		17
Euphorbiaceae		1						3												2											14		8
Lobeliaceae		1						4						17																	308		160
Brassicaceae		50						3167																							81		1697
Malvaceae		1						37																							19		10
Poaceae								17						4																	10		1
Solanaceae		1						14																							10		7
Cucurbitaceae																				1											11		5
Fabaceae (Faboideae)								900																							34		937
Aizoaceae																															7		217
Boraginaceae								1																							133		
Caryophyllaceae								60																									2643
Zygophyllaceae								313																									1
Geraniaceae								3																									
Rubiaceae								2																									
Verbenaceae																															4		

13 COLONIAL WATERBIRD REPRODUCTIVE SUCCESS

13.1 INTRODUCTION

Breeding opportunities for colonial waterbirds are often triggered by flood events at key wetlands. Forty-six per cent of all wetland sites throughout Australia that are used for colonial waterbird breeding occur in the Murray Darling Basin. Of these, relatively few wetlands (<5% recorded) support large colonial waterbird breeding events (Brandis 2010). The Booligal wetlands in the lower Lachlan catchment are one of the key sites for colonial waterbird breeding in the Murray Darling Basin. The management of environmental water to protect and ensure the ecological capacity for the recovery of waterbird habitat and to support waterbird breeding forms part of the strategic direction for the wetland (Commonwealth of Australia 2012).

The wetlands of the Lower Lachlan, which are listed under the *Directory of Important Wetlands in Australia,* are recognised as important colonial waterbird breeding sites. The swamps of the Merrowie, Merrimajeel and Muggabah creeks collectively known as the Booligal Wetlands and encompass between 10 –15,000 ha of the Lower Lachlan floodplain (Armstrong et al. 2009). The Booligal Wetland inland floodplain swamp complex includes Booligal Swamp, Upper Gum Swamp, Lower Gum Swamp, Merrimajeel Swamp and Murrumbidgil Swamp.

Straw-necked ibis have been recorded breeding in the Booligal wetlands since 1984 (Table 25) with breeding occurring over average every 2-3 years.

Table 25. Recorded Straw-necked ibis breeding events at Booligal Wetlands.

Year	Number of ibis nests	Comments	Reference
1984	80 000	Colony failed due to rapid water level drop	(Magrath et al. 1991)
1989	25 000	Colony failed due to rapid water level drop	(Magrath et al. 1991)
1990	45 000		(Driver et al. 2005)
1992	10 000		(Driver et al. 2005)
1993	40 000		(Driver et al. 2005)
1996	450		(Driver et al. 2005)
1998	40 000	Natural flood	(Driver et al. 2005)
2000	36 000	“Miracle” event, 350GL flow - managed	(Driver et al. 2005)
2005	10 000	Merrowie Creek colony. Environmental flow 6.65GL	(Wettin et al. 2007)
2010	75 000		(Porter et al. 2016)
2015	-	Abandoned nesting attempt, no eggs laid	(Brandis 2017)
2016	100 000 8,000	Upper Merrimajeel Blockbank	

During the spring-summer period 2016-2017 two colonial waterbird colonies, Upper Merrimajeel and Blockbank colonies established in early September 2016 and late December 2016 respectively. Colony sites were in the channelized lignum characteristic of the Lower Lachlan Selected Area.

The Upper Merrimajeel colony was the larger (>100 000 nests) and established following widespread rainfall and flooding in August and September 2016. It established in an area not traditionally used as a colony site but in an adjacent area with significant areas of suitable nesting habitat i.e. lignum.

The Blockbank colony was relatively small (~8,000 nests) and established in late December 2016, it was supported by both Commonwealth and NSW environmental water. This colony was located in the traditional Blockbank colony site were previous colonies have been recorded.

Regular surveys of waterbird nesting in both colonies enabled us to determine reproductive success for predominantly straw-necked ibis (*Threskiornis spinicollis*), but also Australian white ibis (*T. molucca*), glossy ibis (*Plegadis falcinellus*) and royal spoonbill (*Platelea regia*). Water depth and quality measurements were also recorded to provide information to water managers and understand specific water requirements for successful colonial waterbird breeding.

This monitoring program addressed the following evaluation question:

- What did Commonwealth environmental water contribute to waterbird breeding, fledging and survival?

13.2 METHODS

The two colonies were surveyed between September – November 2016 and January – March 2017 for the Upper Merrimajeel and Blockbank colonies respectively (Table 26). Colony survey methods were consistent with those for Category 1 Optional Waterbird Monitoring in the Lachlan Monitoring and Evaluation Plan (Dyer et al. 2014). Modifications to these methods included the use of an unmanned aerial vehicle (UAV) to capture imagery of the colonies (Lyons et al. 2017). UAV video and still photo capture were completed on the 12th October 2016 (Upper Merrimajeel) and 26th January 2017 (Blockbank). Photo orthomosiacs of each colony were created from which total nests were counted and vegetation layers derived (Upper Merrimajeel only). The accuracy of UAV derived nests counts was assessed against ground based counts of nests at survey sites.

Reproductive success monitoring of the Blockbank colony was funded by the NSW Office and Environment and Heritage (NSW OEH). Colony surveys were conducted by the Centre for Ecosystem Science, UNSW, NSW OEH, and CEWO.

Table 26. Ground survey dates for Upper Merrimajeel and Blockbank colony monitoring, 2016-17.

Survey	Upper Merrimajeel survey dates	Blockbank survey dates
1	16-17th September 2016	7th January 2017 (NSW, OEH)
2	4-5th October 2016	19th January 2017 (CES, UNSW)
3	19-20th October 2016	3rd February 2017 (NSW, OEH)
4	4^{-5th} November 2016	16th February 2017 (CES, UNSW)
5	15th November2016	1st March 2017 (NSW, OEH)
6	30st November 2016	15th March 2017 (CES, UNSW)

Colony surveys were undertaken every two weeks monitoring a marked set of randomly selected nest clumps. Water depths at each nest clump were measured during each survey and water quality measurements (temperature, pH, conductivity, salinity, total dissolved solids, and resistivity) were recorded from four random locations on each survey date in each colony. Observations of other waterbird species were also recorded.

During each colony survey development stages of chicks were recorded. Surveys were timed to correspond with chick development stages. Reproductive success was calculated for between survey periods (e.g. survival rates between survey 1 and 2) and total breeding period (overall survival rate from egg to fledging).

Table 27. Chick development stages recorded during each survey (Marchant and Higgins 1990, Brandis et al. 2011).

Development stage	Characteristics	Age (days)
Egg	Whole egg, being incubated by adult	1-20
Chicks	Recently hatched (1-5 days old), downy feathers, immobile	21-25
Squirters	Early sheathed feathers starting on wings, still in nest, immobile	26-30
Runners	Development of pin feathers. Mix of down and feathers, walking awkwardly, can leave nest on foot	31-35
Flappers	Nearly fully feathered, cannot fly but flaps between nests	36-40
Flyers	Fully feathered, able to fly and leave nests, still attended by parents at nest	41-47
Fledged	Independent, does not return to nest but roosts in nearby trees	>48

13.3 RESULTS

A total of 499 straw-necked ibis nests were marked in the Upper Merrimajeel colony. At the Blockbank colony 139 straw-necked ibis nests were marked and three additional colonially breeding species, glossy ibis (n=4 nests), Australian white ibis (n=1 nest) and Royal Spoonbill (n=2 nests).

Straw-necked ibis breeding in the Upper Merrimajeel colony was confirmed on the 26th August 2016 with approximately 4,000 straw-necked ibis on nests with eggs in lignum (*Duma florulenta*). At its peak, the colony exceeded 200,000 adults (October). The main colony boundary extended beyond the Lachlan Valley State Conservation, with a total area of 68 hectares (Figure 41). Mean clutch size for straw-necked ibis were 2 (2.08) eggs/ nest.

Ibis and spoonbills began nesting at the Blockbank colony site in late December 2016. This second colony was detected through aerial survey flown by the Lachlan LTIM team and NSW OEH on 19 December 2016. The colony was 9 ha in area and at its peak had ~8,000-10,000 adults (total four species) (January 2017). Mean clutch size for straw-necked ibis were 2 (1.99) eggs/ nest.

More than 40 wetland-dependent bird species were observed (12 breeding) in the Upper Merrimajeel and Blockbank colonies (Supplement 2, p. 148).

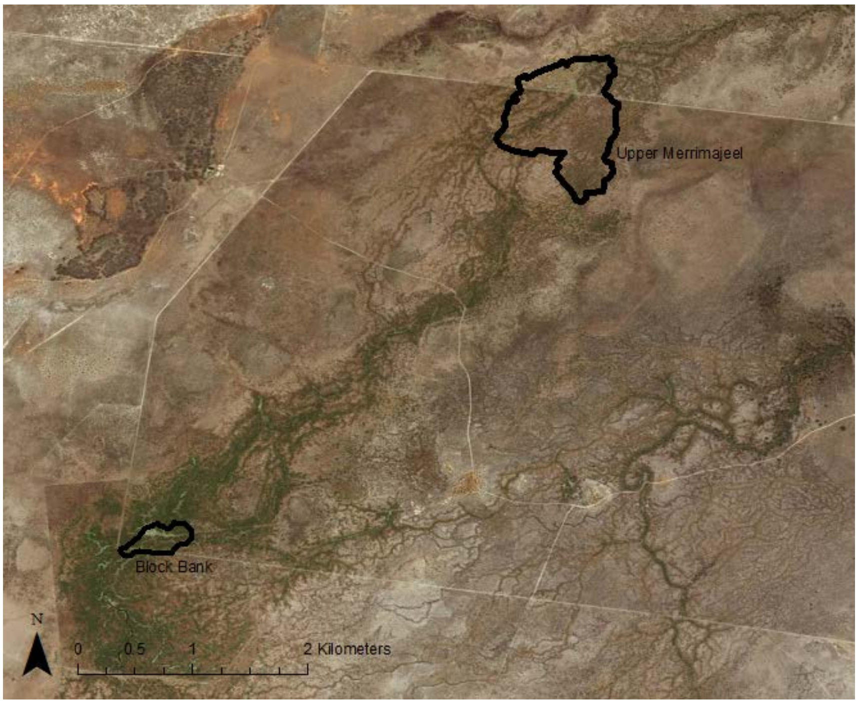
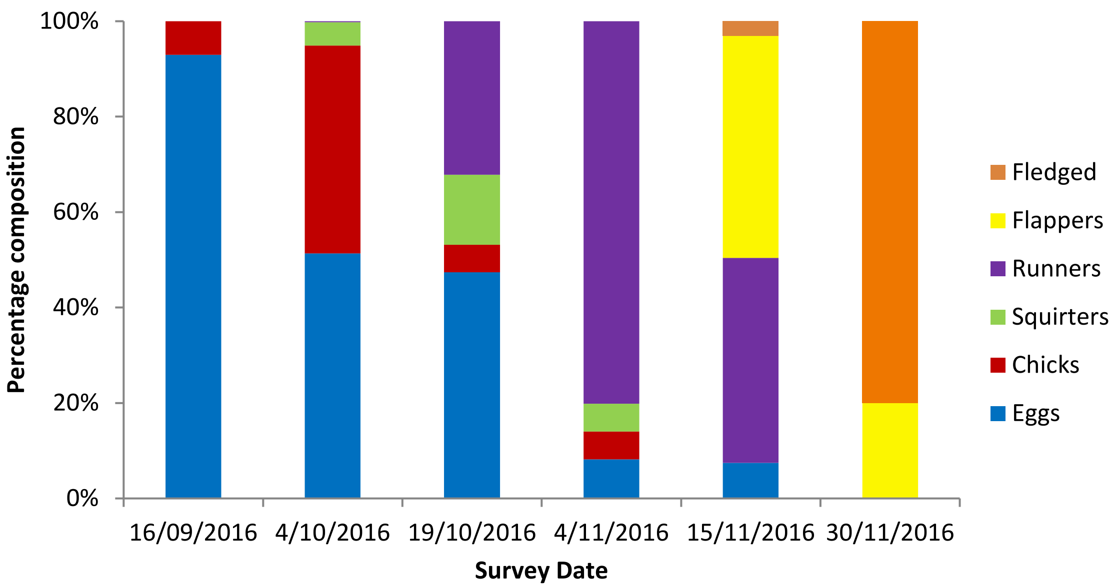


Figure 49. Upper Merrimajeel (2016) and Blockbank (2017) waterbird colony boundaries.

13.3.1 CHICK DEVELOPMENT

Figure 50 shows the age composition of chicks in the colonies during each survey. Records from the final survey show that the majority of chicks had fledged and left the nest. They were observed roosting and foraging in areas around the colonies.

A)



B)

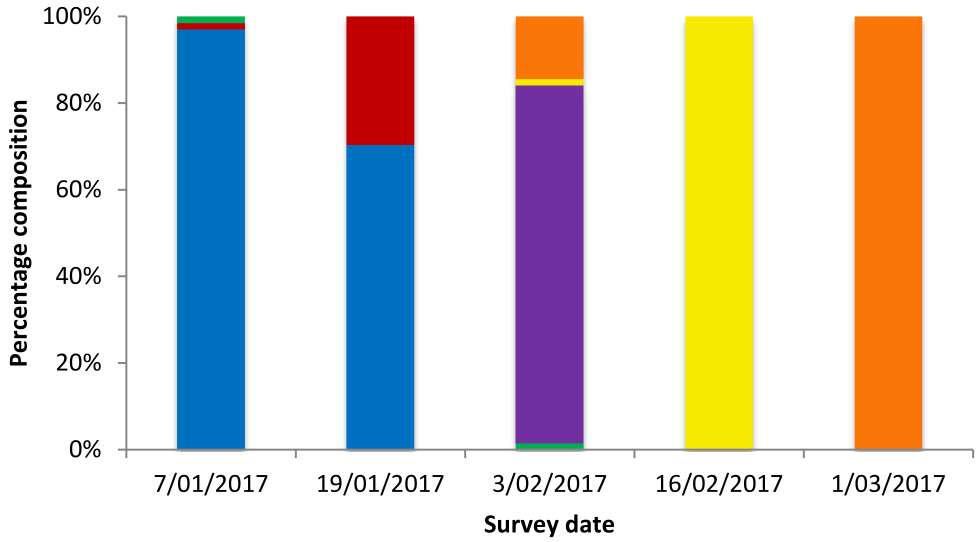


Figure 50. Composition of chick development stages at each survey of A) Upper Merrimajeel colony and B) Blockbank colony.

13.3.2 REPRODUCTIVE SUCCESS

In the Upper Merrimajeel colony reproductive success between survey time 1 to 2 was 91.45% and 100% from time 2 to 3 (Table 28). The overall reproductive success of the colony was 83.32%.

Table 28. The number of straw-necked ibis nests and offspring (eggs and/or chicks) monitored for reproductive success between each survey for the Upper Merrimajeel colony.
Interpretation of this table; there were 166 nests marked on 16/09/2016, additional nests were added on the second survey 4/10/2016 bringing the total to 249, on the 19/10/2016 there were 165 nests still being used of the 249. Of the 316 offspring counted on the 16/09/2016, 289 were present on the 4/10/2016. Changes in offspring numbers may be due to eggs being laid (increases in offspring) or chicks fledging or death (decreases in offspring). When chicks crèche (gather together) the total number of offspring per nest clump is counted – taking into account movement of chicks out of their nest.

Upper Merrimajeel	16/09/2016	4/10/2016	19/10/2016	4/11/2016
Nests	166			
Offspring	316			
Nests		249		
Offspring		473	549	
Nests			165	
Offspring			359	210

Table 29. The number of straw-necked ibis nests and offspring (eggs and/or chicks) monitored for reproductive success between each survey for the Blockbank colony.

See Table 28 caption for interpretation.

Blockbank	07/01/2017	19/01/2017	03/02/12017	16/02/2017
Nests	108			
Offspring	214	144		
Nests		204		
Offspring		403	67	
Nests			225	
Offspring			76	83

Overall reproductive success for straw-necked ibis in the Upper Merrimajeel colony was 83%. Reproductive success was high between surveys 1 -2 (91%) and between surveys 2-3 as the colony expanded and more eggs were laid (100%). Survival rates were lowest (58%) between surveys 3-4. Chicks were at runner and flapper stages during survey 4, this rate may be reflective of creching behaviour and the difficulty in associating young birds with marked nests.

Overall reproductive success for straw-necked ibis in the Blockbank colony was 64%. Success rates were highest between surveys 1 and 2 when nests were at egg and chick stages. Success rates were lowest between surveys 2 and 3 when chicks were at squirter and runner stages (Table 29).

Reproductive success for glossy ibis, Australian white ibis or royal spoonbill have not been calculated because of low sample numbers. The low numbers of nests monitored for these species is indicative of their abundance in the colony i.e. very low numbers.

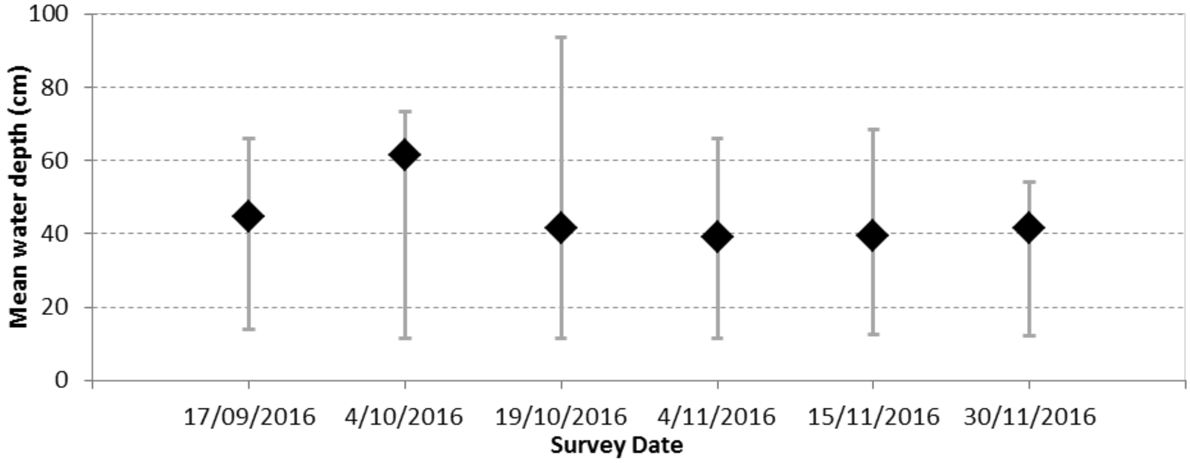
13.3.3 WATER MEASUREMENTS

Mean water depths in the Upper Merrimajeel colony remained relatively stable (range 39-62 cm) throughout the breeding event, with depths at the start of breeding similar to those at completion of breeding (Figure 51 A).

Mean water depths in the Blockbank colony were also relatively stable throughout the breeding period with no major fluctuations (range 44 – 61 cm) (Figure 51 B). Mean water depths at the Blockbank colony were slightly deeper than the Upper Merrimajeel colony (45 cm, 52 cm respectively) with similar ranges in depths (minimums and maximums).

Water quality measures were relatively stable throughout each of the breeding periods at each colony, however water temperature, pH, conductivity and total dissolved solids were higher throughout the breeding period at the Blockbank colony (Supplement 1, p. 147).

A)



B)

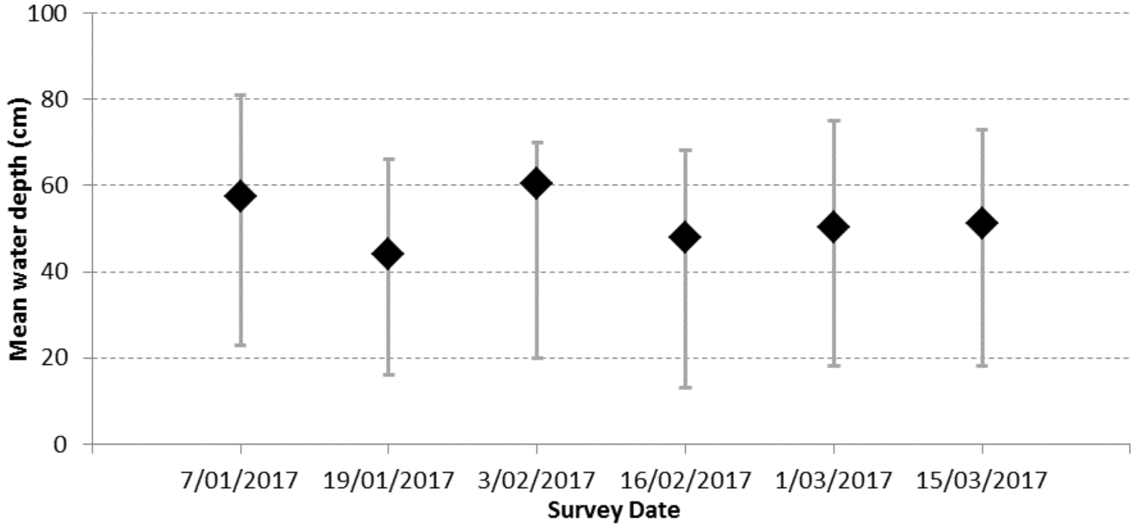


Figure 51: Mean (diamond), and maximum and minimum water depths (grey line) at A) Upper Merrimajeel and B) Blockbank colonies during each colony survey.

13.3.4 UAV IMAGERY

A total of 101,360 (±3,040) nests were counted in the Upper Merrimajeel colony on the 12th October 2016 using the photo orthomosaic derived from the UAV imagery (Figure 52). Accuracy of nest identification when compared to ground surveys was 97.26% with UAV derived counts underestimating.

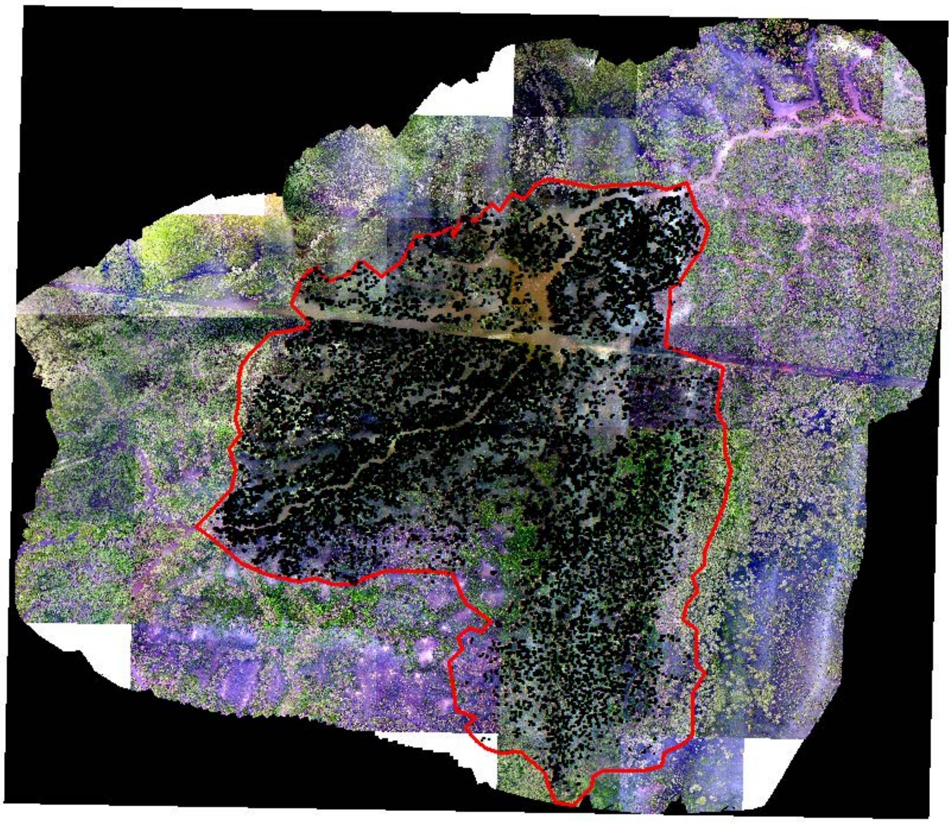


Figure 52: Upper Merrimajeel colony orthomosaic compiled from UAV imagery (12th October, 2016) (background) with colony boundary (red) and nests (black dots) marked.

A total of 7.997 (±960) nests were counted from UAV derived photo orthomosaic of the Blockbank colony on the 26th January 2017 (Figure 53). Nest count accuracy when compared to ground counts was 88% with the UAV derived counts underestimating total count.

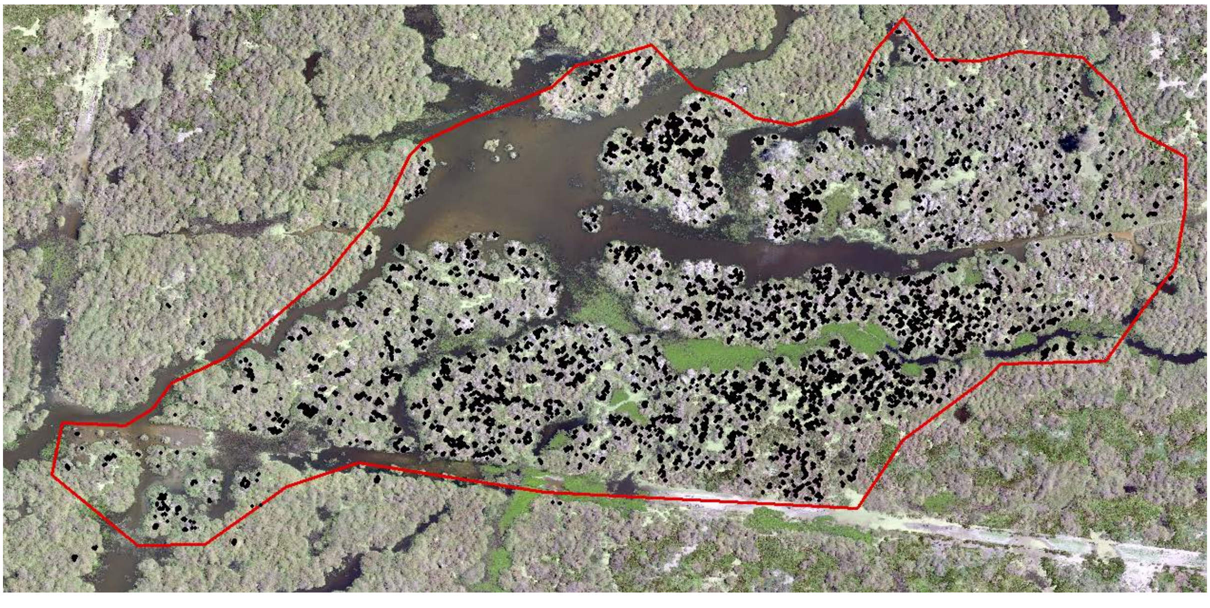


Figure 53: Blockbank colony orthomosaic compiled from UAV imagery, (26th January 2017) with colony boundary (red line) and nests (black dots) marked.

13.4 DISCUSSION

Reproductive success rates from the Upper Merrimajeel colony were high (83%), reflecting the optimal breeding conditions at the time including stable water levels, availability of nesting habitat, widespread inundation, long duration of inundation, and sufficient food resources (implied by high fledgling rates). The Upper Merrimajeel colony was not supported by Commonwealth or NSW water as the required duration and water levels for the colony were provided by naturally occurring flooding. Widespread flooding was the result of unregulated flows in the Lachlan River following high rainfall.

The Blockbank colony had a lower reproductive success rate (64%). Water levels were similar to those experienced in the Upper Merrimajeel colony and fluctuations were minimal. Possible reasons for the lower reproductive success rate includes; breeding started later in the season once peak flooding had passed, the second colony may have been established by less experienced birds that did not breed in the Upper Merrimajeel colony, different availability of food resources and/or predation by feral pigs and ravens (observed in the colony).

The Blockbank colonial waterbird colony was supported by both Commonwealth General Security (1,324 ML) and NSW Environmental Water Allowance (3,571 ML) as well as active management of water levels (See Section 8.3.2). This water maintained water levels in the colony site for the duration of breeding. Stable water levels of adequate depth are critical for preventing nest abandonment (Brandis et al. 2011), limiting access to ground based predators (Frederick and Collopy 1989), and providing suitable nesting and foraging habitat. The provision of water to support this breeding colony resulted in the successful fledging of several thousand juvenile straw-necked ibis, and provided foraging habitats, particularly for species that feed in the wetland e.g. spoonbills. In addition this water also watered flood dependent vegetation that provides nesting and roosting habitats e.g. lignum, river red gums and provided opportunities for fish and frog spawning and the emergence of macro and micro aquatic invertebrates.

The Upper Merrimajeel colony was the largest and most successful colony of straw-necked ibis in the Murray-Darling Basin in 2016-2017. It was also the largest recorded colony since 1984 (UNSW CES unpublished data). The data collected during the monitoring of this and the Blockbank colony adds significant information to our understanding of environmental requirements for successful waterbird breeding. In particular it provided site specific information regarding water requirements for the two wetland/colony sites which are tied to reproductive success (Brandis et al. 2011). This information will be critical for the management of water to support any future breeding events that may occur.

The combination of monitoring data from the breeding events in 2016-17 with the review of the failed breeding attempt in Booligal wetlands from 2015-16 provides extremely valuable information about the conditions required for successful breeding of ibis. It is clear that October-November are the normal starting times for breeding in the Lower Lachlan and this is matched to experiences in the Lower Murrumbidgee. Water level thresholds identified by Driver et al (2005) of more than 50 cm water depth to prevent predation and stable water levels to prevent drowning or desertion have been reinforced as important.

13.5 SUPPLEMENT 1

Table 30. Mean values of water quality variables measured during each waterbird colony survey for Upper Merrimajeel

Water quality metric	17/09/2016	4-5/10/2016	19-20/10/2016	4/11/2016	15/11/2016
Temperature (^{0}C)	18.1	18.2	20.5	21.9	18.8
pH	7.8	8.1	7.9	7.7	8.1
Conductivity (S/m)	0.3	0.4	0.3	0.4	0.4
Salinity (ppt)	0.2	0.2	0.2	0.2	0.2
Total Dissolved Solids (mg/L)	179.0	224.3	172.5	188.7	215.0

Table 31. Mean values of water quality variables measured during each waterbird colony survey for Blockbank

Water quality metric	19/01/2017	3/02/2017	16/02/2017	15/03/2017
Temperature (^{0}C)	24.1	20.9	20.9	21.2
pH	9.3	7.0	12.8	8.5
Conductivity (S/m)	0.5	0.5	0.6	0.6
Salinity (ppt)	0.2		0.3	0.3
Total dissolved solids (mg/L)	251.0		279.3	305.7
Turbidity NTU		34.1		
Dissolved Oxygen%		34.3		

13.6 SUPPLEMENT 2

Table 32. List of wetland-dependent bird species observed in the Lachlan colonies during 2016-17

Common Name	Scientific Name	Confirmed Breeding
Australasian darter	*Anhinga novaehollandiae*	
Australasian grebe	*Tachybaptus novaehollandiae*	Yes
Australasian shoveler	*Anas rhynchotis*	
Australian pelican	*Pelecanus conspicillatus*	
Australian raven	*Corvus coronoides*	
Australian Reed-warbler	*Acrocephalus australis*	
Australian shelduck	*Tadorna tadornoides*	
Australian White Ibis	*Threskiornis moluccus*	Yes
Australian wood duck	*Chenonetta jubata*	
Ballion's crake	*Porzana pusilla*	
Black swan	*Cygnus atratus*	
Black-tailed native-hen	*Tribonyx ventralis*	
Black-winged stilt	*Himantopus himantopus*	
Blue-billed duck	*Oxyura australis*	
Eurasian coot	*Fulica atra*	Yes
Glossy Ibis	*Plegadis falcinellus*	Yes
Great cormorant	*Phalacrocorax carbo*	
Great crested grebe	*Podiceps cristatus*	
Great egret	*Ardea alba*	
Grey teal	*Anas gracilis*	Yes
Hardhead	*Aythya australis*	Yes
Hoary-headed grebe	*Poliocephalus poliocephalus*	Yes
Little black cormorant	*Phalacrocorax sulcirostris*	
Little grassbird	*Megalurus gramineus*	
Little pied cormorant	*Microcarbo melanoleucos*	
Magpie goose	*Anseranas semipalmata*	
Masked lapwing	*Vanellus miles*	Yes
Musk duck	*Biziura lobata*	
Nankeen night heron	*Nycticorax caledonicus*	Yes
Pacific black duck	*Anas superciliosa*	
Pacific heron	*Ardea pacifica*	
Pink-eared duck	*Malacorhynchus membranaceus*	
Plumed whistling duck	*Dendrocygna eytoni*	
Purple swamphen	*Porphyrio porphyrio*	Yes
Royal Spoonbill	*Platalea regia*	Yes
Straw-necked Ibis	*Threskiornis spinicollis*	Yes
Swamp harrier	*Circus approximans*	
Whiskered tern	*Chlidonias hybrida*	
Whistling kite	*Haliastur sphenurus*	
White-faced heron	*Egretta novaehollandiae*	
White-necked heron	*Ardea pacifica*	
Yellow-billed spoonbill	*Platalea flavipes*	

14 BOOLIGAL VEGETATION MONITORING

14.1 INTRODUCTION

The condition and complexity of the vegetation associated with a waterbird breeding colony is assumed to be important to a successful breeding event but specific requirements are not clear. In 2015-16 environmental watering (including both Commonwealth and NSW water) of the Booligal wetlands improved the condition of the vegetation (Dyer et al. 2016). Observations at watered sites were that the lignum had responded to the watering with increased growth and vigour. While the specific vegetation requirements for successful bird breeding are unclear, either through the condition of the lignum (nesting habitat) or food resources in the landscape, it is assumed that the growth of lignum caused by environmental watering would have improved the habitat available for nesting (if nothing other than to provide additional nesting material). It was also assumed that the additional vegetation growth in the area in 2015-16 that was caused by environmental watering is likely to have provided a more productive landscape in which the birds could breed.

Thus, in association with the waterbird monitoring, information about the condition and structure of the vegetation was collected to answer the following questions:

1. What is condition, structure and health of the vegetation associated with the nesting colony?
2. What was the contribution of Commonwealth environmental water to the condition, structure and health of the nesting and foraging habitats?

14.2 METHODS

The condition and complexity of the vegetation in the area was measured using Drone (Unmanned Aerial Vehicles, UAVs) based methods and compared with measures of structure and condition from the LTIM vegetation survey data. The aim was to provide baseline vegetation data against which to compare future measurements but also to enable a pilot comparison of Drone captured vegetation data with field measurements. This was a very small pilot study and was conducted to contribute to a discussion about the potential to use Drones for future monitoring of environmental watering responses.

14.2.1 VEGETATION STRUCTURE AND CONDITION: DRONE SURVEY

The Drone survey was conducted on 12-13/10/2016 as part of the colony image capture. Flying conditions did not permit the capture of multispectral and infrared data at the time of the survey and only standard RGB imagery was captured. The aircraft model used to capture imagery was the DJI Phantom 3 Professional. The photos were captured using the stock RGB camera. Flights were conducted at 100 m above take off level, which over the colony generally corresponded to 100 m above ground level. Forward and lateral overlap of photos was approximately 80% and 60% respectively. 34 individual flight transects were flown to cover the approximately 7 km^2 colony. A true colour rectified orthomosaic (~4 cm pixels) was generated via Structure from Motion photogrammetry, using the proprietary processing software Pix4D.

The original orthomosaic pixel resolution was 4cm; the imagery used to produce the vegetation products was resampled to 20 cm to enable vegetation mapping at a more appropriate and tractable scale. The resampled orthomosaic was run through an unsupervised (k-means) classification using the "Unsupervised KMeans image classification" tool from the Orfeo Toolbox in QGIS (open source GIS software). It was parameterised with 60 classes, training set size of 20 000, maximum iterations of 500 000 and convergence threshold of 0.0001. Each individual class was then inspected manually and labelled as vegetation or water, as best as possible given that many pixels are a mixture of vegetation and water in a flooded area. The classes were then collapsed to a binary vegetation mask. A vegetation percentage cover map was then produced by calculating the percentage of vegetation (as determined by the binary 20 cm mask) within a grid of 1m pixels. Each pixel thus has a value between 0 and 1, indicating the percentage cover of vegetation.

14.2.2 VEGETATION STRUCTURE AND CONDITION: FIELD SURVEY

The LTIM standard methods for vegetation survey (Dyer et al. 2014) were conducted for three 20 x 20 m plots on the margins of the colony (Figure 54) on the 14th November 2016. Sites were selected to minimize disturbance to the breeding birds during field surveys, yet still capture the character of the colony vegetation. Species abundance, heights and cover were recorded during the survey. The 3 plots were surveyed again in autumn (14th June 2017) as part of the regular LTIM vegetation assessments.

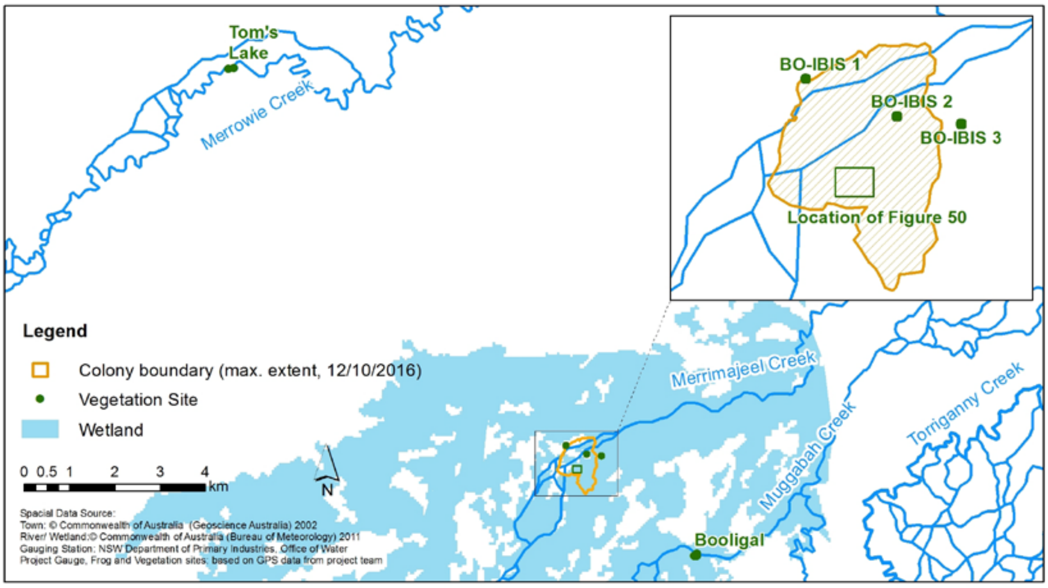


Figure 54. Location of LTIM vegetation monitoring sites and the plots within the colony.

14.2.3 COMPARISON OF DRONE SURVEY AND FIELD SURVEY DATA

Data from the drones and field surveys were used to calculate the following vegetation condition and structure metrics:

- Percentage cover of all (live) vegetation
- Height and percentage cover of lignum
- Species richness and species composition

- Relative proportion of native/non-native species (as cover and as number of species)
- Relative proportion of vegetation functional groups

14.2.4 VEGETATION CLASS AND CONDITION: QUALITATIVE ASSESSMENT

The dominant vegetation type of the colony was identified using the interim ANAE typology developed for the MDB (see Brooks et al. 2013). The condition of the vegetation for nesting was assigned a rank according to Table 33 and a condition based on that expected for lignum shrublands (NSW OEH Plant Community Type PCT17, Bowen et al. (2017), Table 34).

Table 33: Vegetation condition ranks for colonial nesting locations[1].

RANK	DESCRIPTION
Good	Vegetation structure in dominant layer healthy, good cover (>70%) with virtually no weeds evident. No obvious indication of altered processes which may affect vegetation condition.
Moderate	50-70% cover in dominant vegetation layer, some areas of dead branches present, or limited evidence of disease (i.e. die back), shrub layer more sparse, less connected and somewhat patchy. Some evidence of weeds and or indication of altered processes
Poor	Significant loss, <30%, of cover in dominant vegetation type, considerable amount of weeds, large number of dead branches, crown highly patchy. Stands of vegetation patchy and disconnected, considerable or obvious evidence of altered processes (i.e. drowned stumps).

[1] For live vegetation only, not for species which prefer to nest in dead trees.

Table 34. Condition scoring for Lignum Shrublands (PCT17) after Bowen et al. (2017). Overall condition is based on the sum of the condition scores where >20 = good; 15-19 = Intermediate/Good; 12-15 = Intermediate; 10-12 = Poor; <10 = very poor.

		Bare Ground	Invasive native terrestrial	Exotic Species	Lignum[1]	Wetland functional groups
Good	% Cover	10	10	10	20-40	15-40
	Score	4	4	4	4	4
Intermediate	% Cover	50-10	40-10	50-10	10-20	10-15
	Score	3	3	3	3	3
Poor	% Cover	80-50	80-40	80-50	0-10	0-10
	Score	2	2	2	2	2
Very Poor	% Cover	100-80	100-80	100-80	0	0
	Score	0	0	0	0	0

[1] Modify lignum score as follows. +1 if >80% live; +1 for >50% plants >1 m and +1 for >50% plants flowering

14.3 RESULTS

14.3.1 DRONE IMAGERY

The orthomosaic successfully covered the full extent of the breeding colony at a detail level sufficient to discriminate birds, nests and dominant vegetation type (Figure 52, p. 145). However, there were two issues that effected image quality in some parts of the image product. Firstly, varying illumination conditions results in some flight path artefacts in the image data; these were accentuated by the high reflectivity of the ground surface during flooding. Secondly, wind conditions were on the upper end of operational limits so at times the speed of the craft (from wind gusts) resulted in slightly blurry imagery. Nevertheless, the image blur rarely obfuscates birds/nests or identification of vegetated areas.

Figure 55 (left) shows how the nesting sites are clearly discernible from the imagery. Most nests are in clumps and we can observe both small and large inter-connected patches of nesting sites. The areas of bright green vegetation have clearly not been used as nesting material. The corresponding vegetation mask (Figure 55, right) identifies both undisturbed green vegetation and the lignum used for nesting material. Note that some of the areas not shown as vegetation may indeed have submerged vegetation not visible under the flood waters. The corresponding vegetation cover map (Figure 56) clearly differentiates between the more patchy cover of the dry/dead lignum and the undisturbed vegetation.

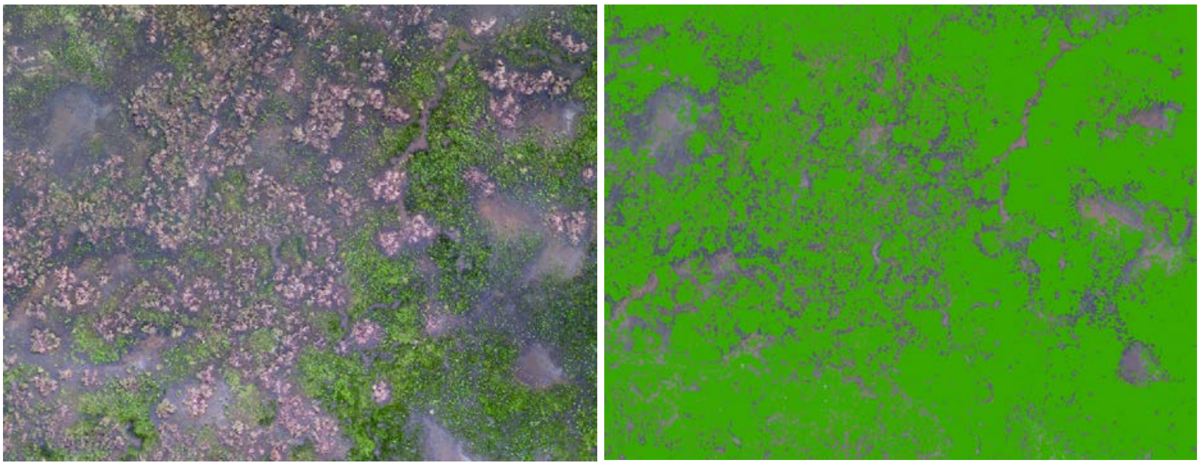


Figure 55. The orthomosaic (left) and vegetation mask (right) for an approximately 150 x 200 m area within the Upper Merrimajeel Creek Colony. Image source: M. Lyons UNSW

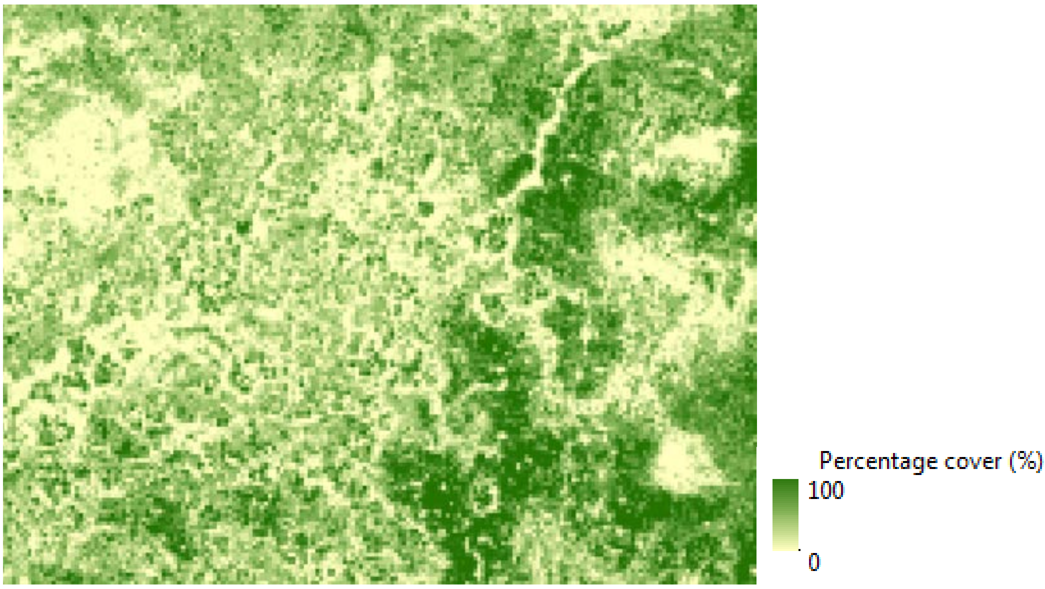


Figure 56. The percentage cover map for an approximately 150 x 200 m area within the upper Merrimajeel Creek colony.
The cover map corresponds to the images shown in Figure 56. Image source: M. Lyons UNSW.

14.3.2 FIELD SURVEYS

All field surveys showed a high proportion of native vegetation cover (>80%) with no introduced species observed in any of the plots (Table 35). The vegetation was dominated by Lignum (*Duma florulenta*) and small spike rush (*Eliocharis acuta*), with notable cover of blown grass (*Lachnagrostis filiformis*) in some plots. Unsurprisingly the majority of species were water respondent species (classified as amphibious or terrestrially damp species according to the classification of Brooks and Casanova (1997) and Casanova (2011). The vegetation condition was classified as Good according to the criteria in Table 33 and the condition scoring for Lignum Shrublands was classified as Good according to the criteria in Table 34.

Table 35. Vegetation metrics for the Booligal Ibis plots from 14 November 2016.

Vegetation metric	Plot 1	Plot 2	Plot 3
% cover (live) vegetation	87	82	100
% cover Lignum	25	20	40
Height Lignum (avge)	2 m	1.7 m	3.0 m
Species richness (# species)	13	11	16
% Native species	100	100	100
Dominant species (%cover)	*Duma florulenta (25%)* *Eliocharis acuta (50%)* *Pratia concolor (4%)*	*Duma florulenta (20%)* *Lemna minor (50%)*	*Duma florulenta (40%)* *Eliocharis acuta (20%)*

	Lachnagrostis filiformis (2%)	*Eliocharis acuta (10%)*	*Lachnagrostis filiformis (20%)* *Stellaria augustifolia (20%)*

14.3.3 COMPARISON WITH NEARBY VEGETATION MONITORING SITES

The two LTIM vegetation monitoring sites nearest the Upper Merrimajeel bird colony are at Booligal on Muggabah Creek and at Tom's Lake on Merrowie Creek (Figure 54), are not directly analogous to the Upper Merrimajeel colony (Booligal Ibis Colony), as they are within intermittent black box floodplain swamps rather than in an intermittent lignum floodplain swamp and the vegetation data highlights significant differences in the character of the site vegetation (Table 36) and the response to flooding. This means that it is not possible to extrapolate responses from the long term vegetation monitoring sites to the bird colony.

Table 36. Vegetation metrics from the nearby vegetation monitoring sites Booligal Wetland and Tom's Lake, compared to the Booligal Ibis plots

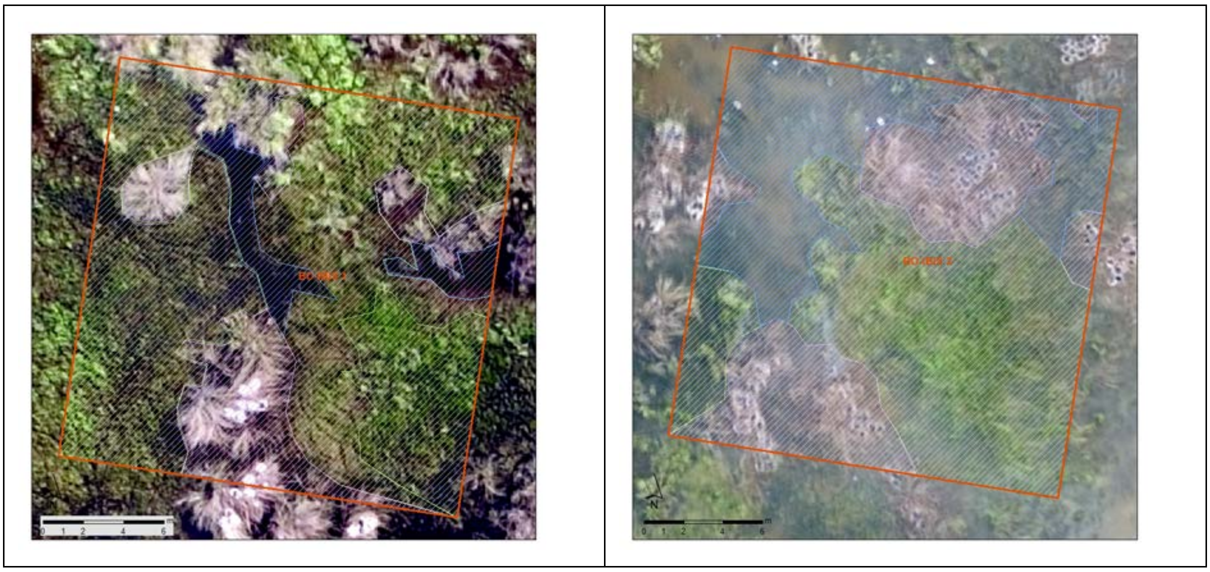
Vegetation metric	Booligal Ibis Colony (Upper Merrimajeel Creek)		Booligal Wetland		Tom's Lake	
	Spring	**Autumn**	**Spring***	**Autumn**	**Spring**	**Autumn**
date	14/11/2016	14/06/2017	1/11/2016	14/06/2017	15/11/2016	15/06/2017
% cover (live) vegetation	91.4	23.3	30.3	29.7	52.3	65.9
% cover Lignum	28.3	35.3	7	6.5	50	57.7
Height Lignum (avg)	2.2 m	1.5 m	2 m	1.6 m	2.5 m	2.5 m
Species richness (# species)	13	23	18	35	7	25
% Native species^	100	72	73	65	100	73
Dominant species"	*Duma florulenta*	*Duma florulenta*	*Eleocharis acuta*	*Paspalidium jubiflorum*	*Duma florulenta*	*Duma florulenta*
	Eleocharis acuta	*Eleocharis acuta*	*Pratia concolor*	*Duma florulenta*	*Asperula gemella*	*Eleocharis acuta*
	Lemna minor	*Chenopodium pumilio*	*Duma florulenta*	*Lachnagrostis filiformis*	*Eleocharis acuta*	*Galium gaudichaudii*

	Stellaria angustifolia	*Lachnagrostis filiformis*	*Phalaris minor*	*Eleocharis acuta*	*Chenopodium nitrariaceum*	*Lachnagrostis filiformis*
	Lachnagrostis filiformis	*Medicago polymorpha*	*Acacia stenophylla*	*Pratia concolor*	*Azolla filiculoides*	*Sporobolus mitchellii*

*no data from BO-P2: 100% submerged
^ unknown grass and germinant excluded
" rank after average coverage

14.3.4 COMPARING VEGETATION SURVEY RESULTS

Unsupervised classification was a reasonable solution for a lightweight vegetation mapping procedure. Using imagery resampled to 20 cm appeared to be a good balance between preserving detail and minimising variance for the unsupervised classification. Figure 55 shows the orthomosaic, vegetation mask and Figure 56 shows the percentage cover map for a ~150 m square area. In situ data was not available for a systematic assessment of mapping accuracy, however, the three vegetation assessment sites were used to make a superficial assessment of the vegetation mask and percentage cover product. Note the vegetation surveys were approximately a month after the imagery was acquired, and some changes would be expected in that time. The percentage cover values derived from the drone imagery corresponded well to the vegetation cover estimated for the field plots (Table 37), but statistical inference would be inappropriate with only three plots. Structurally similar vegetation was difficult to separate, but distinctive types (e.g. lignum) were relatively easy to identify (Figure 57). Taking plot 3 as an example: lignum cover was observed at 40%, which corresponds well to the cover of brown/pale green vegetation in the drone image; rush cover was observed at 20%, which again corresponds well to the bright green vegetation in the drone plot. Cover of grasses and other small aquatic vegetation are difficult to identify from the drone imagery, unless they are in large or distinctive floating mats (Figure 58).



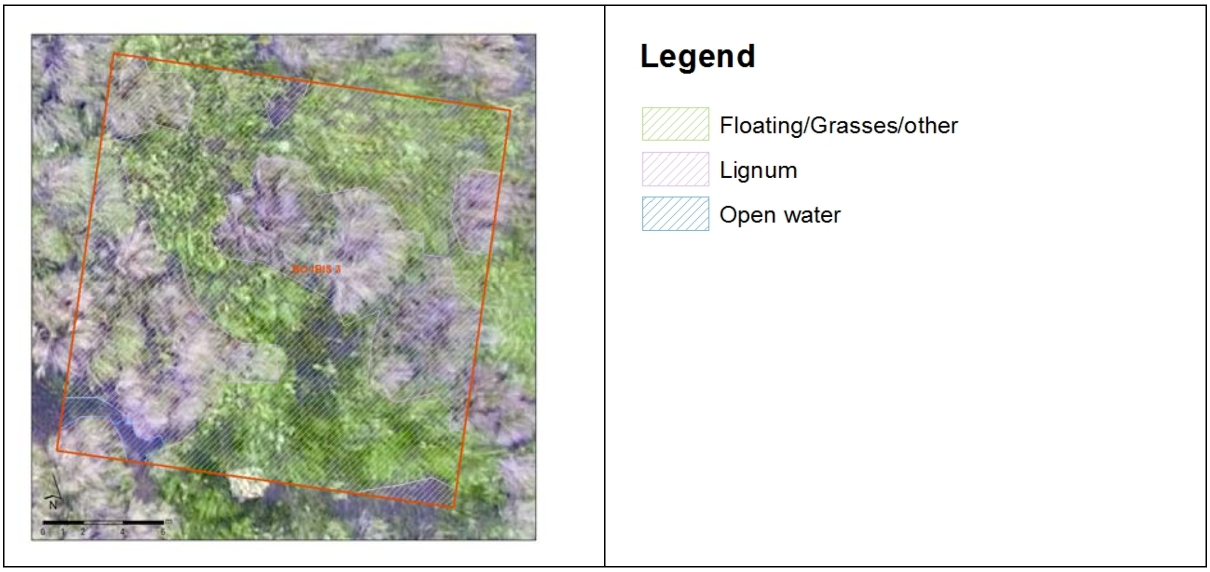


Figure 57. Field survey plots (20x20m) with the only two obvious and distinctive vegetation classification possible (lignum and floating/ grasses/ others) plus open water.
The calculation of coverage percentages compared to field survey coverages are presented in the table below.

Table 37. Comparison of field and drone vegetation metrics.

	Booligal Ibis Plot 1			Booligal Ibis Plot 2			Booligal Ibis Plot 3		
	field	drone	**Diff**	field	drone	**Diff**	field	drone	**Diff**
Lignum (%)	25	22	3	20	30	10	40	47	7
Floating/Grasses /other (%)	62	72	10	62	44	18	66	52	14
Open water (%)	13	6	7	18	26	12	1	1	0

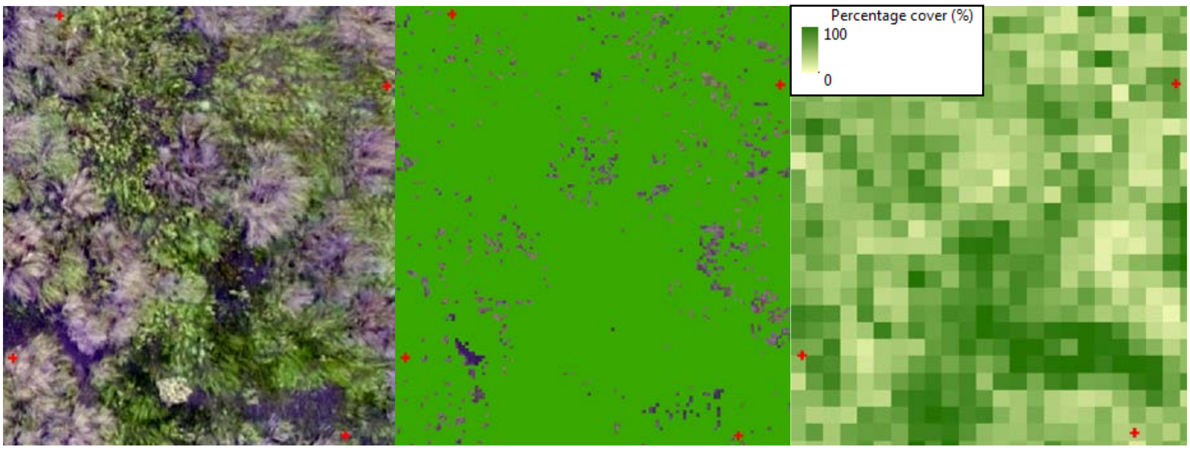


Figure 58. The 20 x 20 m vegetation plot (Plot 3, corners marked) and the corresponding vegetation mask and percentage cover products.
The major vegetation composition as estimated from the floristic plot was lignum (Duma florulenta, 40%), small spike rush (Eleocharis acuta, 20%), blown grass (Lachnagrostis filiformis, 20%) and swamp starwart (Stellaria angustifolia, 20%).

14.4 DISCUSSION

14.4.1 USING DRONE IMAGE CAPTURE FOR VEGETATION SURVEY: LEARNING

The vegetation mask appeared to be a good general representation of vegetation cover. One main type of confusion occurred; very turbid water appeared very bright in the image data and was often confused with multiple vegetation classes, making it very difficult or impossible to separate without excessive manual work. Depending on the application of the vegetation map, a supervised classification may be more appropriate, because of the combination of variation within vegetation types and the high resolution of the drone captured imagery. Otherwise, considerably more manual work would be required working with an unsupervised classification. Options include increasing the number of classes, or reclassifying classes with high levels of confusion. Alternatively, manual API (aerial photo interpretation) methods might also be appropriate, as the imagery can be of sufficient resolution to estimate vegetation to family and often to genus or species level. The time for such manual image interpretation will need to be taken in to consideration and will depend on the size of the area to be mapped and the complexity of the vegetation.

The percentage cover map was also a reasonable representation of the vegetation cover, although it was somewhat conservative. The high resolution of the drone imagery meant that areas of bare ground or water could be distinguished in amongst vegetation. When summarised to 1 m pixels for the percentage cover map, cover appears to be somewhat underestimated. The more open structure of lignum (compared to sedges, rushes, grasses and other herbs) exacerbated this issue (Figure 57). This could be rectified by using smaller or larger areas to summarise vegetation cover, but this would depend heavily on the intended application of the percentage cover product.

14.4.2 WHAT IS CONDITION, STRUCTURE AND HEALTH OF THE VEGETATION ASSOCIATED WITH THE NESTING COLONY?

The vegetation associated with the nesting colony was an excellent example of good quality intermittent lignum floodplain swamp vegetation. The cover was high (>80%) and comprised solely native water respondent species or species that are known to require damp environments. The vegetation structure was dominated by lignum, small spike rush and blown grass with a number of native herbs also observed. More than 80% of the lignum plants comprised live material and had an average height of >1.5 m. Thus the vegetation was considered to be ‘Good’ for nesting waterbirds and in good condition.

14.4.3 WHAT WAS THE CONTRIBUTION OF COMMONWEALTH ENVIRONMENTAL WATER TO THE CONDITION, STRUCTURE AND HEALTH OF THE NESTING AND FORAGING HABITATS?

The Booligal wetlands vegetation monitoring site was visited in November 2016, at the peak of the waterbird colony. Water depths were around 0.3- 0.4 m and large numbers of ibis were observed to be foraging at the sites, most commonly in open ground rather than within the black box and river cooba. The 2015-16 Commonwealth environmental watering produced a small but noticeable improvement in tree condition within the monitoring site (Dyer et al. 2016), but the ibis did not appear to be using the areas in which an improvement had been observed.

We lack vegetation data from the Upper Merrimajeel bird colony prior to the bird breeding event. We also do not have suitable sites within the current monitoring program to investigate the way in which the vegetation condition and structure may have responded to the flooding or infer the contribution of past use of Commonwealth environmental water to the condition, structure and health of nesting and foraging habitats. To better understand the relationship between vegetation condition, structure and health and how it relates to waterbird habitats requires a more targeted research program.

14.5 FINAL COMMENTS AND RECOMMENDATIONS

- Future monitoring of a colony of this size should consider image capture over a 4-5 day period, to enable more control for sun angle and weather conditions.
- To better understand the relationship between vegetation condition, structure and health and how it relates to waterbird habitats requires a more targeted research program.
- To establish protocols for monitoring vegetation using Drone imagery requires a specific research program with directly comparable sites, rather than retrofitting sites to make the comparison.
- Given the importance of the lignum shrublands for colonial nesting waterbirds, future vegetation monitoring should consider establishing plots within this plant community type.

14.6 SUPPLEMENTARY MATERIAL

See the image meta data for full technical specifications of the output image products, including orthomosaic, digital surface model and 3D point cloud.

General Properties

File Identifier	**3C72D246-316F-41D4-AF59-674D20E4ECEA**
Hierarchy Level	**dataset**
Hierarchy Level Name	**dataset**
Standard Name	**ANZLIC Metadata Profile: An Australian/New Zealand Profile of AS/NZS ISO 19115:2005, Geographic information - Metadata**
Standard Version	**1.1**
Date Stamp	**2017-01-19**
Resource Title	**Orthorectified mosaic of Upper Merrimajeel Creek**
Format Name	***.xml**
Format Version	**Unknown**

Key Dates and Languages

Date of creation	**2016-10**
Metadata Language	**eng**
Metadata Character Set	**utf8**
Dataset Languages	**eng**
Dataset Character Set	**utf8**
Abstract	**This image is a mosaic generated via Structure from Motion photogrammetry. The individual photos used to generate the mosaic were captured using a Phantom 3 Professional unmanned aerial vehicle. The stock RGB camera was used and the image product was processed in Pix4D.**
Purpose	**This imagery was captured to monitor a breeding Straw-necked Ibis colony**

Metadata Contact Information

Name of Individual	**Name withheld**
Organisation Name	**Centre for Ecosystem Science, UNSW Australia**
Position Name	
Role	**resourceProvider**
Voice	
Facsimile	
Email Address	**ecosystem@unsw.edu.au**

Address	
	Sydney NSW 2055
	Australia

Resource Contacts

Lineage Statement	**Data format: GeoTIFF (public domain format for TIFF files with embedded georeferencing information) Camera Model Name(s): FC300X_3.6_4000x3000 (RGB) Average Ground Sampling Distance (GSD): 4.09 cm / 1.61 in Area Covered: 1.8151 km2 / 181.506 ha Images: median of 48400 keypoints per image Dataset: 1821 out of 1821 images calibrated (100%), all images enabled Camera Optimization: 31.66% relative difference between initial and optimized internal camera parameters Matching: median of 15128.4 matches per calibrated image Georeferencing: yes, no 3D GCP Photo overlap in image pixel: >5 overlapping photos for every orthomosaic pixel Number of 2D Keypoint Observations for Bundle Block Adjustment: 27973102 Number of 3D Points for Bundle Block Adjustment: 10150481 Mean Reprojection Error [pixels]: 0.197**

Data Quality

Test Type	**DQ_AbsoluteExternalPositionalAccuracy**
Specification	**Absolute Geolocation Variance**
Specification Date	
Specification Edition	
Explanation	**These RMS errors are within the image. The GPS unit that geotagged the photos has 5 m X/Y accuracy and 10 m Z accuracy. RMS Error X [m]: 3.675596 RMS Error Y [m]: 4.512628 RMS Error Z [m]: 2.358501**
Pass	**true**

Jurisdictions

New South Wales

Search Words

ECOLOGY-Habitat

FAUNA-Native

WATER-Wetlands

Themes and Categories

Topic Category	**biota**
Topic Category	**environment**

Status and Maintenance

Status	**completed**
Maintenance and Update Frequency	**notPlanned**

Date of Next Update	

Reference system

Reference System	**EPSG::32755 (WGS 84 / UTM zone 55S)**

Data Scales/Resolutions

Resolution	**0.04 m**

Spatial Representation Type

Spatial Representation Type	**grid**

Schedule

	schedule

Metadata Security Restrictions

Classification	**unclassified**
Authority	
Use Limitations	

Dataset Security Restrictions

Classification	**unclassified**
Authority	
Use Limitations	

Dataset Access Constraints

Identifier	**intellectualPropertyRights**
Annotation	

Dataset Use Constraints

Identifier	**intellectualPropertyRights**
Annotation	

Extent - Geographic Bounding Box

North Bounding Latitude	**-33.74388**
South Bounding Latitude	**-33.75821**
West Bounding Longitude	**144.88232**
East Bounding Longitude	**144.89903**

Additional Extent - Temporal

Date/Time	**2016-10-12**

General Properties

File Identifier	**3C72D246-316F-41D4-AF59-674D20E4ECEA**
Hierarchy Level	**dataset**
Hierarchy Level Name	**dataset**
Standard Name	**ANZLIC Metadata Profile: An Australian/New Zealand Profile of AS/NZS ISO 19115:2005, Geographic information - Metadata**
Standard Version	**1.1**
Date Stamp	**2017-01-19**
Resource Title	**Vegetation percentage cover map of Upper Merrimajeel Creek**
Format Name	***.xml**
Format Version	**Unknown**

Key Dates and Languages

Date of creation	**2016-11**
Metadata Language	**eng**
Metadata Character Set	**utf8**
Dataset Languages	**eng**
Dataset Character Set	**utf8**
Abstract	**This vegetation map was produced from a binary vegetation mask that was generated via unsupervised classification of a remotely sensed orthomosaic. The orthomosaic was generated via Structure from Motion photogrammetry. The individual photos used to generate the mosaic were captured using a Phantom 3 Professional unmanned aerial vehicle. The stock RGB camera was used and the image product was processed in Pix4D.**
Purpose	**This mapping was carried out to monitor a breeding Straw-necked Ibis colony**

Metadata Contact Information

Name of Individual	**Name withheld**
Organisation Name	**Centre for Ecosystem Science, UNSW Australia**
Position Name	
Role	**resourceProvider**
Voice	
Facsimile	
Email Address	**ecosystem@unsw.edu.au**
Address	

	Sydney NSW 2055
	Australia
Resource Contacts	
Lineage Statement	**Data format: GeoTIFF (public domain format for TIFF files with embedded georeferencing information) Methodology: The original orthomosaic pixel resolution was 4cm; the imagery used to produce the vegetation mask was resampled to 20cm to enable vegetation mapping at a more appropriate and tractable scale. The resampled orthomosaic was run through an unsupervised (k-means) classification using the "Unsupervised KMeans image classification" tool from the Orfeo Toolbox in QGIS. It was parameterised with 60 classes, training set size of 20000, maximum iterations of 500000 and convergence threshold of 0.0001. Each individual class was then expected manually and labelled as vegetation or water, as best as possible given that many pixels are a mixture of vegetation and water in a flooded area. The classes were then collapsed to a binary vegetation mask. The vegetation percentage cover map was then produced by calculating the percentage of vegetation cover within a grid of 1m pixels; each pixel has a value between 0 and 1, indicating the percentage cover of vegetation.**
Data Quality	
Test Type	**DQ_AbsoluteExternalPositionalAccuracy**
Specification	**Absolute Geolocation Variance**
Specification Date	
Specification Edition	
Explanation	**These RMS errors are within the image. The GPS unit that geotagged the photos has 5 m X/Y accuracy and 10 m Z accuracy. RMS Error X [m]: 3.675596 RMS Error Y [m]: 4.512628 RMS Error Z [m]: 2.358501**
Pass	**true**
Jurisdictions	
	New South Wales
Search Words	
	ECOLOGY-Habitat
	FAUNA-Native
	WATER-Wetlands
Themes and Categories	
Topic Category	**biota**
Topic Category	**environment**
Status and Maintenance	
Status	**completed**

Maintenance and Update Frequency	**notPlanned**
Date of Next Update	

Reference system

Reference System	**EPSG::32755 (WGS 84 / UTM zone 55S)**

Data Scales/Resolutions

Resolution	**1 m**

Spatial Representation Type

Spatial Representation Type	**grid**

Schedule

	schedule

Metadata Security Restrictions

Classification	**unclassified**
Authority	
Use Limitations	

Dataset Security Restrictions

Classification	**unclassified**
Authority	
Use Limitations	

Dataset Access Constraints

Identifier	**intellectualPropertyRights**
Annotation	

Dataset Use Constraints

Identifier	**intellectualPropertyRights**
Annotation	

Extent - Geographic Bounding Box

North Bounding Latitude	**-33.74388**
South Bounding Latitude	**-33.75821**
West Bounding Longitude	**144.88232**
East Bounding Longitude	**144.89903**

Additional Extent - Temporal

Date/Time	**2016-10-12**

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