Appendix A Hydrology (Darling River)

A.1 Introduction

The timing, quantity and movement of water through river systems, hydrology, is the primary driver of aquatic ecosystems (Walker *et al.* 2005). Therefore, hydrology is the dominant management tool that the Commonwealth Environmental Water Office (CEWO) uses to achieve environmental outcomes.

The Hydrology (Darling River) indicator provides information on the influence of Commonwealth environmental water and/or management decisions on the hydrological conditions and extent of inundation experienced in the Darling River zone within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). Flows into the top of the Darling River zone are influenced by contributions to the Barwon-Darling River from upstream catchments (referred to as northern tributaries in Appendix C) and are augmented by flows down the Warrego River. This indicator describes the connection of water in the Darling River zone between Weir 19A and Louth and defines the connection events along the Darling River and the inundation of habitat (benches, anabranches and snags) within the channel. The Hydrology (Darling River) indicator quantifies this hydrological connectivity maintained through the Darling River zone for the five-year span of the LTIM Project from 2014 to 2019.

Information in this Appendix is directly relevant to several other indicators measured in the Warrego-Darling Selected Area during the LTIM Project including water quality, vegetation, waterbirds, fish, and microcrustaceans, as well as Hydrology (River) in relation to the Warrego River. The influence of hydrology on these indicators is addressed under their respective Appendices.

One specific question was addressed in relation to the Hydrology (River) indicator:

- What did Commonwealth environmental water contribute to hydrological connectivity?

One specific question was addressed in relation to the Hydrology (Habitat) indicator:

- What did the Commonwealth environmental water contribute to in-channel habitat availability along the Darling River?

A.1.1 Environmental watering during the LTIM Project

Barwon-Darling and northern tributaries

Flows into the Darling River zone during the LTIM Project were influenced by both unregulated and regulated environmental water (Appendix C). Over the first four years of the Project, 12 flow events entered the Warrego-Darling Selected Area containing environmental water contributions ranging from 1.8% to 99.6%.

During 2014-15, one regulated flow out of the Gwydir river system and two unregulated flows containing environmental water flowed into the Warrego-Darling Selected Area. All three events were small in magnitude, being less than 2,500 ML/d at Louth, but did increase connectivity in the Darling River zone in the 2014-15 water year. Similarly, 2015-16 was another relatively dry year, characterised by three flow events of low magnitude. Environmental water contributions during this year ranged from 3.4% to 30%. In contrast, 2016-17 was characterised by one large flow event that occurred in late spring-summer which peaked at 33,700 ML/d at Louth.

While only containing 2.4% environmental water, this flow inundated all available in-channel habitat along the Darling River zone. In addition to this, three other smaller inundation events occurred in 2016-17, containing between 2.4% and 36.5% environmental water. 2017-18 was again a relatively dry year, with three small flow events providing connection through the Warrego-Darling Selected Area. The flow event in May-June 2018 was a targeted environmental flow called the Northern Connectivity Event, which was a combination of both state and Commonwealth environmental water (for more information see https://www.environment.gov.au/water/cewo/northern-rivers). This flow was delivered to re-connect the Barwon-Darling River and was also supported by pumping embargos along the length of the channel. This flow contained 99.6% environmental water when it passed through the Warrego-Darling Selected Area. During the 2018-19 water year, there was limited flow into the Darling River zone from upstream tributaries. A flow event in February-June 2019 including around 10,324 ML of environmental water contributed to flows in the Darling River below the confluence during this event.

A.2 Methods

A.2.1 Longitudinal connectivity

An assessment of the hydrological connectivity experienced along the Darling River within the Warrego-Darling Selected Area was undertaken by comparing flow regimes at the upstream Weir 19A gauge (425037) with the gauging station at Louth (425004) which is the first reliable gauge downstream of the Warrego-Darling Selected Area (Figure A-1, Commonwealth of Australia 2015). This reach was considered to be fully connected when water was flowing past both gauges.

Even during periods of no flow through the Darling River zone, Weir 20A which is located on the Darling River downstream of the Warrego-Darling Selected Area, backs water up through the Warrego-Darling Selected Area, providing continued connectivity. Given the dry prevailing conditions and cessation of river flows in the Darling River upstream of the Warrego-Darling Selected Area in 2018-19, a trial was undertaken to assess the continuity of the weir pool in the Darling within the Warrego-Darling Selected Area during the 2018-19 water year. Continuity was assessed by visually analysing remote sensed imagery accessed through the publicly available Sentinel-hub Playground (https://www.sentinel-hub.com/) for times when the weir pool separated into a series of isolated waterholes. The sentinel satellite captures imagery every 5 days. Within the Sentinel-hub Playground, the pre-defined normalised difference water index (NDWI) was used which combines Band 3 and Band 8 imagery and is designed to highlight areas of open water. Analysis of the imagery suggested that a section of the Darling River towards the upstream end of the zone was the first to become disconnected as water levels receded. Therefore, the trial assessment of weir pool continuity concentrated on this reach (Figure A-1).

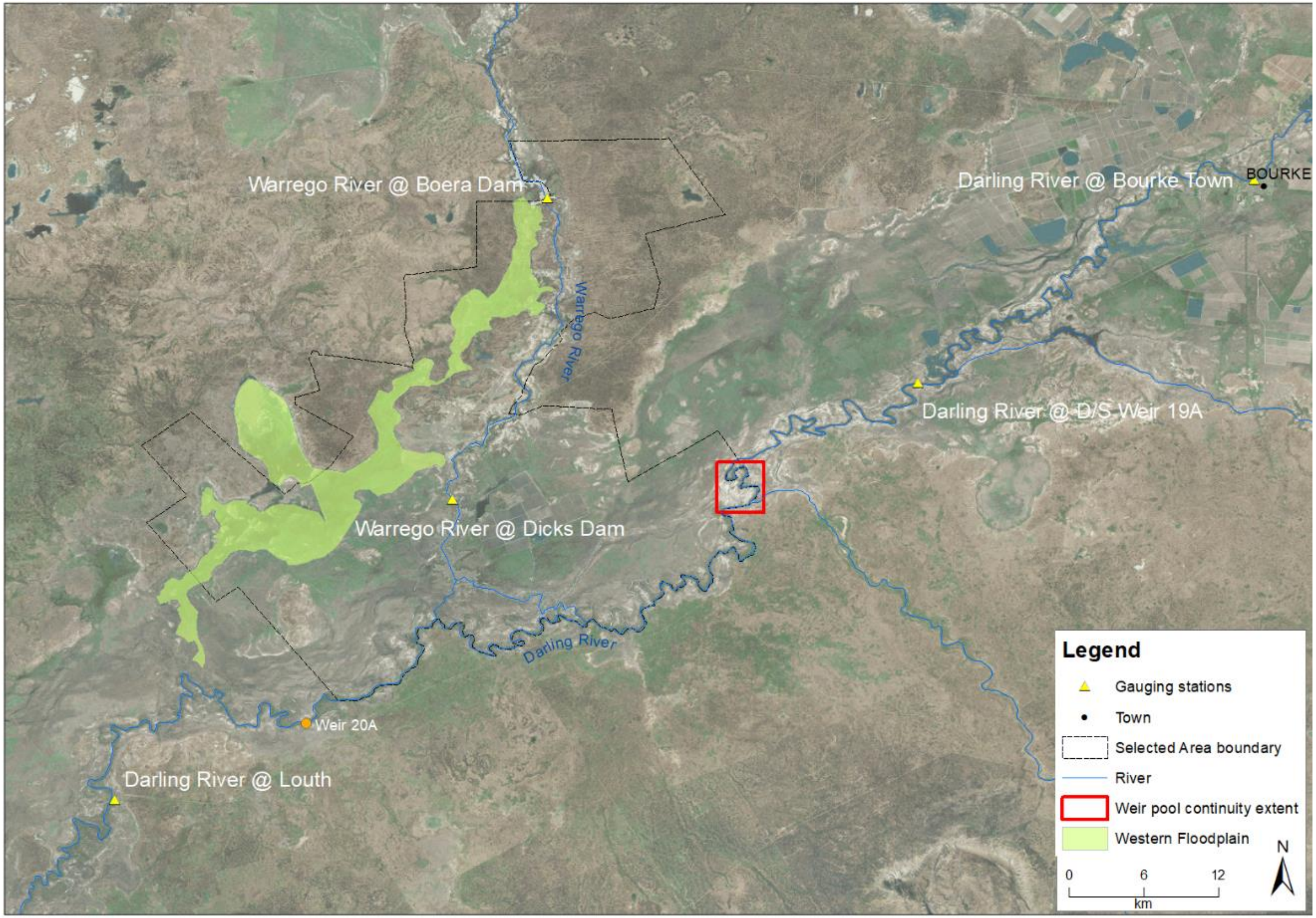


Figure A-1: Location of flow gauging stations used in the hydrological connectivity analysis and location of the reach used for trial pool continuity assessment.

A.2.2 Habitat inundation

Benches and anabranches were identified through desktop mapping of in-stream habitat and aerial photograph interpretation along the Darling River within the Warrego-Darling Selected Area (Commonwealth of Australia 2015). A field survey was undertaken to verify the in-stream habitat features and map additional features. In addition to the number and size of individual habitat features present, height above the current water level was noted using a hypsometer to measure the commence-to-inundate level of benches and the commence-to-inundate for anabranch channels (Commonwealth of Australia 2015). Commence-to-inundate heights were recorded to the nearest vertical metre.

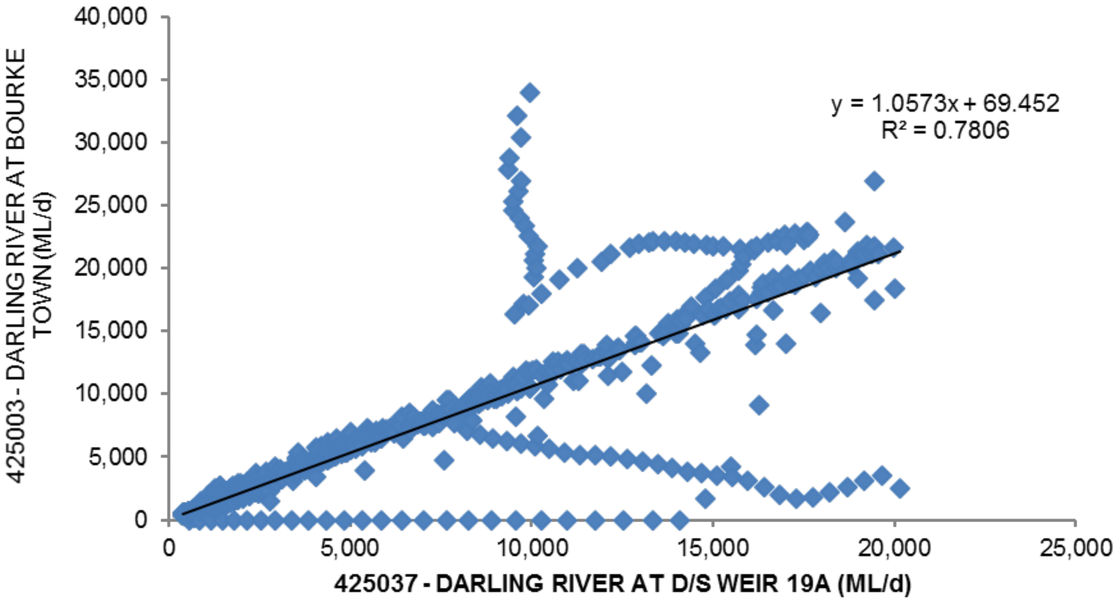
Snag (large woody debris) data was obtained from NSW DPI Fisheries that had been collected for the *Fish and Flows in the Northern Basin Project* in 2015 (NSW DPI 2015). The height above the current water level was recorded using a similar method as that used for benches and anabranches. As part of the *Fish and Flows in the Northern Basin Project* snags were classified into four grades of complexity (Figure A-2). Most snags in the Darling River channel were classified as Grade 1 or Grade 2 in complexity (Figure A-2).

Figure A-2: Classification system used to grade complexity of snags (NSW DPI 2015).

The vertical commence-to-inundate heights of individual habitat features above the current water level at the time of field survey were converted to a gauged height at the nearest river flow gauge. Benches and anabranches upstream of the Warrego River confluence were linked to the Weir 19A (425037) gauge upstream of the Warrego-Darling Selected Area, while benches and anabranches downstream of the confluence were linked to the gauging station at Louth (425004) (Figure A-1). Snags for the entire reach of the Darling River within the Warrego-Darling Selected Area were linked to the Weir 19A gauge only. These gauges were chosen as they best reflected the hydrology of these sections of the Darling River. However, final commence-to-inundate discharges were reported at the Bourke Town (425003) gauging station as it has a more comprehensive flow record. To do this, relationships between the Louth and Weir 19A gauging stations and the Bourke Town gauge were identified by plotting respective flows between 400 ML/d and 20,000 ML/d at the gauges from 2002 to present (total length of Weir 19A gauge record). Travel time between gauges was considered, with trendlines and associated regression equations of the relationship between gauges calculated (Figure A-3). These equations were used to express the commence-to-inundate discharges measured at the Louth and Weir 19A gauges to the Bourke Town gauge. The commence-to-inundate for each anabranch channel was determined using the entry or exit with the highest gauge height to better represent water flow into each channel.

Total organic Carbon (TOC), Nitrogen (TN) and Phosphorus (TP) release rates from in-channel benches, observed on the Darling River upstream of Bourke by Southwell (2008), were combined with the duration of time that benches in the Warrego-Darling Selected Area were inundated during 2018–19. This was to provide an estimate of total nutrient loads contributed to the river from these benches during the water year.

Due to the recent verification and adjustment of gauge data by WaterNSW, the five-year analysis of habitat inundation and the TOC, TN and TP release rates have been updated for each water year. Therefore, some figures presented in this report may differ slightly from those presented in reports from previous years.



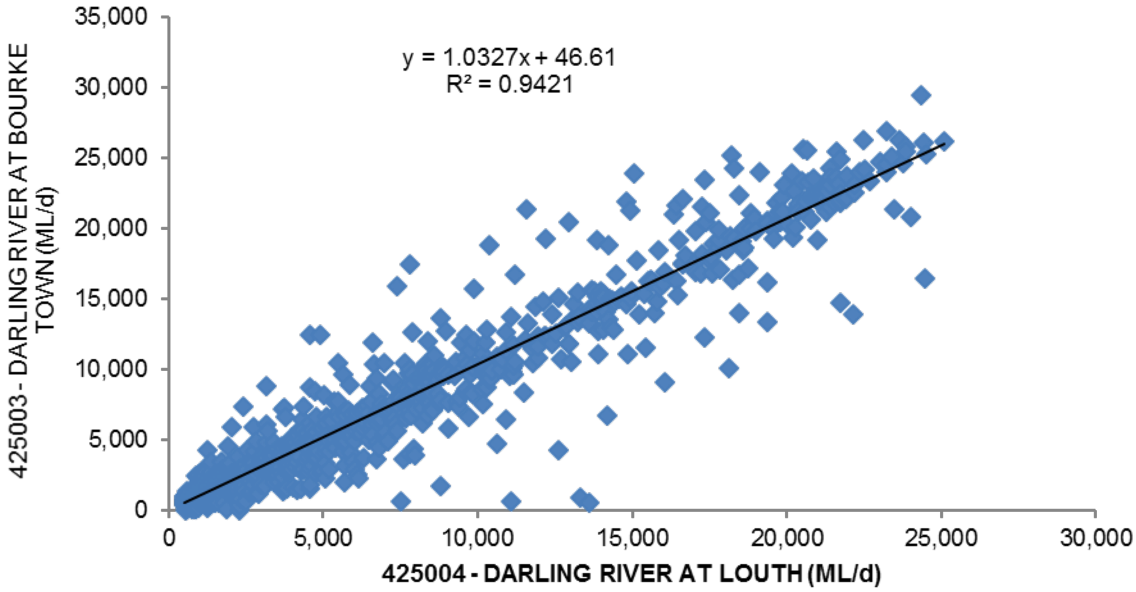


Figure A-3: Relationships between the Darling River @ Bourke Town gauge and, a) Darling River @ Weir 19A, b) Darling River @ Louth gauging stations.

A.3 Results

A.3.1 Longitudinal connectivity

The Darling River within the Warrego-Darling Selected Area was connected (flowing past Weir 19A and Louth simultaneously) for 1,136 days or 62% of the time during the 2014-19 period (Figure A-4 and Figure A-5). In the 2016-17 water year during the largest flow event of the project, connectivity was assumed for a portion of the year because data at the Weir 19A gauge was not available. The magnitude of flows at the next upstream gauge (Bourke Town), suggests the Darling River remained connected between these gauges for the duration of this period.

River flow and connectivity through the Darling River zone was characterised by small magnitude events, well below bankfull, of less than 3,500 ML/d for the majority of time. An exception to this was the larger near-bankfull flow event, peaking at 33,700 ML/d at Louth that occurred during spring/summer 2016. This event contributed to the longest period of connection of 575 days, occurring between June 2016 and January 2018 (Figure A-4 and Figure A-5). The shortest connection event was for two days while the average duration of connection events was 95 days. Darling River connectivity was primarily driven by flow events containing Commonwealth environmental water (Figure A-4), while smaller connection periods were due to localised rainfall. The most recent connection event in April-June 2019 was augmented by flows from the Warrego River that contained 10,324 ML of environmental water. This Warrego River flow increased flows below the Darling/Warrego River confluence in the Warrego-Darling Selected Area considerably (from around 50 ML/d upstream to over 700 ML/d downstream; Figure A-5).

Conversely, the Darling River ceased to flow within the Warrego-Darling Selected Area for a total of 690 days, or 38% of the time. There were 13 no-flow periods ranging in length from 1 to 273 days (Figure A-4 and Figure A-5). The longest period of no flow was recorded from July 2018 until May 2019 when a small flow event resulting from localised rainfall, augmented by Warrego River flows reinstated flow through the zone.

The results from the weir pool continuity trial concentrated on the two longest cease-to-flow periods of the project, from January to April 2018, and from July 2018 to May 2019. During the first of these periods, flow through the reach ceased on the 13 January 2018 and water remained backed up through the Warrego-Darling Selected Area for at least two weeks (Figure A-6). The first indication of weir pool fragmentation was in the 16 February 2018 image, 34 days after flow ceased through the reach. Pools continued to contract through to 28 March (represented by the 1 April 2018 image in Figure A-6), when the reach was connected once again. During the second cease-to-flow event, inflows stopped on 30 July 2018, and water remained backed up through the Warrego-Darling Selected Area for around 20 days until the weir pool again fragmented on 19 August 2018 (Figure A-6). The reach dried significantly over the next seven months, with water restricted to several remnant pools visible on the 21 April 2019 image. Flow was again restored on the 26 April 2019, 250 days after the reach began to fragment.

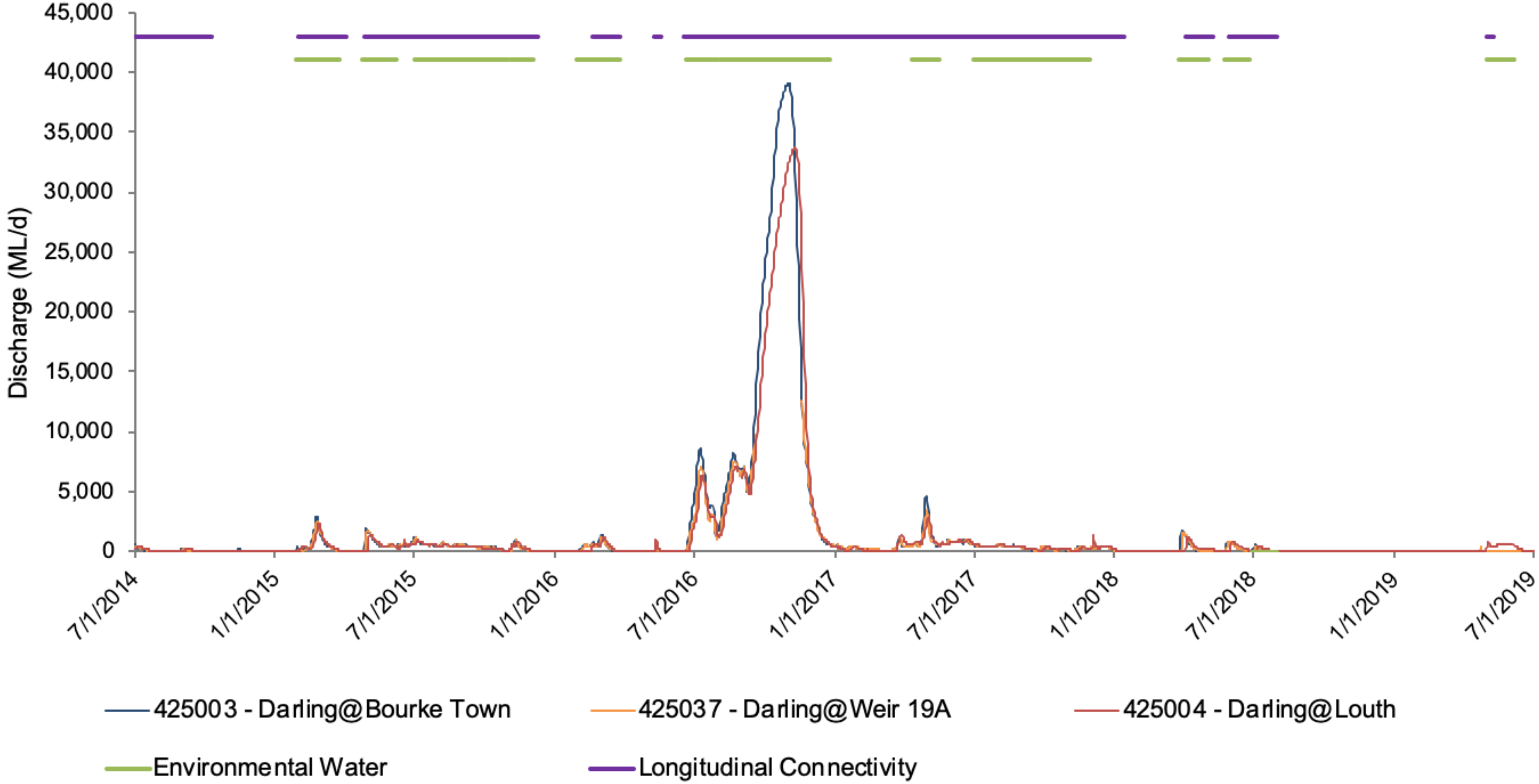


Figure A-4: River flows down the Darling River channel and the timing of longitudinal connectivity in the Warrego-Darling Selected Area. More description of the periods of environmental water are provided in Appendix C.

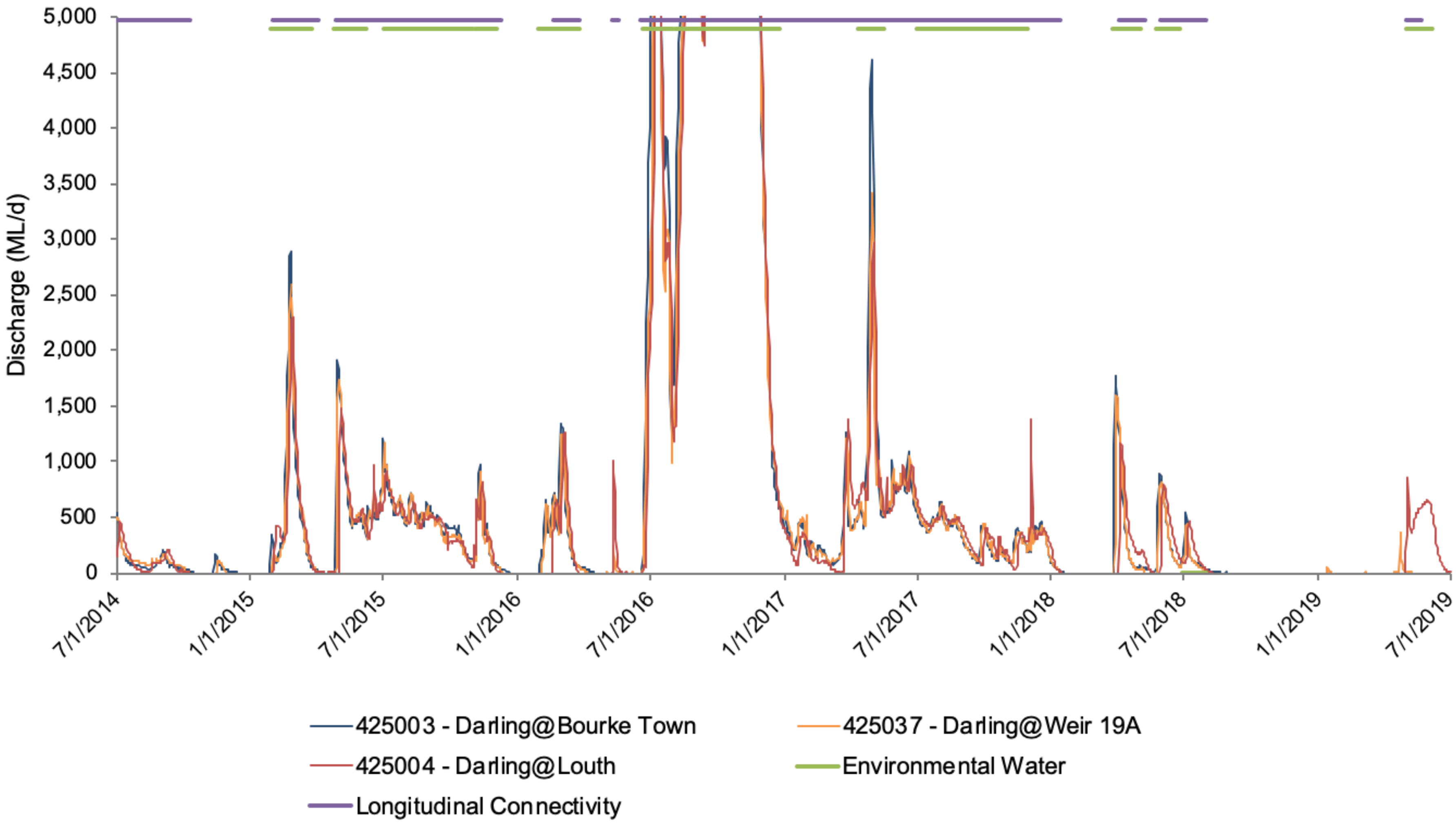


Figure A-5: River flows down the Darling River channel and the timing of longitudinal connectivity in the Warrego-Darling Selected Area (same as Figure A-4 but with a reduced y-axis to show smaller flows that dominated the period).

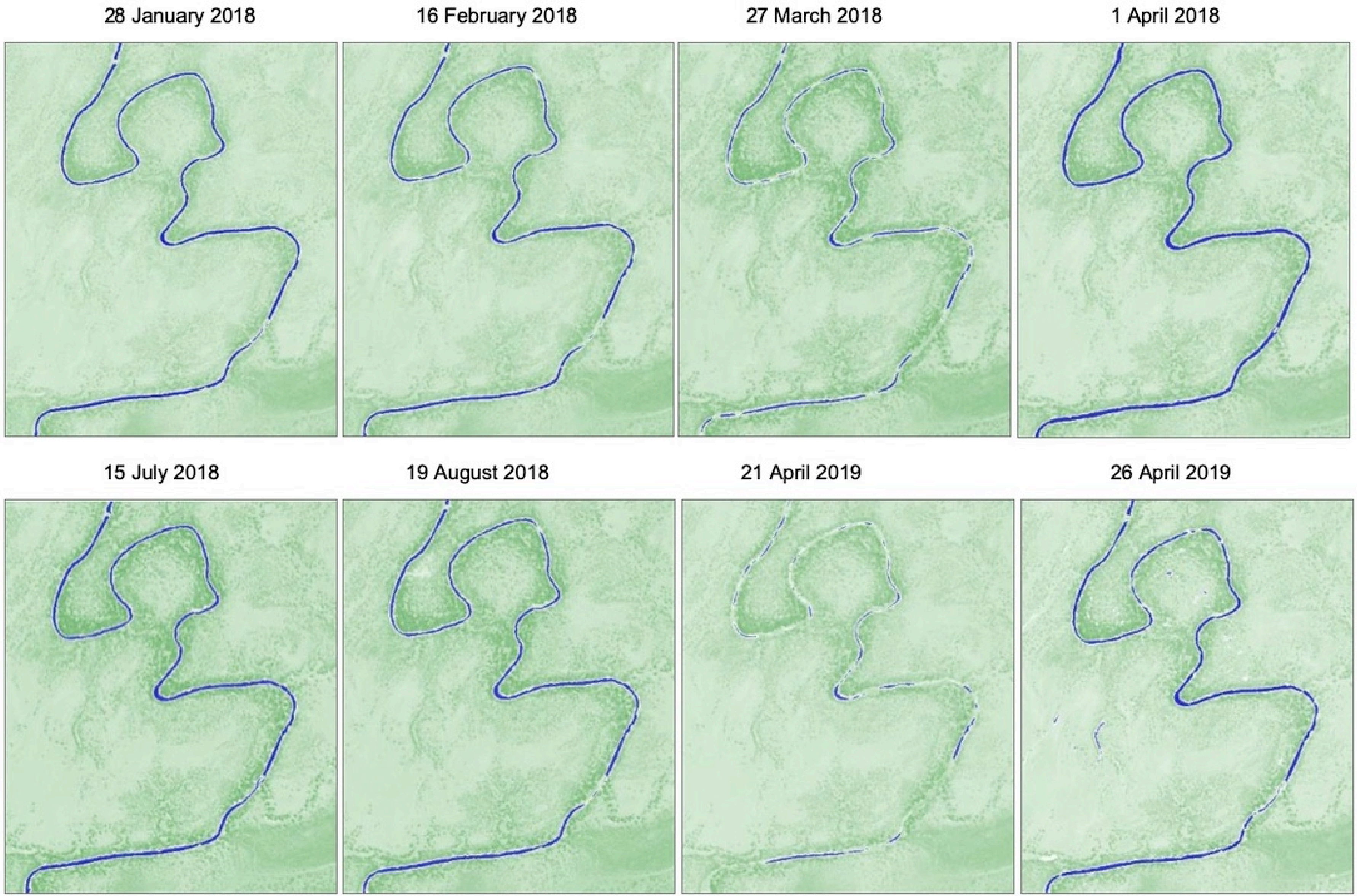


Figure A-6: Weir pool fragmentation over two cease-to-flow periods during 2018-19 within the Darling River zone of the Warrego-Darling Selected Area.

A.3.2 Habitat inundation

Twelve environmental flow events occurred in the 2014-19 period which inundated all three target habitat types in the Darling River zone.

Snags

All of the mapped snags (3,375) along the Darling River zone of the Warrego-Darling Selected Area were inundated for at least 23 days during the LTIM Project (Figure A-8; Table A-1). Overall, low level snags (snags that become inundated at 69 ML/d) make up 26% of the total snags in the reach that were inundated for 56% of the time (1,033 days in total). The maximum duration of inundation was achieved during the larger flow event from June 2016 to January 2017. In this event, 50% of the snags were inundated for at least 71 days, with 26% of snags inundated for a continuous period of 562 days (Figure A-8). During other flow events, snags that become inundated at flows between 283 ML/d and 3,600 ML/d were inundated for shorter durations (maximum duration of 17 days).

Table A-1: Duration and proportion of snags inundated in the Darling River in 2014-19.

Flow Height Range Bourke to Weir 19A (ML/d)	Snags	Proportion of total snags (%)	Days inundated	% Total time
<69	973	26.1	1,033	56.57
69 – 1,793	151	4.0	182	9.97
1,793 – 9,109	1,138	30.5	66	3.61
9,109 – 14,872	860	23.0	57	3.12
14,872 – 18,889	354	9.5	53	2.9
18,889 – 40,000	259	6.9	23	1.26

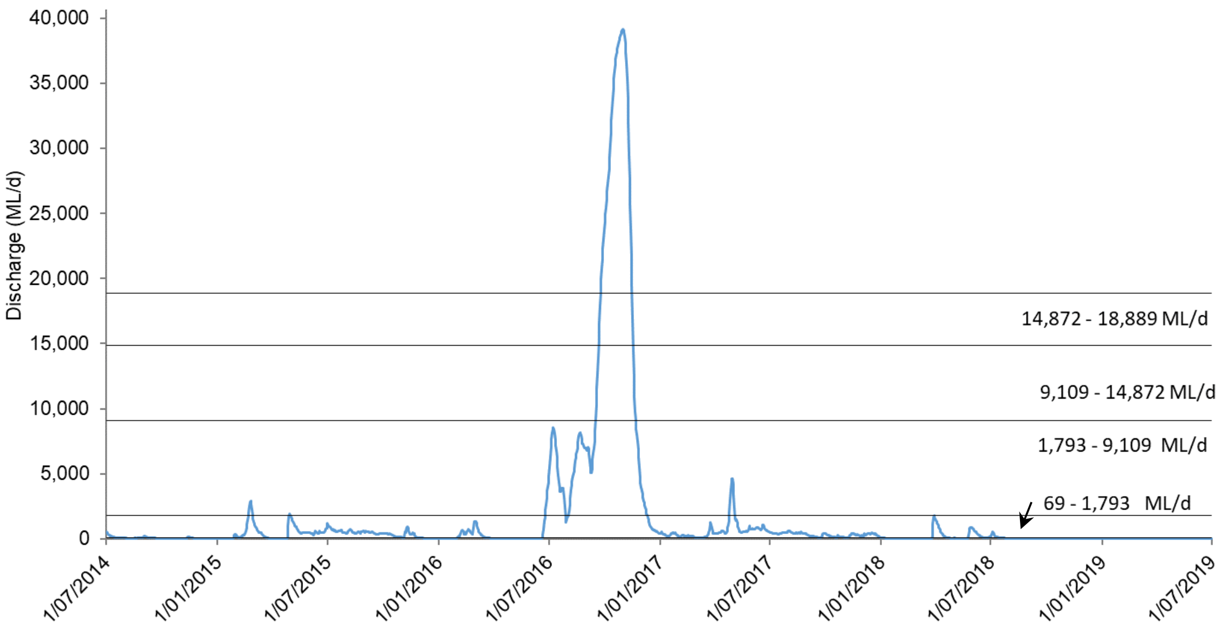


Figure A-7: Snag inundation during the LTIM Project along the Darling River zone of the Warrego-Darling Selected Area. Snags grouped by discharge in ML/d measured at the Bourke Town gauge (NSW 425003).

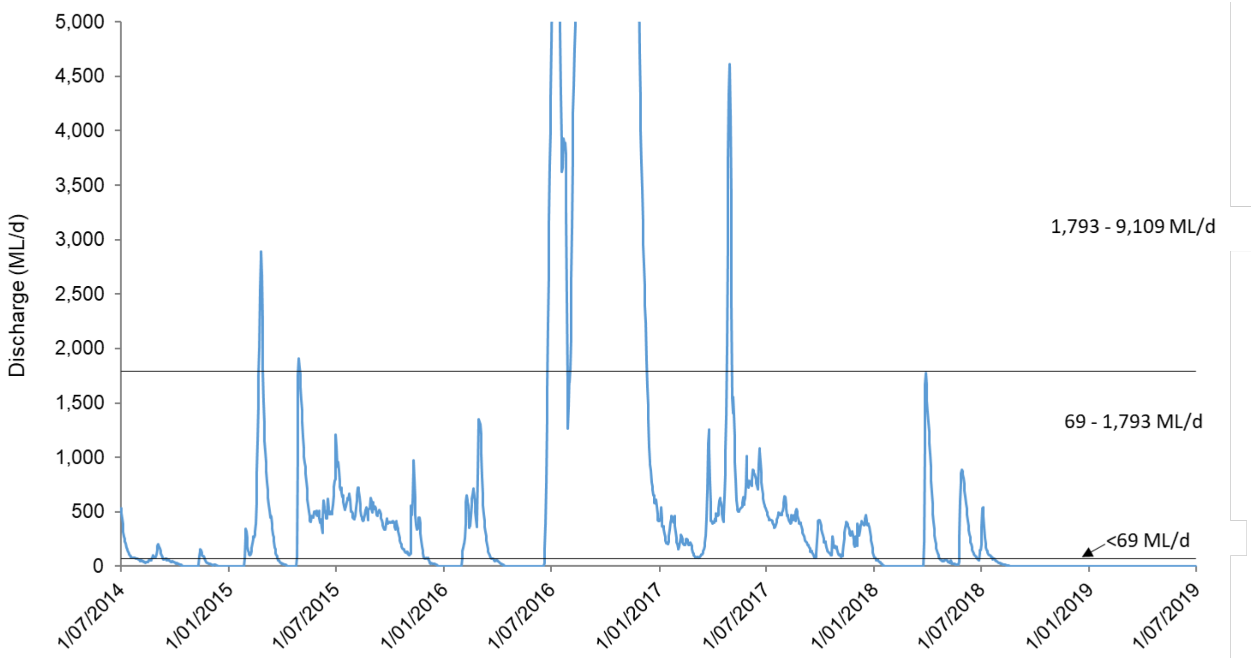


Figure A-8: Snag inundation during the LTIM Project along the Darling River zone of the Warrego-Darling Selected Area for flows <5,000 ML/d. Snags grouped by discharge in ML/d measured at the Bourke Town gauge (NSW 425003).

Bench surfaces

One hundred and seventy-three benches with a total area of 8.4 ha were identified along the 76 km reach of the Darling River within the Warrego-Darling Selected Area. Benches tended to be located low in the river channel, with 124 (71%) benches becoming inundated at flows less than 10,000 ML/d. Of these, 45 (25%) surfaces become inundated at flows less than 2,000 ML/d.

Whilst a proportion of snags were inundated in all years, benches were only inundated in the first three years of the LTIM Project (2014-17; Figure A-9 and Figure A-10). All benches were inundated for a total of 50 days (2.7% of time), providing access to 83,837 m^2 of available habitat. Low level benches that become inundated at flows less than 2,000 ML/d were inundated for 174 days (9.5% of time) providing 19,762 m^2 of available habitat (Figure A-9; Figure A-10; Table A-2).

Combining the amount of bench habitat provided in the Darling River zone with the average 72-hourly nutrient release rates (as reported in Southwell, 2008), it is estimated that benches would have contributed a total of 209.5 kg of dissolved organic carbon (DOC), 63.7 kg of total nitrogen (TN), and 71.3 kg of total phosphorus (TP) to the river system during the time they were connected over the 2014-2019 period (Table A-2).

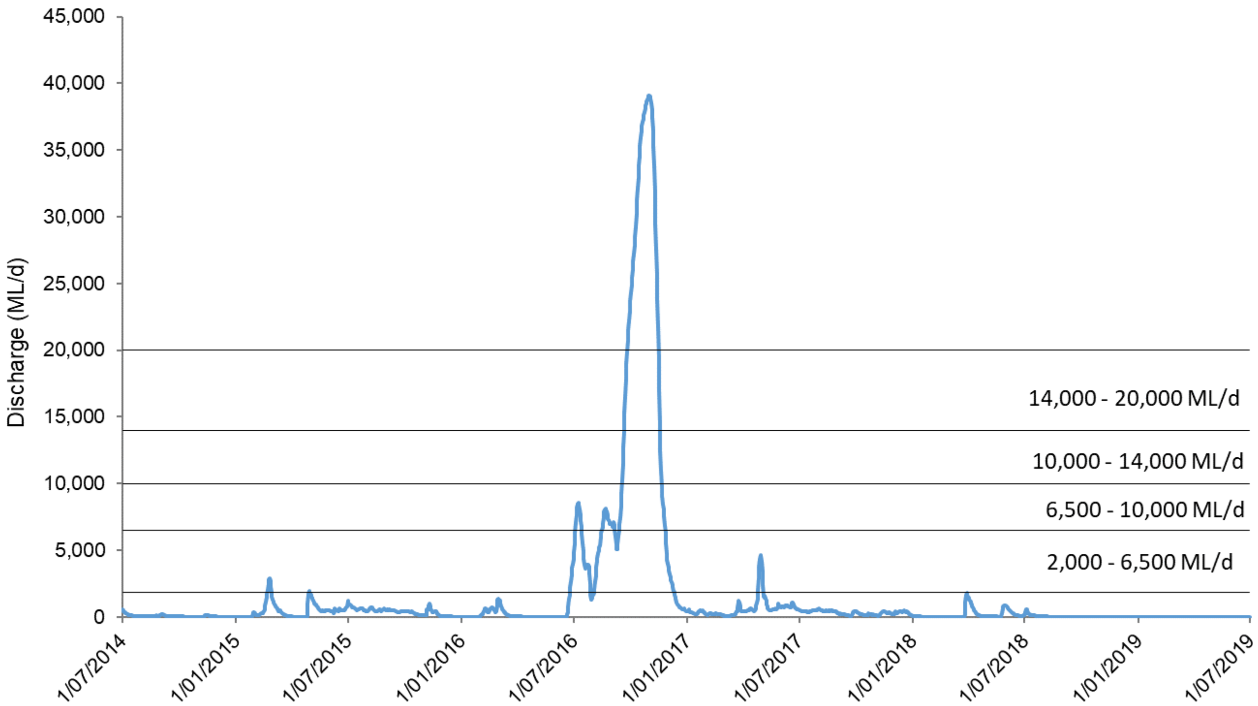


Figure A-9: Bench inundation during the LTIM Project along the Darling River zone of the Warrego-Darling Selected Area. Benches grouped by discharge in ML/d measured at the Bourke Town gauge (NSW 425003).

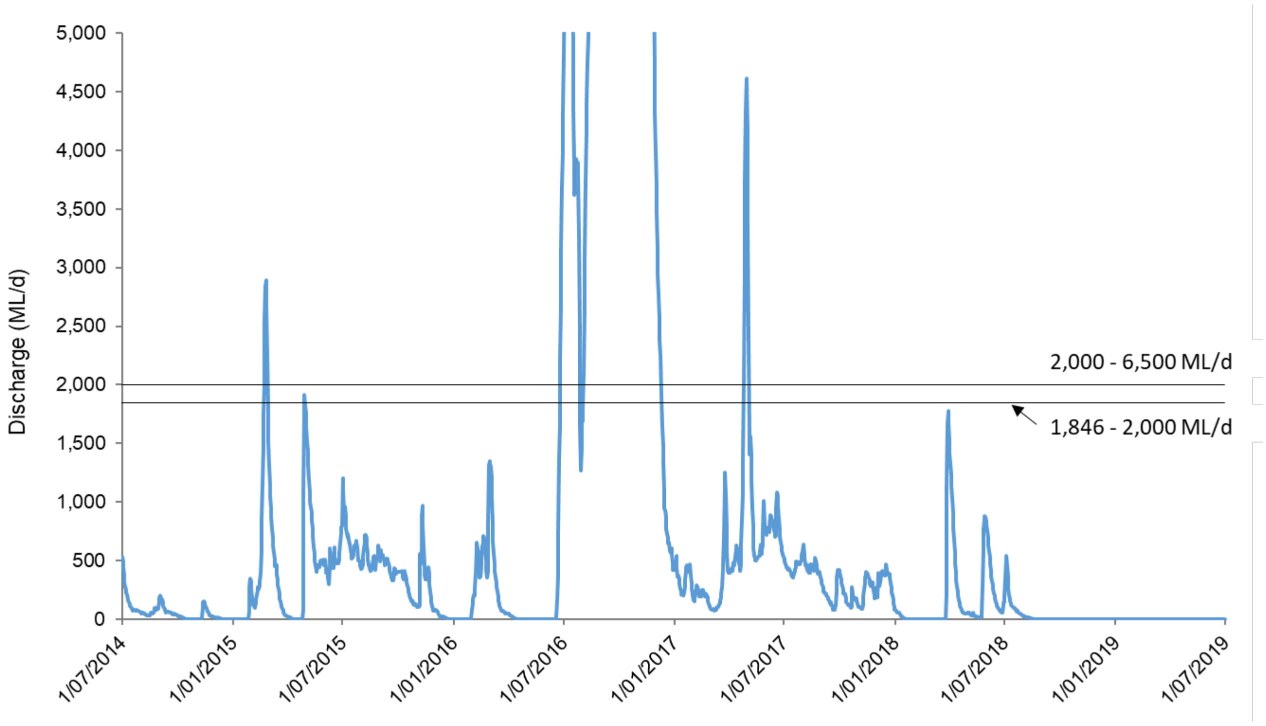


Figure A-10: Bench inundation during the LTIM Project along the Darling River zone of the Warrego-Darling Selected Area for flows <5,000 ML/d. Benches grouped by discharge in ML/d measured at the Bourke Town gauge (NSW 425003).

Table A-2: Bench connection and the total release of dissolved nutrients from bench surfaces in the Darling River zone of the Warrego-Darling Selected Area during the LTIM Project (2014-19).

Discharge class (ML/d)	Days connected (% of total time)	Total release of nutrients (kg)		
		TOC	TN	TP
<2,000	174 (9.5%)	89.5	27.2	30.5
2,000-6,500	107 (5.9%)	46.3	14.1	15.7
6,500-10,000	64 (3.5%)	40.6	12.4	13.8
10,000-14,000	58 (3.2%)	21.7	6.6	7.4
14,000-20,000	50 (2.7%)	11.3	3.4	3.9
All classes		209.5	63.7	71.3

Anabranch channels

Twenty anabranch channels were identified within the study reach. The total combined length of anabranches was 60 km, which is 44% of the total length of channel in the study reach including the Darling River. Commence-to-inundate discharges of anabranch channels ranged from 1,846 ML/d to 16,673 ML/d, with most channels (90%) commencing-to-flow at discharges less than 10,000 ML/d.

As with benches, anabranch channels only commenced-to-flow in the first three years of the project (Figure A-11 and Figure A-12). During the June 2016 to January 2017 event, all channels were inundated for at least 53 days, providing access to the full 60.27 km of available anabranch channel. Overall, anabranches that commence-to-inundate at < 2,000 ML/d, which make up 25% of all anabranch channels, were connected for a total of 175 days or 9.6% of the time, providing 14.9 km of additional channel habitat (Table A-3). Anabranches that commence-to-inundate at <10,000 ML/d were connected for 64 days (3.5% of time) providing 56 km of additional inundated channel habitat.

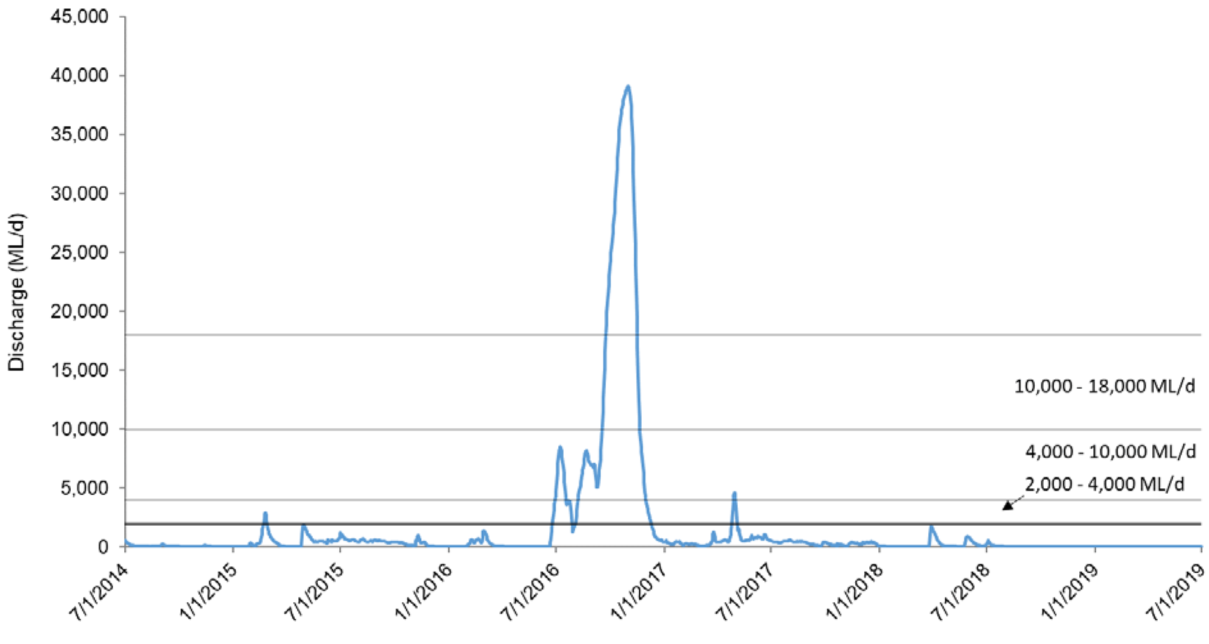


Figure A-11: Anabranch connection during the LTIM Project (2014-19) along the Darling River zone of the Warrego-Darling Selected Area. Anabranches grouped by discharge in ML/d measured at Bourke Town (NSW 425003).

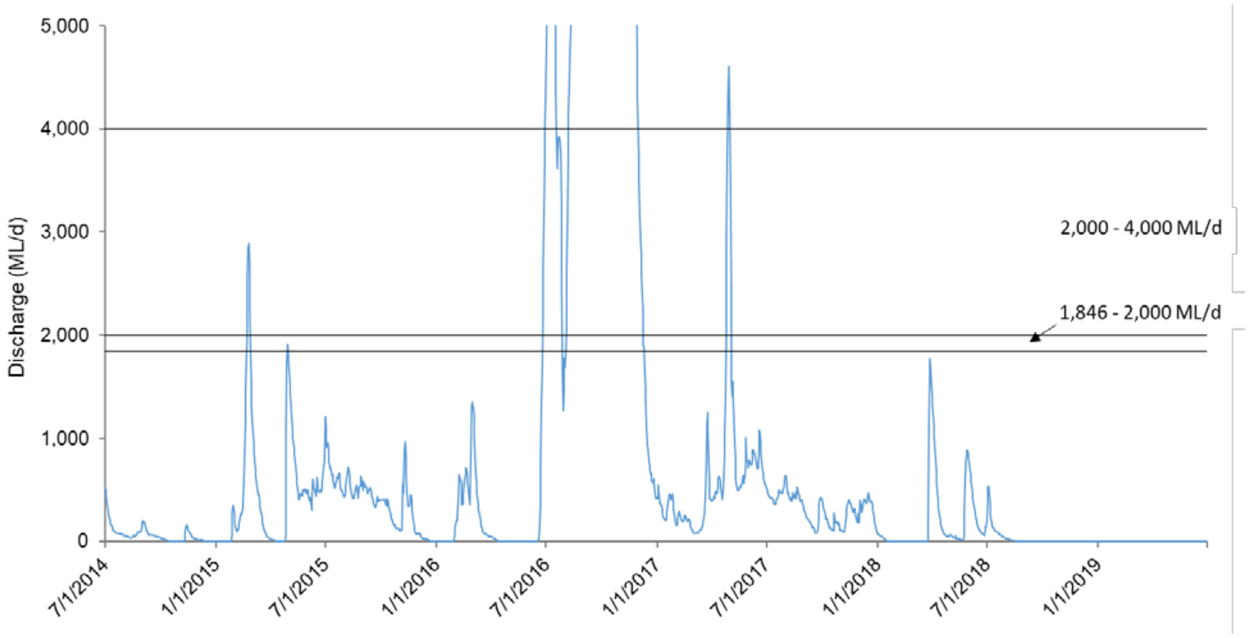


Figure A-12: Anabranch connection during the LTIM Project (2014-19) along the Darling River zone of the Warrego-Darling Selected Area for flows <5,000 ML/d. Anabranches grouped by discharge in ML/d measured at the Bourke Town gauge (NSW 425003).

Table A-3: Anabranch channel connection in the Darling River zone of the Warrego-Darling Selected Area during the LTIM project (2014-19).

Discharge class (ML/d)	Number of anabranches	Proportion of channel length	Channel length (m)	Days inundated 2014-19 (% total)
<2,000	5	25%	14,936	175 (9.6%)
2,000 – 4,000	7	26%	15,586	138 (7.6%)
4,000 – 10,000	6	42%	25,491	64 (3.5%)
10,000 – 18,000	2	7%	4,256	53 (2.9%)
Total	**20**	**100%**	**60,269**	**175 (9.6%)**

A.4 Discussion

The hydrology of the Darling River zone in the Warrego-Darling Selected Area over the LTIM Project was dominated by one large flow pulse of approximate bankfull magnitude from July 2016 to December 2016. This flow provided longitudinal connection to all measured in-channel habitat features, including snags, benches and anabranches within the Darling River zone. This flow provided access to 3,375 individual snags for biota, around 60 km of anabranch channel and was estimated to liberate over 340 kg of dissolved nutrients from in-channel bench surfaces. Increased access to habitat and transfer of organic material provided by flow pulses such as this are believed to be important for supporting in-channel productivity by providing movement opportunities and shelter for fish (Koehn and Nicol 2014; Treadwell 1999) and basal food resources that drive riverine food webs (Thom *et al.* 2005). While the volumetric contribution of environmental water during this event was the greatest of any of the monitored flows during the LTIM Project period (42,227 ML; Commonwealth of Australia 2017), given the significant tributary inflows during this time, the proportional contribution of environmental water (2.45%) was only relatively small.

Environmental water played a larger role in providing connectivity during low flow periods, especially during flow events that were augmented by environmental water released out of regulated catchments. Several of these events broke prolonged cease-to-flow periods during the 2017-18 and 2018-19 water years. Several small flow pulses between March and June 2018 reinstated flow through the Darling River zone which had not been flowing for around 73 days.

The first of these events originated out of the Condamine-Balonne and Moonie catchments and contained 24% environmental water. The second was the Northern Connectivity Event which was a regulated release of held environmental water from the Border Rivers and Gwydir catchments. Although not large in magnitude these flows improved the water quality (Commonwealth of Australia 2018) and provided movement opportunities for fish in the Darling River (NSW DPI 2019).

These flows were followed by a prolonged period (over 270 days) of no flow, during which time the Weir 20A weir pool dried back to a series of disconnected pools. While connectivity was provided by some localised rainfall above the Warrego-Darling Selected Area, inflows from the Warrego River including Commonwealth environmental water increased the magnitude of flows below the Warrego confluence.

Hydrological connectivity is aided in the Darling River zone of the Warrego-Darling Selected Area by Weir 20A which backs water up through the reach, providing some connectivity through the reach even when upstream inflows have ceased. The trial continuity analysis undertaken in this chapter using the Sentinel imagery suggests that this connection is maintained for between 20 and 35 days after upstream inflows have stopped. The time it takes for the reach to fragment is likely influenced by prevailing seasonal conditions and the duration of preceding flow. While the second of the two events that were monitored in this chapter occurred during winter/spring, the fragmentation time was quicker than the previous event which occurred in summer. This is likely the result of the longer period of connectivity preceding the first flow, increasing bank water storage, which contributed baseflow down the reach for a longer time.

A.5 Conclusion

Commonwealth environmental water take in upstream tributaries contributed to hydrological connectivity within the Darling River zone of the Warrego-Darling Selected Area throughout the LTIM Project. The relative contribution of this water was greater during small fresh events, rather than in the larger flow experienced through the reach in 2016-17. These flows inundated in-channel habitat featured such as snags, benches and anabranches that provide a range of benefits to the river system. These benefits include structural and hydrologic refuges, habitat for aquatic animals, and promoted the transfer of organic material that drives the food webs of the river. Strategic regulated environmental flow releases delivered from upstream catchments were effective at breaking longer periods of no flow in the Warrego-Darling Selected Area, highlighting the benefits of a basin wide watering strategy.

A.6 References

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Appendix B Hydrology (Warrego)

B.1 Introduction

The Hydrology (Warrego) indicator provides information on the influence of Commonwealth environmental water and/or management decisions on the extent of inundation on the Western Floodplain and flows down the Warrego River channel network within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). This information is directly relevant to all indicators measured in the LTIM Project.

Watering the Western Floodplain is an important aspect of water management in the Selected Area. Apart from being a target for Commonwealth environmental water (Commonwealth of Australia 2014), it also has a separate high-flow floodplain water licence (Commonwealth of Australia 2015), which can only be accessed when flows in the Darling at Louth reach 979 Ml/d. Water managers can preferentially direct water down the Western Floodplain to meet watering targets by opening or closing the regulating gates at Boera Dam. Given this, knowledge of the extent and volume of water directed down the Western Floodplain throughout each water year is essential base information from which to evaluate the success of these watering decisions. Similarly, flows down the Warrego River maintain critical refugial habitat, and provide flows downstream of the confluence in the Darling River. The Hydrology (Warrego) indicator aims to quantify the degree and nature of inundation on the Western Floodplain and down the Warrego River within the Warrego-Darling Selected Area. Specifically, this Appendix addresses the following questions:

- What did Commonwealth environmental water and management contribute to hydrological connectivity of the Western Floodplain?
- What did Commonwealth environmental water contribute to hydrological connectivity of the Warrego River?

B.1.1 Environmental watering during the LTIM Project

Unlike other Selected Areas, most environmental water is not specifically delivered to the Warrego-Darling Selected Area. Rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Selected Area have been sporadic over the LTIM Project (Figure B-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16, with flows refilling waterholes and providing a connection to the Darling River. The small flow event from January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, between June 2016 and February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, March-April 2018 and June 2018. Commonwealth environmental water made up 17.3% of the flow event during March and April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure B-1).

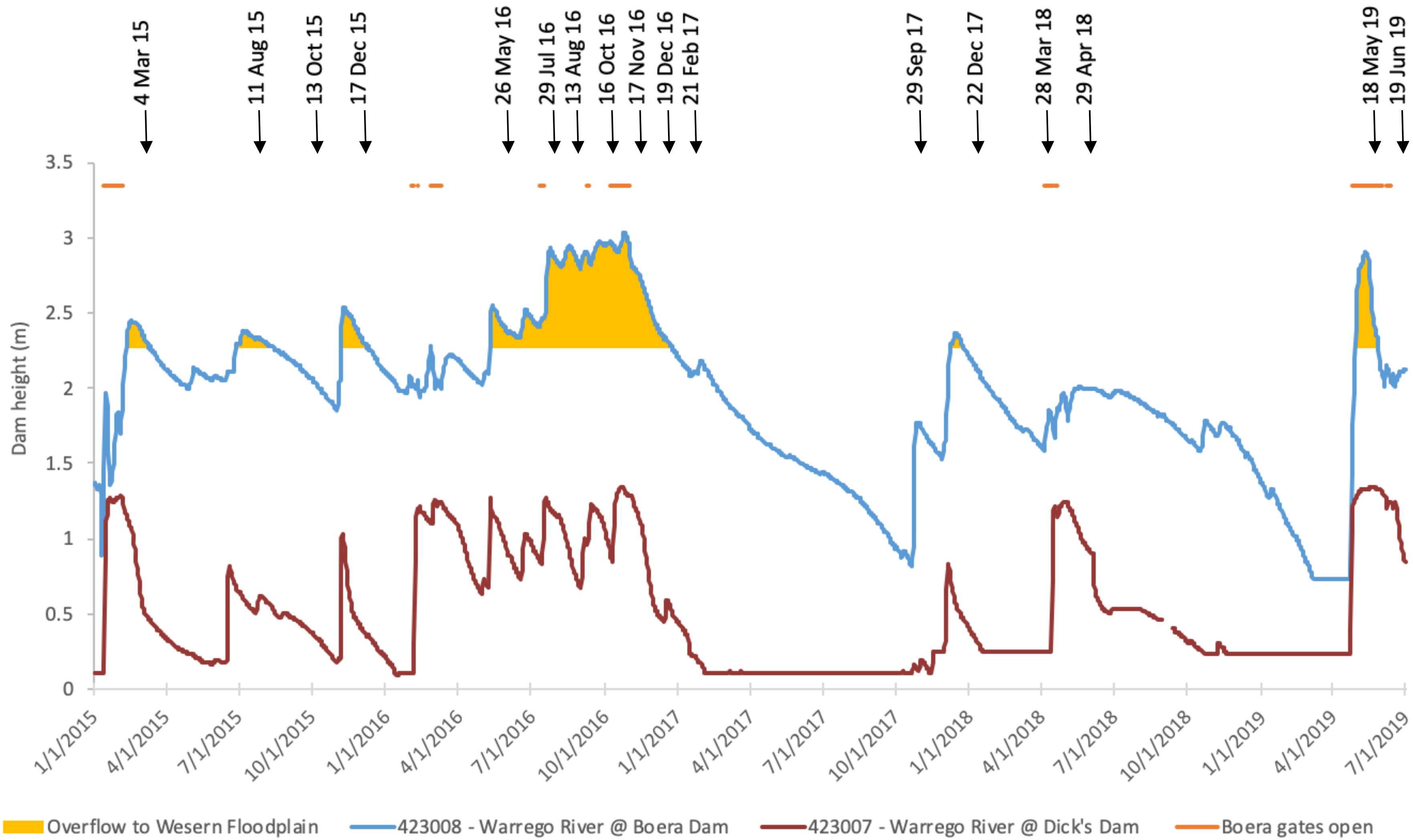

Figure B-1: Boera and Dicks Dam levels during the LTIM project and flow to Western Floodplain and/or into lower Warrego Channels (gates open). Arrows indicate Landsat image dates using in the analysis.

During the March to April 2018 flow event, the Boera Dam regulating gates were partially opened for 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego and provided connection through to the Darling River.

No flows were experienced through the lower Warrego River system during the majority of 2018-19, with levels receding in both Boera and Dicks Dams (Figure B-1). Widespread rainfall from a tropical depression in the upper Warrego catchment produced a flow event down the Warrego that entered the Warrego-Darling Selected Area in April 2019. The gates at Boera Dam were opened on the 22 April 2019 and remained open for 40 days until the flow pulse had moved through the system. During this time 8,106 ML of environmental water was accounted against the Toorale Warrego River licence, which comprised 40% of the total flow.

B.2 Methods

Many data sources were used to build a model of inundation extent and volume in the Western Floodplain of the Warrego River (Commonwealth of Australia 2015). These included:

- Landsat imagery
- Existing vegetation mapping
- Water level records associated with water sensors and gauging stations
- Hydrodynamic models recently developed as part of the LTIM Project.

These data sources were analysed and combined to derive relationships between inflow, inundation extent and volume. Existing vegetation mapping was used to determine the area of inundation associated with each vegetation community on the Western Floodplain.

For the Warrego River, flows entering the Warrego-Darling Selected Area were measured by plotting flows past Fords Bridge (Figure B-2). Flows at 423001–Warrego River @ Fords Bridge (Main channel) were combined with flows past 423002–Warrego River @ Fords Bridge Bywash to give a total flow past Fords Bridge. Connectivity within the lower Warrego Channel below Boera Dam was assessed by comparing times when the Boera Dam regulating gates were open (obtained from the Commonwealth environmental water office; Figure B-1) to water levels at the 423007 – Warrego @ Dicks Dam gauge. The maximum area of the Warrego Channel inundated each year was also calculated by Landsat analysis described below (Section B.2.1). In addition, periods when dams were dry in the Warrego-Darling Selected Area were visually assessed using remotely sensed imagery accessed through the publicly available Sentinel-hub Playground (https://www.sentinel-hub.com/). The sentinel satellite captures imagery every 5 days from January 2015. Within the Sentinel-hub Playground, the pre-defined normalised difference water index (NDWI) was used which combines Band 3 and Band 8 imagery and is designed to highlight areas of open water. Dates between images that showed no visible water in the dams were compared to inflows through the system. Prior to January 2015, dam drying was estimated from Landsat inundation mapping following methods outlined below.

B.2.1 Landsat image analysis

All available Landsat 8 images captured during the LTIM project (2015-19) were assessed via the USGS Glovis website (http://glovis.usgs.gov/). Those with no cloud cover or other problems were chosen for further analysis. Seventeen images were used for analysis from 4 March 2015 to 19 June 2019 (Figure B-1).The extent of inundation within each image was classified using density slicing of Band 6 as described in Frazier and Page (2000). All inundated areas within the extent of the Western Floodplain were mapped,

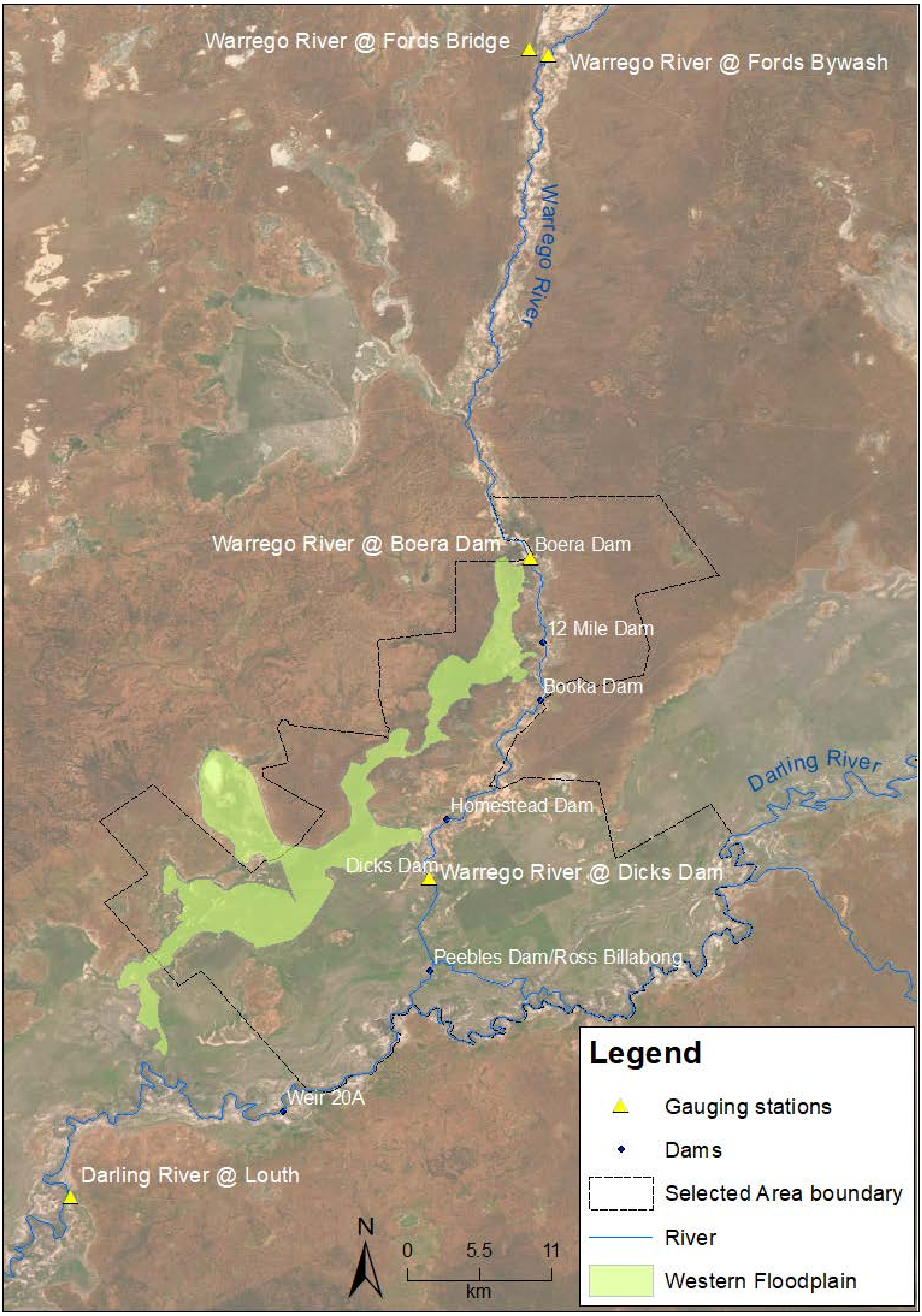

Figure B-2: Location of flow gauging stations used in the hydrological connectivity analysis and extent of the Western Floodplain.

hence, inundation because of rainfall was also included (Figure B-3). This may potentially overestimate the degree of inundation resulting from overland flow from Boera Dam but provides a broader picture of Western Floodplain wetting during the LTIM project. Each classified inundation image was then intersected with existing vegetation community layers (Commonwealth of Australia 2015) to determine the extent of inundation within each vegetation community at each image capture time.

To estimate the volume of water present in the Western Floodplain at the time of image capture, relationships generated through the hydrodynamic model of the Western Floodplain were used for images on the rising limb of the inflow hydrograph (Eco Logical Australia 2017). The maximum volume achieved during the LTIM Project was estimated by modelling inundation volume at the maximum gauge height of Boera Dam (3.04 m). To estimate the volume present for images on the falling limb of the hydrograph, the extent of inundation was multiplied by an estimated average water depth. A depth of 0.25 m was used based on the average depth of water over the floodplain estimated from the hydrodynamic model.

B.2.2 Average monthly rainfall

Historically, rainfall in the region is summer dominated, however, monthly rainfall has been variable over the LTIM Project (Figure B-3). During the 2014-15 water year, rainfall was above average in August, December, and from February to April. During 2015-16 rainfall was above average in November and June, with the June 2016 being the highest recorded monthly rainfall of the project (110 mm: Figure B-3). The 2016-17 water year was a relatively wet year with above average rainfall in August, September, October, January, May and June. This was the only year of the project that had an annual rainfall greater than average (389 mm compared to historical average of 355 mm). Monthly rainfall in 2017-18 exceeded the historical average from October to December and in March. The 2018-19 water year was the driest year of the project (annual total 205 mm), but falls were above average in August, October and November (Figure B-3).

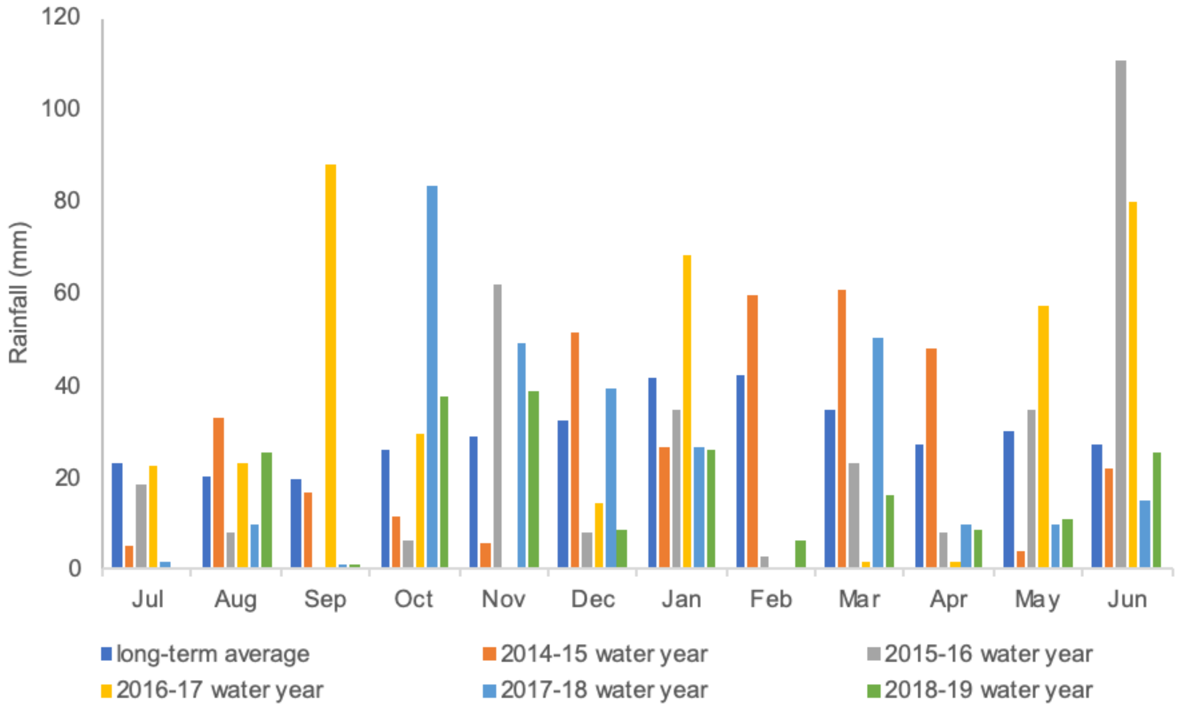

Figure B-3: Average monthly rainfall over the LTIM Project at Bourke compared to long term average monthly rainfall.

B.3 Results

B.3.1 **Warrego River**

<u>Upstream inflows</u>

The Warrego Channel upstream of the Warrego-Darling Selected Area experienced a highly variable flow regime during the LTIM Project (Figure B-4). During the first year of the Project, one significant flow event occurred in the Warrego-Darling Selected Area as a result of rainfall in the upper Warrego catchment between December 2014 and January 2015. This caused the river to flow at Fords Bridge for a total of 63 days during this event (Figure B-4). Several small flow peaks occurred later in 2014-15 at Fords Bridge as a result of local runoff from storm events, which produced minor inflows to the Warrego-Darling Selected Area. Two significant flow events in February and March 2016 entered the Warrego-Darling Selected Area from the Warrego catchment (Figure B-4). These occurred in February and March 2016 and included approximately 315 ML of Commonwealth environmental water accounted in the upstream catchment. There were several smaller flow peaks throughout the water year driven by local rainfall runoff.

During 2016-17, three significant flow events in late 2016 entered the Warrego-Darling Selected Area from the Warrego catchment. These occurred in July, August and from September to November 2016 and included approximately 2,958 ML of Commonwealth environmental water accounted upstream in the Warrego catchment. These produced the longest period of continuous flow at Fords Bridge for the whole LTIM Project (172 days). Five flow events entered the Warrego-Darling Selected Area from the Warrego catchment during the 2017-18 water year (Figure B-4). These occurred in October 2017, December 2017, from March to April 2018, and in June 2018. Over the March to April 2018 period, 1,137 ML of Commonwealth environmental water flowed down the Warrego River into the Warrego-Darling Selected Area. Only one significant flow event occurred in the Warrego River during 2018-19, occurring from April to June 2019. As of 30 June 2019, flow had been continuous at Fords Bridge for 71 days and included 2,624 ML of Commonwealth environmental water (Appendix C).

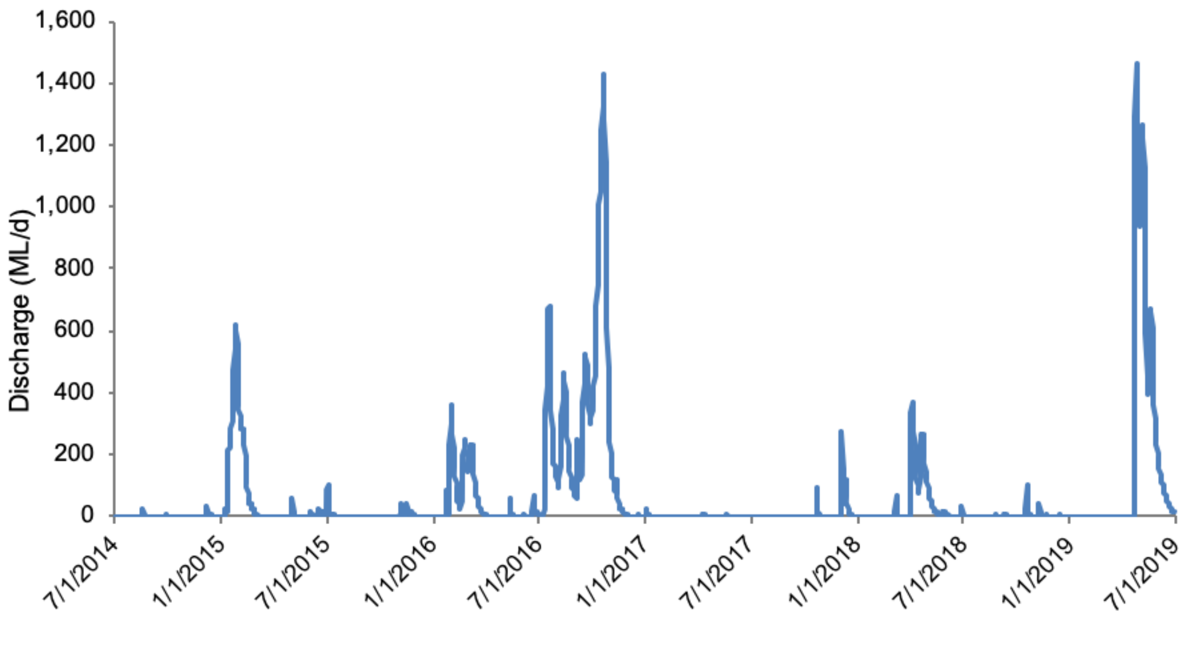

Figure B-4: Flow hydrograph for Warrego River at Fords Bridge upstream of the Warrego-Darling Selected Area. Note gauges 423001 and 423002 have been combined to produce a total flow past Fords Bridge.

Longitudinal connectivity

Flows down the Warrego River were controlled by releases from Boera Dam on all occasions except for the flow event in May 2019. This flow occurred when a breach in the eastern embankment (which controls the return of water from the Western Floodplain back into the Warrego River above Booka Dam) allowed water back into the channel (Figure B-5). This produced downstream flows at Dicks Dam to peak at 729 ML/d. In all other events discharge at Dicks Dam remained below 420 ML/d.

Figure B-5: Breach in the eastern embankment allowing floodplain water to return to the Warrego River. Date: 15 May 2019.

During the LTIM Project, 13 flow events occurred down the Warrego River within the Warrego-Darling Selected Area, with flow occurring in every water year (Figure B-6). The gates at Boera Dam were open for a total period of 144 days over the 5-year period, providing flows through the lower Warrego River network and into the Darling River. Typically flows to the Darling River occur within one day of the Boera Dam gates being opened (Commonwealth of Australia 2015). The average period of connection down the Warrego River within the Warrego-Darling Selected Area was 11 days, with the longest event being 40 days (occurring in May-June 2019) and the shortest event 1 day, in June 2019.

In 2014-15 connection was achieved for a total of 24 days in January and February 2015. This was the only connection event during this water year. Water levels in Boera Dam were relatively high early in 2014-15 as a result of an inflow event in March 2014 (Figure B-6). Dam levels declined through the water year until inflows increased as the December 2014 to January 2015 flow event reached the Dam. To meet downstream license conditions, the gates at Boera Dam were opened on 13 January 2015 to let flows down the lower Warrego Channel. These flows allowed full connection through to the Darling River. The lower Warrego was fully connected for a 24-day period before the gates were closed on 5 February. Continued inflows to Boera Dam resulted in the dam rising to a level of 2.44 m and spilling onto the Western Floodplain. While connection was broken down the Warrego Channel, water levels persisted in Boera and Dicks Dams and Ross Billabong through to the end of the season. In addition, due to inflows upstream of Bourke, the Darling River continued to rise and peaked later in January 2015.

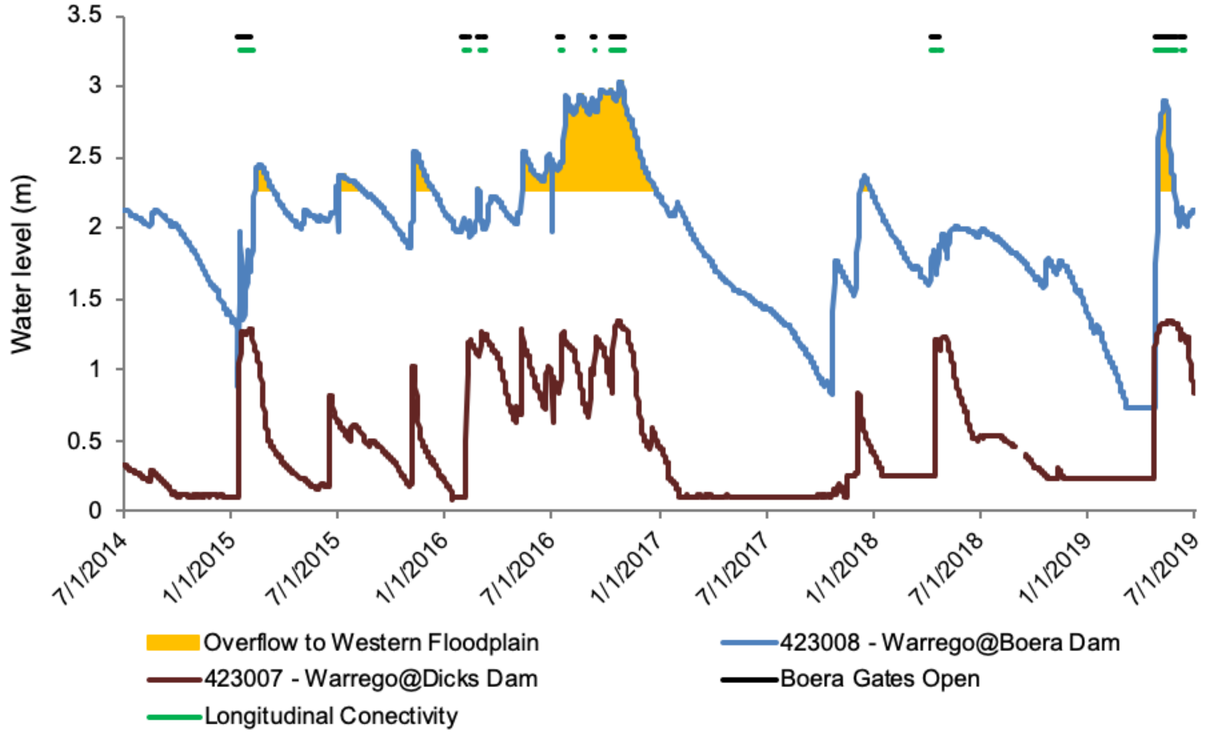

Figure B-6: Water levels in Boera and Dicks dam and periods of connection onto the Western Floodplain and down the Warrego River within the Warrego-Darling Selected Area.

Boera Dam was above the estimated overflow level of 2.26 m at the commencement of the 2015-16 water year and remained above this level until mid-August 2015. During July and August 2015 there was a small increase in water level in Dicks Dam with no connection to Boera Dam. It is likely this increase was a result of localised rainfall recorded in late July/early August. Levels in Boera Dam declined steadily from mid-August until November 2015 when significant inflows were received, and the dam again overflowed to the Western Floodplain (gauge height reaching 2.54 m). Boera Dam levels declined steadily again until February 2016 when inflows from the Warrego River increased. In line with existing operating rules, the gates at Boera were opened to allow flow through to the Darling River, with connection of the lower Warrego Channel occurring within 1 day. As inflows continued into the Warrego-Darling Selected Area from the Warrego River, the Boera Dam gates were opened four times between 3 February and 9 March 2016 and connection occurred in each of these events resulting in connection for a total of 16 days, with the longest period of continuous connection lasting five days (Figure B-6). No Toorale licences on the Warrego River were triggered during the 2015-16 water year.

In 2016-17, three flow events occurred down the Warrego Channel below Boera Dam in July, August, and from October to November 2016. During the July and August events, the gates at Boera Dam were opened to allow flow through to the Darling River to meet the licence requirements of the Toorale river access licences. After connection with the Darling was achieved and the flow at Louth was >979ML/d, the gates were closed, and water flowed out onto the Western Floodplain to be accounted against the Western Floodplain high flow licence until it was exhausted. During the third inflow event in October and November, the Boera gates were opened for a period of 25 days, to provide opportunities for native fish to access habitat and to support recruitment. This included operating the gates to achieve a steady flow increase, several days at peak flow, then a protracted falling limb. The Commonwealth Toorale Warrego River licence was accessed for 20 days of this flow, with NPWS operation of the gates extending the flow to 25 days. This flow was also managed to ensure water continued to flow onto the Western Floodplain.

In total, the Boera Dam gates were opened three times between 11 July and 11 November 2016 resulting in connection for a total of 35 days (Figure B-6).

Levels in Boera Dam declined steadily from the beginning of the 2017-18 water year until two small inflows entered Boera Dam during October to December 2017. The first inflow was too small to overflow to the Western Floodplain and was not noted downstream at Dick's Dam. The second flow in December 2017 caused Boera Dam to fill to a level of 2.26 m and overflow to the Western Floodplain for 19 consecutive days. Rises at Dicks Dam during this same period suggests that localised rain also fell within the Warrego-Darling Selected Area. During the April inflow events, the gates at Boera Dam were opened to allow flow to the Darling River, with connection of the lower Warrego Channel occurring after one week. This flow aimed to protect and restore ecosystem functions and aquatic habitats in the Warrego River. The gates were opened to a maximum of 225 ML/d for 11 days (from 5 to 15 April 2018) and again for five days (from 17 to 21 April 2018), peaking at 300 ML/d, with volumes based on inflows to Boera Dam. This strategy resulted in connection for 16 days.

Due to minimal inflows to the Warrego-Darling Selected Area in 2018, water levels in Boera Dam receded to the lowest levels observed in the project (Figure B-7). Considerable inflows to the Warrego-Darling Selected Area during April to June 2019 increased Boera Dam levels to a maximum of 2.89 m, producing flooding on the Western Floodplain. During this flow event, the gates at Boera Dam were left open for the entire flow (40 days), to maximise downstream contributions to the Darling River. At the end of this flow event, the gates were closed, but then reopened several times to provide further downstream contributions from Boera Dam. Gates were closed for the final time on 14 June once Boera Dam levels hit 2.0 m.

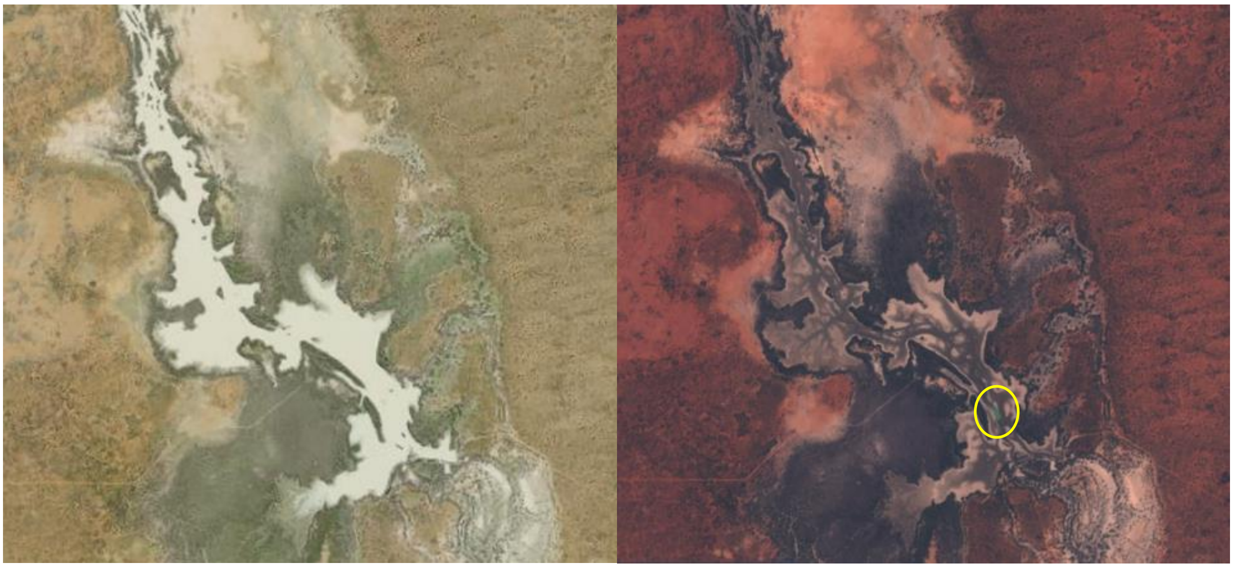

Figure B-7: Boera Dam. Image on left shows full extent, while image on right shows remaining water on 16 April 2019 circled in yellow (right).

Channel inundation

The maximum mapped area of inundated Warrego Channel below Boera Dam was 1,007.2 ha, measured on 17 November 2016 (Table B-1; Figure B-10). This image capture date was two weeks after the Boera Dam gates were closed, so observed inundation extents were much larger in the lower sections of the Warrego River. These extents were also likely influenced by water backed up from the Darling River, which had a coincidental large fresh flow (Appendix A). The second largest annual maximum inundation extent was 705.81 ha, peaking on the 18 May 2019. Here inundation was more even throughout the Warrego River reach (Table B-1; Figure B-12). Other annual maximum inundation extents recorded were 621.44 ha on 13 January 2015 (Figure B-8), 503.81 ha on 26 May 2016 (Figure B-9), with the lowest annual maximum inundated extent, 182.22 ha, on 12 March 2018 (Figure B-11).

Table B-1: Annual maximum inundation extent of the Warrego River channel network below Boera Dam over the duration of the LTIM Project.

Year	Image date	Channel area (ha)
2014-15	13-Jan-15	621.44
2015-16	26-May-16	503.81
2016-17	17-Nov-16	1007.20
2017-18	12-Mar-18	182.22
2018-19	18-May-19	705.81

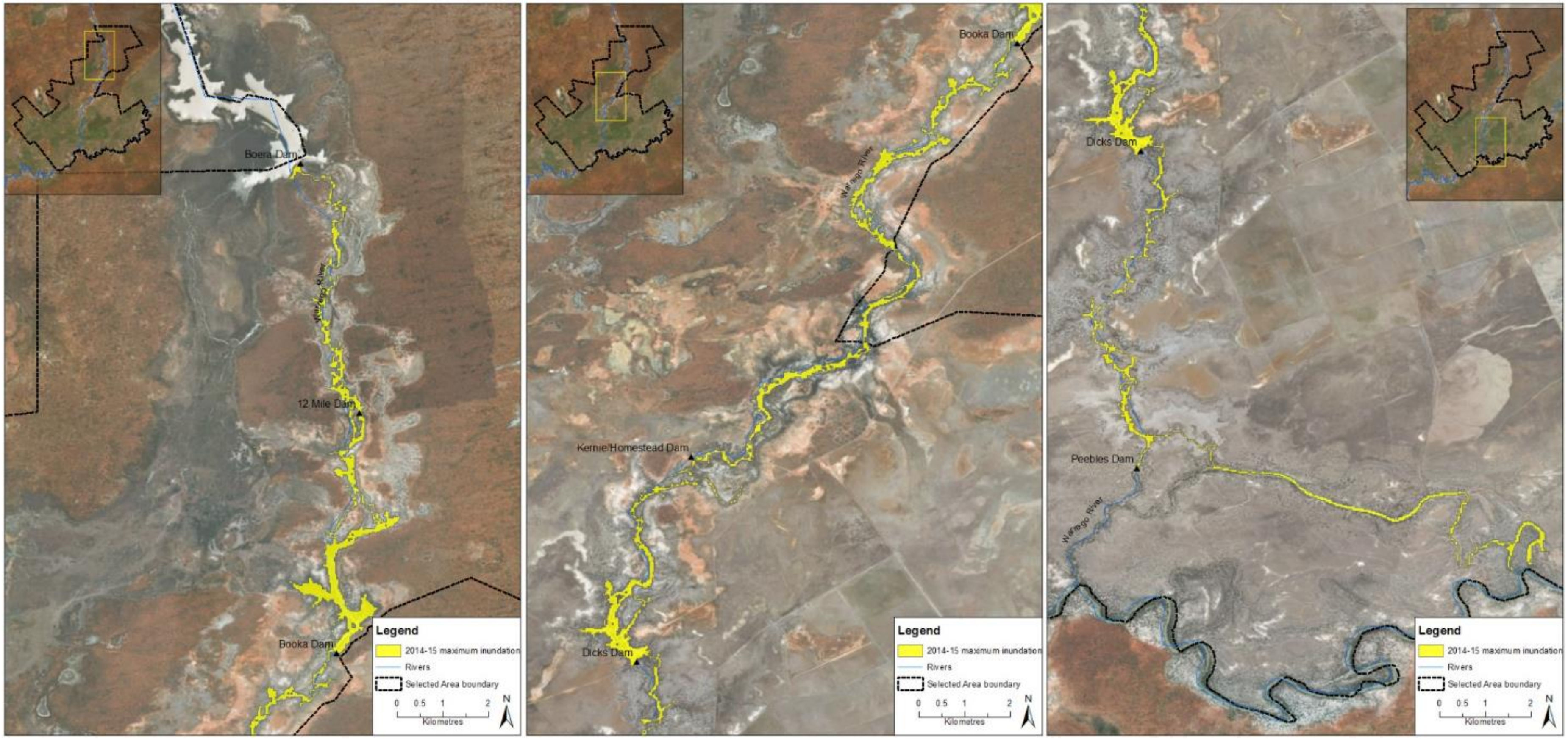

Figure B-8: Maximum inundation of the Warrego River channel network during 2014-15, in the northern (left), central (middle) and southern (right) sections of the Warrego-Darling Selected Area.

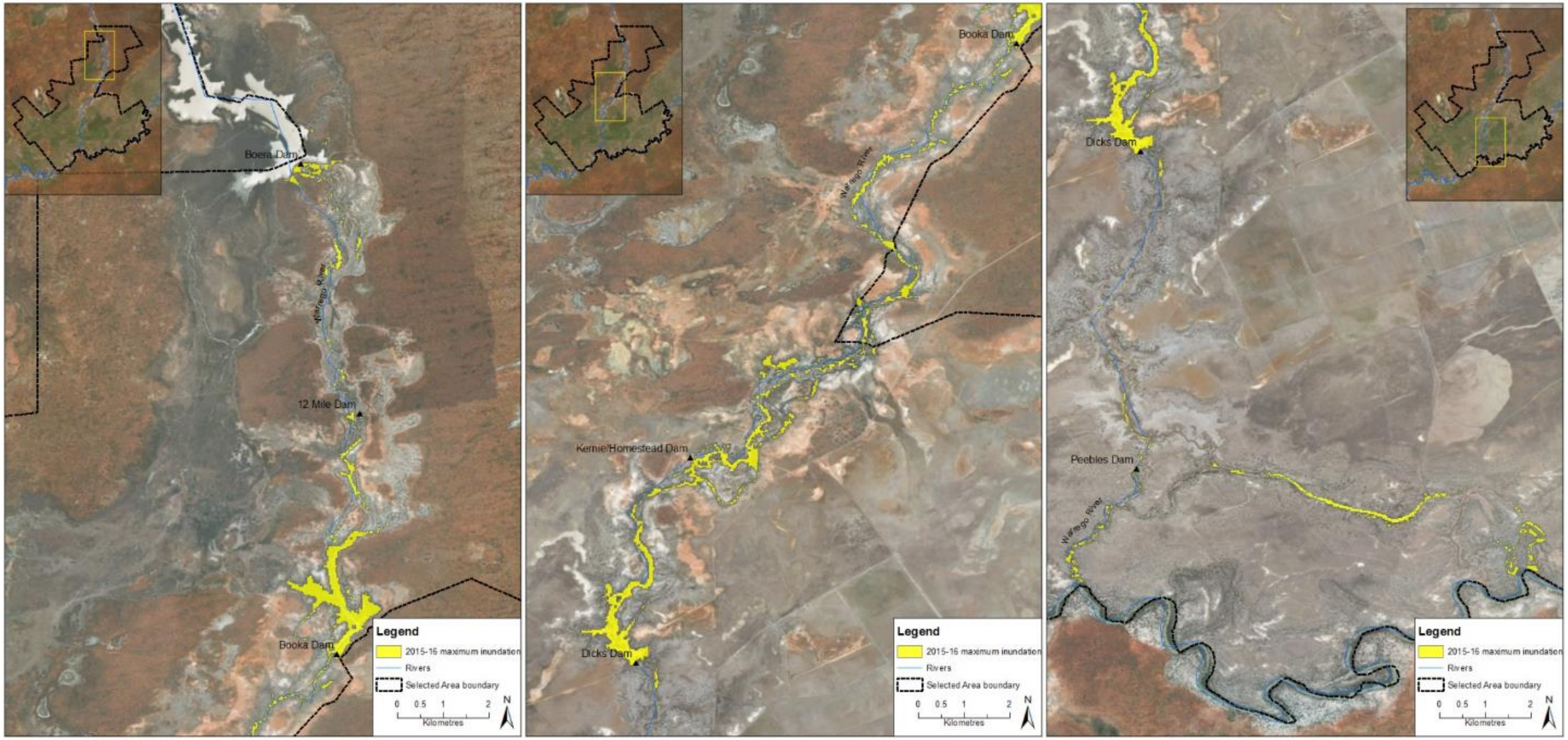

Figure B-9: Maximum inundation of the Warrego River channel network during 2015-16, in the northern (left), central (middle) and southern (right) sections of the Warrego-Darling Selected Area.

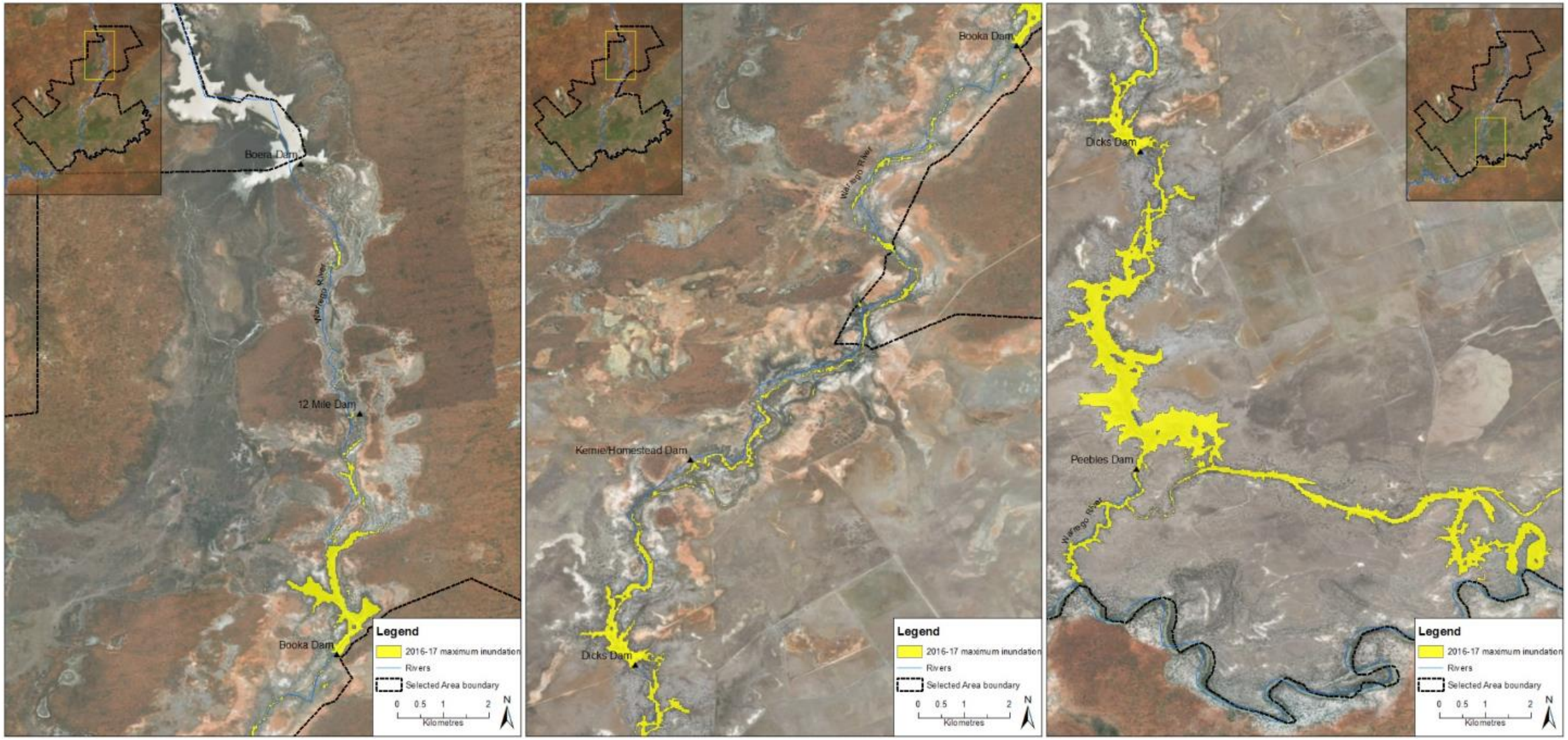

Figure B-10: Maximum inundation of the Warrego River channel network during 2016-17, in the northern (left), central (middle) and southern (right) sections of the Warrego-Darling Selected Area.

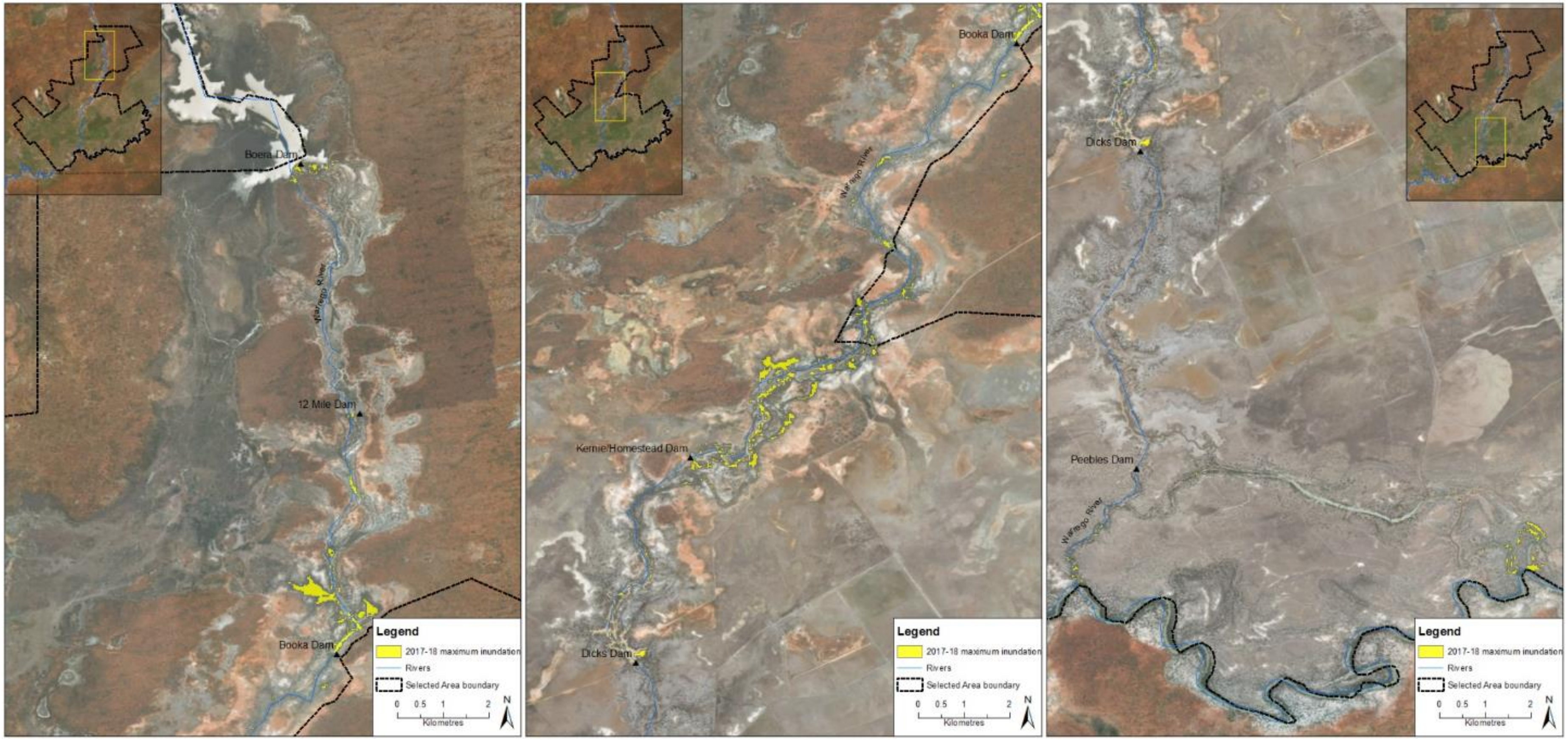

Figure B-11: Maximum inundation of the Warrego River channel network during 2017-18, in the northern (left), central (middle) and southern (right) sections of the Warrego-Darling Selected Area.

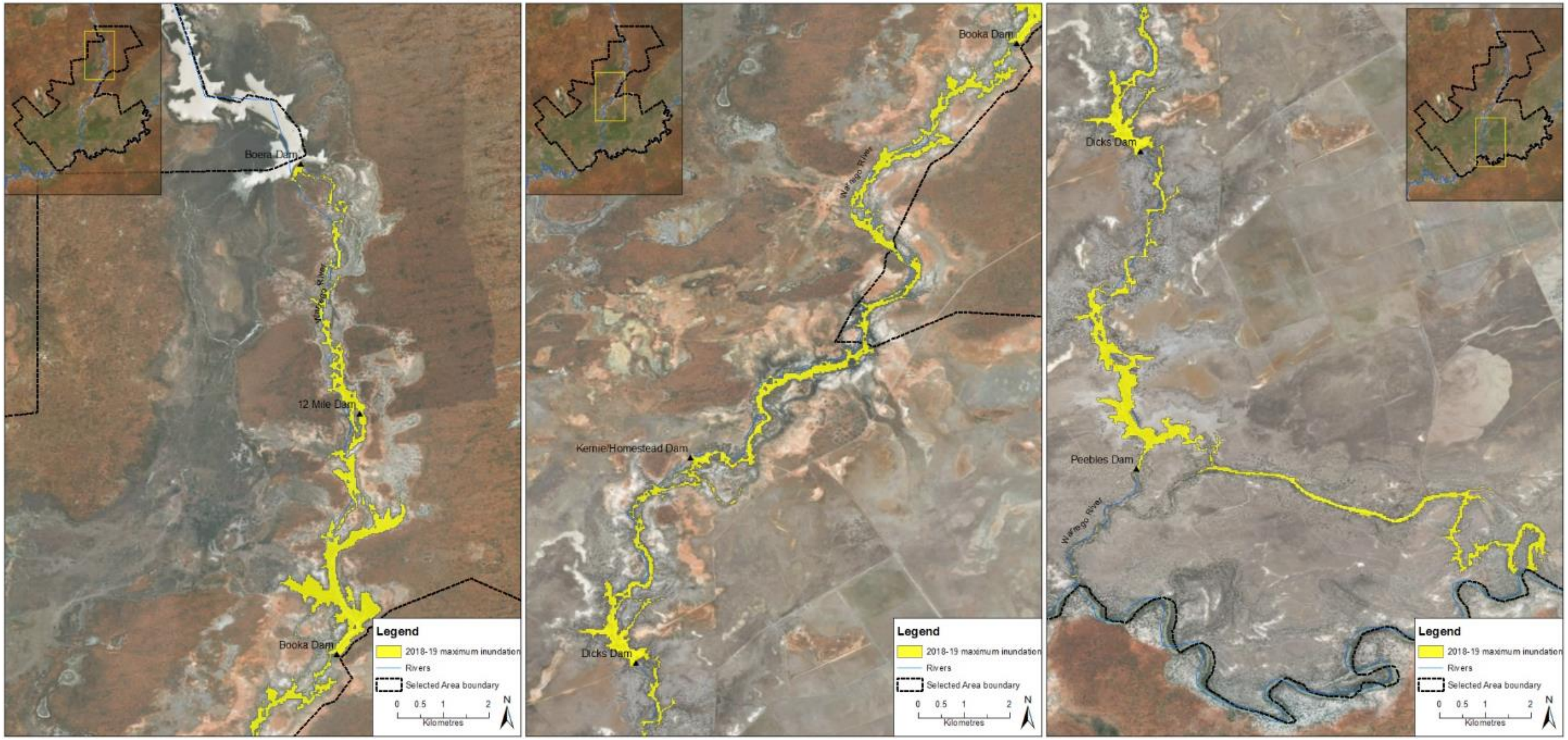

Figure B-12: Maximum inundation of the Warrego River channel network during 2018-19, in the northern (left), central (middle) and southern (right) sections of the Warrego-Darling Selected Area.

Warrego dam drying

In contrast to Boera Dam, which retained some water (Figure B-7), Ross Billabong, Booka, Homestead and Dicks Dams, have all dried out completely during the LTIM Project period (Figure B-13). Apart from Boera Dam, Booka Dam was the most permanent, with two dry periods of 26 days in December 2017 and 43 days in March to April 2019 (Figure B-13). Similarly, Ross Billabong dried twice, but for much longer durations: 174 days in November 2017 to May 2018, and 210 days in September 2018 to April 2019. Dicks and Homestead Dams both experienced 4 dry periods each, with Dicks Dam drying for 213 days from March to October 2017, 72 days from November 2014 to January 2015, 51 days from February to April 2018 and 118 from January to April 2019. Homestead Dam was the least permanent dam on the Warrego River within the Warrego-Darling Selected Area due to a breach in the wall present for the duration of the project. Even so, Homestead Dam held water for extended periods, especially through the 2016-17 water year. Homestead Dam dried in late 2014 for 72 days then for 233 days from March 2017 to October 2017, 67 days from January to April 2018 and then 111 days from January to April 2019 (Figure B-13).

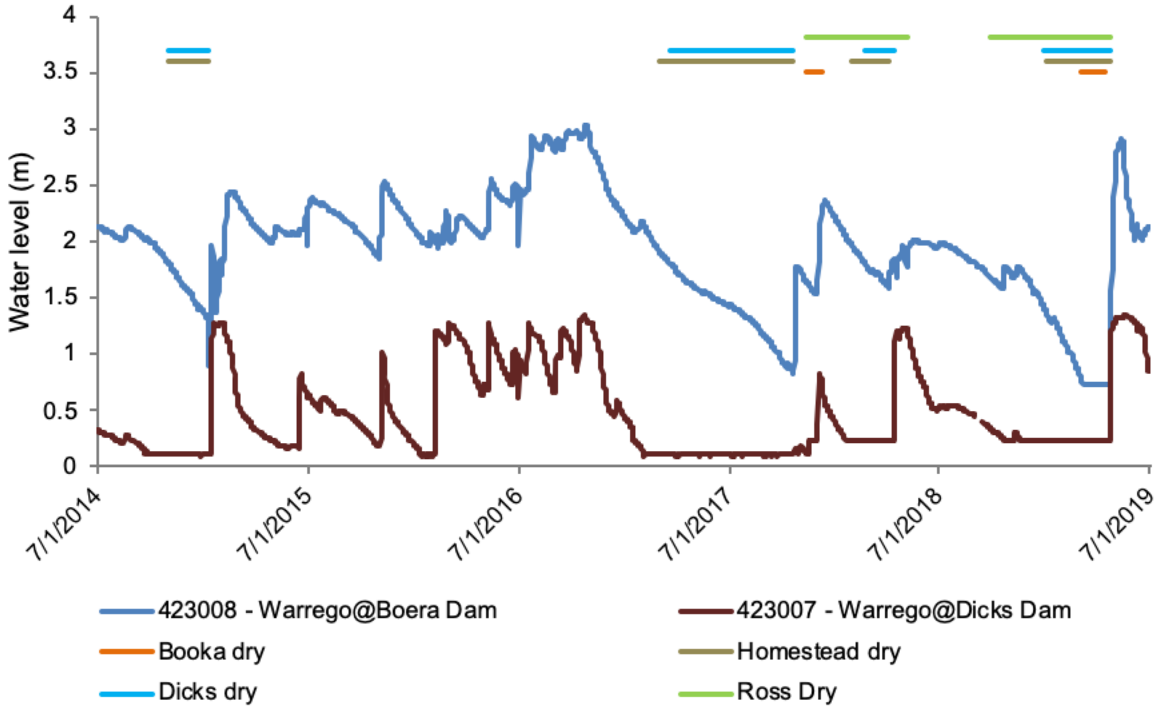

Figure B-13: Boera and Dicks Dam levels and periods of Warrego River Dam drying during the LTIM Project.

B.3.2 **Western Floodplain**

Inundation of the Western Floodplain was variable throughout the LTIM Project. Seventeen Landsat images were used to map floodplain inundation during the LTIM Project. The greatest inundation extent mapped was recorded in October 2016 with 3,839 ha inundated. During this time, it is estimated that 9,597 ML of water was on the floodplain (Figure B-14). The smallest extent measured (apart from completely dry periods) was 20.5 ha recorded in the December 2018 image, with an estimated 6 ML of water on the floodplain.

During the 2014-15 water year, Warrego River inflows provided connection to the floodplain, with maximum inundation of 44.76 ha recorded in March 2015 (Table B-2; Figure B-15). During this time, an estimated 112 ML of floodwater was on the floodplain. Of the vegetation communities, Lignum shrubland (30.09 ha) and Coolibah open woodland wetland (12.77 ha) were the most inundated (Table B-2).

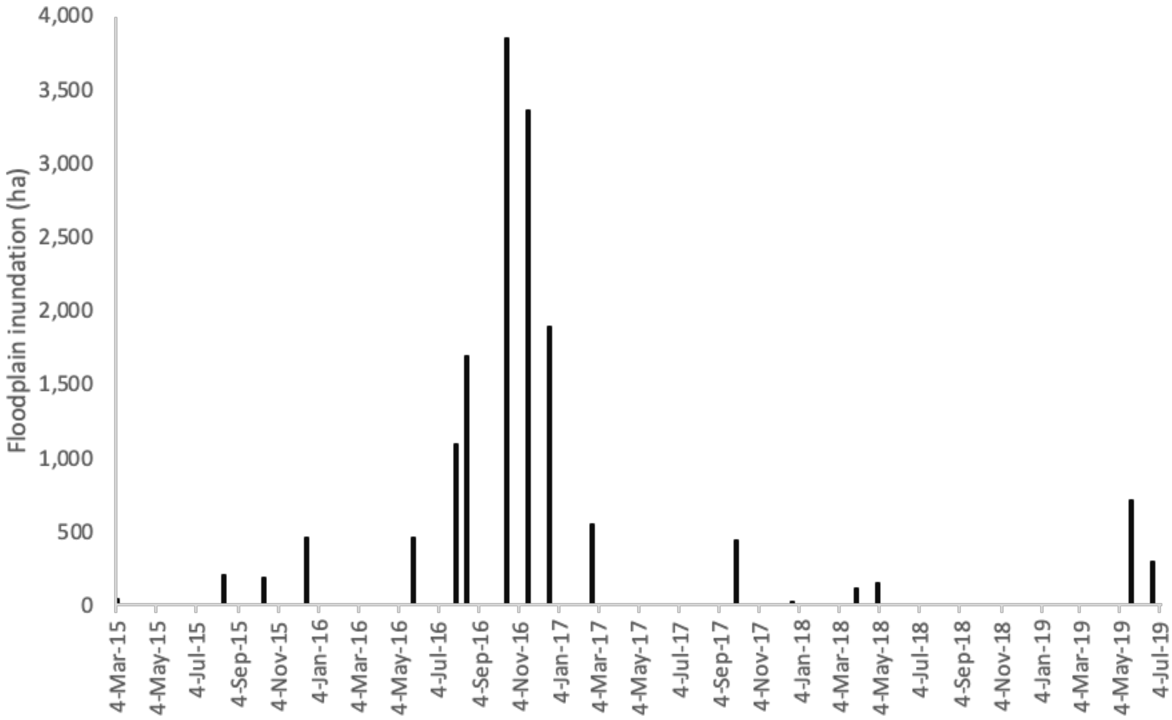

Figure B-14: Inundation extents on the Western Floodplain measured over 17 Landsat images.

Table B-2: Inundation extent of vegetation communities on Western Floodplain based on Landsat image analysis during 2014-15.

Vegetation Community	Inundated area (ha)
	4 March 15
Anthropogenic herbland	0.09
Coolibah - River Cooba - Lignum woodland	1.79
Coolibah open woodland wetland	12.77
Lignum shrubland wetland	30.09
Stream/River/Dam	0.02
Total area inundated (ha)	**44.76**
Boera Dam height (m)	**2.348**
Total volume on Western Floodplain (ML)	**111.91**

During the 2015-16 water year, inundation was estimated at 206.31 ha in August 2015. This followed a period of overflow onto the floodplain that occurred between late June and mid-August 2015. Gauge heights did not exceed 2.38 m during this time but overflow to the floodplain continued for over 45 days prior to image capture. Inundation in the 13 October 2015 image was estimated at 194.29 ha. This followed a period of no overflow onto the Western Floodplain for 62 days and it is assumed that the extent of inundation represents water retained on the floodplain following the previous event.

Inundation peaked in December 2015 with an estimated extent of 464.65 ha. Image capture on 17 December followed a significant flow peak, where the gauge height at Boera Dam reached 2.54 m on 10 November 2015. Gauge height exceeded the estimated overflow level of 2.26 m until 11 December 2015.

The final image captured on 26 May 2016 showed an estimated inundation of 451.67 ha. This followed shortly after the largest flow peak entering Boera Dam in the 2015-16 water year during which gauge height reached 2.55 m on 14 May 2016. There had also been significant localised rainfall in the two weeks prior to the final image capture.

Lignum shrubland was the most commonly inundated vegetation community in the 2015-16 water year (Table B-3, Figure B-15), followed by Coolibah open woodland wetland and Coolibah - River Cooba - Lignum woodland. Beefwood - Coolibah woodland and Ironwood woodland were the least frequently inundated of the mapped communities, with only 0.01 ha inundated in August 2015 and May 2016 respectively. These communities occur in small patches on the eastern extent of the floodplain and inundation was likely a result of localised rainfall runoff rather than being river flow related.

A maximum of 1,162 ML was estimated to be on the floodplain during December 2015 when Boera Dam was at a level of 2.23 m (Table B-3). Towards the end of the water year in May 2016 there was approximately 1,126 ML of water on the Western Floodplain.

Table B-3: Inundation extent of vegetation communities on Western Floodplain based on Landsat image analysis during 2015-16.

Vegetation Community	Inundated area (ha)			
	11 Aug 15	13 Oct 15	17 Dec 15	26 May 16
Beefwood - Coolibah woodland	0.01	0.00	0.00	0.00
Belah/Black Oak - Western Rosewood - Leopardwood	1.21	1.59	4.79	3.16
Chenopod low open shrubland	1.61	5.66	13.18	16.03
Coolibah - River Cooba - Lignum woodland	54.60	49.32	62.72	60.20
Coolibah open woodland wetland	59.24	48.58	97.34	94.45
Ironwood woodland	0.00	0.00	0.00	0.01
Lignum shrubland wetland	89.49	88.90	285.75	273.30
Narrow-leaved Hopbush-Scrub Turpentine-Senna shrub	0.13	0.07	0.28	0.44
Poplar Box grassy low woodland	0.00	0.00	0.08	0.09
Stream/River/Dam	0.02	0.17	0.50	4.00
Total area inundated (ha)	**206.31**	**194.29**	**464.65**	**451.67**
Boera Dam height (m)	**2.28**	**1.99**	**2.23**	**2.41**
Total volume on Western Floodplain (ML)	**516**	**486**	**1,162**	**1,129**

Inundation mapped using Landsat imagery showed that the total extent of inundation spread south across the Western Floodplain from July through to October 2016 and began to contract from mid-November 2016 (Table B-4; Figure B-16). Inundation was estimated at 1,101.79 ha in July 2016, resulting from a period of overflow onto the floodplain commencing mid-May 2016. Overflow onto the floodplain continued through to late December, peaking at 3.04 m on 24 October.

Inundation mapped from the image captured on 16 October (prior to this peak) covered 3,839.11 ha, the maximum mapped extent for the 2016-17 water year. This represents about 35% of the total area of floodplain located within the Warrego-Darling Selected Area.

Analysis of the final image captured on 21 February 2017 showed an estimated inundation of 550.08 ha. The reduction in inundation extent is consistent with overflow onto the floodplain ceasing in late December, and continuing to evaporate when the Boera Dam level dropped below 2.26 m.

Several vegetation communities were inundated during the image capture period. Lignum shrubland wetland was the most extensively inundated for each image capture date, followed by Chenopod low open shrubland (Table B-4). Of the thirteen mapped vegetation communities present on the western floodplain, only two had less than 0.01 ha inundated during the 2016-17 water year; Gidgee chenopod woodland and Supplejack woodland. Gidgee chenopod woodland is mapped to occur in three areas on the very perimeter of the floodplain, occupying less than 400 ha. Only one area (<2.5 ha) of Supplejack woodland is mapped in the area, which is also located on the perimeter of the floodplain.

A maximum volume of 9,978 ML of water is estimated to have been on the floodplain during 2016-17 when Boera Dam reached its peak of 3.04 m on the 24 October 2016. By the 21 February 2017, this had dropped to 1,375 ML (Table B-4).

Water was detected on the Western Floodplain in four Landsat images, during the 2017-18 water year. During these times, inundation ranged from 20.5 ha on the 20 December 2017, to 436.85 ha on 29 September 2017 (Table B-5). Relating inundation to the water levels in Boera Dam (Figure B-1), it is likely that the only floodplain inundation from overflows from Boera Dam would have occurred in December 2017. From the inundation pattern in December 2017 (Figure B-16), inundation derived from Boera Dam is likely to have been restricted to the northern sections of the floodplain, with wetting observed further south, likely derived from local rainfall. The hydrodynamic model suggests that for a similar area of inundation around Boera Dam, a volume of 6 ML would have been spilled onto the floodplain during this event. Inundation observed in the other three times – September 2017 (436.85 ha), March (115.68 ha) and April 2018 (154.78 ha) – was likely the result of rainfall alone.

It is likely that only 20.5 ha was inundated by the small December connection event (Table B-5). This inundation event partially covered 5 mapped vegetation communities including Coolibah open woodland, Lignum shrubland, Chenopod shrubland, Coolibah-river Cooba-Lignum woodland and Anthropogenic herbland (Table B-5). Rainfall derived inundation accounted for a much larger area of floodplain inundation with the greatest inundation shown on the September image 2017 (Figure B-16).

Zero inflows down the Warrego River for the first 10 months of the 2018-19 water year resulted in no inundation of the Western Floodplain (Figure B-6). During April to June 2019, Warrego River inflows filled Boera Dam to a maximum level of 2.91 m on the gauge, 0.65 m higher than the Western Floodplain connection level. This resulted in 705.81 ha of the Western Floodplain becoming inundated on the 18 May 2019 (Figure B-17). During this time significant areas of Lignum shrubland (417.8 ha) and Chenopod shrubland (110.94 ha; Table B-6) were inundated. By the 19 June 2019, the inundation area had dropped to 288 ha (Figure B-17), assisted by floodwater returning to the Warrego River from the floodplain through the breach in the eastern embankment.

Table B-4: Inundation extent of vegetation communities on Western Floodplain based on Landsat image analysis for the 2016-2017 water year.

Vegetation Community	Inundated area (ha)					
	29-Jul-16	13-Aug-16	16-Oct-16	17-Nov-16	19-Dec-16	21-Feb-17
Anthropogenic herbland		1.43	2.52	2.25	2.88	0.05
Beefwood - Coolibah woodland	0.012	0.012	0.15	0.04		
Belah/Black Oak - Western Rosewood - Leopardwood low open woodland		0.12	0.71	0.08	0.07	0.44
Chenopod low open shrubland - ephemeral partly derived forbland	224.66	659.33	1,512.90	1,121.68	275.06	168.56
Coolibah - River Cooba - Lignum woodland	70.16	68.40	77.09	69.08	61.03	51.77
Coolibah open woodland wetland with chenopod/grassy ground cover	181.00	256.96	712.94	659.49	372.63	69.68
Ironwood woodland			0.41	0.08		
Lignum shrubland wetland	621.55	704.60	1,524.80	1,508.32	1,178.98	258.28
Mulga shrubland			0.07			
Narrow-leaved Hopbush-Scrub Turpentine-Senna shrubland	0.315	0.803	3.25	0.72	0.24	0.04
Poplar Box grassy low woodland	0.10	0.08	0.25	0.10	0.02	
Water	4.01	4.01	4.00	4.00	4.01	1.27
Total area inundated (ha)	**1,101.79**	**1,695.74**	**3,839.11**	**3,365.83**	**1,894.92**	**550.08**
Boera Dam height (m)	**2.88**	**2.91**	**2.91**	**2.69**	**2.31**	**1.98**
Total volume on Western Floodplain (ML)	**5,819**	**6,457**	**9,597**	**8,414**	**4,737**	**1,375**

Table B-5: Inundation extent of vegetation communities on Western Floodplain based on Landsat image analysis for the 2017-18 water year.

Vegetation Community	Inundated area (ha)			
	29-Sept-17	22-Dec-17	28-Mar-18	29-April-18
Anthropogenic herbland	0.82	0.36	0.54	0.51
Belah/Black Oak - Western Rosewood - Leopardwood low open woodland	1.21			1.82
Chenopod low open shrubland - ephemeral partly derived forbland	40.53	2.17	23.45	16.50
Coolibah - River Cooba - Lignum woodland	57.70	0.79	27.24	3.39
Coolibah open woodland wetland with chenopod/grassy ground cover	110.94	9.47	31.87	76.91
Ironwood woodland	0.51		0.10	0.57
Lignum shrubland wetland	224.03	7.69	32.43	54.56
Narrow-leaved Hopbush-Scrub Turpentine-Senna shrubland	0.27		0.02	0.10
Poplar Box grassy low woodland	0.35			0.27
Water	0.39	0.02	0.02	0.11
Total area inundated (ha)	**436.85**	**20.50**	**115.68**	**154.78**
Boera Dam height (m)	**0.94**	**2.30**	**1.63**	**1.96**
Total volume on Western Floodplain (ML)*	**-**	**6**	**-**	**-**

* Volumes not calculated for these dates as they contain 100% rainfall generated inundation

Table B-6: Inundation extent of vegetation communities on Western Floodplain based on Landsat image analysis for the 2018-19 water year.

Vegetation Community	Inundated area (ha)	
	18 May 2019	19 June 2019
Anthropogenic herbland		0.54
Chenopod low open shrubland - ephemeral partly derived forbland	164.41	30.55
Coolibah - River Cooba - Lignum woodland	23.62	28.70
Coolibah open woodland wetland with chenopod/grassy ground cover	95.71	50.19
Lignum shrubland wetland	417.85	173.96
Narrow-leaved Hopbush-Scrub Turpentine-Senna shrubland	0.23	0.09
Water	4	3.97
Total area inundated (ha)	**705.81**	**288.00**
Boera Dam height (m)	**2.695**	**2.054**
Total volume on Western Floodplain (ML)	**1,764.53**	**720**

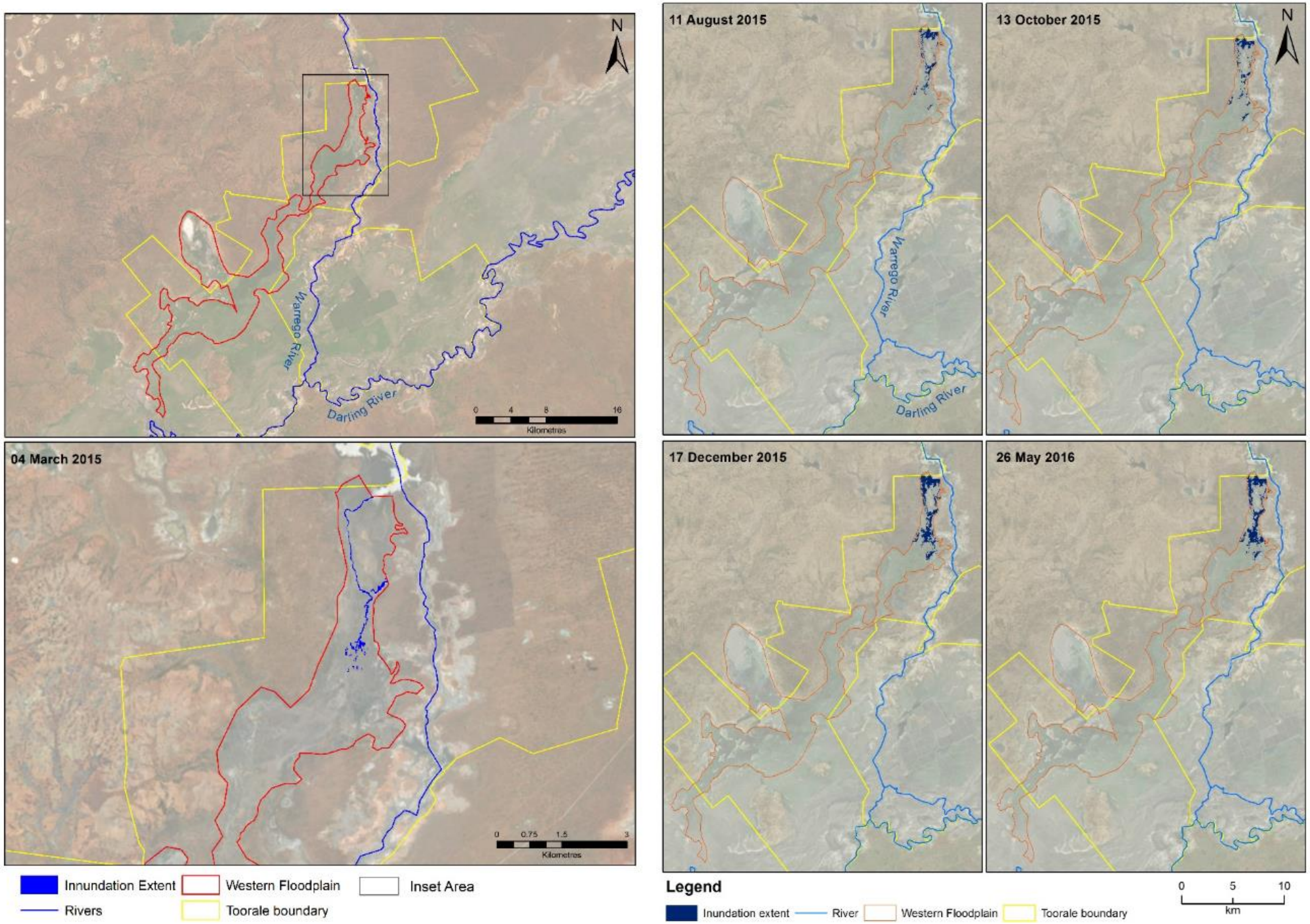

Figure B-15: Inundation of the Western Floodplain mapped from Landsat imagery during the 2014-15 (Left) and 2015-16 (Right) water years.

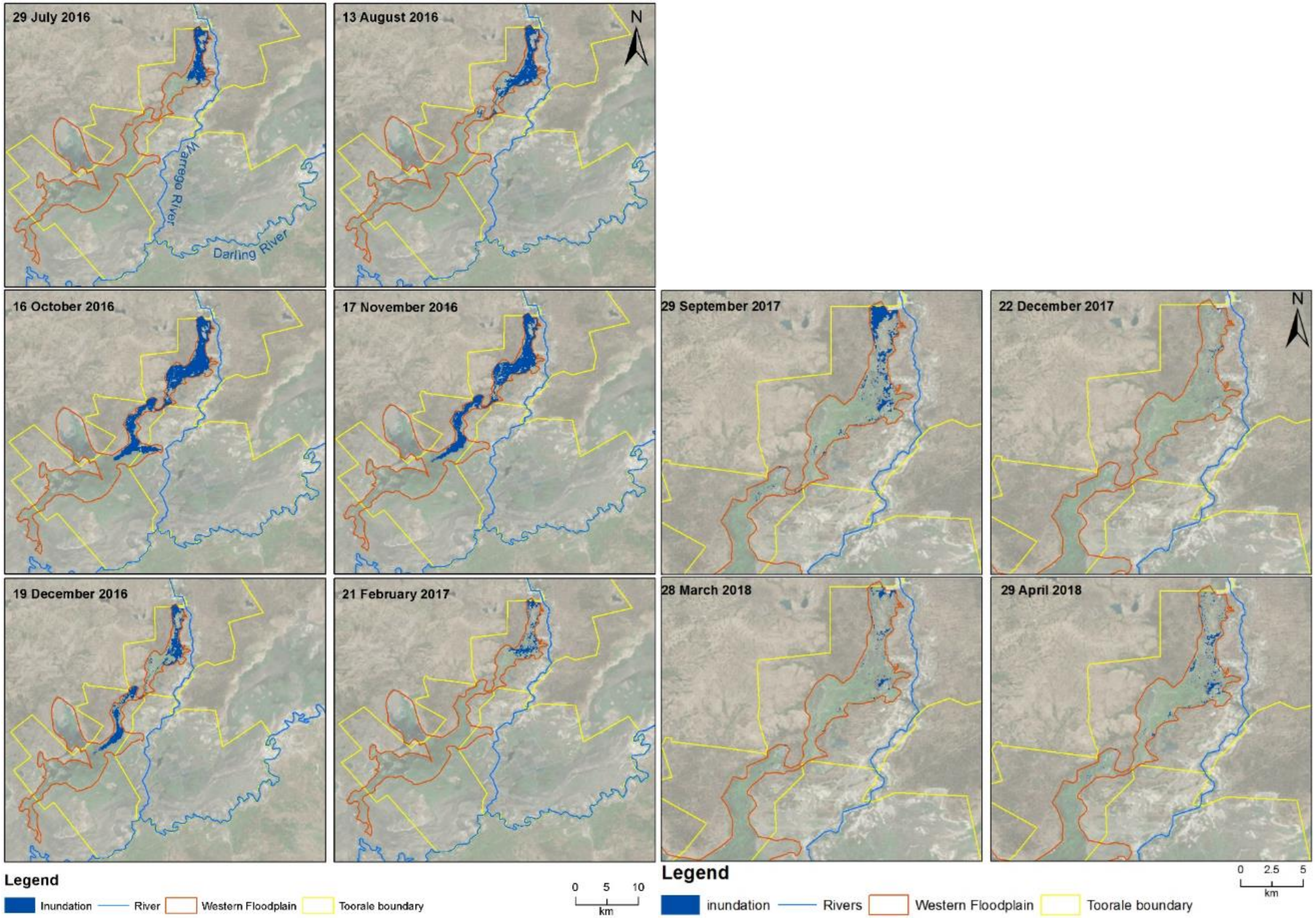

Figure B-16: Inundation of the Western Floodplain mapped from Landsat imagery during the 2016-17 (Left) and 2017-18 (Right) water years.

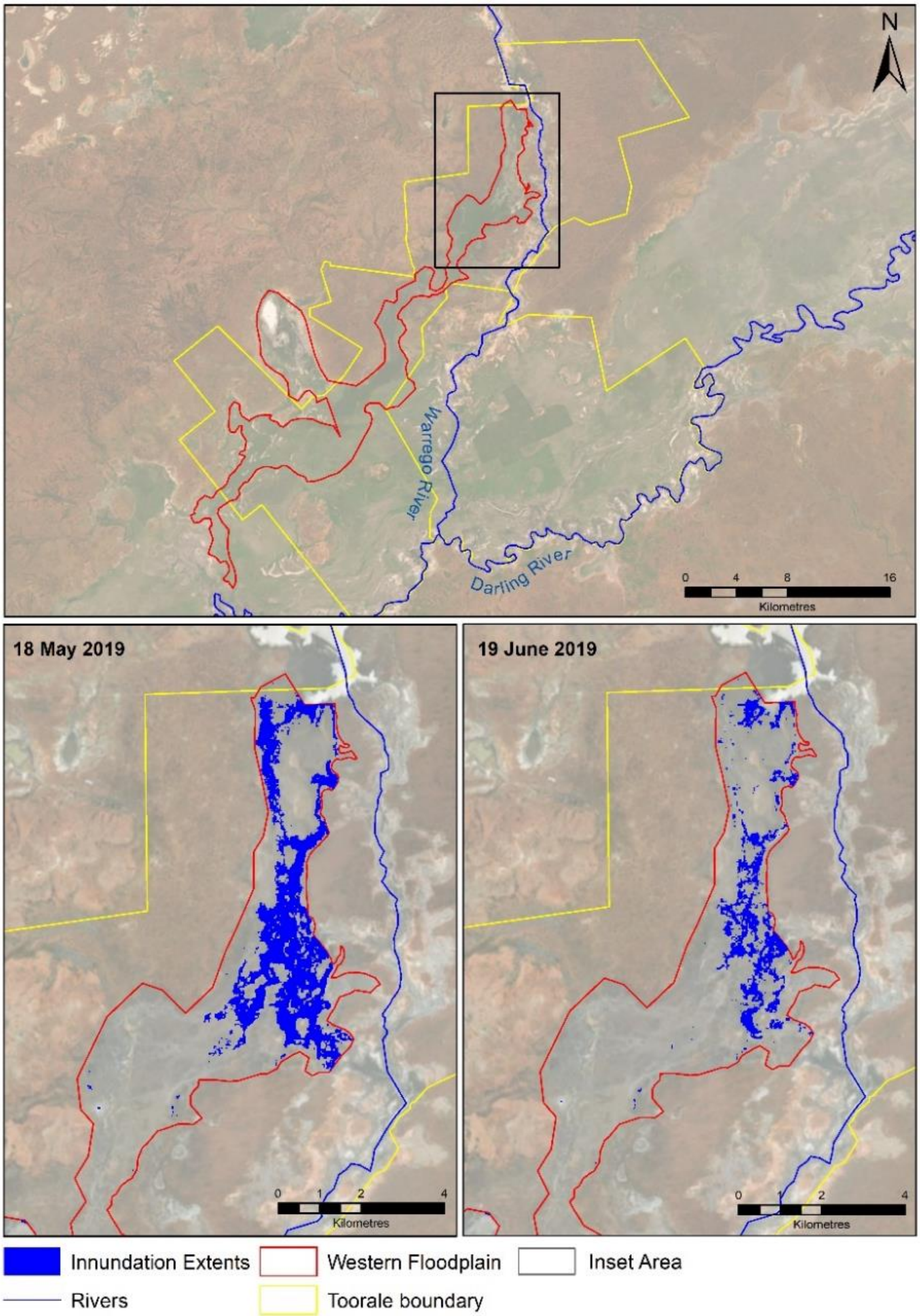

Figure B-17: Inundation of the Western Floodplain mapped from Landsat imagery during the 2018-19 water year.

B.4 Discussion

Hydrological connectivity in the Warrego River and Western Floodplain zones of the Warrego-Darling Selected Area is solely driven by unregulated flows that are typically derived from tropical depression-driven rainfall in the upper sections of the catchment. Over the duration of the LTIM Project, connectivity was episodic, peaking in both the Warrego River channel and on the Western Floodplain during 2016-17. This was followed by a period of minimal inflows during 2017-18 and 2018-19, with limited floodplain inundation and drying of many of the dams along the Warrego River. Moderate inflows late in 2018-19 once again inundated the floodplain and refilled the waterholes of the lower Warrego River. Before these flows, the only water in the Warrego River and Western Floodplain zones was one small waterhole remaining in Boera Dam (Figure B-7). The hydrological variability experienced in the Warrego over the LTIM Project is typical of semi-arid rivers and supports the boom and bust ecology documented in the other indicators measured in the Project.

Commonwealth environmental water and its management has undoubtedly contributed to hydrological connectivity in the Warrego system within the Warrego-Darling Selected Area. Entitlements held upstream of the Warrego-Darling Selected Area on the Warrego River have contributed to the magnitude of flows entering Boera Dam (Appendix C). Similarly, operation of the Boera and Booka Dam regulating gates in line with the Toorale water licences has increased flow to the lower Warrego River and Western Floodplain throughout the 2014-19 period. Decisions to shut the regulating gates at Boera in July 2016 resulted in inundation of around 35% or 3,839 ha of the Western Floodplain, inundating all of the 13 vegetation communities on the floodplain, most of which had not been inundated since the large floods of 2012. The 2016 inundation event included around 61% environmental water accounted on the Western Floodplain water licence. Downstream flows to the Warrego and Darling Rivers were prioritised during the LTIM project. During the most recent flow event in April to June 2019, the regulating gates at Boera and Booka Dams were left open for the duration of the inflow event (40 days), with around 77% of the inflows flowing downstream of Dicks Dam, contributing enough flow to the Darling River to reconnect the river and push flows below Wilcannia. During this time 8,106 ML of environmental water was accounted against the Toorale Warrego River licence, which comprised 40% of the total flow.

B.5 Conclusion

Given the relatively unregulated nature of the Warrego River catchment upstream of the Warrego-Darling Selected Area, inflows and the availability of Commonwealth environmental water are dependent on upstream rainfall events. Once water reaches Boera Dam, the CEWO has the ability to make watering decisions to inundate the Western Floodplain or increase the downstream connectivity in the lower Warrego River. These decisions have undoubtedly contributed to hydrological connectivity in the Warrego system within the Warrego-Darling Selected Area. Commonwealth environmental water that has flowed onto the Western Floodplain has inundated large areas of the floodplain, rejuvenating vegetation communities and providing a range of productive habitats for birds, frogs and fish. On other occasions, decisions to pass water down the lower Warrego River has improved both flow conditions and water quality in the Darling River, along with replenishing water levels in the Warrego River dams that provide important refuge habitats for aquatic species.

B.6 References

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Appendix C Hydrology (Northern Tributaries)

C.1 Introduction

This chapter examines environmental water in the northern tributaries of the Murray-Darling Basin. In particular, it considers the hydrological influences of environmental water at the Junction of the Warrego and Darling Rivers Selected Area (Warrego-Darling Selected Area) over the duration of the LTIM Project. While the majority of unregulated licences are held by the Commonwealth Environmental Water Holder, some regulated deliveries that influenced flows through the Warrego-Darling Selected Area (primarily the Darling River zone) also included state managed environmental water. For this reason, this Appendix refers to the influence of 'environmental water' which includes both Commonwealth and state-owned entitlements. This indicator links closely with other hydrology indicators as well as the water quality and metabolism indicators.

The specific question addressed in this Appendix is:

- What did Commonwealth environmental water from upstream tributaries contribute to hydrological connectivity within the Selected Area?

C.1.1 Northern Tributaries of the Murray-Darling Basin

The northern tributaries of the Murray-Darling Basin upstream of the Warrego-Darling Selected Area drain the Great Dividing Range in southern Queensland and northern New South Wales, flowing more than 500 km, generally in a westerly direction. The Warrego River catchment defines the western extent of the catchment upstream of the Warrego-Darling Selected Area, meeting the Darling River at Toorale (Figure C-1).

Major tributaries upstream of the Warrego-Darling Selected Area include:

- Warrego River
- Moonie River
- Condamine – Balonne River system
- Border Rivers
- Gwydir River
- Namoi River
- Barwon – Darling River system
- Macquarie River
- Castlereagh River

The stream network, longitudinal connectivity and hydrological behaviour of the Northern Basin upstream of the Warrego-Darling Selected Area is complex. Catchments are poorly defined and inconsistently applied and river tributaries alternate between gaining and losing systems through complex interactions with each other and their floodplains. Water management activities are equally complex. The northern tributaries comprise a mixture of regulated, unregulated and ephemeral streams managed across two states with differing government agencies, legislation and policies. This challenge is being addressed through work under the NSW Water Reform Action Plan (https://www.industry.nsw.gov.au/water-reform).

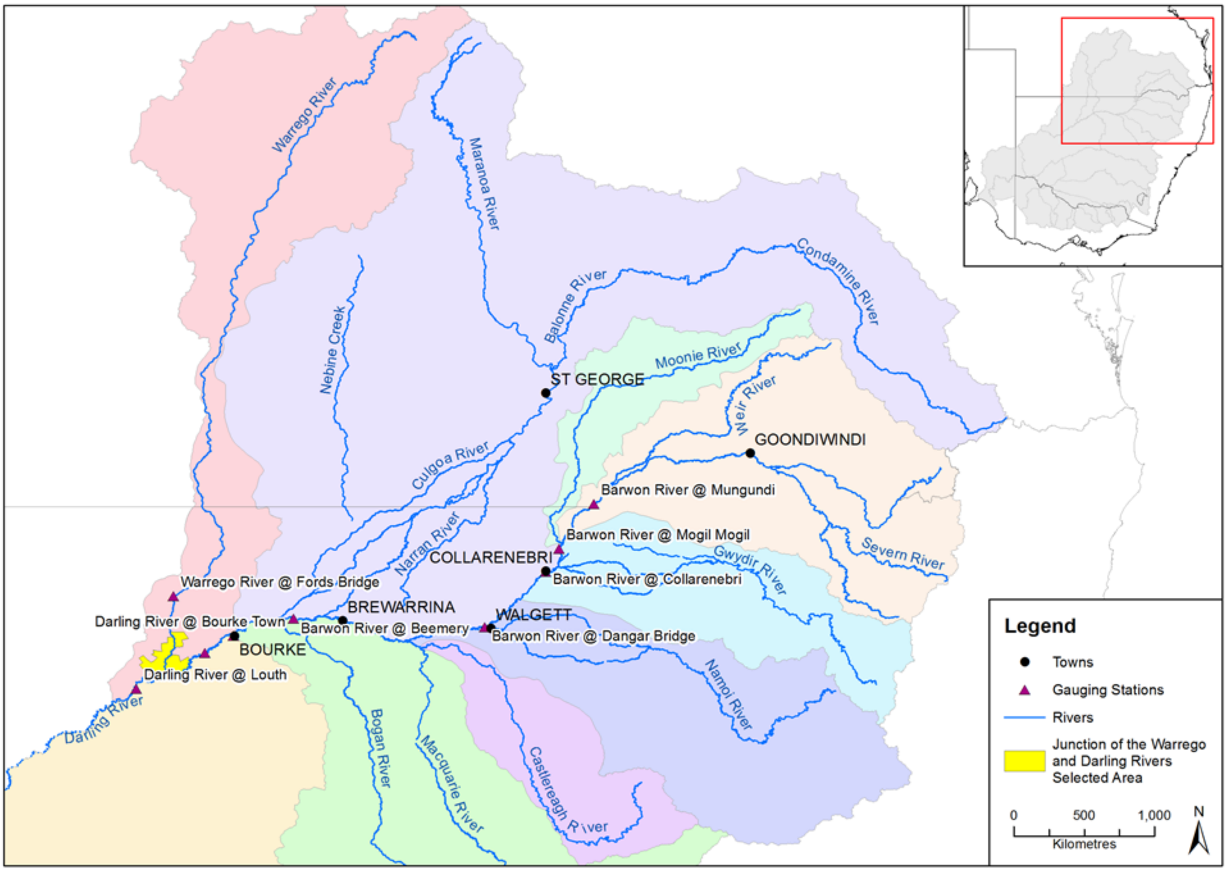

Figure C-1: Northern Tributaries of the Murray-Darling Basin (Commonwealth Environmental Water Office).

C.1.2 Commonwealth environmental water holdings

Total Commonwealth environmental water holdings (entitlements) for the northern tributaries are currently 481,867 ML (Table C-1). Long Term Average Annual Yield (LTAAY) provides an indication of the long-term reliability of these entitlements and is generally used by the Commonwealth Environmental Water Holder for annual decision-making regarding water use priorities. At the time of writing, LTAAY of Commonwealth environmental water for the northern tributaries upstream of Louth was 300,032 ML. Current Commonwealth environmental water license information is available at:

http://www.environment.gov.au/water/cewo/about/water-holdings

Table C-1: Commonwealth surface water Holdings for Northern Tributaries to May 2019 (source Commonwealth Environmental Water Holder).

Catchment	Regulated (ML)		Unregulated (ML)		Total (ML)	
	Entitlement	LTAAY	Entitlement	LTAAY	Entitlement	LTAAY
Condamine-Balonne[1]	45	43	172,881	91,198	172,926	91,241
Moonie	0	0	5,671	2,523	5,671	2,523
Warrego (Qld)	0	0	39,455	20,096	39,455	20,096
Warrego (NSW)	0	0	17,826	13,773	17,826	13,773
Barwon-Darling	0	0	28,631	28,631	28,631	28,631
Border Rivers[2]	18,346	6,187	21,423	9,096	39,769	15,283
Gwydir[2]	94,033	38,014	20,451	9,919	114,484	47,933
Namoi	13,653	10,281	0	0	13,653	10,281
Peel	1,257	263	0	0	1,257	263
Macquarie[2]	126,224	65,132	8,292	4,876	134,516	70,008
TOTAL	***253,558***	***119,920***	***314,630***	***180,112***	***568,188***	***300,032***

Notes:

[1] Includes (all LTAAY): Nebine Creek (3,842 ML); lower Balonne unsupplemented and overland flow: 86,543 ML; Condamine unsupplemented: 813 ML

[2] Supplementary Water entitlements in the NSW Border Rivers, Gwydir and Macquarie catchments are listed for the purposes of this table as unregulated entitlements

In addition to upstream entitlements, there are a number of local Commonwealth environmental water entitlements directly associated with agreed watering actions at the Warrego-Darling Selected Area (Table C-2). The Commonwealth Environmental Water Office has the potential to take against these licences when conditions are satisfied.

Table C-2: Commonwealth environmental water entitlements associated with the Warrego-Darling Selected Area.

Water source	Water Access Licence	Registered entitlement (ML)	LTAAY (ML)	Trigger flow conditions (ML/d – location)
Intersecting Streams Unregulated River	**Boera Dam** WAL27558	1,134	8,106	Fresh in Warrego reaching Darling (approx. 300 ML/d at Fords Bridge) plus >330 ML/d at Louth (425004).
	Upstream Boera WAL27555	972		
	Peebles Dam WAL27552	6,000		
Intersecting Streams Unregulated River	**Special High Flow–Boera Dam (for Western Floodplain)** WAL31152	9,720	9,720	Visible flow in Warrego at or near Darling plus >979 ML/d at Louth (425004).
Barwon Darling Unregulated River Access	**A Class** WAL33701 WAL33704	20 47	7,672	>350 ML/d at Bourke (425003) and >260 ML/d at Louth (425004).
	B Class WAL33784 WAL35944	1,437 1,090		>1,250 ML/d at Bourke (425003) and > 1,130 ML/d at Louth (425004).
	C Class WAL35943	5,078		>1,339 ML/d at Louth (425004).

C.1.3 Hydrology within the Warrego-Darling Selected Area

The hydrology within the Warrego-Darling Selected Area is governed by flows in either the Darling River, the Warrego River, or both.

Barwon-Darling River

Located in a semi-arid setting, upstream climatic conditions are the key driver of hydrology within the Warrego-Darling Selected Area, with the upstream easterly catchments capable of providing overbank flows within the Barwon-Darling River. During major events, floodwaters may extend along the length of the river system.

During drier times, such as this year (2019), the relationship becomes more complex. From a water management point of view, the Barwon-Darling River system is considered an unregulated stream; however, it is fed by both regulated and unregulated upstream catchments with stream flows, in part, reflecting upstream water management decisions. Further complicating the hydrology is the influence of a series of weir pools, terminal wetlands, anabranches and anastomosing streams.

Warrego River

The Warrego River is essentially unregulated, and due to its semi-arid setting, provides water to the Warrego-Darling Selected Area intermittently. Within the Warrego-Darling Selected Area, Warrego flows are further influenced by in-stream structures, such as Boera, Booka, Dicks and Peebles Dams.

Environmental water in the Warrego may only be accounted for once the individual conditions associated with each entitlement are met. This is usually based on a flow trigger that differs for each entitlement, based on its location and relative security. Depending on chosen watering strategies, environmental water may or may not be accounted for once the flow trigger is reached.

C.2 Methods

The downstream passage of environmental water events was observed and assessed using WaterNSW real-time flow data for gauging stations located along the Barwon-Darling River system. Mean daily discharge data for the following hydrometric stations was used:

- 416001 – Barwon River at Mungindi
- 422004 – Barwon River at Mogil Mogil
- 422003 – Barwon River at Collarenebri
- 422001 – Barwon River at Walgett
- 422028 – Barwon River at Beemery
- 425003 – Darling River at Bourke
- 425037 – Darling River at Weir 19a
- 425004 – Darling River at Louth

The relationship between these gauging stations and key tributary inflows is shown in Figure C-2.

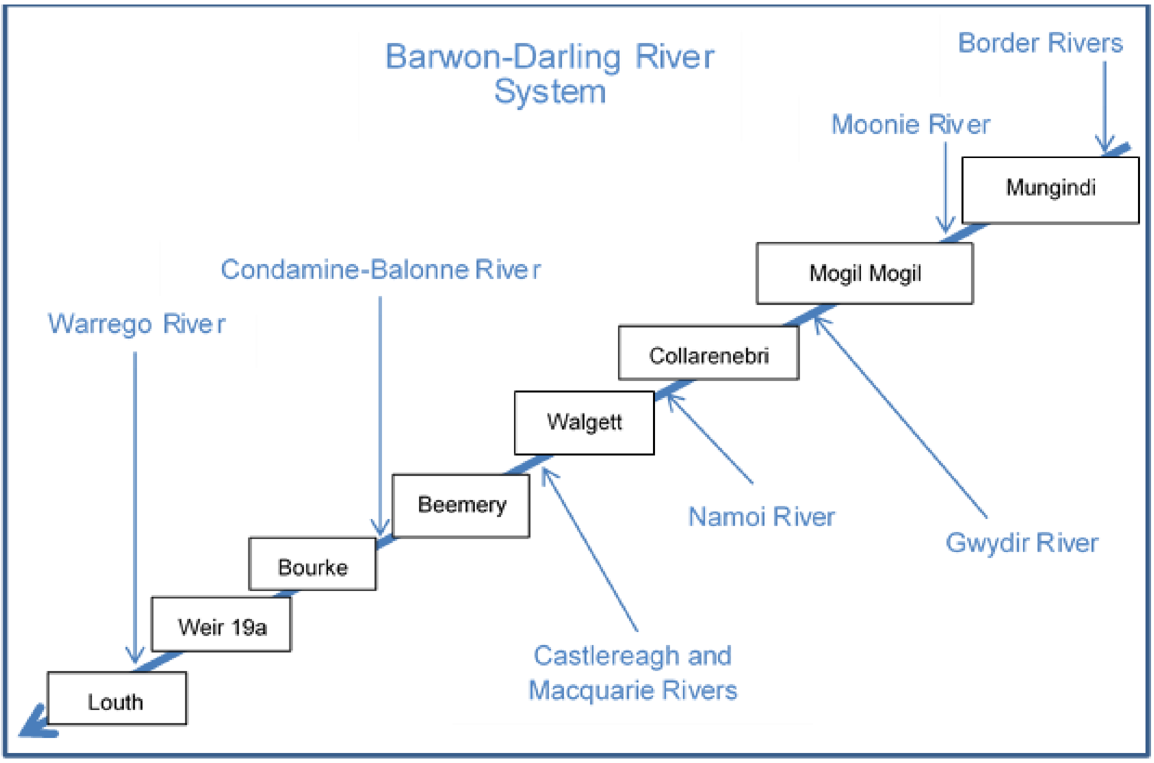

Figure C-2: Gauging stations and key tributaries of the Barwon-Darling River system.

Within each water year (from 2014 to 2019), end of system (EOS) environmental water was estimated based on advice from the Department of the Environment and Energy, NSW Department of Industry and Environment - Water (Formerly NSW Department of Industry - Water) and the CSIRO MDB Sustainable yield project (Table C-3). The EOS measure was used to estimate the amount of water (as a proportion of the total) that would have made it out of the end of each catchment, considering losses such as evaporation, infiltration etc.

Throughout the project, environmental water events were divided into regulated and unregulated events. Unregulated events were linked to prevailing seasonal conditions, requiring specific streamflow conditions to be met in order to trigger use of individual environmental water entitlements. Regulated environmental water events were not dependent on specific stream flows and were triggered in response to a wider range of river management or environmental decision criteria. No regulated entitlements exist in the Barwon-Darling channel itself, rather for this analysis it refers to holdings in the Namoi, Gwydir, Macquarie and Border Rivers sub-catchments only. It should be noted that while environmental water protection actions like pumping embargoes influence the movement of environmental water through the system, these were not considered in the current analysis.

Table C-3: End of system (EOS) flow estimates used to assess passage of environmental water downstream

Catchment	Applied EOS flow (%)
Border Rivers	80
Moonie	73
Gwydir	24
Namoi	63
Macquarie/Castlereagh	76
Condamine-Balonne	37
Barwon-Darling (Mungindi to Bourke)	80
Warrego	34

C.3 Results

C.3.1 Environmental water flow events

WaterNSW daily flow records (Figure C-3) were cross-referenced with internal data and operational reports provided by the Commonwealth Environmental Water Office to assess key flow events where environmental water take was accounted in the northern tributaries during the LTIM project. Water 'take' is defined as the amount of environmental water accounted during unregulated events where specific streamflow conditions are met to trigger individual environmental water entitlements.

Daily flow records for 2014/15 (Figure C-3) indicate the following environmental flow events:

14-15 Event 1. 16,972 ML of environmental water delivered from the Gwydir catchment (10 October 2014 – 17 December 2014).

14-15 Event 2. 22,069 ML of upstream environmental water take from the Border Rivers, Condamine Balonne and Warrego Rivers (19 December 2014 – 25 March 2015).

14-15 Event 3. 1,740 ML of upstream environmental water take from the Border Rivers, Moonie, and Gwydir Rivers (2 April 2015 – 7 June 2015).

During 2015/16, four flow 'events' were identified that included a component of environmental water (Figure C-3):

15-16 Event 1. 3,547 ML upstream environmental water take from the Queensland Border Rivers, Moonie and upper Barwon Rivers as well as localised entitlements at Toorale (2 July 2015 – 31 October 2015).

15-16 Event 2. 1,208 ML upstream environmental water take from Queensland Border Rivers and Gwydir River (2 November 2015 – 4 December 2015).

15-16 Event 3. 13,955 ML upstream environmental water take from Queensland Border Rivers, Upper Barwon, Condamine-Balonne and Warrego Rivers (4 January 2016 – 22 March 2016).

During 2016/17, four flow 'events' were identified that included a component of environmental water take. Events between June 2016 and January 2017 were continuous, but with three distinct flow peaks (Figure C-3). We considered each of these peaks as separate events. Each event is described below:

16-17 Event 1. 13,087 ML environmental water from the Queensland Border Rivers, Castlereagh, Condamine-Balonne and Barwon-Darling River, as well as localised entitlements at Toorale. (22 June 2016 – 1 August 2016)

16-17 Event 2. 5,194 ML upstream environmental water take from Barwon-Darling River system (2 August – 8 September 2016)

16-17 Event 3. A very large event comprising 77,588 ML upstream environmental water take from all upstream catchments (9 September – 25 December 2016)

16-17 Event 4. 50,967 ML upstream environmental water take from the Border Rivers, Condamine-Balonne catchment, Namoi and the Castlereagh / Macquarie Rivers (10 April – 17 May 2017).

Three flow 'events' were identified during 2017/18 that included a component of environmental water :

17-18 Event 1. 170,670 ML of upstream environmental water take and delivery from the Border Rivers, Moonie, Gwydir and Macquarie-Castlereagh Rivers (1 July – 29 November 2017).

17-18 Event 2. 9,162 ML of upstream environmental water take and delivery from the Condamine Balonne, Moonie and Namoi Rivers (10 March – 29 April 2018).

17-18 Event 3. 23,232 ML of upstream environmental water delivered from the Border Rivers and Gwydir catchments (4 May – 26 June 2018).

During the 2018/19 water year, due to the lack of longitudinal connectivity along the Barwon-Darling during River (Figure C-3), only one flow 'event' was identified that influenced water availability in the Warrego-Darling Selected Area:

18-19 Event 1. 15,824 ML of upstream environmental water take in the Warrego River (30 April – 30 June 2019).

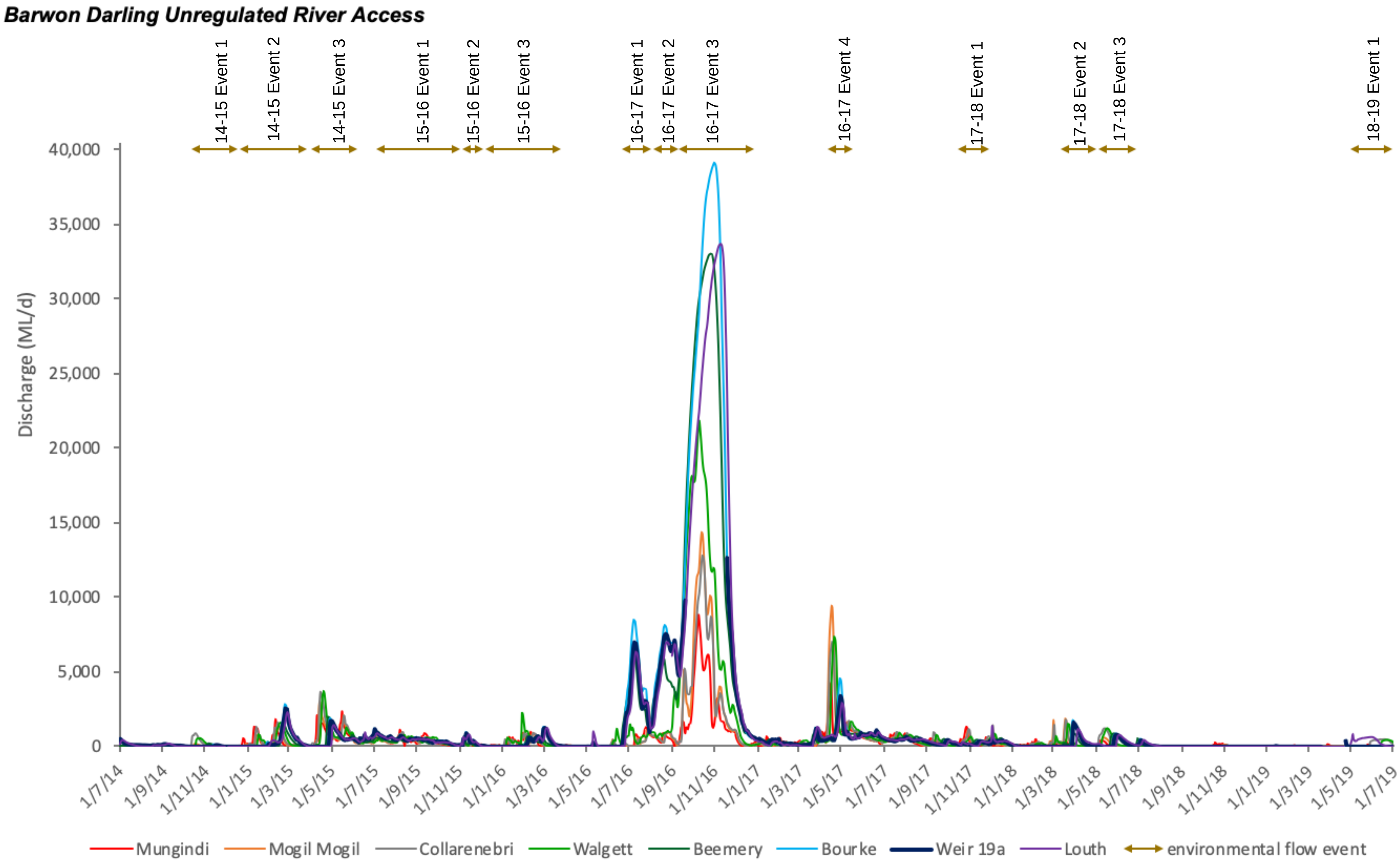

Figure C-3: Mean daily flows at gauging stations on the Barwon-Darling River system over the duration of the LTIM Project.

C.3.2 2014-15 environmental water events

<u>2014-15 Environmental water Take</u>

A summary of environmental water take during the 2014-15 events, and their likely influence on flows within the Warrego-Darling Selected Area is presented in Table C-4.

Table C-4: Environmental water (EW) events for 2014–15.

Basin Plan Region	Tributary	EW take (ML)	Comments
QLD Border Rivers	Dumaresq-Macintyre River	14-15 event 2 —294.4	Possible effect at Darling River zone
		14-15 event 3 —205.4	Possible effect at Darling River zone
	Severn River	14-15 event 2—1,248.7	Possible effect at Darling River zone
		14-15 event 3 —2.0	Unlikely effect at Darling River zone
QLD Moonie	Lower Moonie River	14-15 event 2—806.4	Possible effect at Darling River zone
		14-15 event 3 —608.6	Possible effect at Darling River zone
QLD Condamine–Balonne	Nebine Creek	0	No EW usage events
QLD Warrego	Upper Warrego River	14-15 event 2—329.2	Possible effect at Darling River zone
		14-15 event 3 —43.6	Possible effect at Darling River zone
	Lower Warrego River	14-15 event 2—1,887.3	Possible effect at Darling River zone
		14-15 event 3 —281.6	Possible effect at Darling River zone
NSW Condamine-Balonne	Lower Balonne	14-15 event 2—16,238.5	Flows reached Barwon River—Possible effect at Darling River zone
		14-15 event 3 —147.6	Flows did not reach Barwon River—Unlikely effect at Darling River zone
NSW Gwydir	Gwydir River	59,895 (combined NSW / CEWH)	Regulated flow release to support environmental conditions within the Gwydir Wetlands—Unlikely effect at Darling River zone
	Mallowa Creek	10,666.5	Regulated flows into Mallowa Creek wetlands—Unlikely effect at Darling River zone
	Mehi River	13,316	Regulated release for fish populations during October–November 2014—Possible effect at Darling River zone
	Carole-Gil Gil Creek	3,656	Regulated release for fish populations during October–November 2014—Possible effect at Darling River zone

Basin Plan Region	Tributary	EW take (ML)	Comments
NSW Macquarie-Castlereagh	Macquarie Marshes	0	Nil to date
	The Macquarie River	28,494 (combined NSW / CEW)	Regulated flow release to support environmental conditions within the Macquarie—Unlikely effect at Darling River zone as no EW water flowed through to the end of this sub-catchment.
NSW Intersecting Streams—Warrego	Lower Warrego River	0	Events in late December and early January provided upstream (QLD) access; however, flows at Louth were insufficient to trigger EW take for this licence. Accordingly flows progressed downstream within the Warrego—Likely effect at Darling River zone.
NSW Intersecting Streams	Toorale Western Floodplain	0	No trigger flows for this high flow licence. Accordingly flows progressed downstream within the Warrego—Likely effect at Darling River zone
Barwon-Darling	Barwon-Darling River	14-15 event 2 — 1,264.27	Barwon received 8–12 GL inflows from Border rivers in late December. Flows peaked at Collarenebri on 12 January. B Class access was triggered 11–18 January. On 28 January NSW announced no B and C class access in Barwon Darling until embargo lifted—Likely effect at Darling River zone.
		14-15 event 3 — 451.48	Likely effect at Darling River zone

2014-15 Event 1

The Gwydir was the only regulated catchment within the Northern Tributaries where environmental water was considered likely to influence flows within the Warrego-Darling Selected Area during 2014/15 (Table C-4). A regulated block release of 16,972 ML from Copeton Dam to support native fish populations passed through the lower Gwydir catchment during the second half of October and early November 2014, progressing along both Carole Creek and the Mehi River and further downstream into the Barwon River.

Carole Creek enters the Barwon River upstream of Mogil Mogil, where the flow event was seen as a peak flow of approximately 200 ML/d. A second 200 ML/d peak following immediately after this was the result of an operational water release by State Water NSW (now WaterNSW) to allow maintenance works on Tareelaroi Weir on Carole Creek and is not related to environmental water. The Mehi River enters the Barwon River downstream of Mogil Mogil and the environmental water flow event of 900 ML/d was apparent at Collarenebri during this period (Figure C-5).

From Collarenebri, the environmental water flow pulse was observed to attenuate as it passed down the Barwon-Darling system as far as Weir 19A downstream of Bourke (Figure C-5). Apart from some minor B-class pumping that occurred downstream of Collarenebri, no pumping of this event occurred. No effect on flow was apparent at Louth, due to the low flow conditions present downstream of Weir 19A. As a regulated flow release, environmental water accounted for 78% of the total flow volume of this flow event (Table C-5).

This flow was of sufficient size to stimulate 10 consecutive days of connecting flows through the fish ladder over the Brewarrina Weir, providing suitable conditions for fish movement over this barrier. It is also considered likely that a small pulse reached the Warrego-Darling Selected Area below Bourke around 20 November 2014. However, it is unlikely that this pulse would have exceeded 100 ML/d or caused water to flow over Weir 20A at the downstream extent of the Warrego-Darling Selected Area.

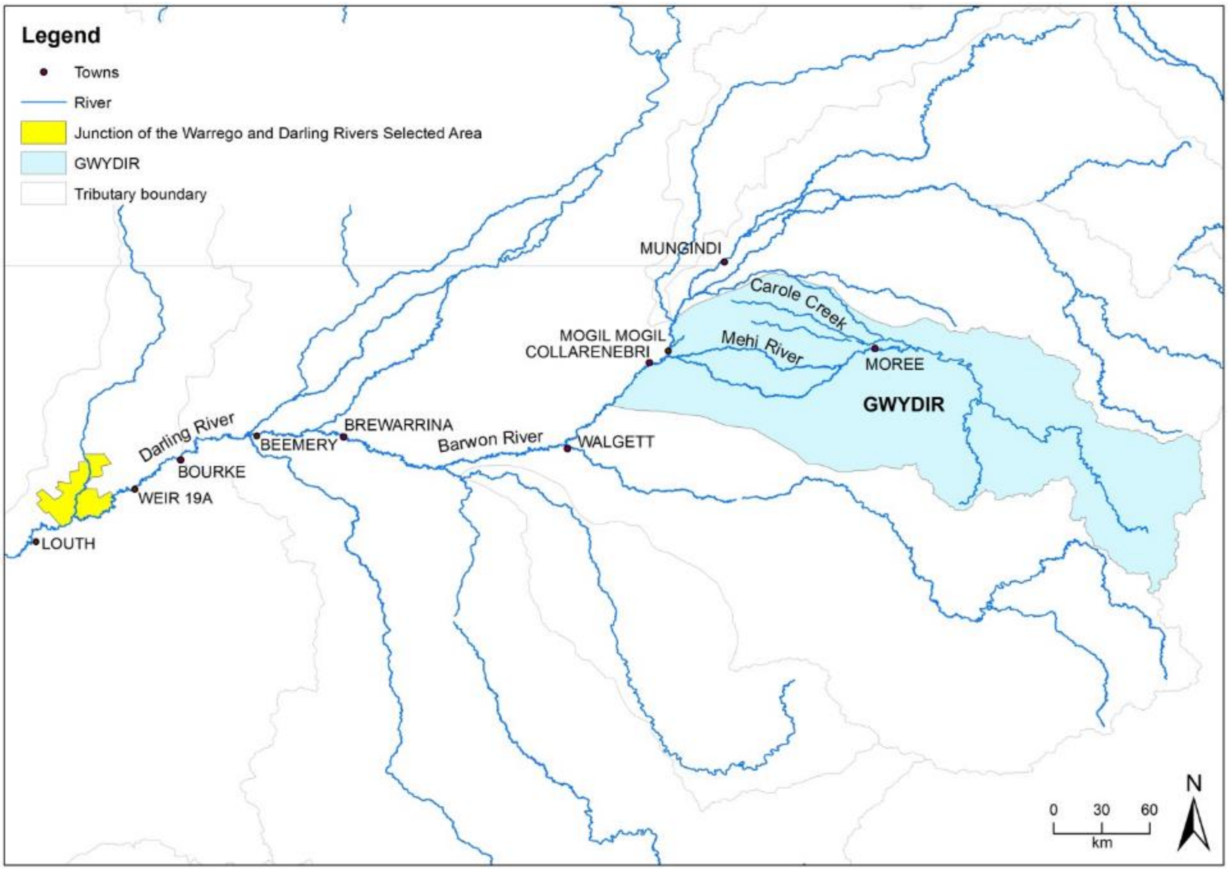

Figure C-4: Location of rivers in the Gwydir Catchment and gauging stations used in the upstream tributaries analysis.

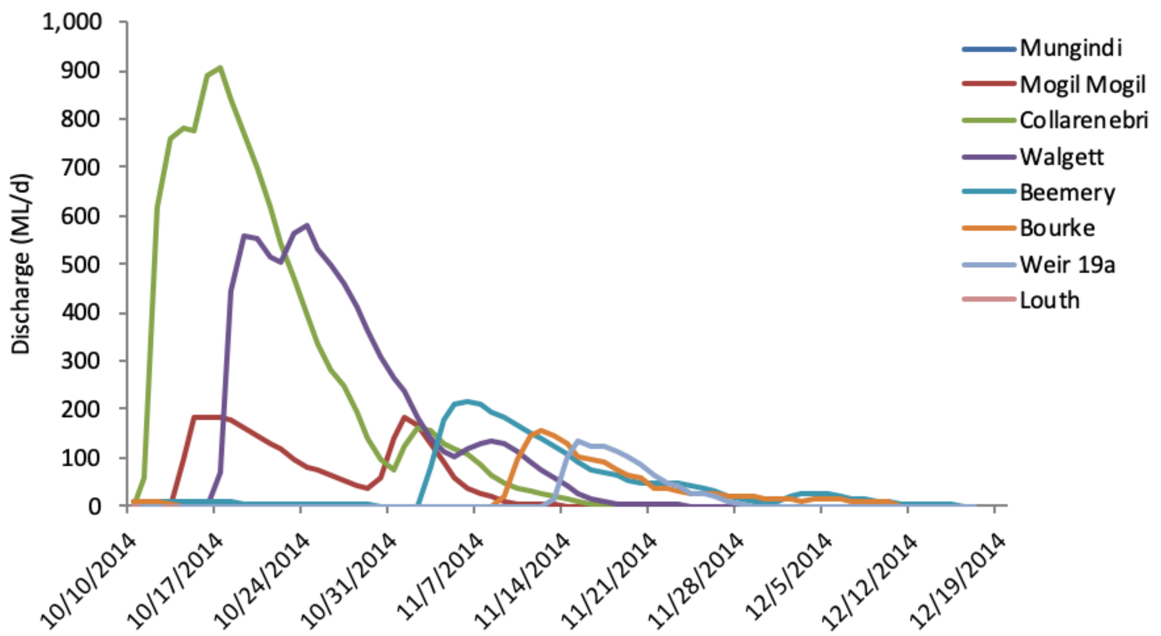

Figure C-5: Barwon-Darling regulated environmental water event, October to December 2014.

Table C-5: Total event discharge for regulated environmental water (EW) event 2014/15.

Monitoring Location	Total EW (ML)	Total Discharge (ML)
Gwydir catchment at Mehi River and Carole Creek	16,972	21,717
Barwon River at Collarenebri		11,620
Barwon River at Walgett		7,911
Barwon River at Beemery		2,858
Darling River at Bourke		1,511
Darling River at Weir 19a		1,036
Darling River at Louth		0

<u>2014-15 Event 2</u>

The methodology for assessing unregulated environmental water events is more complex than for regulated events. This is because of the complexities of separating environmental water from the naturally occurring flow events that trigger environmental take. Based on the information presented in Table C-4, unregulated environmental water flows in the Border Rivers, Moonie, Condamine-Balonne, Warrego and Barwon-Darling had the potential to influence the hydrology in the Warrego-Darling Selected Area during the 2014–15 water year.

Event 2 occurred from 1 December 2014 to 24 March 2015 and was driven by three separate small flow events originating within the Border Rivers. Daily discharge volumes increased noticeably at Bourke, where the upstream flow pulse was augmented by significant inflows from the Condamine-Balonne catchment. Small inflows from the Warrego River also contributed to the duration of the flow's rising limb in early February.

Total environmental water accounted and delivered upstream during this period comprised 22,069 ML. Allowing for downstream losses, this water was estimated to contribute 23.7% of the total flow volume at the Warrego-Darling Selected Area (Table C-6).

Table C-6: Environmental water (EW) flow event 2 (1 December 2014 - 24 March 2015) EOS flow assessment.

Gauging station	Event duration			Total event discharge	Upstream EW take	Estimated EOS EW	
	Start	Stop	Days	ML	ML	ML	%
Mungindi	18/12/2014	24/03/2015	96	33,591	1,543	1,234	3.7
Mogil Mogil	24/12/2014	24/03/2015	90	29,640	2,349	1,821	6.1
Collarenebri	31/12/2014	24/03/2015	83	36,333	2,349	1,821	5.0
Walgett	4/01/2015	24/03/2015	79	31,844	2,349	1,821	5.7
Beemery	2/02/2015	24/03/2015	50	19,237	2,349	1,821	9.5
Bourke	26/01/2015	24/03/2015	57	40,790	19,852	8,841	21.7
Weir 19A	29/01/2015	24/03/2015	54	37,354	19,852	8,841	23.7
Louth	29/01/2015	24/03/2015	54	37,389	22,069	9,593	25.7

<u>2014-15 Event 3</u>

A third flow event occurred down the Darling River in 2014-15. Recorded over 1 April to 6 June 2015, this flow comprised two flow peaks originating in the eastern catchments (Border Rivers, Moonie and Gwydir) with limited inflows from the Condamine-Balonne catchment. Total environmental water accounted and delivered upstream during this period comprised 1,740 ML. Allowing for downstream losses, this water was estimated to contribute 4% of the total flow volume at the Warrego-Darling Selected Area (Table C-7).

Table C-7: Environmental water (EW) flow event 2 (1 December 2014 - 24 March 2015) EOS flow assessment.

Gauging station	Event duration			Total event discharge	Upstream EW take	Estimated EOS EW	
	Start	Stop	Days	ML	ML	ML	%
Mungindi	1/04/2015	6/06/2015	66	51,004	207	165	0.3
Mogil Mogil	4/04/2015	6/06/2015	63	64,220	816	609	0.9
Collarenebri	1/04/2015	6/06/2015	66	74,185	816	609	0.8
Walgett	7/04/2015	6/06/2015	60	67,332	816	609	0.9
Beemery	23/04/2015	6/06/2015	44	39,966	816	609	1.5
Bourke	25/04/2015	6/06/2015	42	33,443	1,415	1,025	3.1
Weir 19A	26/04/2015	6/06/2015	41	31,131	1,415	1,025	3.3
Louth	30/04/2015	6/06/2015	37	28,529	1,740	1,135	4.0

C.3.3 2015-16 environmental water events

2015-16 Environmental Water Take

Unregulated environmental water take for each event monitored during 2015-16 is presented for each catchment in Table C-8.

Table C-8: Unregulated environmental water (EW) events for 2015/16 water year.

Basin Plan Region	Tributary	Unregulated EW take (ML)	Comments
Qld Border Rivers	Dumaresq-Macintyre River	15-16 Event 1: 644.2	Series of small short fresh flows triggered take in late July/early August and late August.
		15-16 Event 2: 243.5	10,000 ML/d flow recorded at Goondiwindi in November 2015.
		15-16 Event 3: 137.1	Early February 2016.
	Severn River	15-16 Event 3: 22.22	Very brief period of take on 31 January-1 February.
Qld Moonie	Lower Moonie River	15-16 Event 1: 200.98	Brief period of take 25-28 July, 2015.
Qld Condamine – Balonne	Nebine Creek	15-16 Event 4: 997.78	Take recorded during June 2016.
Qld Warrego	Upper Warrego River	0	No environmental water triggering events during 2015/16.
	Lower Warrego River	15-16 Event 3: 859.29	Early January flows peaking at 10,000 ML/d at Cunnamulla allowed take during 17-19 January 2016.
Qld Condamine-Balonne	Lower Balonne	15-16 Event 3: 9,454.90	Flows peaked at 25,000 ML/d at St George on 11 February 2016. Take during 9-16 February.
NSW Gwydir	Mallowa Creek	15-16 Event 2: 336	Supplementary water event triggered by natural flow events during November 2015.
	Mehi River	15-16 Event 2: 964	Supplementary water event mid-November 2015.
NSW Intersecting Streams – Warrego	Lower Warrego River	0	Early January flows peaking at 10,000 ML/d at Cunnamulla did not trigger access to licences at Toorale.
NSW Intersecting Streams	Toorale Western Floodplain	0	Two small local run-off events in July and November 2015 raised water levels in Boera Dam above commence-to-inundate for the Western Floodplain, however, as these were local events and not observed at Fords Bridge, no environmental water was accounted for.

Basin Plan Region	Tributary	Unregulated EW take (ML)	Comments
NSW Barwon - Darling	Barwon-Darling River	15-16 Event 1: 2,702.36	July – August flow events allowed 2,629.36 ML of B Class entitlements at Collarenebri, and 73 ML A Class at Toorale.
		15-16 Event 3: 3,481.13	Late January – February event 3,481.13 ML of B Class entitlements at Collarenebri.
		15-16 Event 4: 1,456.67	June 2016 – 1,100 ML B Class and 356.67 ML C Class at Toorale.

Regulated environmental water events are not as dependent on specific stream flows and may be triggered in response to a wider range of river or environmental management decision criteria. Regulated environmental water take for each river system in 2015-16 is presented in Table C-9.

Assessing the regulated environmental water accounted during 2015-16, the following environmental water events were considered likely to influence flows within the Warrego-Darling Selected Area:

- 964 ML of supplementary water in the Mehi River during November 2015.
- 1,243 ML of water from all sources (Commonwealth and NSW environmental water, stock and domestic and surplus flows) from the Macquarie Marshes passed through to the Barwon Darling between September and mid-December 2015. Additional contributions were made from the Water Resource Plan Area from other streams, but environmental water was not delivered to these. Flows remained below the 50 ML/d threshold above which unregulated pumping can occur, so it is expected that much of this water should have reached the Barwon River, however, actual unregulated pumping volumes in the river section below Bells Bridge is unknown as no pumping data is available.

Other regulated releases fulfilled a range of in-channel and riparian functions, including:

- Within-reach releases for local environmental benefit including habitat provision for fish and waterbirds and other in-channel processes.
- Wetland watering for Gwydir wetlands and Macquarie Marshes to maintain vegetation health and wetland habitat.
- Releases made after a supplementary river flow to offset water extracted during earlier natural flows.
- Low-flow augmentation to restore connectivity.

Table C-9: Regulated environmental water (EW) take for 2015/16.

Basin Plan Region	Tributary	Regulated EW take (ML)	Comments
NSW Gwydir	Gwydir River	1,750	750 ML EW released to offset extracted flows during January 2016 flow event. 600 ML EW in February, 2016. 400 ML low-flow augmentation release commenced 10 April for 30-40 days duration.
	Mallowa Creek	3,486	2,136 ML released between 25 December and 10 January to offset extracted flows from November event. 1,350 ML released 24 January-5 February, 2016.
	Mehi River	3,155	964 ML released between 25 December and 10 January to offset extracted flows from November event. 2,191 ML Low flow event during April-May 2016.
	Carole – Gil Gil Creek	409	Low flow event during April-May 2016.
NSW Namoi	Namoi River	0	No environmental water used in the Namoi during 2015/16.
NSW Macquarie-Castlereagh	Macquarie Marshes	12,114	A total of 52,554 ML (40,440 ML NSW and 12,114 ML Commonwealth) environmental water delivered in two pulses (6 August – 9 Sept 2015 and 21 Sept – 17 Oct 2015) to the Macquarie Marshes Nature Reserve and Core Wetlands.
	The Macquarie River	2,125	Supplementary event 22 June to 30 June. A total of 2,500 ML of supplementary environmental water was delivered as part of the supplementary event which included 2,125 ML of Commonwealth environmental water, and 375 ML of NSW environmental water.

2015-16 Event 1

Event 1 was characterised by an ongoing series of small in-channel pulses that kept the Barwon-Darling River above base flow conditions between 1 July and 1 November 2015 (Figure C-3). Environmental water take during this period comprised 3,547.54 ML. Allowing for system losses, this was estimated to contribute around 5% of flow volume at the Warrego-Darling Selected Area (Table C-10).

Table C-10: Environmental water (EW) 2015-16 flow event 1 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream EW Take	Estimated EOS EW	
	Start	Stop	Days	ML	ML	ML	%
Mungindi	1 July 2015	1 November 2015	123	43,741	644.2	515.36	1.2
Mogil Mogil	1 July 2015	1 November 2015	123	44,961	845.2	661.7	1.5
Collarenebri	1 July 2015	1 November 2015	123	50,783	845.2	661.7	1.3
Walgett	1 July 2015	1 November 2015	123	46,995	845.2	661.7	1.4
Beemery	1 July 2015	1 November 2015	123	47,158	845.2	661.7	1.4
Bourke	1 July 2015	1 November 2015	123	58,288	3,547.5	2,823.6	4.8
Weir 19a	1 July 2015	1 November 2015	123	52,811	3,547.5	2,823.6	5.3
Louth	1 July 2015	1 November 2015	123	56,324	3,547.5	2,823.6	5.0

2015-16 Event 2

Event 2 was a short duration natural fresh that occurred between 2 November and 4 December 2015 (Figure C-3). Environmental water take during this period comprised 1207.5 ML. Allowing for system losses, this was estimated to contribute 3.4% of flow volume at the Warrego-Darling Selected Area (Table C-11).

Table C-11: Environmental water (EW) 2015-16 flow event 2 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream EW Take	Estimated EOS EW	
	Start	Stop	Days	ML	ML	ML	%
Mungindi	2 November 2015	4 December 2015	32	3,238	243.5	194.8	6.0
Mogil Mogil	2 November 2015	4 December 2015	32	2,028	243.5	194.8	9.6
Collarenebri	2 November 2015	4 December 2015	32	1,921	1,207.5	427.66	22.3
Walgett	2 November 2015	4 December 2015	32	3,678	1,207.5	427.66	11.6
Beemery	2 November 2015	4 December 2015	32	5,996	1,207.5	427.66	7.1
Bourke	2 November 2015	4 December 2015	32	10,485	1,207.5	427.66	4.1
Weir 19a	2 November 2015	4 December 2015	32	9,592	1,207.5	427.66	4.5
Louth	2 November 2015	4 December 2015	32	12,589	1,207.5	427.66	3.4

2015-16 Event 3

Environmental water event 3 occurred between 4 January and 25 March 2016 (Figure C-3). Environmental water take during this period comprised 13,954.64 ML with significant take within the Condamine–Balonne and Warrego systems. Allowing for system losses, it was estimated that environmental water contributed 30.3% of flow volume at the Warrego-Darling Selected Area during this event (Table C-12). During this event approximately 7,880 ML entered the Warrego-Darling Selected Area via the Warrego River, of which approximately 4% was considered to be environmental water, allowing for system losses.

Table C-12: Environmental water (EW) 2015-16 flow event 3 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream EW Take	Estimated EOS EW	
	Start	Stop	Days	ML	ML	ML	%
Mungindi	4 January 2016	25 March 2016	81	25,883	159.3	127.46	0.5
Mogil Mogil	4 January 2016	25 March 2016	81	27,496	159.32	127.46	0.5
Collarenebri	4 January 2016	25 March 2016	81	29,244	159.32	127.46	0.4
Walgett	4 January 2016	22 March 2016	78	32,634	159.32	127.46	0.4
Beemery	24 January 2016	25 March 2016	61	16,605	159.32	127.46	0.8
Bourke	30 January 2016	25 March 2016	55	25,819	13,095.35	6,329.45	24.8
Weir 19a	2 February 2016	25 March 2016	52	23,105	13,095.35	6,329.45	27.7
Louth	11 February 2016	25 March 2016	43	22,098	13,954.64	6,620.97	30.3

C.3.4 2016-17 environmental water events

<u>2016-17 Environmental water Take</u>

Unregulated environmental water take for each environmental watering event during 2016-17 is presented for each Murray-Darling Basin catchment in Table C-13.

Table C-13: Unregulated environmental water (EW) events for 2016/17 water year.

<table>
<tr><th>Basin Plan Region</th><th>Tributary</th><th>Unregulated EW take (ML)</th><th>Annual Total (ML)</th><th>Comments</th></tr>
<tr><td rowspan="4">QLD Border Rivers</td><td rowspan="3">Dumaresq-Macintyre River</td><td>16-17 Event 1: 914.3</td><td rowspan="3">21,805.8</td><td>Flow Event 1 (7 July – 13 July)</td></tr>
<tr><td>16-17 Event 3: 14,376.8</td><td>Flow event 2 (25 August – 25 October)</td></tr>
<tr><td>16-17 Event 4: 6,492.1</td><td>Flow Event 4 (20 March – 3 April)</td></tr>
<tr><td>Severn River</td><td>16-17 Event 3: 823</td><td>823</td><td>Streamflow in the Severn River at Farnbro peaked at around 6,000 ML/d in early Oct 2016 allowing take on the Severn River in QLD. Flows receded to around 190 ML/d by 12 October.</td></tr>
<tr><td>QLD Moonie</td><td>Lower Moonie River</td><td>16-17 Event 3: 1,415</td><td>1,415</td><td>A small flow pulse in late August, peaking at around 1,500 ML/d at Flinton initiated take on the licence. A larger flow in late September, peaking at around 8,000 ML/d on 20 September exhausted the approved volume of take at Flinton for 2016-17.</td></tr>
<tr><td>QLD Condamine – Balonne</td><td>Lower Floodplain</td><td>16-17 Event 3: 28,869.6
16-17 Event 4: 16,892.2</td><td>45,761.8</td><td>16-17 Event 3 take during September 2016
16-17 Event 4 take during April 2017.</td></tr>
<tr><td rowspan="2">QLD Warrego</td><td>Upper Warrego River</td><td>16-17 Event 3</td><td>794.84</td><td>QLD DNRM annouceed an access period for upper Warrego entitlements between 19/09/2016 18:00 and 29/09/2016 18:00 allowing take</td></tr>
<tr><td>Lower Warrego River</td><td>16-17 Event 1: 1,912
16-17 Event 2: 602
16-17 Event 3: 6,205</td><td>8,719.96</td><td>Four water harvesting periods were announced by QLD DNRM so far during 2016-17:
Flow event 1: 1/07/2016 18:00 - 7/07/2016 6:00 (Flow peak ~11,000 ML/d)
Flow event 2: 31/07/2016 6:00 - 2/08/2016 6:00 (Flow peak ~5,000 ML/d)
Flow event 3: 6/09/2016 6:00 - 7/09/2016 12:00 (Flow peak ~4,000 ML/d)
Flow event 4: 23/09/2016 12:00 - 10/10/2016 12:00 (Flow peak ~50,000 ML/d)</td></tr>
<tr><td rowspan="2">NSW Gwydir</td><td>Mallowa Creek</td><td>0</td><td>0</td><td>No Supplementary take</td></tr>
<tr><td>Mehi River</td><td>16-17 Event 3: 5,000</td><td>5,000</td><td>Supplementary water event between 17 and 21 September 2016</td></tr>
</table>

Basin Plan Region	Tributary	Unregulated EW take (ML)	Annual Total (ML)	Comments
	Carole – Gil Gil Creek	16-17 Event 3: 1,351	1,351	Take comprised 1,351 ML of 60,000 ML diverted into Carole Creek between 15 and 21 September 2016.
NSW Macquarie-Castlereagh	Macquarie River	16-17 Event 1: 3,000 16-17 Event 3: 4,250	7,250	3,000 ML of supplementary water was delivered between 24 and 30 July. 3,500 ML of supplementary water was delivered between 6 and 13 September. 750 ML of supplementary water was delivered between 19 and 21 December.
NSW Intersecting Streams – Warrego	Lower Warrego River	16-17 Event 3: 7,762.5	7,762.5	Flows in the Warrego River at Toorale in October 2016 (7,762.50 ML) for fish spawning, recruitment and movement.
NSW Intersecting Streams	Toorale Western Floodplain	16-17 Event 1: 1,166 16-17 Event 2: 5,194 16-17 Event 3: 3,359	9,720	Three flows combined during June-Sept in the Warrego system allowing take of environmental water for the Western floodplain from 19 July (following visible connection of the Warrego with the Darling and closure of the regulators at Boera Dam). The gates at Boera were opened again from the 9-12 September in accordance with licence conditions for a new event. Following this, further inflows were spilled to the Western Floodplain with total approved volume reaching the annual allocation of 9,720 ML by 20 Sept 2016.
NSW Barwon - Darling	Barwon-Darling River	16-17 Event 1: 9,173 16-17 Event 2: 5,361 16-17 Event 3: 13,719	26,796	2016-17 Event 1 includes take during June 2016. All classes of entitlement in the Barwon Darling had exceeded the approved volume by mid October 2016.

Regulated environmental water take for each regulated river system during the 2016-17 water year is presented in Table C-14.

Table C-14: Regulated environmental water (EW) take, 2016/17

Basin Plan Region	Tributary	Regulated EW take (ML)	Comments
QLD Border Rivers	Dumaresq-Macintyre River	0	Regulated environmental water not released during 2016/17
NSW Border Rivers	Severn-Macintyre River	0	Regulated environmental water not released during 2016/17
NSW Gwydir	Gwydir River	9,000	Delivery of 30,000 ML (total) during summer 2017 to inundate broad areas of semi-permanent wetland vegetation
	Mallowa Creek	7,496	Very little of the natural flows occuring in the Gwydir catchment in September were diverted into the Mallowa wetlands. In response planned deliveries of 5,000 ML were increased to 10,000 ML for delivery over two months between January and March 2017.
NSW Namoi	Namoi River	9,109	March – May 2017. Water was delivered from Keepit Dam to maintain 100 ML/d at Gunnedah for Silver Perch. Water was also being delivered from Gunidgera Weir to maintain flows in the lower river and connection with Barwon River flows. Walgett town Weir was drowned out by water backing up from Walgett Weir (11A) on the Barwon River providing fish passage over the Walgett town Weir. Environmental water provided connectivity along the lower Namoi River from Gunidgera Weir to Walgett allowing fish to move from the Barwon River into the Namoi River.
NSW Macquarie-Castlereagh	Macquarie River and floodplain	47,270	24 January – 18 February 17,039 ML to support completion of colonial waterbird breeding (WUM 10055-1) 4 April – 12 April 2,648 ML to allow post-spawning dispersal (WUM 10055-2) 16 April – 15 May 27,583 ML to provide connection from the mid-Macquarie River to the Barwon River via the Macquarie Marshes and lower Macquarie River, to facilitate native fish movement between the two river systems (WUM 10055-3).

Assessing the regulated environmental water accounted during 2016-17, the following environmental water events were considered likely to influence flows within the Warrego-Darling Selected Area:

Namoi River:

9,109 ML during May 2017 (of this, approximately 6,086 ML was estimated to reach the Barwon River).

Macquarie-Castlereagh:

27,583 ML during May 2017 (of this, approximately 3,226 ML was estimated to reach the Barwon River)

Other regulated releases fulfilled a range of instream and riparian functions, including:

- Within-reach releases for local environmental benefit.
- Wetland watering for Gwydir Wetlands and Macquarie Marshes.

2016-17 Event 1

Event 1 was characterised by increased instream flows within the lower reaches of the Barwon-Darling River downstream of Walgett, suggesting significant flow contributions from the Castlereagh and the Condamine-Balonne Rivers. Environmental water take during this period comprised 13,086.97 ML. Allowing for system losses, this was estimated to contribute 6% of the total flow volume at the Warrego-Darling Selected Area (Table C-15).

Table C-15: Environmental water (EW) flow event 1 (22 June to 1 August, 2016) EOS flow assessment.

Gauging Station	Event Duration	Total Event Discharge	Upstream EW Take	Estimated EOS EW	
	Days	ML	ML	ML	%
Mungindi	40	20,065	914.3	731.44	3.6
Mogil Mogil	40	14,224	914.3	731.44	5.1
Collarenebri	40	14,312	914.3	731.44	5.1
Walgett	40	29,670	914.3	731.44	2.5
Beemery	40	140,297	3,914.3	3,011.44	2.1
Bourke	40	184,162	11,630.3	9,184.24	5.0
Weir 19A	40	140,679	11,630.3	7,015.71	5.0
Louth	40	129,820	13,086.97	7,818.41	6.0

2016-17 Event 2

Occurring between 2 August and 8 September 2017, flow event 2 exhibited a similar pattern of water contributions as Event 1. Environmental water take during this period comprised 5,194 ML. Allowing for system losses, this was estimated to contribute 1.8% of flow volume at the Warrego-Darling Selected Area (Table C-16).

Table C-16: Environmental water (EW) flow event 2 (2 August – 8 September, 2016) EOS flow assessment.

Gauging Station	Event Duration	Total Event Discharge	Upstream EW Take	Estimated EW EW	
	Days	ML	ML	ML	%
Mungindi	37	18,977	0	0	0
Mogil Mogil	37	22,513	0	0	0
Collarenebri	37	24,300	0	0	0
Walgett	37	50,225	0	0	0
Beemery	37	156,487	0	0	0
Bourke	37	230,256	5,194	4,155.2	1.8
Weir 19A	37	209,264	5,194	3,776.38	1.8
Louth	37	171,909	5,194	3,102.26	1.8

2016-17 Event 3

Flow event 3 occurred from 9 September to 25 December 2016. This larger flow event included significant environmental water take from all upstream sub catchments. Total environmental water take during this period was 77,588.2 ML with significant take within the Border Rivers, Condamine–Balonne and Barwon Darling river systems. Despite large amounts of environmental water take, high natural river flows meant that the relative contribution of this take to be 2.4% of flow volume at the Warrego-Darling Selected Area (Table C-17).

Table C-17: 2015/16 Environmental water (EW) flow event 3 (9 September to 25 December, 2016) EOS flow assessment.

Gauging Station	Event Duration	Total Event Discharge	Upstream EW Take	Estimated EOS EW	
	Days	ML	ML	ML	%
Mungindi	107	250,736	15,222	12,177.60	4.9
Mogil Mogil	107	451,693	16,637	13,207.61	2.9
Collarenebri	107	403,852	22,988	14,741.75	3.7
Walgett	107	930,081	22,988	14,741.75	1.6
Beemery	107	1,746,459	27,238	17,971.75	1.0
Bourke	107	1,989,197	69,826.2	39,628.56	2.0
Louth	107	1,772,486	77,588.2	42,227.64	2.4

2016-17 Event 4

Flow event 4 occurred after a period of approximately 4 months of low river flows within the Barwon-Darling river system (Table C-13). This event was characterised by rainfall and increased river flows in catchments upstream of Bourke. Unregulated environmental water take was limited to the Border Rivers and Condamine-Balonne system (Table C-18). However, this event was augmented by regulated releases from the Macquarie into the Barwon-Darling and from the Namoi catchment to facilitate connectivity and fish passage (Table C-21). Accordingly, environmental water contributed 36.5% of the total volume of water at the Warrego-Darling Selected Area (Table C-18).

Table C-18: 2015/16 environmental water (EW) flow event 4 (10 April – 17 May, 2017) EOS flow assessment.

Gauging Station	Event Duration	Total Event Discharge	Upstream EW Take and regulated EOS contributions.	Estimated EOS EW	
	Days	ML	ML	ML	%
Mungindi	37	57,851	6,492.1	5,193.68	9.0
Mogil Mogil	37	110,500	6,492.1	5,193.68	4.7
Collarenebri	37	91,688	6,492.1	5,193.68	5.7
Walgett	37	89,208	12,578.1	11,279.68	12.6
Beemery	37	47,174	34,075.1	14,505.68	30.7
Bourke	37	54,401	50,967.3	20,755.79	38.2
Weir 19A	37	42,200	50,967.3	16,100.73	38.2
Louth	37	44,161	50,967.3	16,100.73	36.5

Warrego River end of system flows

Within the Warrego catchment, environmental water was accounted during flow events 1, 2 and 3. EOS flow assessment at Fords Bridge (Table C-19) provides an estimate of the volumes and proportions of environmental water entering the Warrego-Darling Selected Area at Boera Dam. The estimated proportion of environmental water during individual events ranged between 3.3% and 8.4% of total flows. Overall, it is estimated that approximately 2,958 ML of environmental water entered Boera Dam during 2016/17. This comprised 6.0% of all inflows.

Table C-19: EOS flow assessment for environmental water (EW) in Warrego River.

Flow Event	Total Event Discharge (Fords Bridge)	Upstream Warrego EW Take	Estimated EOS EW	
	ML	ML	ML	%
16-17 Event 1	7,720	1,912	649	8.4
16-17 Event 2	6,119	602	204	3.3
16-17 Event 3	35,358	6,205	2105	5.9
Total	**49,197**	**8,719**	**2,958**	**6.0**

C.3.5 2017-18 environmental water events

2017-18 Environmental Water Take

Unregulated environmental water contribution for each event during 2017-18 is presented for each Murray-Darling Basin catchment in Table C-20.

Table C-20: Unregulated environmental water (EW) events for 2017-18 water year.

Basin Plan Region	Tributary	Unregulated EW take (ML)	Total (ML)	Comments
Qld Border Rivers	Dumaresq-Macintyre River	17-18 Event 1: 292	641	Flow Event 1 (July 2017) in Macintyre and Dumaresq Rivers (Qld)
		17-18 Event 1: 349		Flow Event 1 (mid October 2017) from Lower Macintyre River (Qld)
	Severn River	0	0	No EW take
Qld Moonie	Lower Moonie River	17-18 Event 1: 762 17-18 Event 2: 381	1,143	Flow event 1 in October and November 2017 Flow event 2 in March 2018
Qld Condamine –Balonne	Lower Floodplain	17-18 Event 2: 3,985	3,985	Flow Event 2 in April 2018. 3,985 ML contributed to in-stream flows reaching the Darling River,
Qld Warrego River	Upper	0	0	No EW take
	Lower	3,347	3,347	Two periods of announced take in March and April 2018 fall into Flow Event 2.
NSW Gwydir	Mallowa Creek	0	0	No EW take
	Mehi River	0	0	No EW take
	Carole – Gil Gil Creek	0	0	No EW take
Macquarie-Castlereagh	Macquarie River	0	0	No EW take
Intersecting Streams-Warrego	Lower Warrego River		0	No EW take
NSW Intersecting Streams	Toorale Western Floodplain	0	0	No EW take
NSW Barwon - Darling	Barwon-Darling River	17-18 Event 1: 10,154 17-18 Event 2: 696	10,850	Small fresh of ~400 to 500 ML/d in July. B class access was available in July on the 'Boomi River Confluence to upstream Mogil Mogil Weir Pool Management Zone' and the 'Downstream Mogil Mogil to Collarenebri'. A class access was available in the 'Bourke to Louth Zone' (annual share of A class now spent). During December some C class access was available at Toorale. A small volume of water was available in the Barwon River in February-March 2018 before the embargo took effect.

Regulated environmental water delivered in each regulated river system during 2017-18 is presented in Table C-21.

Table C-21: Regulated environmental water (EW) delivered in 2017-18.

Basin Plan Region	Tributary	Regulated [a] EW take (ML)	Comments
QLD Border Rivers	Dumaresq	17-18 Event 1: 3,252 CEW	Between 2 and 26 October 2017. Total of 3,252 ML. Delivered as stable baseflow (up to 160 ML/d) for three weeks, in conjunction with some small natural inflows.
	Severn River		No EW delivered
	Dumaresq-Lower Macintyre River NSW	17-18 Event 3: 4,286 CEW	This release was part of the Northern Connectivity Event delivered between 4 and 20 May 2018. CEW contributed to flows at Mungindi for 17 days, with at least 10 days at ~260-428 ML/d followed by 6-day recession ~41-193 ML/d.
NSW Border Rivers	Severn-Macintyre River	17-18 Event 1: 684 CEW + 8,000 NSW	NSW water delivered on 21 August. Peaked at 2,079 ML/d (Pindari Dam) on 23 August. CEW delivered on 24 September with NSW 'translucency flow' provisions. Stable baseflows (~50 ML/d) until mid-October 2017.
NSW Gwydir	Gwydir River	Amounts accounted for in Mehi River and Carole Creek below	
	Mallowa Creek	0	No EW delivered
	Mehi River	17-18 Event 1: 11,200 CEW 17-18 Event 3: 9,204 CEW + 4,956 NSW	Small fresh over 10 days from late Aug 2017 (30/08/17 to 4/09/17; 7,000 ML). Small stable baseflow spring 2017 (Late Nov 2017; 4,200 ML). April 2018 release as part of Northern Connectivity Event provided end of system pulse to Barwon River (April to May 2018; 14,160 ML).
	Carole – Gil Gil Creek	17-18 Event 1: 800 CEWH + 800 NSW 17-18 Event 3: 3,086 CEW + 1,662 NSW	Small fresh over 10 days from late Aug 2017 (30/08/17 to 4/09/17; 800 ML). Small stable baseflow spring 2017 (Late Nov 2017; 800 ML) April 2018 release as part of Northern Connectivity Event provided end of system pulse to Barwon River (April to May 18; 4,748 ML).
NSW Namoi	Namoi River	17-18 Event 2: 4,100 CEW	March to May 2018. 4,100 ML delivered in lower Namoi River.
NSW Warrego River	Toorale	0	While environmental water management provided connection to the Darling River, no entitlements were acquitted against this licence.
NSW Macquarie-Castlereagh	Macquarie River and floodplain	17-18 Event 1: 4,529 combined CEW & NSW[b]	Between 19 July and 12 November 2017. Delivered to the Mid Macquarie river and Macquarie Marshes (50,660 CEW + 83,717 NSW). Regulated take figure is an end of system estimate from CEWO.

[a] CEW is water managed by the Commonwealth Environmental Water Office, NSW is water managed by NSW water departments.
[b] based on prior CEWO advice, approximately 10,000 ML is estimated to reach the Barwon River.

2017-18 Event 1

Event 1 was characterised by a series of instream flow pulses that occurred from the start of the water year through until the end of November 2017 over a total of 151 days. During this time, unregulated flows including environmental water originating in the Border Rivers and Moonie River were augmented with regulated CEW and NSW environmental water from the Border Rivers, Gwydir and Macquarie–Castlereagh River systems. Total environmental water accounted and delivered upstream during this period comprised 170,670 ML. Allowing for system losses, this was estimated to contribute 42.9% of the total flow volume at the Warrego-Darling Selected Area (Table C-22).

Table C-22: Environmental water **flow event 1 (1 July – 29 November 2017) EOS flow assessment.**

Gauging Station	Total Event Discharge	Upstream EW	Estimated EOS EW	
	ML	ML	ML	%
Mungindi	53,741	12,577	10,062	18.7
Mogil Mogil	52,293	13,339	10,616	20.3
Collarenebri	59,496	26,139	13,709	23.0
Walgett	53,785	26,139	13,709	25.5
Beemery	54,563	160,516	18,238	33.4
Bourke	47,692	170,670	26,361	55.3
Weir 19A	47,337	170,670	21,669	45.8
Louth	50,514	170,670	21,669	42.9

2017-18 Event 2

Occurring between 10 March and 29 April 2018 (50 days total event duration), flow event 2 was underpinned by unregulated environmental water contributions from the Condamine-Balonne River system and some minor flows from the Moonie River augmented by regulated environmental water from the Namoi. Total environmental water accounted and delivered during this period comprised 9,162 ML. Allowing for system losses, this was estimated to contribute 24.3% of flow volume at the Warrego-Darling Selected Area (Table C-23).

On 8 March 2018, the NSW Department of Industry, Planning and Environment - Water announced temporary restrictions on A, B and C class water access licences in the Barwon-Darling Unregulated River to protect low flows entering the river. The restrictions were extended on 29 March to 28 April 2018.

Table C-23: Environmental water flow event 2 (10 March – 29 April 2018) EOS flow assessment

Gauging Station	Total Event Discharge	Upstream EW	Estimated EOS EW	
	ML	ML	ML	%
Mungindi	4,750	0	0	0.0
Mogil Mogil	13,098	381	277	2.1
Collarenebri	12,967	381	277	2.1

Gauging Station	Total Event Discharge	Upstream EW	Estimated EOS EW	
	ML	ML	ML	%
Walgett	13,987	381	277	2.0
Beemery	13,041	4,481	2,860	21.9
Bourke	20,095	9,162	4,892	24.3
Weir 19A	17,711	5,062	4,311	24.3
Louth	14,157	9,162	3,446	24.3

2017-18 Event 3

Flow event 3 was a regulated flow event between 4 May and 26 June 2018 (total event duration 53 days) as part of the Northern Connectivity Event. Total environmental water delivered during this period was 23,232 ML, comprising both CEW and NSW environmental water from the Queensland Border Rivers and Gwydir catchments. This significantly increased flows in the Barwon-Darling River.

There was a second embargo to protect the Northern Connectivity Event flows from 27 April to 22 June for the entire length of the Barwon-Darling for A, B, C class licences. The relative contribution of environmental water was estimated to be 99.6% of flow volume at the Warrego-Darling Selected Area (Table C-24).

Table C-24: 2017/18 Environmental water flow event 3 (4 May – 26 June 2018) EOS flow assessment

Gauging Station	Total Event Discharge	Upstream EW	Estimated EOS EW	
	ML	ML	ML	%
Mungindi	4,653	4,286	3,429	73.7
Mogil Mogil	8,693	4,286	3,429	39.4
Collarenebri	19,899	23,232	19,829	99.6
Walgett	18,768	23,232	18,702	99.6
Beemery	13,962	23,232	13,906	99.6
Bourke	13,436	23,232	13,382	99.6
Weir 19A	11,385	23,232	11,339	99.6
Louth	13,386	23,232	13,332	99.6

Warrego River end of system flows

Within the Warrego catchment, environmental water was accounted during flow event 2. EOS flow assessment at Fords Bridge provides an estimate of the volumes and proportions of environmental water entering the Warrego-Darling Selected Area at Boera Dam. During the period 1 April 2018 – 22 May 2018, 6,566 ML flowed past Fords Bridge. Upstream environmental water contributions totalled 3,347 ML. Allowing for EOS losses, this constitutes 17.3% of the water that flowed past Fords Bridge and into the Warrego-Darling Selected Area at Boera Dam.

C.3.6 2018-19 environmental water events

2018-19 Environmental water Take

While environmental water take occurred in multiple upstream tributaries during the 2018-19 water year, flows in the Barwon-Darling remained low throughout the year. At Bourke, upstream of the Warrego-Darling Selected Area, flow over the weir ceased on 19 August 2018, and had not commenced to the 30 June 2019 – the end of this project. Some local rainfall generated flow in the Darling around Weir 19A that influenced flows through the Warrego-Darling Selected Area in April to June 2019 (Appendix A). As no environmental water take was registered in this event, environmental water in the Darling tributaries upstream of the Warrego-Darling Selected Area did not influence flows through the Darling River zone in 2018-19.

Warrego River end of system flows

Within the Warrego catchment, environmental water was accounted during a flow event that moved through the system in February – June 2019. EOS flow assessment at Fords Bridge provides an estimate of the volumes and proportions of environmental water entering the Warrego-Darling Selected Area at Boera Dam. During the period 21 April 2018 – 30 June 2019, 33,081 ML flowed past Fords Bridge. Upstream environmental water contributions totalled 7,718 ML. Allowing for EOS losses, this constitutes 7.9% of the water that flowed past Fords Bridge and into the Warrego-Darling Selected Area at Boera Dam. An additional 8,106 ML of water was accounted against the Toorale Warrego River licence. For the purposes of the analysis presented below, we have assumed that 95% of this amount made its way to the Darling River confluence, therefore, a total of 10,324 ML of environmental water is calculated to have flowed into the Darling River during this event.

2018-19 Event 1

Widespread rainfall from a tropical depression in the upper Warrego catchment produced a flow event down the Warrego that entered Toorale in April 2019. The gates at Boera Dam were opened on 22 April 2019 and remained open for 40 days until the flow pulse had moved through the system. For the period 20 April 2019 to 30 June 2019, total flows past Fords Bridge (combined gauges) and Dicks Dam on the Warrego River were 33.08 GL and 25.47 GL respectively. The hydrograph at Louth on the Darling River showed a short peak in flows at the start of the event, likely a result of inflows down the Darling from around Weir 19A (Figure C-6). The influence of the Warrego water can then be observed causing a peak flow at Louth of 647 ML/d on 30 May 2019. The volume of water that flowed past Louth on the Darling River over the event was 23.9 GL. This suggests that 77% of the water that went past Fords Bridge on the Warrego, travelled down the lower Warrego River either through the gates at Boera Dam or via the Western Floodplain returning to the Warrego River through a breach in the eastern embankment (Appendix B). In addition, around 2% of the flow past Fords Bridge remained in Boera Dam and 21% remained on the Western Floodplain and in the Warrego River upstream of Toorale. Once in the Darling River, this flow progressed downstream, ending below Wilcannia. The total contribution of environmental water out of the Warrego River, measured at Louth, was estimated to be 43%.

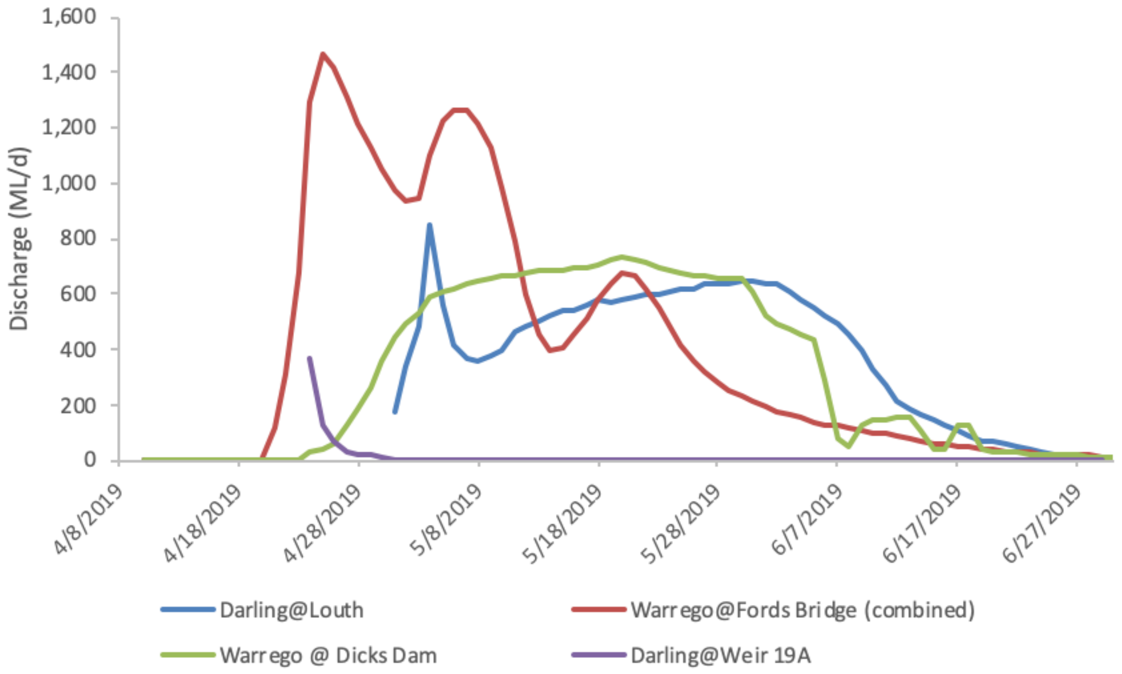

Figure C-6: Flows down the Darling and Warrego River during the 2019 flow event 1 (4 April to 30 June)

C.3.7 Multi-year comparison

Comparing all environmental flow events in the Darling River zone over the LTIM Project, event 3 in 2016-17 was by far the largest event to flow through the system (Figure C-7). While the volume of environmental water was large (42,228 ML), the overall proportion was small (2%; Table C-25).

The proportion of environmental water was typically higher in other events, being dependent on which catchment the flows were generated in and the level of regulated water contribution. For example, flows that predominantly came from the Condamine-Balonne catchment (15-16 Event 3) tended to have larger proportions of environmental water due to the relatively large volume of unregulated entitlements in those catchments. In addition, flows that were composed of regulated flows such as the three events in 2017-18 tended to have a higher proportion of environmental water (24% to 100%). This was aided by pumping embargos put in place to protect these flows through the system.

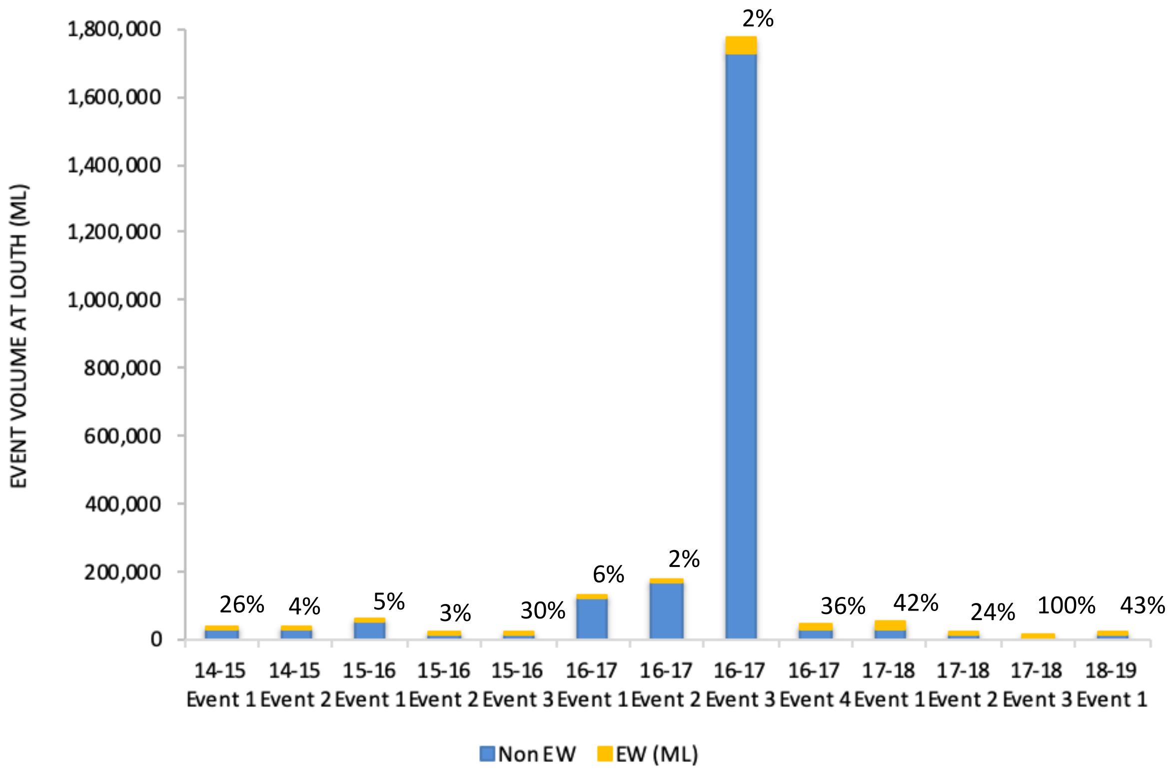

Figure C-7: Multi-year comparison of total flow volumes at Louth gauge.

Table C-25: Multi-year comparison of total flow and estimated environmental flow volumes at Louth gauge.

Water Year	Flow Event	Total Event Discharge (Louth)	Estimated EOS EW	
		ML	ML	%
2014/15	Event 1	27,797	9,593	25.7
	Event 2	27,394	1,135	4.0
2015/16	Event 1	53,501	2,824	5.0
	Event 2	12,161	428	3.4
	Event 3	15,477	6,621	30.0
2016/17	Event 1	129,820	7,818	6.0
	Event 2	171,909	3,102	1.8
	Event 3	1,772,486	42,228	2.4
	Event 4	44,161	16,101	36.5
2017/18	Event 1	50,514	21,669	42.9
	Event 2	14,157	3,446	24.3
	Event 3	13,386	13,332	99.6
2018/19	Event 1	23,939	10,325	43.1

C.4 Discussion

Over the duration of the LTIM project, environmental water has played a part in increasing the magnitude of flows through the Warrego-Darling Selected Area. Apart from the larger flow event in late 2016, all other flows that occurred through the Darling River were small fresh events of less than a one tenth bankfull stage in magnitude (peak discharges less than 3,000 ML/d at Louth). Out of the thirteen flow events monitored, the contribution of environmental water ranged from 1.8 to 99.6%. The relative contribution of environmental water is related to several factors, including the origin of the upstream flow (i.e. which tributary/s it originated in), the size of the flow event and the relative input of regulated deliveries to the event. As the distribution of Commonwealth owned water entitlements is not uniform across the northern tributaries, the origin of flows dictates how much environmental water is accounted for in each flow. Flow events that originate in catchments where the relative amount of entitlement is high, usually have a higher contribution of environmental water. Associated with this is the size of the event. For larger flow events such as Event 3 in 2016-17, the amount of environmental water accounted for is low, due to there being a lot more water in the system. Conversely, for smaller events or events that are of longer duration and reduced magnitude, environmental water contribution also tends to be low. Lastly, the relative input of regulated environmental water influences the contribution of environmental water during flow events, with increased regulated inputs increasing the proportional contribution.

The significant influence of regulated environmental flow releases during flow events in the Warrego-Darling Selected Area is a good example of the extended lengths of river channel that can be effectively targeted with environmental water. All of these regulated releases are made from storages over 500 river-kilometres upstream of the Warrego-Darling Selected Area, yet there is still a noticeable influence on flow volumes, durations and magnitudes.

Most of these flows were also protected by pumping embargos that restricted take from these events as they flowed through the system. The use of environmental water to target hydrological connectivity in multiple river valleys is an emerging trend in environmental water management, and regulated flows such as the Northern Connectivity Event (2017/18 Event 3) demonstrate the effectiveness of this approach.

In most water years, the relative contribution of Warrego River flows to the Darling River at Louth was quite small with flows either decreasing in volume from Weir 19A to Louth or only increasing by several thousand megalitres. However, during 2018-19 the contribution was larger, with the Warrego River contributing almost all of the water that flowed past Louth. Of this, around 43% of the flow past Louth was environmental water. This high contribution was enhanced by the management of water through Toorale, with the gates at Boera Dam being held open for the duration of the flow and then opened for several days following the flow to maximise water delivery to the Darling River. In addition, a breach in the embankment on the Western Floodplain allowed additional water to re-enter the Warrego River (Appendix B). During this event, the extremely low flow conditions in the Darling River at the time, meant that downstream contribution from the Darling River above the Warrego River confluence were negligible.

C.5 Conclusion

For most of the LTIM Project (2014-19) flow conditions down the Darling River were low. Thirteen events were monitored in which contributions of environmental water from upstream ranged from 1.8% to 99.6%. Regulated environmental water from the Border Rivers, Gwydir, Namoi and Macquarie catchments all increased flow volumes through the Warrego-Darling Selected Area, with relative contributions of environmental water usually being higher during these regulated events. These results show the potential for improving connectivity, access to habitat and water quality across large geographic areas in multiple catchments using environmental water deliveries.

Appendix D Category I Water Quality

D.1 Introduction

The Category I Water Quality indicator aimed to assess the contribution of Commonwealth environmental water to the improved quality of water in the Darling River within the Junction of the Warrego and Darling Rivers Selected Area (Warrego-Darling Selected Area). As such this indicator is linked to Fish (Channel), Stream Metabolism, Waterbird Diversity, Microinvertebrates, Macroinvertebrates, Frogs, and Hydrology (River, Northern Tributaries, Channel and Habitat) indicators. Several specific questions were addressed through this indicator within the Darling River zone during 2014-19:

- What did Commonwealth environmental water contribute to temperature regimes?
- What did Commonwealth environmental water contribute to pH levels?
- What did Commonwealth environmental water contribute to turbidity regimes?
- What did Commonwealth environmental water contribute to salinity regimes?
- What did Commonwealth environmental water contribute to dissolved oxygen levels?
- What did Commonwealth environmental water contribute to algal suppression?

D.2 Methods

Water quality indicators were monitored at two long-term stations in the Darling River zone of the Warrego-Darling Selected Area. The upstream station was located near Yanda homestead, and all Commonwealth environmental water derived in the upstream tributaries of the Darling River (except the Warrego River) passes through this reach (Figure D-1). The downstream station was located downstream of the confluence of the Warrego and Darling Rivers near Akuna homestead (Figure D-1). As such, the Darling downstream station was used to assess the influence of Warrego River flow on the water chemistry of the Darling River.

Continuous monitoring of the dependant variables temperature (°C), pH, turbidity (NTU), conductivity (mS/cm), dissolved oxygen (%) and chlorophyll *a* (µg/L) occurred at two stations using Hydrolab DS5-X loggers at 10-minute intervals. Each logger was mounted to a floating pontoon to ensure it was kept under the water but away from obstructions. All data was downloaded during each visit or periodically by NPWS staff. Due to issues with power supply, instrument failure at both sites and the permanent loss of the instrument in the Darling upstream station, datasets were partly discontinuous.

From the 2016-17 water year, two additional PME miniDOT loggers were installed to monitor temperature and dissolved oxygen concentration; one logger at microinvertebrates sites Darling Pump (DARPUMP) to replace the lost Hydrolab DS5-X logger in the Darling upstream station and another logger in the Darling downstream station to ensure data continuity and comparability (Figure D-1). Discharge data was collated from the Darling @ D/S Weir 19a (NSW425037) gauge for the Darling upstream station and the Darling @ Louth (NSW425004) for the Darling downstream station. Daily means (midnight to midnight) of each water quality indicator were calculated from 10-minute interval data, with analyses based on the temporally independent mean values. There were 13 recorded environmental water events/periods in the Darling River in 2014-19 (Table D-2 and Appendix C). These flow events varied in magnitude, duration and variability in discharge. The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicator was calculated. Australian and New Zealand Environment and Conservation Council (ANZECC) South-East Australia lowland river water quality trigger values (ANZECC, 2000) and the Lower Warrego River Catchment water quality target values (EHP, 2016) are also indicated.

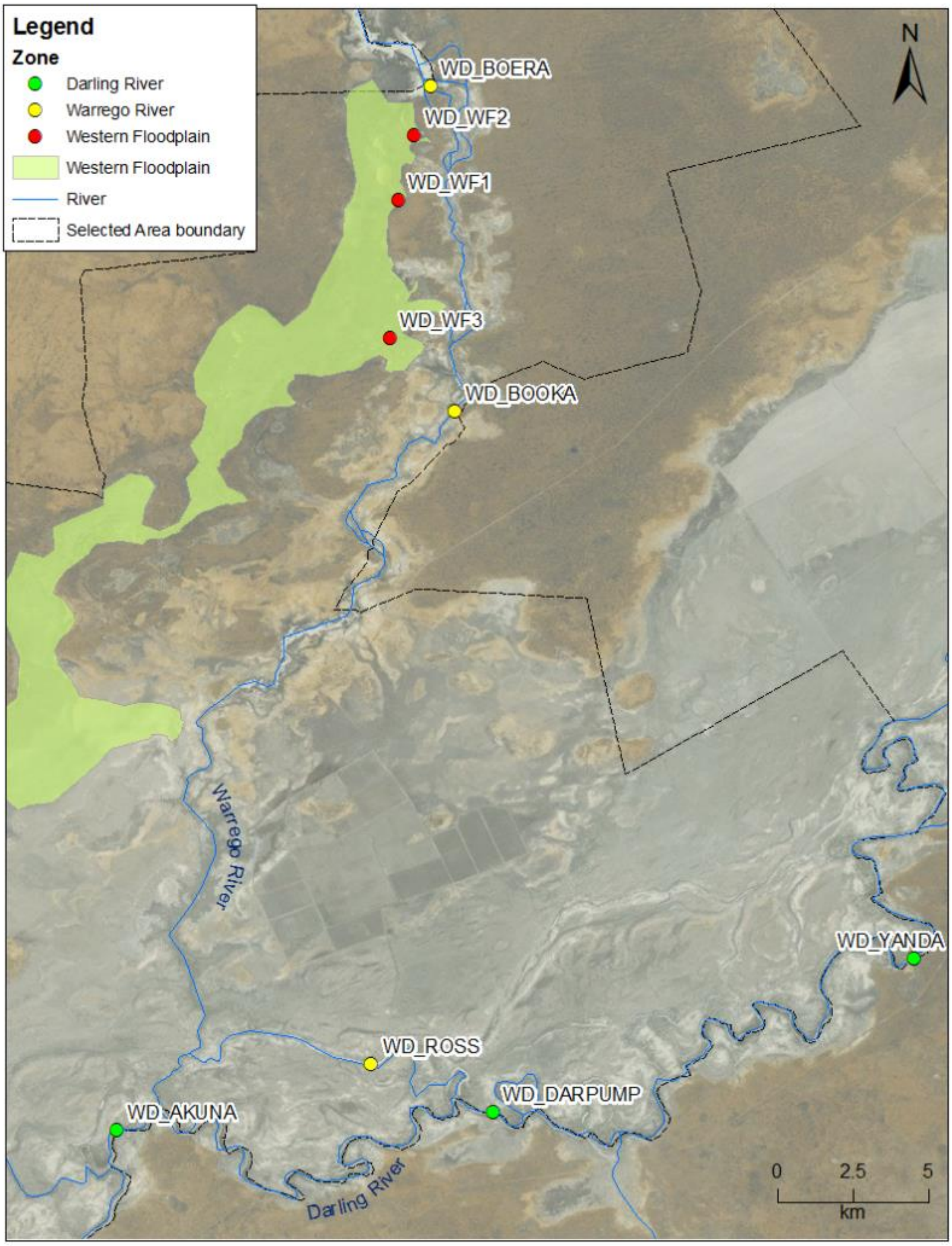

Figure D-1: Location of three long-term water quality monitoring stations (Cat I) in the Darling River within the Warrego-Darling Selected Area. WD_DARPUMP (2017-19) and WD_YANDA (2014-17) are the upstream stations and WD_AKUNA is the downstream station.

Table D-1: Category I Water Quality indicators measured at two stations in 2014-19.

Indicators	Variables		Units	Code
Water chemistry	i.	Temperature	°C	temp
	ii.	pH	-	ph
	iii.	Turbidity	NTU	turb
	iv.	Conductivity	mS/cm	cond
	v.	Dissolved Oxygen	mg/L	do
	vi.	Chlorophyll *a*	µg/L	Chla

Table D-2: Environmental water (EW) events in the Darling River during the LTIM Project (2014-19).

EW event	Water Year	Event	Start date	End date	Flow		
					Total (ML)	EW (ML)	EW%
1	2014-15	Event 1	1/02/2015	25/03/2015	37,390	9,593	25.7
2		Event 2	26/04/2015	7/06/2015	28,529	1,135	4.0
3	2015-16	Event 1	2/07/2015	30/10/2015	56,324	2,824	5.0
4		Event 2	2/11/2015	10/12/2015	12,589	428	3.4
5		Event 3	31/01/2016	25/03/2016	22,098	6,621	30.0
6	2016-17	Event 1	20/06/2016	30/07/2016	129,820	7,818	6.0
7		Event 2	2/08/2016	8/09/2016	171,909	3,102	1.8
8		Event 3	11/09/2016	25/12/2016	1,772,486	42,228	2.4
9		Event 4	21/04/2017	17/05/2017	44,161	16,101	36.5
10	2017-18	Event 1	14/10/2017	29/11/2017	50,514	21,669	42.9
11		Event 2	26/03/2018	29/04/2018	14,157	3,446	24.3
12	2017-18	Event 3	25/05/2018	26/06/2018	13,385	13,332	99.6
13		Event 1	23/04/2019	1/06/2019	23,364	2,624	11.2

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D.3 Results and Discussion

<u>Hydrological patterns</u>

Throughout the LTIM Project, 13 in-channel flow pulses containing environmental water were recorded and used to examine responses in water quality parameters (Table D-2 and Figure D-2). The contributions of environmental water in each event ranged from 1.8% and 99.6% and was sourced from various upstream tributaries (Table D-2).

The Darling River upstream and downstream stations exhibited similar magnitudes of discharge, with a short time lag for the downstream station (Figure D-2). The magnitude of flow events in 2016-17 (‘wet year’: a bankfull event with peak flow around 39,000 ML/d at Bourke, event 6, 7 and 8) was much higher than other years (‘dry year’) due to high rainfall in the upstream Barwon and Darling catchments (Appendix A). All other flow events were in-channel freshes with peak flow less than 5,000 ML/d (Table D-2). Water quality indicators showed high variability during the monitoring program in response to a large range of event volumes.

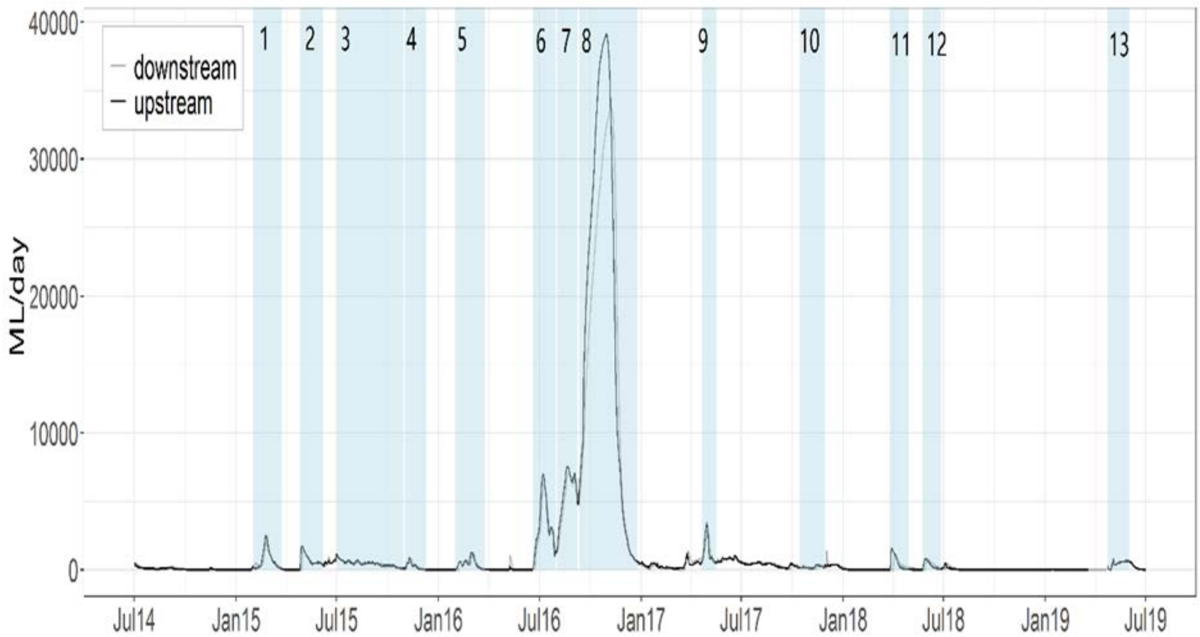
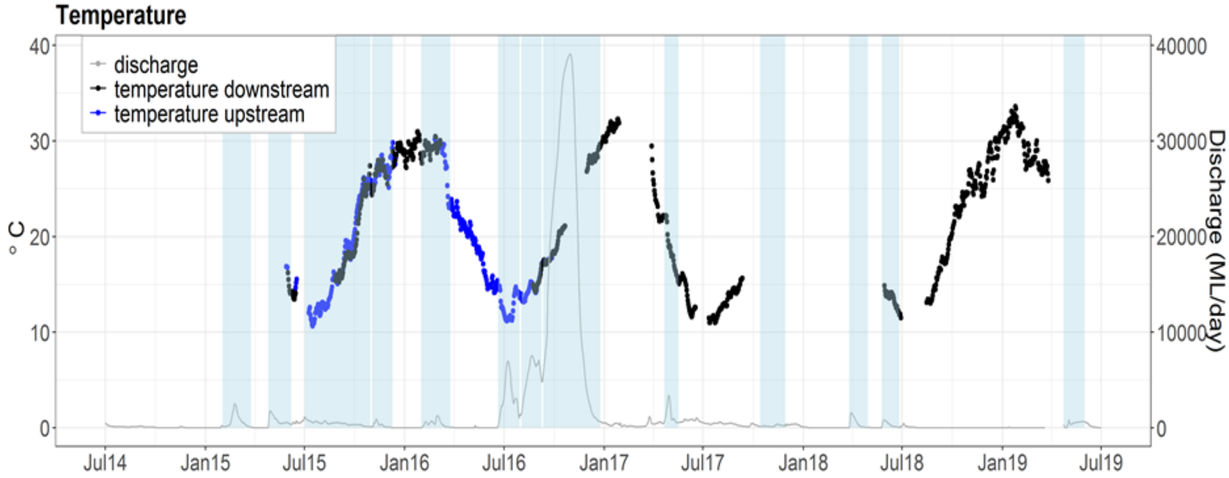


Figure D-2: Mean daily discharge (ML/d) at upstream station (Darling @ D/S Weir 19a (NSW425037)) and downstream station (Darling @ Louth (NSW425004)) with shaded areas representing 13 flow events (details in Table D-2)

Water temperature ranged from 10.7 °C – 29.2 °C (Table D-3). Water temperature records were higher in summer than in winter months, as expected, due to seasonal variation (Figure D-3). Temperature did not show a relationship linked to changes in discharge, hence environmental water did not influence water temperature at the two stations during the study period.



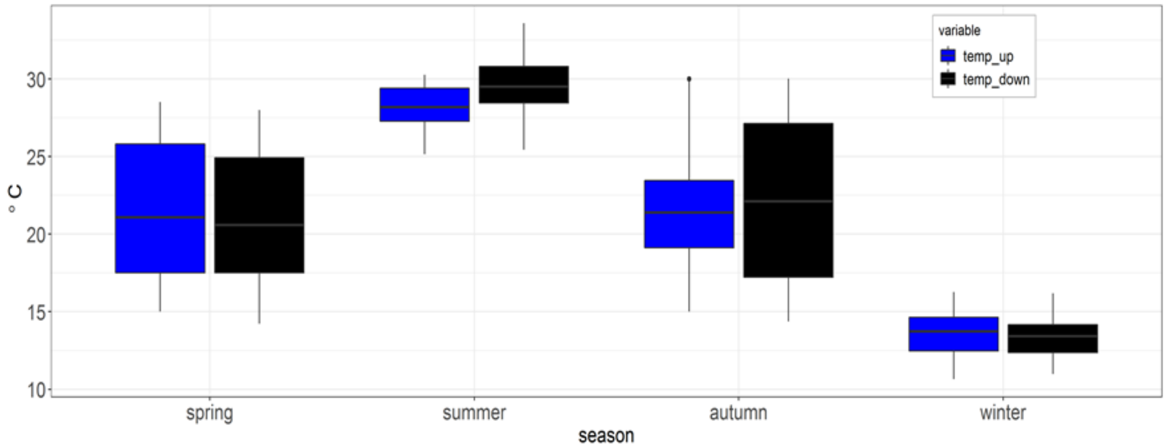


Figure D-3: (Top) Mean daily temperature at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom) Boxplot of average temperature by season in 2014-19.

Table D-3: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicators in 10 sampling occasions between 2014 and 2018 were calculated in three zones within the Warrego-Darling Selected Area with water quality guidelines from ANZECC (2000) and EHP (2016).

Indicator	ANZECC	EHP (2016)	Station	Minimum	Percentile			Maximum	Number of samples
					20th	50th	80th		
Temperature (°C)	-	-	Up	10.7	13.9	17.6	25.3	30.3	386
			Down	11.0	15.0	24.0	29.2	33.6	718
pH	6.5 - 8	baseflow: 7-8	Up	7.1	7.5	8.1	8.3	9.1	386
			Down	6.3	6.4	6.5	7.8	9.2	239
Turbidity (NTU)	6 - 50	baseflow: 210, high-flow: 760	Up	0	22	66	112	293	238
			Down	0	11	37	212	2597	658
Conductivity (mS/cm)	0.125 - 2.2	baseflow: 0.145, high-flow: 0.080	Up	0.10	0.22	0.55	0.84	2.77	383
			Down	0.17	0.37	0.65	1.60	2.87	718
Dissolved Oxygen (%)	85 - 110	baseflow: >5 (in mg/L)	Up	15.4	75.7	87.9	101.7	127.4	864
			Down	1.7	65.3	81.7	93.6	148.3	1,227
Chlorophyll *a* (µg/L)	5	baseflow: 10	Up	0.38	6.23	13.41	19.64	33.90	295
			Down	0.54	5.94	12.38	22.54	335.90	598

The pH values were consistently alkaline and occasionally exceeded ANZECC guideline values (Table D-2). In 2015-16, pH increased to higher levels after event 4 ended, possibly from sustained elevated primary production and increased residence time for water in the channel. The process of photosynthesis by algae in water uses hydrogen, and thus affects pH levels. The pH values in 2016-17 were consistently lower than 2014-15 and 2015-16 at the upstream station (Figure D-4). In 2016-17 (the "wet year") event 6 and 7, increase in flow variability and magnitude, augmented by environment water, reduced pH levels to lower values through dilution.

In 2016-17 "wet year", the highest pH values were recorded when discharge was around 10,000 ML/d, suggesting that this may be a key high-flow discharge threshold for the inundation or connection of geomorphic features that subsequently increase ions and suspended sediments inputs in the Darling River.

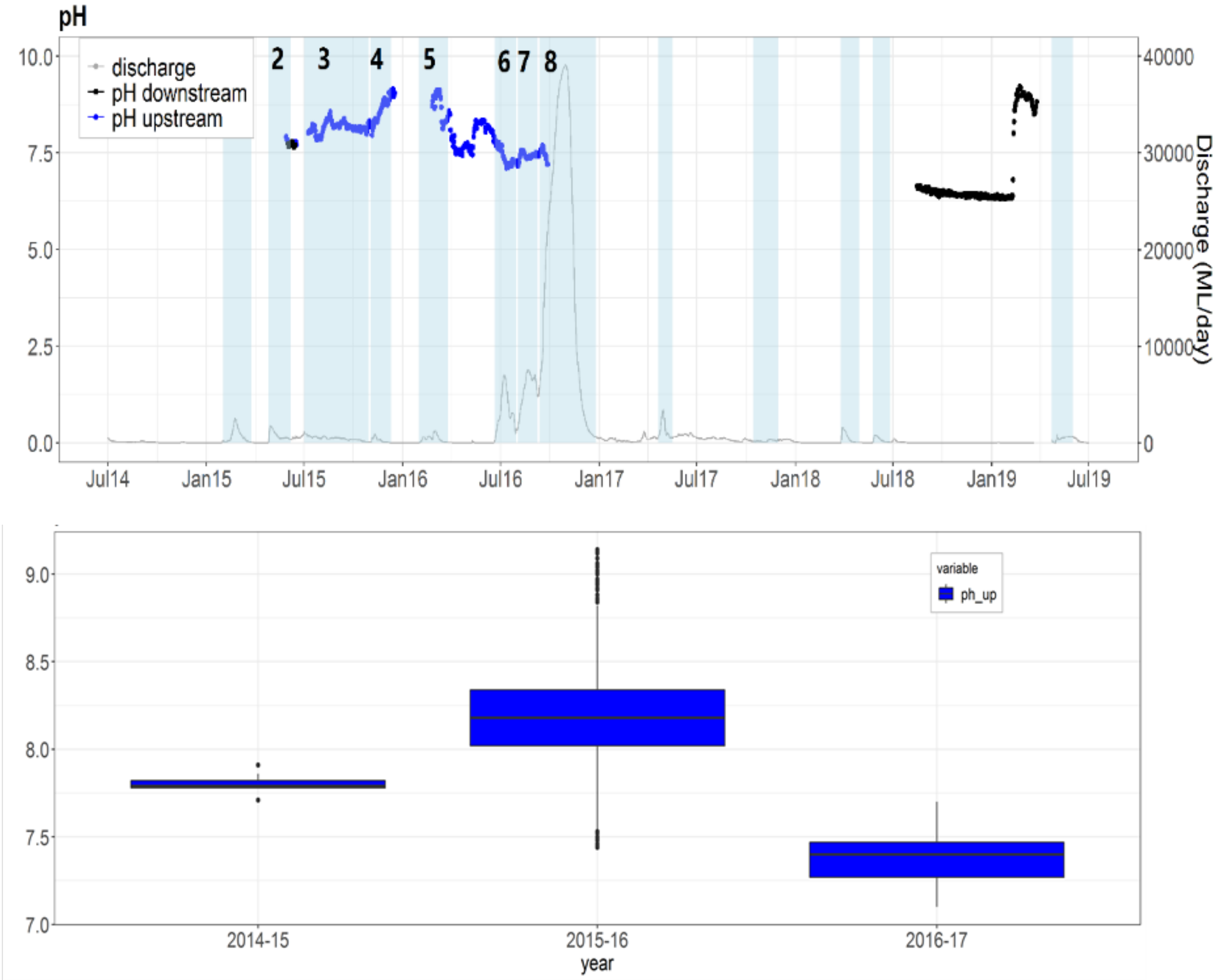


Figure D-4: (Top) Mean daily pH at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom) Boxplot of average pH by year in 2014-17.

The Darling River has naturally high turbidity levels with the majority of particles (80-90%) finer than 2 µm (Woodyer, 1978). At our sites, turbidity was highly variable and consistently higher than the ANZECC guideline value and similar to the EHP guideline value (Table D-3). In particular, turbidity levels were highly variable during base flow conditions and fell to below 500 NTU when discharge was above 5,000 ML/d (Figure D-5). Highly varied turbidity levels were also observed in "dry years" 2014-15, 2017-18 and 2018-19 (Figure D-5). In 2017-18 event 12, turbidity levels decreased sharply in day five of this event to within the ANZECC guideline value (Figure D-5). Increase in flow variability and magnitude augmented by environmental water reduced turbidity through a dilution effect provided by higher discharge. The very high turbidity levels limit benthic primary production in the channel to the shallow edge habitats and promote phytoplankton as the dominant primary producers. However, phytoplankton productivity (and oxygen production) were limited by the very shallow photic depth (light penetration) (Figure D-6).

A potential discharge threshold was observed in 2016-17 “wet year” where the highest turbidity values were recorded when discharge was around 10,000 ML/d, suggesting that this may be a key high-flow threshold for the inundation or connection of geomorphic features that subsequently increase suspended sediments inputs in the Darling River.

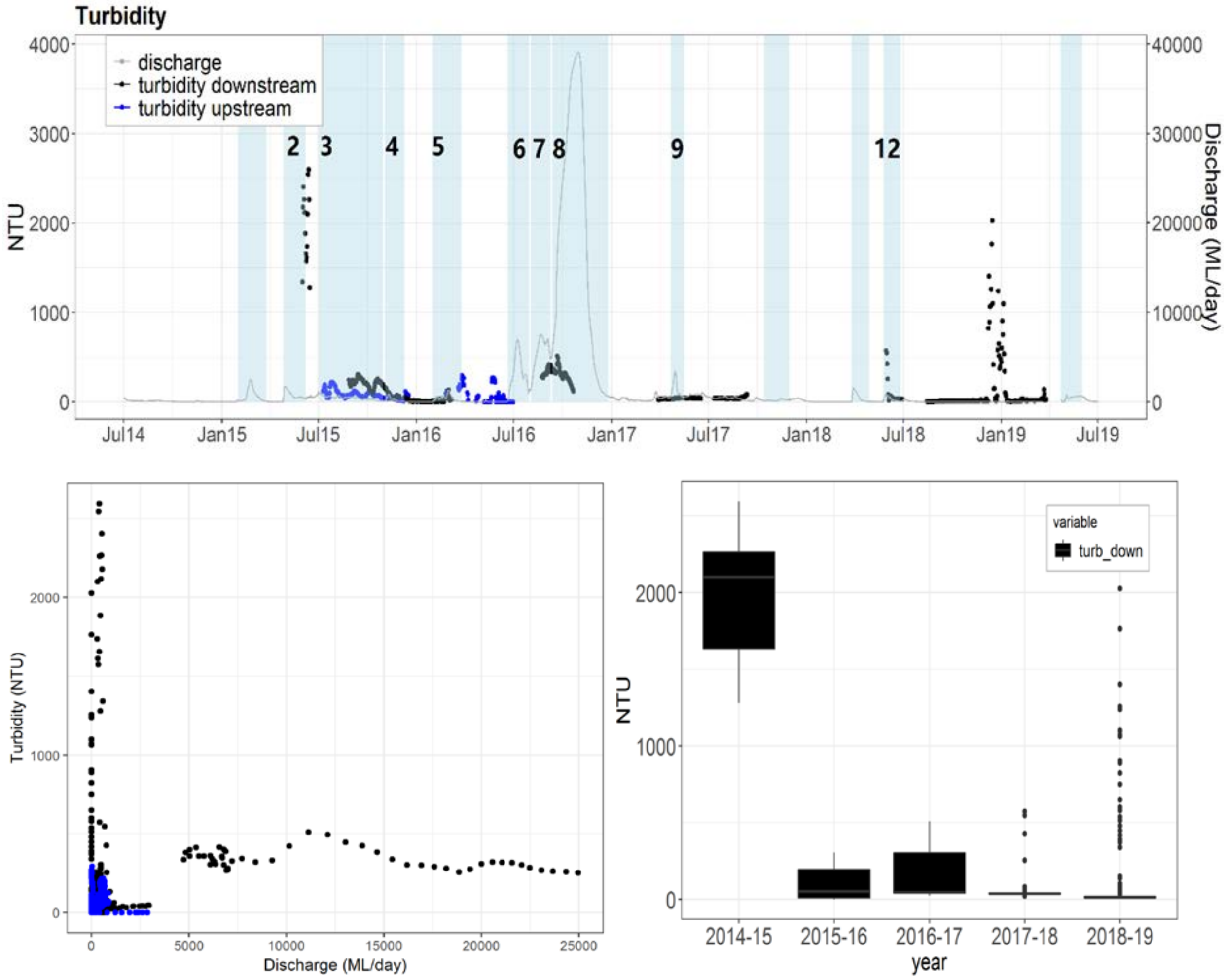


Figure D-5: (Top) Mean daily turbidity at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom left) Regression between discharge and turbidity in 2014-19. (Bottom right) Boxplot of average turbidity by year in 2014-19.

Figure D-6: Darling Pump water quality station on 25th April 2018 (event 11) and 29th June 2018 (event 12).

Conductivity values were occasionally above the ANZECC and EHP guideline values and had a wide conductivity range, potentially due to highly variable discharge rate and diverse inflow sources from the northern tributaries (Table D-2 and Figure D-7; Appendix C). Conductivity levels were highly variable during base flow conditions and reduced to below 0.4 mS/cm when discharge was above 5,000 ML/d (Figure D-7). The delivery of environmental water generally led to significant improvements in conductivity (lower conductivity). These processes reflect the dilution effects provided by flow events including environmental water, and the changes in water chemistry associated with the increase in discharge and wetted area of channels. For example, in 2017-18, event 11 in the downstream station led to an initial rise in conductivity which then fell within seven days of the commencement of the event. This reduced conductivity was apparent in event 12 and was maintained for at least three months after the flow pulses. In 2016-17 "wet year", an increase in flow variability and magnitude augmented by environmental water caused conductivity to fall at both stations (Figure D-7). Other factors such as intrusion of saline groundwater and evapoconcentration during dry periods also affected conductivity.

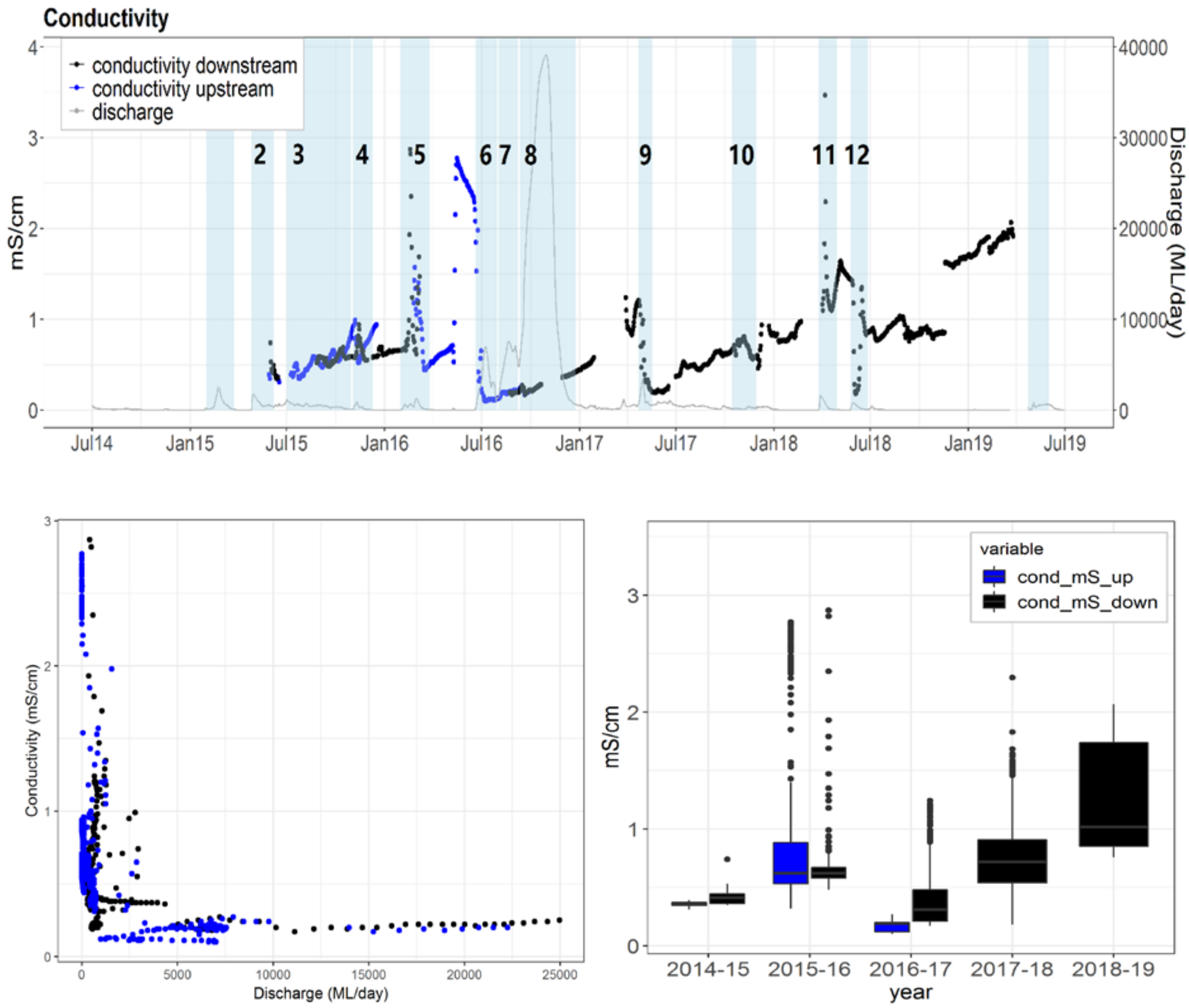


Figure D-7: (Top) Mean daily conductivity at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom left) Regression between discharge and conductivity in 2014-19. (Bottom right) Boxplot of average conductivity by year in 2014-19.

Mean daily dissolved oxygen concentrations were highly variable at both stations and were outside the ANZECC water quality guidelines (Table D-2 and Figure D-8). Dissolved oxygen concentrations were highly variable during base flow and low flow conditions (discharge 0-250 ML/d) and fell with increasing discharge up to 25,000 ML/d (Figure D-8). In four “dry years” throughout the LTIM Project, dissolved oxygen showed inconsistent responses to flow and environmental water events. There are several possible explanations for this inconsistent response of dissolved oxygen. Firstly, differences in upstream water sources contained various amounts and proportions of organic matter and nutrients that may have affected the balance between productivity and respiration in different flow events, and hence dissolved oxygen concentrations. Secondly, antecedent flow conditions associated with time since flow recession may play an important role in dissolved oxygen dynamics in this system. Thirdly, phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015). Dissolved oxygen concentrations were lower in autumn, reflecting that water temperature variation is also attributed to dissolved oxygen patterns (Figure D-8).

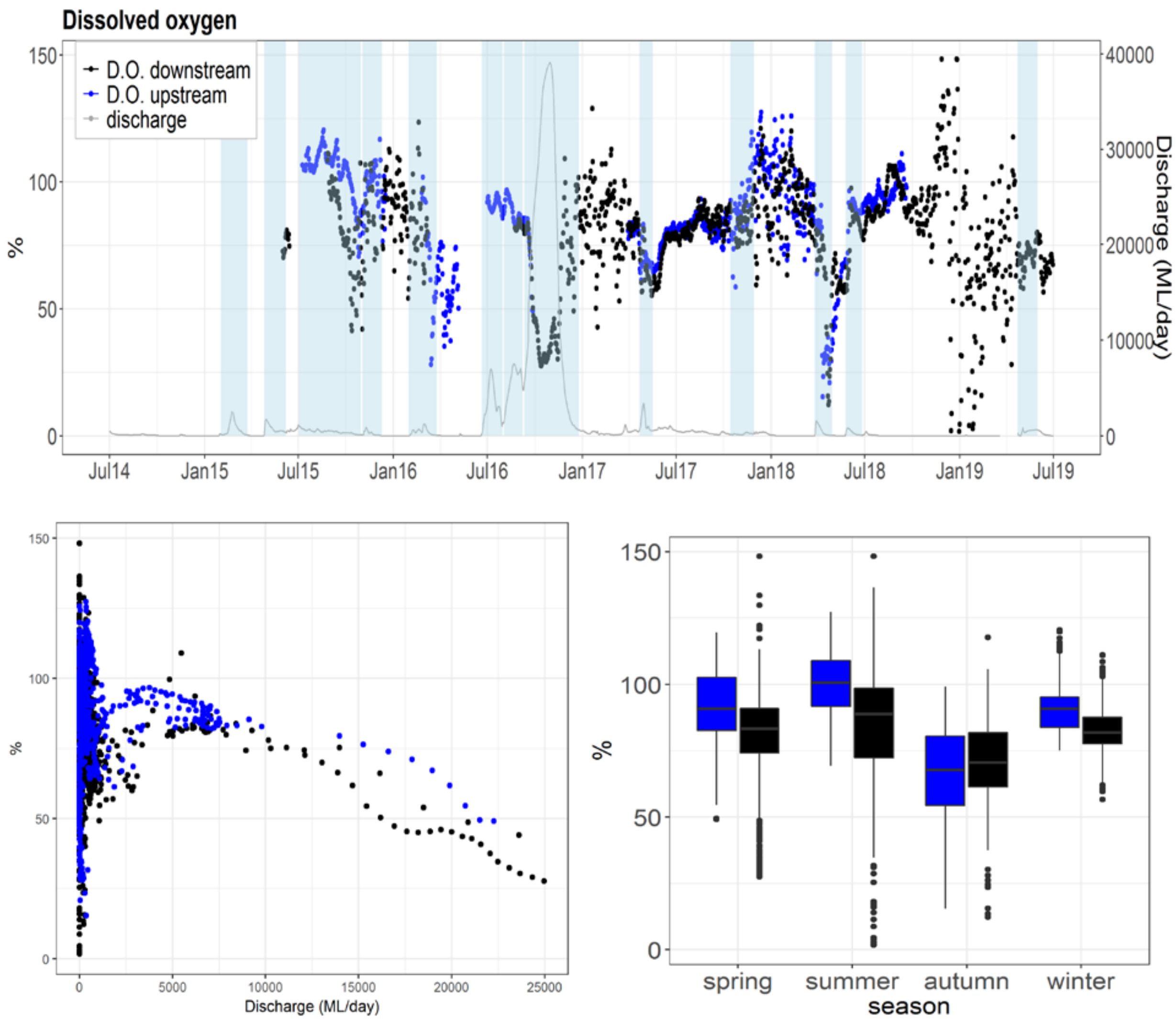


Figure D-8: (Top) Mean daily dissolved oxygen concentration at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom left) Regression between discharge and dissolved oxygen concentration in 2014-19. (Bottom right) Boxplot of average dissolved oxygen concentration by year in 2014-19.

Chlorophyll *a* concentrations were consistently higher than the ANZECC guideline value and similar to the EHP guideline (Table D-2). Increased algal production in the water column occurred in base and low flow (around 4,000 ML/d) periods throughout the monitoring program (Figure D-9). Higher chlorophyll *a* concentrations when discharge around 4,000 ML/d suggest a potential discharge threshold around 4,000 ML/d may inundate low lying in-channel features such as bars and transport nutrients to stimulate primary production measured as chlorophyll *a*. This pattern was observed in 2015-17 Darling stations as well as in spot sampling in the Darling River sites (Appendix E). Chlorophyll *a* concentrations were consistently lower in autumn than other seasons, reflecting water temperature variation also influences patterns in primary production. Similar to the dissolved oxygen pattern, phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015).

A large outbreak of *Azolla* (*Azolla filiculoides*) was recorded in the Darling River between 10 September and 15 November 2015 with no deterioration of water quality that led to algal blooms. It was suggested that a small flow peak mitigated the effects of the *Azolla* bloom and washed it downstream before it decayed. Therefore, the benefit of smaller magnitude flows (highest discharge of 971 ML/d in that event) that contain environmental water could prevent potential water quality problems and ecological consequence such as hypoxia linked to an *Azolla* outbreak.

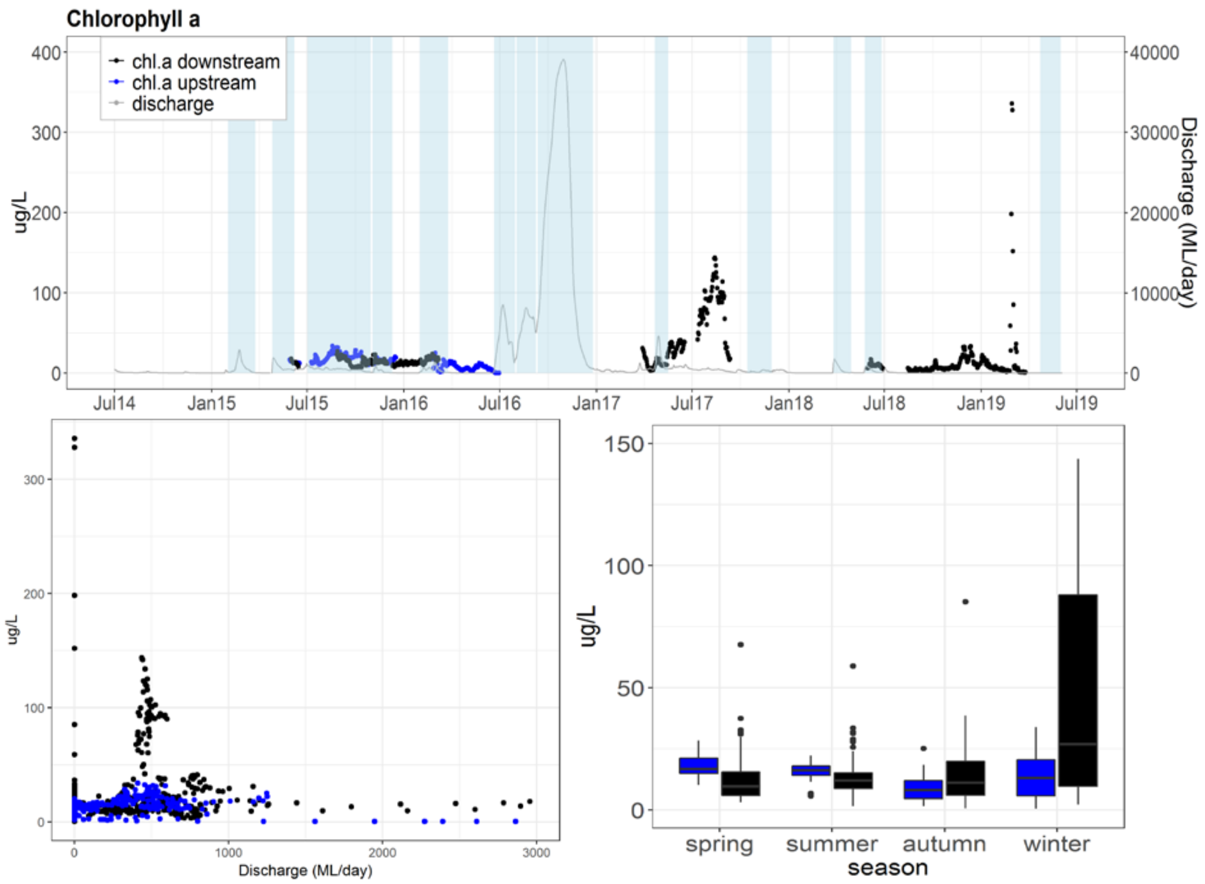


Figure D-9: (Top) Mean daily chlorophyll *a* concentration at two Darling stations with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. (Bottom left) Regression between discharge and chlorophyll a concentration in 2014-19. (Bottom right) Boxplot of average chlorophyll a concentration by year in 2014-19.

In natural freshwater rivers, sediment settling rates can increase by the process of flocculation in different physical and biochemical conditions (Droppo & Ongley, 1994). At conductivity levels above 0.5 mS/cm, turbidity dropped to below 500 NTU, likely due to the flocculation effect of increased concentrations of charged ions (increase in conductivity) flocculating fine clay particles (decrease in turbidity) (Figure D-6). A similar pattern has been observed in the Warrego, Bulloo, Paroo and Nebine River systems at conductivities above 0.2 mS/cm, with turbidity levels consistently dropping to below 50 NTU (EHP, 2016).

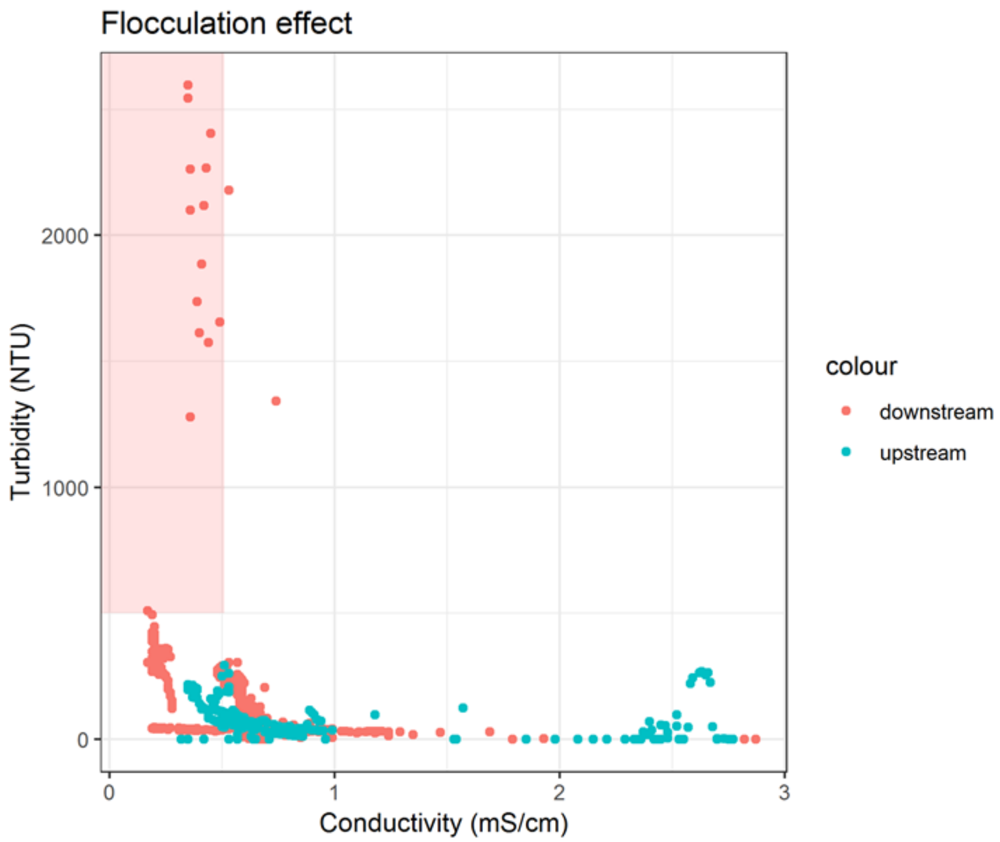


Figure D-10: Regressions between conductivity and turbidity at two Darling stations within the Warrego-Darling Selected Area in 2014-19.

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D.4 Conclusion

Throughout the LTIM Project, 13 in-channel flow pulses containing environmental water were linked to water quality patterns in two Darling River water quality stations. In 2016-17, three flow pulses containing environmental water provided an opportunity to observe how water quality changed in response to an approximate bankfull event.

Five years of water quality monitoring showed the delivery of environmental water contributed to consistent improvements in water quality. The most consistent pattern was a significant reduction in mean daily pH, conductivity and turbidity compared with periods without environmental water. This reflects the dilution effects provided by environmental water, and the changes in water chemistry associated with the increase in discharge and wetted area of channels. In particular, a potential discharge threshold around 10,000 ML/d was observed for pH and turbidity, suggesting that this may be a key high-flow threshold for the inundation or connection of geomorphic features that subsequently increase ions and suspended sediments inputs in the Darling River. Levels of pH and turbidity increased around 10,000 ML/d suggesting longitudinal transport and input of materials from upstream catchments, as predicted by the literature (Bayley & Sparks, 1989). After discharge exceeded these key flow thresholds, water quality parameters declined with discharge. This was likely due to the dilution of existing materials as the resuspension of material decreased at higher river stages.

Dissolved oxygen concentrations were highly variable during base flow and low flow conditions (discharge 0-250 ML/d) and reduced with increasing discharge up to 25,000 ML/d. A similar pattern was also observed in chlorophyll *a* concentration with highly variable concentrations in base flow and low flow (around 4,000 ML/d) and then decreased with increasing discharge. It is likely that seasonal changes in temperature exerted a strong influence on dissolved oxygen and chlorophyll *a* concentrations. A potential discharge threshold around 4,000 ML/d may inundate low lying in-channel features such as bars, and transport nutrients to stimulate primary production measured as chlorophyll *a*. Differences in upstream water sources containing various amounts and proportions of organic matter and nutrients may have affected the balance between productivity and respiration in different environmental events. Moreover, phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015).

D.5 References

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Appendix E Category III Water Quality

E.1 Introduction

The Category III Water Quality indicator aimed to assess the contribution of Commonwealth environmental water to the improved quality of water within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). As such this indicator is linked to Fish (River), Stream Metabolism, Waterbird Diversity, Microinvertebrates, Macroinvertebrates, Frogs and Hydrology indicators. Several specific questions were addressed through this indicator in 2014-18 water years:

- What did Commonwealth environmental water contribute to temperature regimes?
- What did Commonwealth environmental water contribute to pH levels?
- What did Commonwealth environmental water contribute to turbidity regimes?
- What did Commonwealth environmental water contribute to salinity regimes?
- What did Commonwealth environmental water contribute to dissolved oxygen levels?
- What did Commonwealth environmental water contribute to algal suppression?

E.2 Methods

E.2.1 Sampling methods

Category III Water Quality indicators were measured in association with Category III Microinvertebrate (Appendix G) and Macroinvertebrate (Appendix H) indicators on ten sampling occasions between 2014 and 2018. Sampling sites were located in three Sampling Zones within the Warrego-Darling Selected Area: Darling River, Warrego Channel and the Western Floodplain (Figure E-1).

Eleven water quality indicators were measured (Table E-1). *In-situ* spot measurements of water column temperature (°C), pH, turbidity (NTU), conductivity (mS/cm) and dissolved oxygen (mg/L) were taken using a Hydrolab Quanta water quality multi-probe. Chlorophyll *a* was sampled by filtering as much sample water as possible (100–1,000 mL) through a Whatman glass microfiber grade GF/C filter paper using an electric vacuum pump (EYELA Tokyo Rakahikai Corporation Aspirator A-35 at approximately 7 PSI). The sample volume was recorded, and the filter paper placed into a pre-labelled 10 mL vial which was then sealed, wrapped in aluminium foil, placed inside a labelled zip lock bag and then refrigerated below 4 °C. Chlorophyll *a* was analysed by placing 10 mL of 90% acetone solution in the vial and refrigerating the sample for 24 hours. Samples were then centrifuged, and the absorption spectra recorded using a UV-1700 Pharmaspec UV-visible spectrometer at 665 nm and 750 nm. Water nutrients samples were collected and analysed following the methods in 2015-16 report Appendix D (Commonwealth of Australia, 2016).

Stream metabolism indicators were collected in association with Category III Water Quality indicators in the Warrego Channel and the Western Floodplain sites (Figure E-1 and Table E-1). Dissolved oxygen D-opto loggers were deployed for 48 hours to monitor temperature (°C) and dissolved oxygen (%) at 10-minute intervals. Photosynthetically active radiation (PAR) was also logged at 10-minute intervals. Daily rates of gross primary production (GPP), ecosystem respiration (ER) and net primary production (NPP) in mg O_2/L/day were calculated using the BASE modelling package (Grace *et al*., 2015).

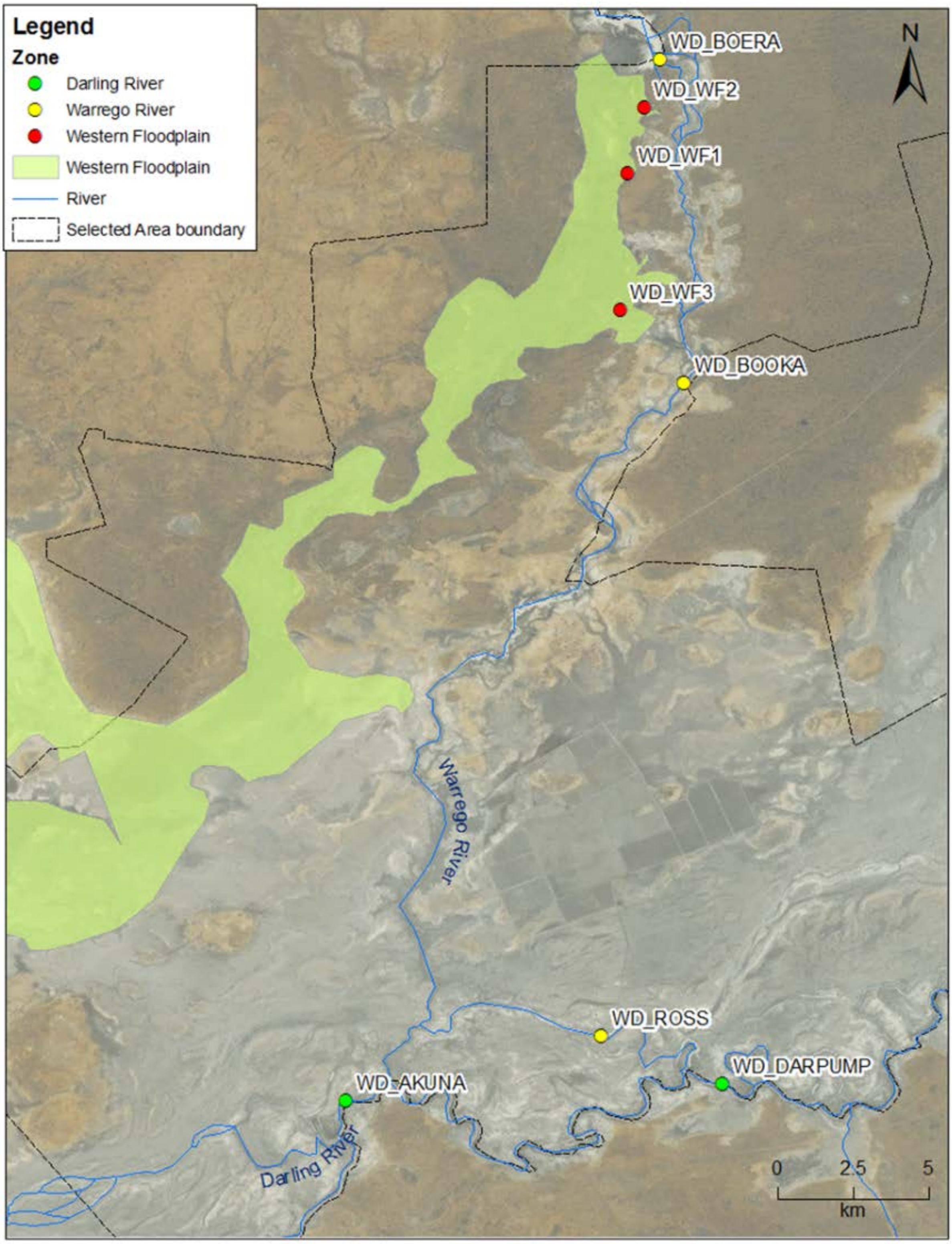

Figure E-1: Location of eleven water quality sites (Cat III Water Quality) within the Warrego-Darling Selected Area between 2014 and 2018.

Table E-1: Category III Water Quality and stream metabolism indicators measured on ten sampling occasions over the LTIM project.

Water quality Indicators			Units	Code
Water chemistry	i.	Temperature	°C	temp
	ii.	pH	-	pH
	iii.	Turbidity	NTU	turb
	iv.	Conductivity	mS/cm	cond
	v.	Dissolved Oxygen	mg/L	DO
	vi.	Chlorophyll *a*	µg/L	chla
Water nutrient	i.	Dissolved Organic Carbon	mg/L	doc
	ii.	Total Nitrogen	µg/L	tn
	iii	Total Phosphorus	µg/L	tp
	iv.	Nitrate-nitrite	µg/L	NOx
	v.	Filterable Reactive Phosphorus	µg/L	frp
Stream metabolism Indicators				
Stream metabolism	i.	Gross primary production	mg O_2/L/day	GPP
	ii.	Ecosystem respiration	mg O_2/L/day	ER
	iii	Net primary production	mg O_2/L/day	NPP

Explanatory (spatial, temporal and hydrological) factors

Spatial and temporal factors were used to test if water quality indicators were spatially or temporally dependent. Eleven sampling sites were analysed in three categories; **ZONE**: Darling River, Warrego Channel and the Western Floodplain (Table E-2). Ten sampling occasions were placed into four **YEARS** and two **SEASONS** categories (i.e. summer from October to April and winter from May to September) (Table E-3).

Hydrological data was used to test the influence of environmental water and natural flow events. In the Darling zone, daily discharge (ML/d) data was collated from the WaterNSW gauge station 425003 Darling River at Bourke Town to identify hydrological thresholds for the water quality indicators (Table E-3). In the Warrego Channel, connection events were identified when Boera Dam gates were opened to allow water to connect the three Warrego Channel sites. Time since connection was calculated using days between when Boera gates were opened (i.e. surface water connection in the Warrego Channel) and the first day of the next sampling trip to test the influence of each of five Warrego connectivity events (Table E-3 and Figure E-2a). In the Western Floodplain zone, inundation events were identified when Boera Dam water levels were above 2.26 m at Boera gauge. Time since inundation was calculated using days between when Boera gauge was above 2.26 m (i.e. water over flow to the Western Floodplain) and the first day of the next sampling trip to test the influence of each of three Western Floodplain inundation events (Table E-3 and Figure E-2b). Three continuous hydrological factors were further transformed into three categorical hydrological factors to infer patterns in statistical analyses.

Table E-2: Location of eleven water quality sites (Cat III Water Quality) within the Warrego-Darling Selected Area in ten sampling occasions in 2014-18 (n=89). Map projection GDA94 Zone 55. Inundation condition Wet=sampled, Dry=no sample.

Sampling Zone	Site Name	Site Code	Easting	Northing	2014-15		2015-16		2016-17			2017-18		
					WD1	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
					Feb-15	May-15	Oct-15	Mar-16	Aug-16	Nov-16	Mar-17	Oct-17	Apr-18	Jun-18
Darling River	Akuna	AKUNA	340008	6634629	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Darling Pump	DARPUMP	350768	6635351	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
Warrego Channel	Boera Dam 1	BOERA1	348526	6669158	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Boera Dam 2	BOERA2	348720	6669094	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 1	BOOKA1	349357	6658461	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 2	BOOKA2	349835	6658024	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Ross Billabong 1	ROSS1	347281	6636893	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Ross Billabong 2	ROSS2	347242	6636926	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Dry	Dry
Western Floodplain	Coolibah-Cooba-Lignum woodland	WF1	348083	6667550	Wet	Wet	Wet	Dry	Wet	Dry	Dry	Dry	Dry	Dry
	Coolibah open woodland	WF2	347848	6665662	Wet	Wet	Dry	Dry	Wet	Wet	Dry	Dry	Dry	Dry
	Lignum shrubland	WF3	347476	6660850	Dry	Dry	Dry	Dry	Wet	Wet	Wet	Dry	Dry	Dry

Table E-3: Explanatory (temporal, continuous hydrological and categorical hydrological) factors to infer Category III Water Quality patterns in statistical analyses.

Temporal factor				Hydrological factor (within each Zone)							
				Darling		Warrego			Western Floodplain		
Year	Sampling occasion	Month	Season	Discharge (ML/d)	Discharge category	Flow/ EW event	Time since connection (day)	Connection category	Flow/ EW event	Time since inundation (day)	Inundation category
2014-15	1	2015-02	summer	2,894	1,000-4,999	1	17	<50	1	13	during
	2	2015-05	summer	462	Base	1	102	100-299	1	98	retention
2015-16	3	2015-10	summer	411	Base	1	242	100-299	2	100	retention
	4	2016-03	summer	51	Base	2	19	<50	-	-	-
2016-17	5	2016-08	winter	7,613	5,000-10,000	3	36	<50	3	105	during
	6	2016-11	summer	3,993	1,000-4,999	4	27	<50	3	203	during
	7	2017-03	summer	572	500-999	4	145	100-299	3	321	retention
2017-18	8	2017-10	summer	184	Base	4	356	>300	-	-	-
	9	2018-04	summer	47	Base	5	3	<50	-	-	-
	10	2018-06	winter	145	Base	5	68	50-99	-	-	-

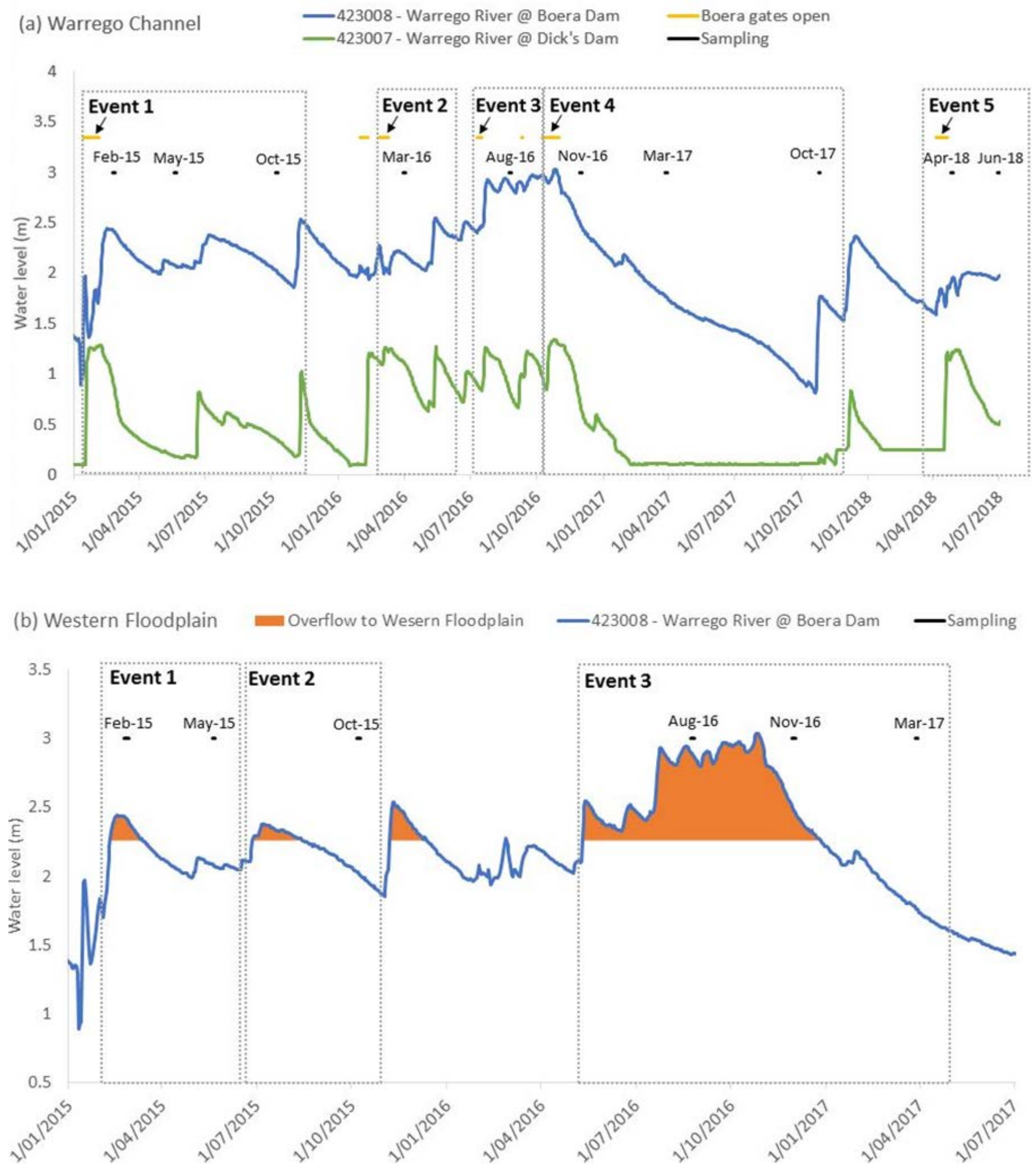

Figure E-2: Mean daily water level in (a) the Warrego Channel and (b) the Western Floodplain with flow events and sampling occasions.

E.2.2 Statistical methods

PCA

To identify spatial and temporal water quality patterns between 2014 and 2018 within the Warrego-Darling Selected Area, principal components analysis (PCA) was performed using a Euclidian distance measure to summarise 11 normalised water quality indicators into several axes (components). PCA analysis was performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

Summary statistics and water quality guidelines

The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicator between 2014 and 2018 was calculated in each zone. ANZECC South-East Australia lowland river water quality trigger values (ANZECC, 2000) and the Lower Warrego River Catchment water quality target values (EHP, 2016) are also indicated.

PERMANOVA

Permutational multivariate analysis of variance (PERMANOVA) was used to test differences in overall water quality indicators and each water quality indicator between spatial, temporal and categorical hydrological factors. This routine can be used to analyse unbalanced experimental design in an analysis of variance experimental design using permutation methods (Anderson, 2008). Up to 999 random permutations estimated the probability of p-values, with levels of significance reported as $p<0.05$. Where statistically significant differences were detected, pair-wise comparisons in PERMANOVA routine were used to determine the source of the significant differences. PERMANOVA analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

PERMANOVA was used to test the overall difference in water quality indicators between YEAR, SEASON and ZONE and their interactions. Within each zone, water quality patterns were mainly driven by different hydrological events and therefore were analysed separately. In the Darling River zone, PERMANOVA was used to test the difference in water quality indicators between discharge categories. In the Warrego Channel zone, PERMANOVA was used to test the difference in water quality indicators between connection categories. In the Western Floodplain zone, PERMANOVA was used to test the difference in water quality indicators between inundation categories.

Regression

Relationships between water quality indicators (Table E-1) and continuous hydrological factors (Table E-3) were analysed using non-linear polynomial or logistic regression. In the Darling River zone, regression was used to explore the relationships between water quality indicators and discharge (ML/d). In the Warrego Channel zone, regression was used to explore the relationships between water quality indicators and time since connection (days). In the Western Floodplain zone, regression was used to explore the relationships between water quality indicators and time since inundation (days). Regression outputs of F-statistic, degree of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

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E.3 Results and Discussion

E.3.1 Overall water quality patterns

A two-dimension PCA mapped 89 samples based on similarity in 11 measured water quality indicators, with adjacent PCA samples having more similar environmental conditions (Figure E-3). PCA showed that the complex spatial and temporal patterns in water quality did not operate independently and were driven by hydrological conditions. PC1 (axis-x) explained 23.6% of the variation, and the vector overlay suggests that water column nutrients and chlorophyll *a* were strongly associated (Figure E-3). PC2 (axis-y) explained 16.1% of the variation with dissolved oxygen being positively aligned, and turbidity being negatively aligned along the axis (Figure E-3).

Broader spatial (zone) patterns were predominantly driven by catchment characteristics and landscape-scale processes, such as sediment and saline inputs. The spatial patterns in the PCA showed that the Warrego Channel and the Western Floodplain samples were overlapping each other with relatively similar environmental conditions, when compared with the Darling River samples (Figure E-3a). There was a distinctive seasonal pattern in water quality condition driven by higher temperature and chlorophyll *a* concentration in summer in all three zones (Figure E-3b). In the northern Murray-Darling Basin, seasonal variation also leads to higher long-term average annual rainfall during summer months and therefore higher hydrological variability, in contrast to the southern Basin. Within each zone, temporal patterns in environmental condition were mainly driven by different hydrological events and are, therefore, presented separately.

In the Darling River, water quality condition was dissimilar between sampling events when discharge was less than 50 ML/d with the highest nutrient concentrations and turbidity recorded. The Warrego Channel samples were the most dispersed along both PC1 and PC2 axes, reflecting the highly variable environmental conditions within the zone and between sample occasions. In particular, exceptionally high dissolved oxygen concentrations were observed on sample occasions 8 and 10, during retention/contraction phases. In the Western Floodplain, environmental conditions were very different on sample occasion 7 from other periods, with exceptionally high nutrient and chlorophyll *a* concentrations and high turbidity levels during a hot retention/contraction phase in summer. In general, very dry periods with very low flow, and a longer time since last inflow reduced water quality. This compounded when these hydrological conditions occurred in summer.

Water temperature ranged from 10 °C – 34.8 °C (Table E-4). Seasonal change exerted a strong influence on temperature as expected, and PERMANOVA analysis showed a significant difference between season (Pseudo-F=142.81, d.f.=1, p=0.001, Table E-5 and Figure E-4). Variations in water temperature were attributed to broader seasonal patterns rather than flow or other environmental conditions.

The pH values were consistently alkaline and occasionally exceeded ANZECC guideline values (Table E-4). Lower pH was found in the Western Floodplain, as leachates from rewetted organic matter in different vegetation habitats lower the pH to more acidic levels (Table E-4). Comparatively, the Daring River and Warrego Channel had relatively high pH (Table E-4). A three-way PERMANOVA analysis showed a significant difference between years (Pseudo-F= 15.545, d.f.=3, p=0.001, Table E-5). In 2016-2017, pH levels were significantly lower than all other years in the pairwise test ($p<0.05$, Figure E-4), reflecting a dilution effect provided by several flow pulses in this ‘wet year’. Inter-annual hydrological variability and antecedent flow conditions could also play important roles in water quality variability, highlighting the importance of long-term monitoring in highly dynamic and largely unregulated systems to allow multi-year comparison.

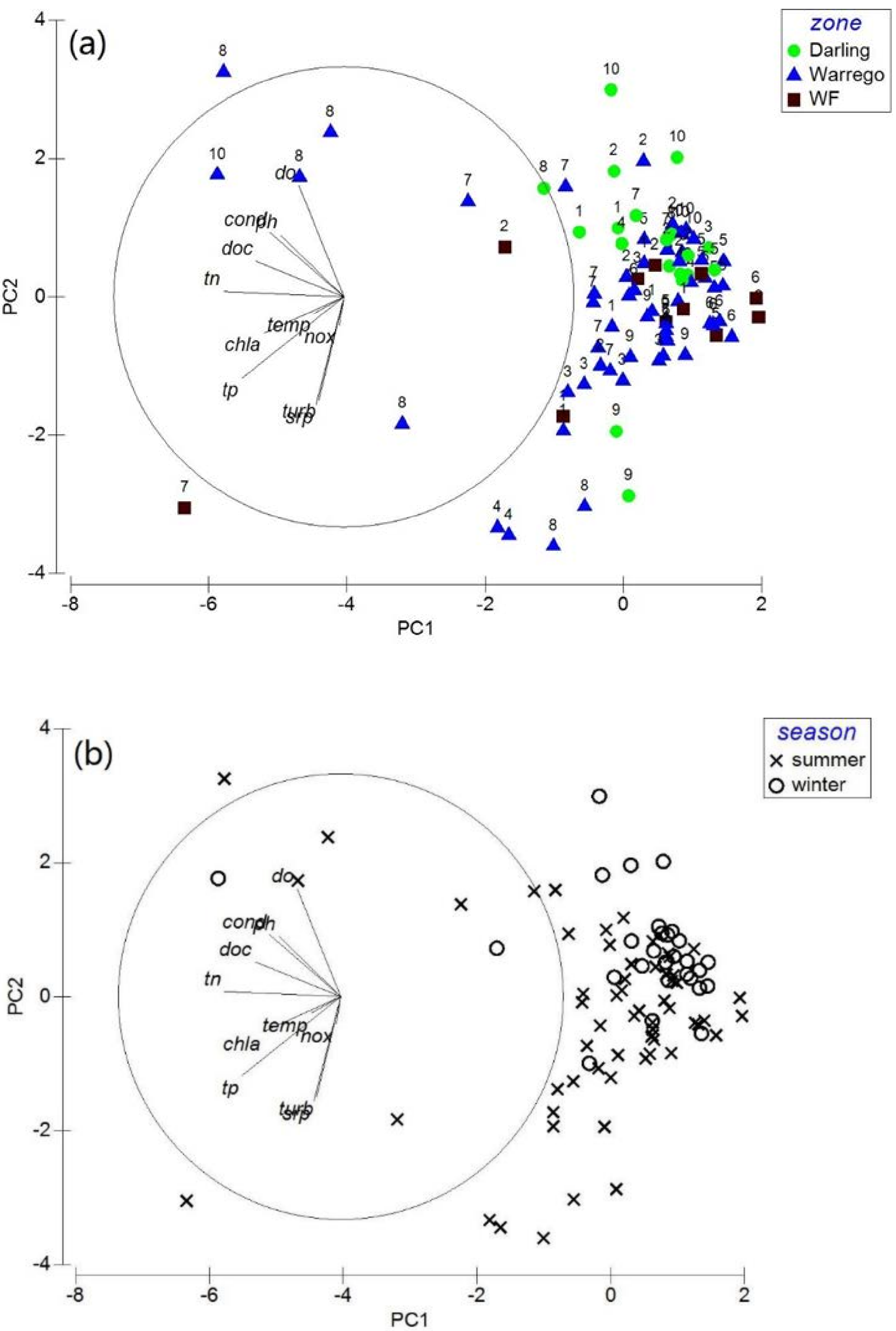

Figure E-3: Principal components analysis (PCA) bi-plot of Category III Water Quality indicators showing spatial and temporal patterns with vectors of eleven water quality indicators (normalised data, Spearman correlation) which underlie the environmental patterns among 89 samples within the Warrego-Darling Selected Area in 2014-18.

Table E-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicators were calculated in three zones within the Warrego-Darling Selected Area with water quality guidelines from ANZECC (2000) and EHP (2016).

Variable	ANZECC (2000)	EHP (2016)	Zone	Minimum	Percentile			Maximum	Number of samples
					20th	50th	80th		
Temperature (°C)	-	-	Darling	12.2	15.4	23.5	27.7	30.3	20
			Warrego	10	15.9	21.5	28.3	34.8	58
			WF	12.5	14.1	21.3	23.5	34	10
pH	6.5 - 8	baseflow: 7 - 8	Darling	7.2	7.3	8.0	8.4	9.02	20
			Warrego	6.7	7.5	8.1	8.8	9.92	58
			WF	6.5	6.8	7.6	8.5	9.79	10
Turbidity (NTU)	6 - 50	baseflow: 210, high-flow: 760.	Darling	0	62	134	281	1,950	18
			Warrego	53	276	382	607	1,846	52
			WF	34	80	214	292	1,214	9
Conductivity (mS/cm)	0.125 - 2.2	baseflow: 0.145, high-flow: 0.080.	Darling	0.177	0.363	0.658	1.110	1.93	20
			Warrego	0.086	0.174	0.216	0.410	1.337	58
			WF	0.088	0.112	0.206	0.284	1.292	10
Dissolved oxygen (mg/L)	85 - 110 (in%)	baseflow: >5	Darling	4.3	5.1	7.1	8.6	11.8	20
			Warrego	1.4	5.8	7.7	10.1	21.18	58
			WF	2.9	3.9	4.7	8.6	12.15	10
Chlorophyll *a* (µg/L)	5	baseflow: 10	Darling	0.0	3.9	10.1	31.2	77.00	20
			Warrego	0.0	1.9	8.1	24.1	206.80	58
			WF	0.6	2.1	3.6	11.6	633.60	11
Dissolved organic carbon (mg/L)	-	-	Darling	8	9	13	14	80	20
			Warrego	7	12	15	21	90	58
			WF	8	9	17	24	35	11
Total nitrogen (µg/L)	500	baseflow: 620, high-flow: 100	Darling	239	517	662	922	1,633	20
			Warrego	295	641	917	1,433	9471	58
			WF	545	989	1,302	1,817	5,889	11
Total phosphorus (µg/L)	40	baseflow: 2	Darling	31	174	272	353	953	20
			Warrego	71	66	206	433	1721	58
			WF	150	88	241	384	1414	11
Nitrate-nitrite (µg/L)	50	baseflow: 180, high-flow: 320.	Darling	13	108	211	521	438	20
			Warrego	13	220	460	794	1,589	58
			WF	45	164	463	829	1,133	11
Filterable reactive phosphorus (µg/L)	20	baseflow: 2	Darling	20	42	66	94	197	20
			Warrego	23	56	94	268	823	57
			WF	49	71	99	153	468	11

Table E-5: Summary of PERMANOVA (P(perm)) results of water quality indicators in the Warrego-Darling Selected Area.

Water quality indicator	Three-way PERMANOVA (all three zones)			
	SEASON	YEAR	ZONE	Interaction terms
Temperature	***0.001****	***0.001****	0.842	Not Significant
pH	0.362	***0.001****	0.51	Not Significant
Turbidity	0.147	0.384	0.109	***SEASON x YEAR (0.027)***
Conductivity	0.502	0.022	***0.001****	***SEASON x YEAR x ZONE (0.009)***
Dissolved oxygen	***0.001****	0.053	0.196	Not Significant
Chlorophyll *a*	0.063	0.118	0.772	Not Significant
Dissolved organic carbon	0.399	0.255	0.395	Not Significant
Total nitrogen	0.614	0.14	0.138	Not Significant
Total phosphorus	0.067	0.462	0.129	Not Significant
Nitrate-nitrite	***0.047****	0.2	0.355	Not Significant
Filterable reactive phosphorus	0.223	0.667	0.145	Not Significant
Gross primary production	0.555	0.673	0.186	Not Significant
Ecosystem respiration	***0.001****	***0.001****	***0.002****	***SEASON x YEAR (0.001)***
Net primary production	***0.001****	***0.001****	***0.001****	***SEASON x YEAR (0.001)***

***** represents significant results of ***p-value <0.05.***

Turbidity was generally highly variable and consistently higher than the ANZECC guideline value in the Warrego-Darling Selected Area (Table E-4). In particular, the Warrego Channel and the Western Floodplain had very high turbidity levels, consistent with the EHP guideline value (EHP, 2016), reported in these intermittent floodplain systems (Sheldon & Fellows, 2010). The highest turbidity levels were recorded in the Warrego Channel sites when compared to the Western Floodplain sites. This may be due to stronger wind action without standing vegetation, thus increased turbidity levels. In the floodplain sites, emergent wetland plants reduce the velocity of water passing through the system allowing sedimentation of particulates, thus reducing the turbidity level. A three-way PERMANOVA analysis showed a significant interaction between season and year (Pseudo-F=4.253, d.f.=3, p=0.027, Table E-5). In 2017-18, turbidity in summer was significantly higher than winter in the pairwise test (p<0.5, Figure E-4), with a few outliers over 1,000 NTU. These exceptionally high turbidity records were observed in the contraction period (October 2017) in the Warrego Channel.

Conductivity values were consistently within the ANZECC guidelines (Table E-4). A three-way PERMANOVA analysis showed a significant interaction between season, year and zone (Pseudo-F= 4.267, d.f.=3, p=0.009, Table E-5). In pairwise tests, the Darling River had significantly higher conductivity than the Warrego Channel (p<0.05, Figure E-4). The Darling River had the widest conductivity range, potentially due to a more variable discharge rate and diverse inflow sources from the northern tributaries, compared with the Warrego Chanel and the Western Floodplain (Figure E-4). Within the Warrego Channel, conductivity tended to be higher in summer than winter with a significant pairwise test (p<0.5, Figure E-4). Other factors such as intrusion of saline groundwater and evapoconcentration during dry periods also affected conductivity.

Dissolved oxygen concentrations had a wide range associated with flow magnitude and was occasionally outside the ANZECC guideline level. Dissolved oxygen concentrations were consistently low in the Western Floodplain, with five out of seven samples below the EHP guideline value of 5 mg/L (Figure E-4). There was a significant seasonal difference in the three-way PERMANOVA (Table E-5), indicating that seasonal change in temperature was exerting a strong influence on dissolved oxygen.

Chlorophyll *a* concentrations were consistently higher than the ANZECC guideline value and similar to the EHP guideline value within the Warrego-Darling Selected Area (Table E-4). The Warrego Channel and Western Floodplain had a few outliers of chlorophyll *a* over 100 µg/L (Figure E-4). This increased algal production in the water column occurred in contraction phases consistently throughout the monitoring program. On the other hand, the Darling River, with more frequent flow connectivity, had a far lower chlorophyll *a* range (Figure E-4). There was no significant result in three-way PERMANOVA (Table E-5).

Measured nutrient (TN, TP, NOx and FRP) concentration were consistently higher than the ANZECC and EHP guideline values (Table E-5) throughout the project. Three-way PERMANOVA analyses did not show significant differences except in NOx (Pseudo-F=4.882, d.f.=1, p=0.047; Table E-5).

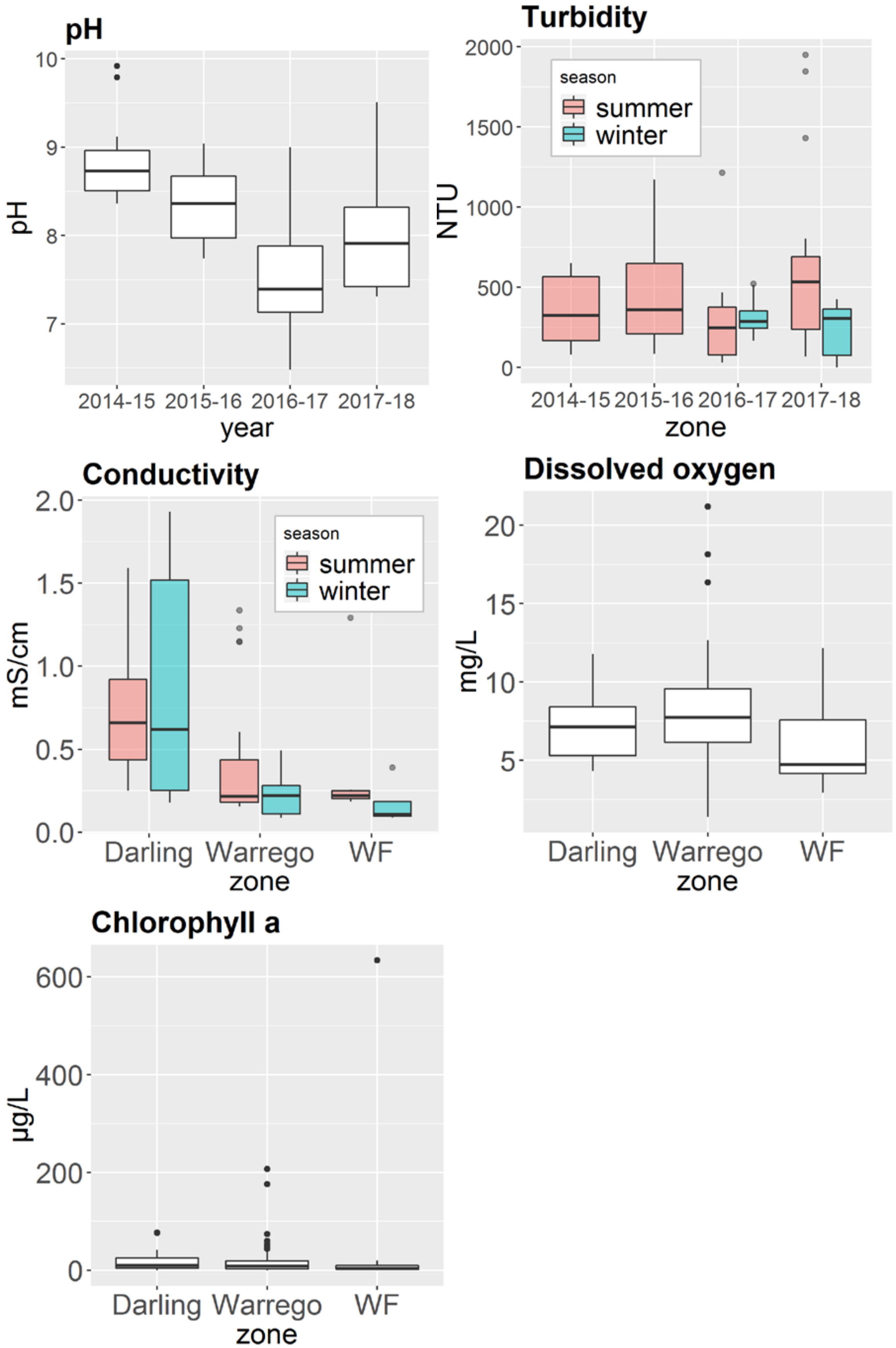

Figure E-4: Boxplot of temperature, pH, turbidity, conductivity, dissolved oxygen and chlorophyll *a* concentrations within the Warrego-Darling Selected Area.

In natural freshwater rivers, sediment settling rates can increase by the process of flocculation in different physical and biochemical conditions (Droppo & Ongley, 1994). To explore the potential natural flocculation processes within the Warrego-Darling Selected Area, relationships between turbidity and conductivity were analysed using regression.

At conductivity levels above 0.25 mS/cm turbidity dropped to below 500 NTU, likely due to the flocculation effect of increased concentrations of charged ions (increase in conductivity) flocculating fine clay particles (decrease in turbidity; Figure E-5). A similar pattern has been observed in the Warrego, Bulloo, Paroo and Nebine River systems at conductivities above 0.2 mS/cm, with turbidity levels consistently dropping to below 50 NTU (EHP, 2016).

With climate change projections of increased drought conditions, reduced rainfall and surface water flow may lead to higher conductivity across rivers of the northern Murray-Darling Basin. Increases in conductivity may flocculate fine clay particles and reduce turbidity levels, sequentially increasing light penetration into nutrient enriched aquatic systems. Turbidity can reduce further with saline and less-turbid groundwater intrusion, especially in the Darling River. In warmer months, increased light penetration to nutrient enriched slow-moving aquatic systems provides ideal conditions for algal blooms, heightening the potential for negative ecological consequence such as hypoxic events and extensive fish kills. The opportunity to optimize connectivity between the Warrego Channel and the Darling River may be crucial in maintaining the salinity regime downstream of the confluence. In this case, the relationship between conductivity, turbidity and chlorophyll *a* concentrations needs further investigation.

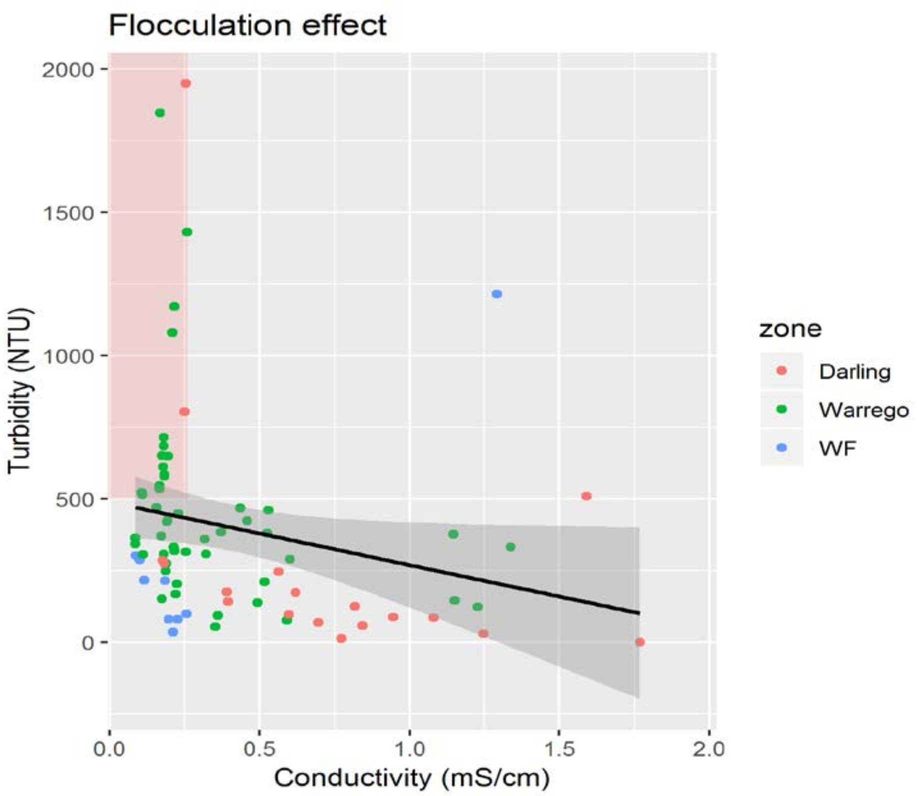

Figure E-5: Regressions between conductivity and turbidity within the Warrego-Darling Selected Area.

E.3.2 Overall Stream metabolism patterns

A total of 26 valid stream metabolism samples from the Warrego and Western Floodplain zones were reported in 2014-18 mainly due to a low percentage of data that met the BASE model output requirements. Three-way PERMANOVA analysis in ER and NPP showed a significant interaction between season and year (Pseudo-F=36.263, d.f.=2, p=0.001 and Pseudo-F=291.25, d.f.=2, p=0.001 respectively, Table E-5).

The highest average GPP rate was recorded on the Western Floodplain regardless of season, and could be due to high levels of algal production (measured as chlorophyll *a* concentration) associated with high nutrient concentrations in the water column during the contraction phases, particularly in summer conditions (Table E-6 and Figure E-6).

Rates of ER were generally higher than GPP rates, with the highest average ER rate in the Western Floodplain in the August 2016 winter samples (Figure E-6). The highest ER in the wettest phase of the Western Floodplain inundation event suggests that the inflow of water was leading to increased rates of respiration, driven by increased supply of carbon and nutrients from re-wetting *in situ* organic matter.

Overall, the Warrego and Western Floodplain zones were a carbon sink. NPP was predominantly net heterotrophic with very few net autotrophic events in the Warrego Channel and Western Floodplain zones. The major reason for heterotrophy in these systems was the low GPP rate and high ER rate (Figure E-6). Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which organic matter is colonised by microbes and fungi or consumed by detritivores that then fuel the invertebrate, fish and waterbird food webs (Kobayashi *et al.*, 2009). In the Western Floodplain in November 2016, a shift from net heterotrophic to net autotrophic suggests that increased GPP led to increased NPP, driven by internal nutrient cycling boosting primary production during prolonged inundation and water retention, particularly in summer with high ambient water temperatures.

Table E-6: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each stream metabolism indicators were calculated in three zones within the Warrego-Darling Selected Area. Unit of measure is mg O_2/L/day.

Variable	Zone	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
GPP	Darling	0.25	1.40	1.84	2.73	5.52	5
	Warrego	0.23	1.28	3.03	3.55	11.16	15
	WF	4.12	4.56	6.14	8.18	9.79	6
ER	Darling	1.86	1.90	4.02	6.93	12.01	5
	Warrego	2.49	3.86	5.43	6.30	11.94	15
	WF	0.03	4.05	6.43	20.80	24.41	6
NPP	Darling	-6.49	-4.36	-1.99	-1.33	-0.23	5
	Warrego	-4.28	-2.85	-2.34	-1.67	0.24	15
	WF	-16.23	-14.80	-1.01	0.08	9.76	6

GPP = gross primary production; ER = ecosystem respiration; NPP = net primary production

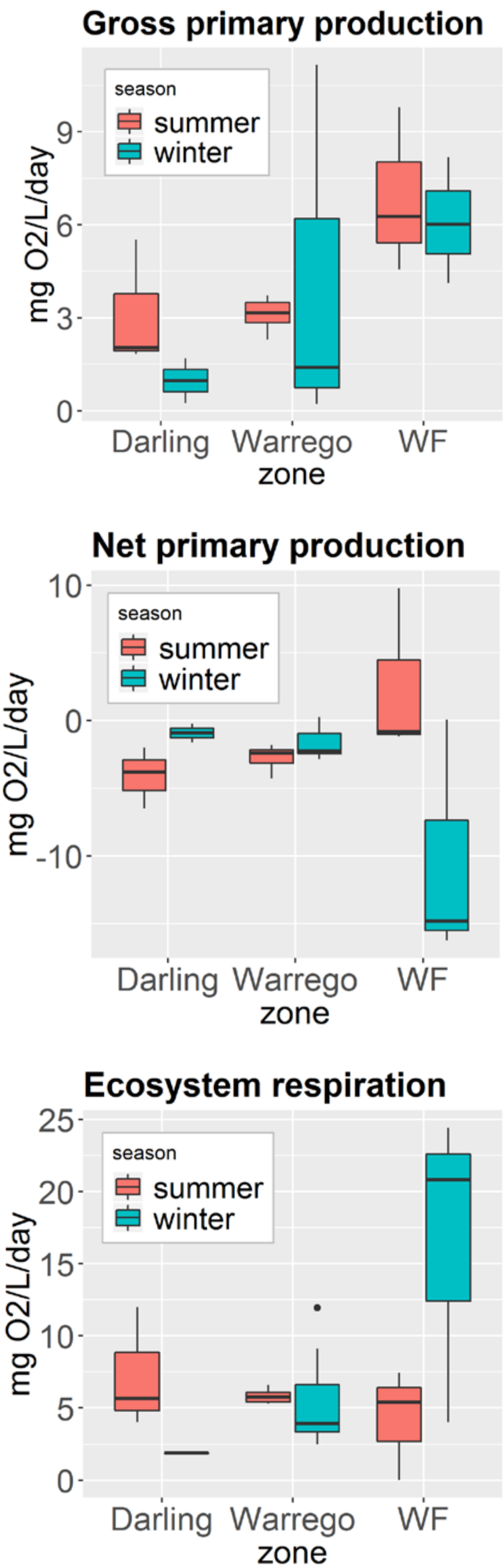

Figure E-6: Boxplot of GPP, ER and NPP rates among 26 samples within the Warrego-Darling Selected Area in 2014-18.

E.3.3 Darling River zone

Similar to overall water temperature records, the Darling zone temperature was higher in summer than in winter months due to seasonal variation (Figure E-4). Environmental water did not contribute an observable change in water temperature.

The pH values were consistently alkaline, and had lower values with increasing magnitude in discharge up to 8,000 ML/d (Figure E-7). This pattern was consistently observed: any increase in flow variability and magnitude, augmented by environmental water, improved pH through a dilution effect, provided by the higher discharge. However, there was no strong predictable relationship with discharge across the ten sampling occasions (Table E-7; Table G-7).

The Darling River has naturally high turbidity levels, with the majority of particles (80%-90%) finer than 2 µm and accordingly suspended in water column (Woodyer, 1978). There was no strong predictable relationship with discharge and turbidity in the dataset (Figure E-7 and Table E-7; Table G-7).

Conductivity was lower with increasing discharge up to 8,000 ML/d (Figure E-7). This pattern was observed in the 2016-17 water year as an increase in flow variability and magnitude augmented by environmental water lowered conductivity. However, there was no strong predictable relationship with discharge and conductivity (Table E-7; Table G-7).

Dissolved oxygen levels were highly variable during base flow conditions (Figure E-7). There was no strong predictable relationship with discharge and dissolved oxygen (Table E-7). One possible explanation is that different water sources from upstream tributaries transported various amounts and proportions of organic matter and nutrients in different connectivity events, consequently, affecting the balance between productivity and respiration. Alternatively, phytoplankton productivity was limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015).

There was a predictable quadratic polynomial relationship between chlorophyll *a* and discharge ($p<0.05$, Figure E-7 and Table E-7). This suggests that discharge around 4,000 ML/d may inundate low lying, in-channel features, such as bars, and transport nutrients to stimulate primary production, measured as chlorophyll *a*. There was no large outbreak of algal blooms observed in in the sampling program that caused deterioration of water quality.

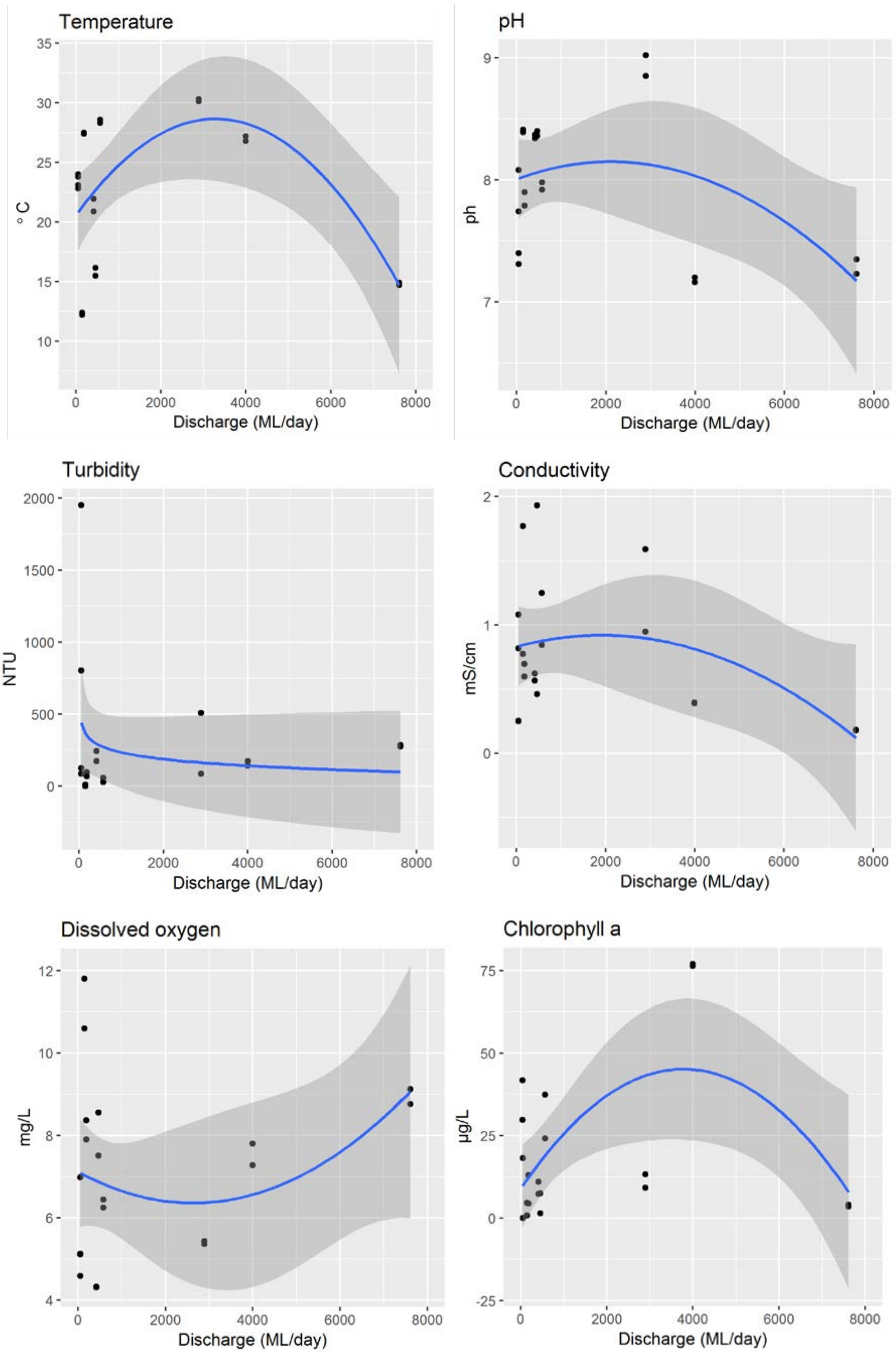

Figure E-7: Regressions between discharge (ML/d) and water quality (chemistry) indicators within the Darling River zone.

Table E-7: Summary of regression results between continuous hydrological factors and water quality and stream metabolism indicators within the Warrego-Darling Selected Area.

Water quality indicator	Darling					Warrego					Western Floodplain				
	F	df	p-value	R^2	model	F	df	p-value	R^2	model	F	df	p-value	R^2	model
Temperature (°C)	5.59	2,17	***0.01****	0.40	poly	1.39	2,55	***<0.01****	*0.05*	poly	2.59	2,7	0.14	0.43	poly
pH	2.63	2,17	0.10	0.24	poly	9.71	2,55	***<0.01****	0.26	poly	1.27	2,7	0.34	0.27	poly
Turbidity (NTU)	1.21	1,16	0.29	0.07	log	3.31	2,49	***0.04****	0.12	poly	8.80	2,6	***0.02****	0.75	poly
Conductivity (mS/cm)	2.02	2,17	0.16	0.19	poly	23.10	2,55	***<0.01****	0.46	poly	21.63	2,7	***<0.01****	0.86	poly
Dissolved oxygen (mg/L)	1.13	2,17	0.35	0.12	poly	3.72	1,56	0.06	0.06	log	1.17	2,7	0.37	0.25	poly
Chlorophyll *a* (µg/L)	4.21	2,17	***0.03****	0.33	poly	0.61	2,55	0.55	*0.02*	poly	37.40	2,8	***<0.01****	0.90	poly
Dissolved organic carbon (mg/L)	0.15	2,17	0.87	0.02	poly	6.65	2,55	***<0.01****	0.19	poly	0.84	1,9	0.38	0.09	log
Total nitrogen (µg/L)	0.36	2,17	0.71	0.04	poly	21.82	2,55	***<0.01****	0.44	poly	6.78	2,8	***0.02****	0.63	poly
Total phosphorus (µg/L)	1.82	1,18	0.19	0.09	log	8.36	2,55	***<0.01****	0.23	poly	4.99	2,8	***0.04****	0.55	poly
Nitrate-nitrite (µg/L)	0.15	2,17	0.86	0.02	poly	12.73	1,56	***<0.01****	0.19	log	0.37	2,8	0.70	0.09	poly
Filterable reactive phosphorus (µg/L)	3.82	1,18	0.07	0.18	log	0.44	2,54	0.65	*0.02*	poly	3.26	2,8	0.09	0.45	poly
Gross primary production (mg O_2/L/day)	13.55	2,2	0.07	0.93	poly	0.20	2,12	0.82	0.03	poly	2.33	2,3	0.24	0.61	poly
Ecosystem respiration (mg O_2/L/day)	50.79	2,2	***0.02****	0.98	poly	0.11	2,12	0.89	0.02	poly	1.53	2,3	0.35	0.51	poly
Net primary production (mg O_2/L/day)	7.90	2,2	0.11	0.89	poly	5.77	2,12	0.02	0.49	poly	2.87	2,3	0.20	0.66	poly

***** represents significant results of ***p-value <0.05***.

‘poly’ represents quadratic polynomial regression model, and ‘log’ represents log regression model.

Similar to the overall nutrient regime, Darling River zone concentrations of nutrients (DOC, TN, TP, NOx and FRP) were consistently higher than the ANZECC and EHP guideline values (Table E-4 and Figure E-8). Total and dissolved phosphorus concentrations decreased with increasing magnitude in discharge up to 8,000 ML/d across the ten sampling occasions (Figure E-8). However, there was no strong predictable relationship with discharge in five measured water nutrient indicators (Figure E-6 and Table E-7).

A total of 5 valid stream metabolism samples from the Darling River zone were reported in three sampling occasions, mainly due to low percentage of data that met the BASE model output requirements. ER rates were generally higher than GPP rates, with both the highest average GPP and ER rates recorded in base flow conditions when discharge was around 50 ML/d (Figure E-9). NPP rates were predominantly heterotrophic, which indicated the system was a carbon sink. The major reason for heterotrophy in these systems was a low GPP rate and high ER rate (Figure E-9). There was a strong quadratic polynomial relationship between discharge and three stream metabolism indicators, possibly due to small sample size (Table E-7).

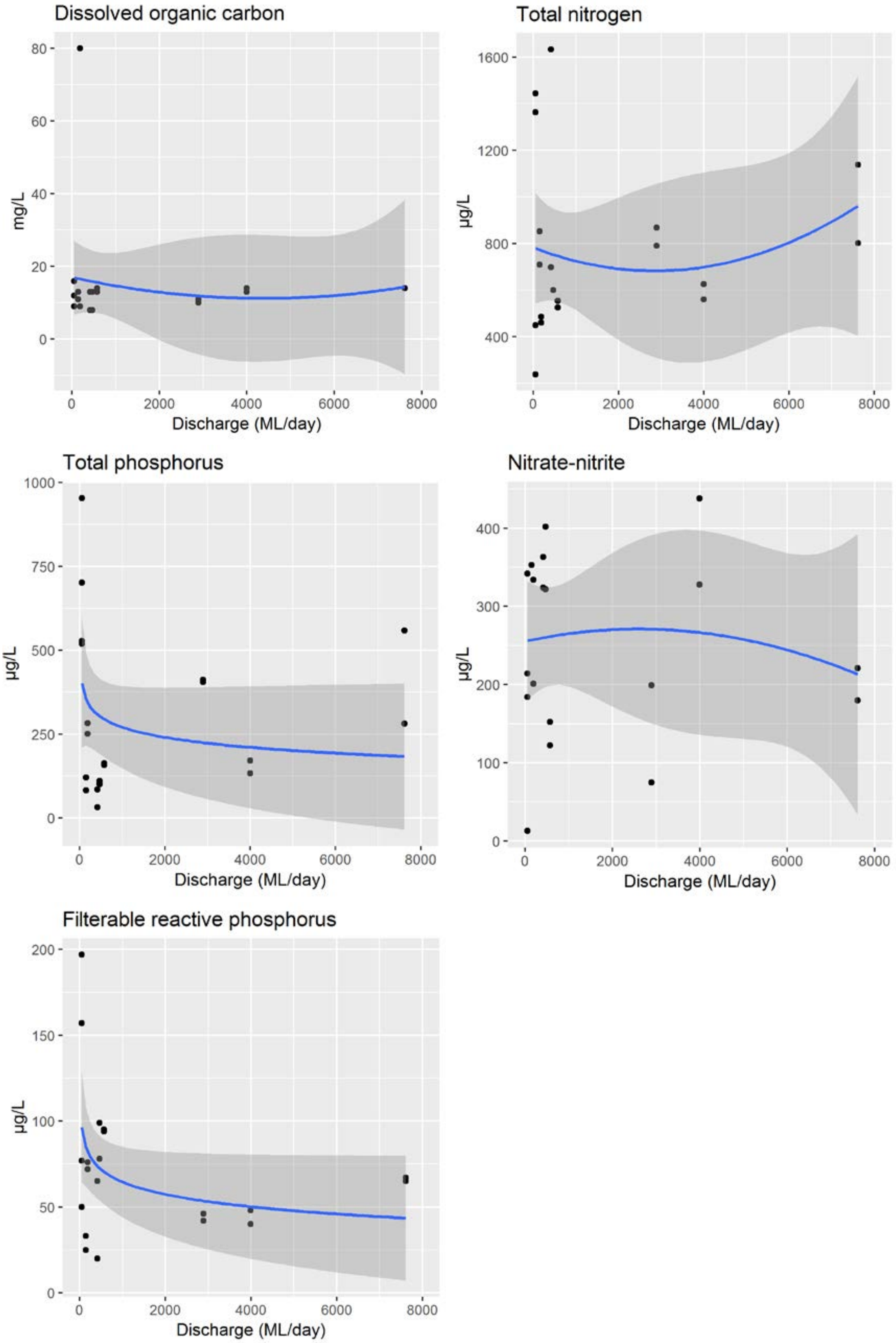

Figure E-8: Regressions between discharge (ML/d) and water quality (nutrient) indicators in the Darling River zone.

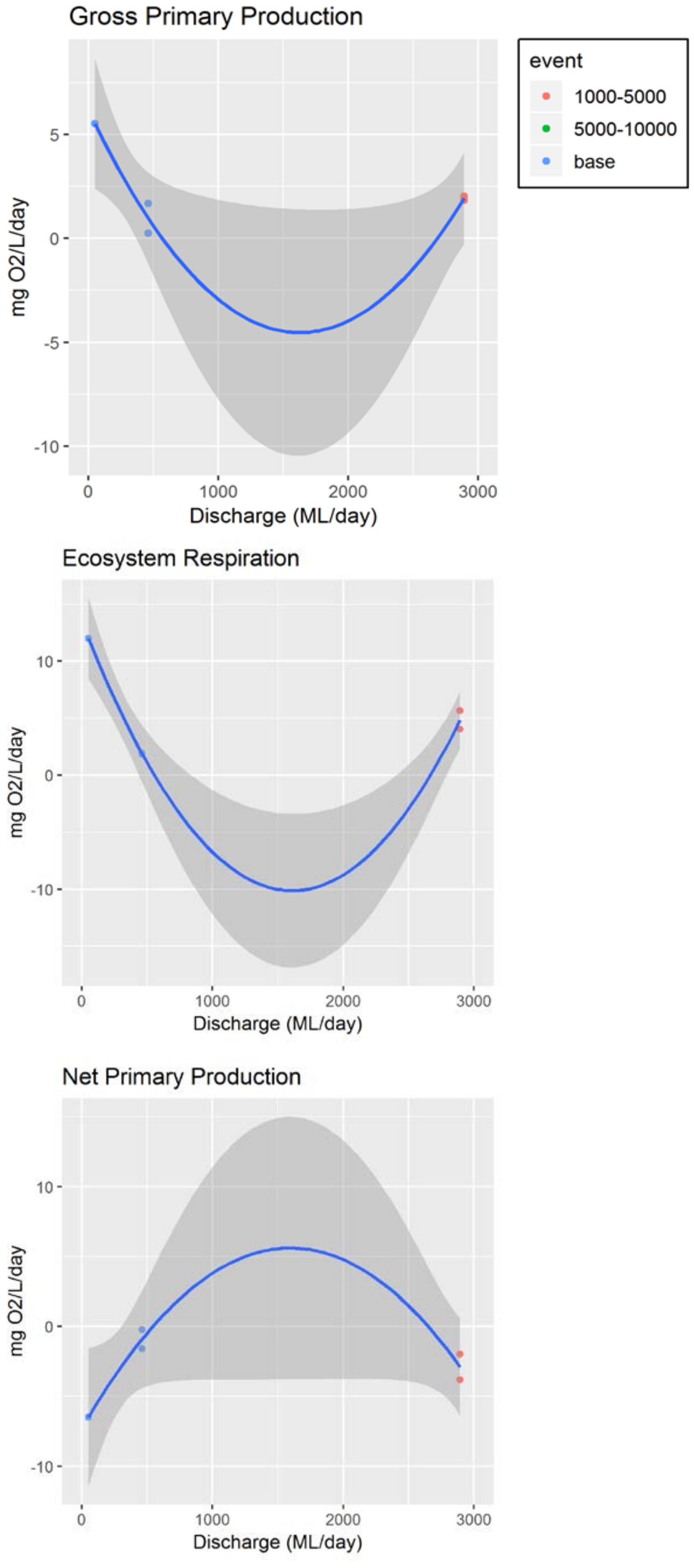

Figure E-9: Regressions between discharge (ML/d) and stream metabolism indicators in the Darling River zone.

E.3.4 Warrego Channel zone

The Warrego River zone within the Warrego-Darling Selected Area includes a series of in-channel dams connected by longitudinal flow events. Connection events were identified when Boera Dam gates were opened to allow water from Boera Dam to connect downstream sites. Water quality indicators were sampled in five out of seven connection events in the Warrego Channel zone (Figure E-2a). Increases in time since connection, in days, represents the system proceeding towards a water retention phase, contraction phase and then dry in extremely dry years.

Similar to overall water temperature, Warrego zone temperature was higher in summer than in winter due to seasonal variation (Figure E-4). Environmental water did not contribute to a change in water temperature.

The pH values were consistently alkaline and had higher values with increasing time since connection (Figure E-10 and Table E-7). A high proportion of pH values (79%) were within the ANZECC guideline range below pH 8 when time since connection was less than 50 days regardless of the event (Figure E-10). This means connection events improved pH due to a dilution effect that was maintained for up to 50 days. This pattern was observed previously, with pH exceeding the guideline during a contraction period in Warrego sites. This reflected the evapoconcentration of ions due to contracting water body size, especially in warm summer conditions.

The Warrego drainage basin has naturally high turbidity level (Sheldon & Fellows, 2010) and turbidity level were consistently above the ANZECC and EHP guidelines (Table E-5). Turbidity increased with increasing time since connection, with a predictable quadratic polynomial relationship (Figure E-10 and Table E-7). It is likely that with increasing time since connection, bioturbation by organisms such as fish and benthic macroinvertebrates contributed to these high values in smaller remnant habitats (Adámek & Maršálek, 2013).

Similar to overall conductivity records, the Warrego zone conductivity was within the ANZECC and EHP water quality guidelines (Table E-4). In the Warrego zone, conductivity increased with increasing time since connection with a predictable quadratic polynomial relationship (Figure E-10 and Table E-7). This pattern was observed in the 2016-17 water year with evapoconcentration during the contraction phase causing conductivity to rise, with extremely high conductivity just before the remnant pools dried.

<u>Warrego Channel dissolved oxygen regime</u>

Dissolved oxygen levels were highly variable in the Warrego zone with no strong relationship with time since connection (Figure E-10 and Table E-7). Lower dissolved oxygen was found in the beginning of events (fewer days since connection). One possible explanation is that flushing of natural organic matter and re-wetting *in situ* organic material both depleted oxygen at a rate faster than it could be replenished (i.e. lower dissolved oxygen) due to increased metabolism (Baldwin *et al.,* 2013). Dissolved oxygen was extremely variable with increases in time since connection, reflecting differences in dissolved oxygen concentrations when sites were disconnected into pools. There were few occasions of dissolved oxygen concentrations below 5 mg/L, but no hypoxic events were observed in the project period.

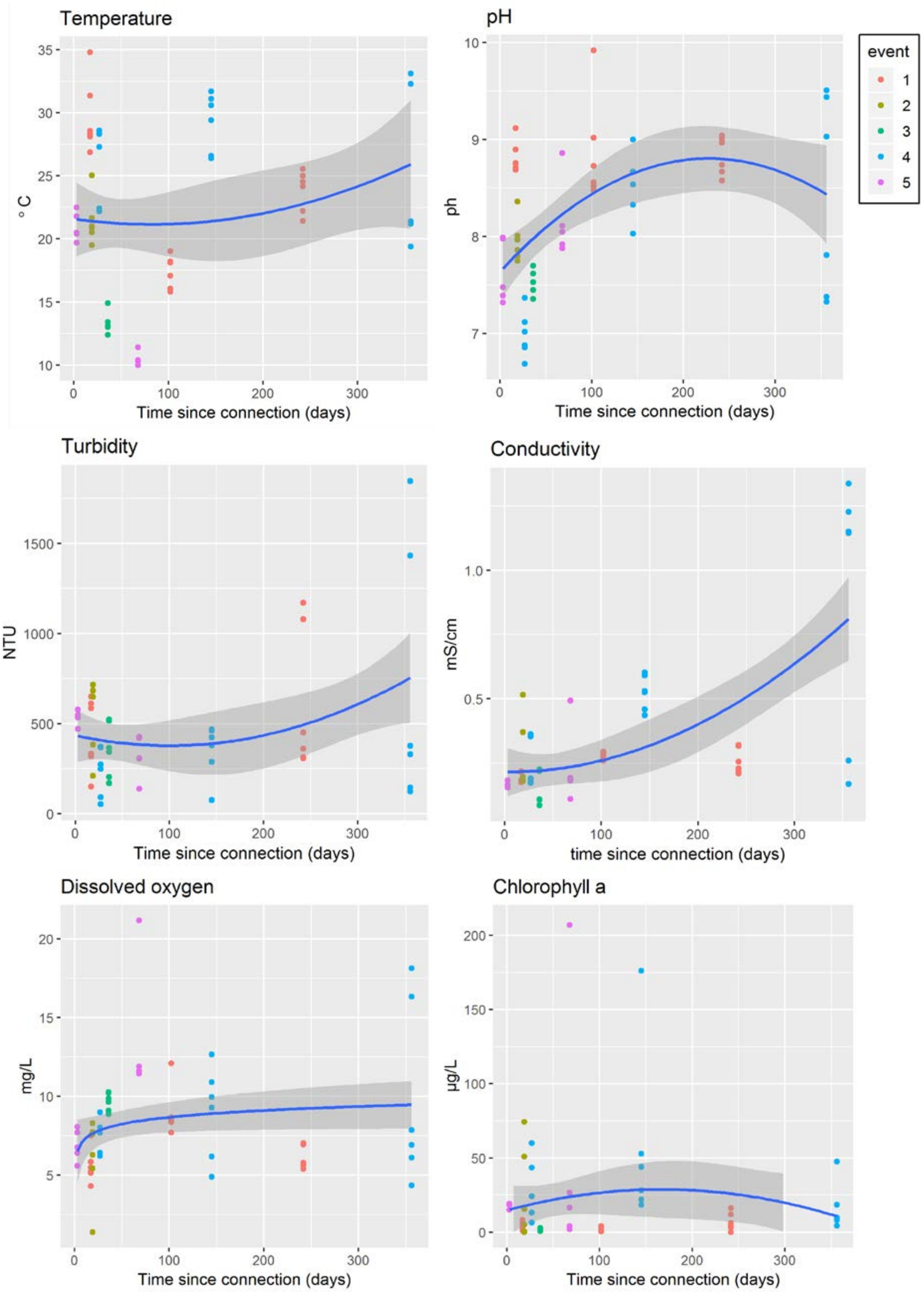

Figure E-10: Regressions between time since connection (days) and water quality (chemistry) indicators within the Warrego Channel zone.

Warrego Channel chlorophyll *a* regime

Chlorophyll *a* concentrations were consistently above the ANZECC and EHP guideline values (Table E-4). There was no strong relationship between time since connection and chlorophyll *a* concentration (Figure E-10 and Table E-7). Previous annual reports observed that chlorophyll *a* concentration was positively associated with peaks in total nitrogen and phosphorus concentrations.

Warrego Channel nutrient regime

Similar to the overall nutrient regime, Warrego zone concentrations of water nutrients (DOC, TN, TP, NOx and FRP) were consistently higher than the ANZECC and EHP guideline values (Table E-4 and Figure E-11). Dissolved organic carbon, total nitrogen and nitrate-nitrite concentrations increased with increasing time since connection with strong predictable relationships (Figure E-11 and Table E-7). Higher carbon and nutrient concentrations were observed in the 2016-17 water year within the contraction period as flows receded, suggesting the internal recycling of nutrients from the sediment and water column. There was no strong predictable relationship between time since connection and filterable reactive phosphorus (Figure E-11 and Table E-7).

Warrego Channel stream metabolism regime

A total of 15 valid stream metabolism samples from the Warrego Channel zone were reported on four sampling occasions mainly due to a low percentage of data that met the BASE model output requirements. ER rates were generally higher than GPP rates, with both the highest average GPP and ER rates around 100 days since connection (Figure E-12). NPP rates were predominantly net heterotrophic which meant the system was a carbon sink. The major reason for heterotrophy in these systems was low GPP rate and high ER rate (Figure E-12). There were strong quadratic polynomial relationships between time since connection and NPP with a single net autotrophic record of 0.24 mg O_2/L/day in Boera Dam in May 2015 (Table E-7 and Figure E-12).

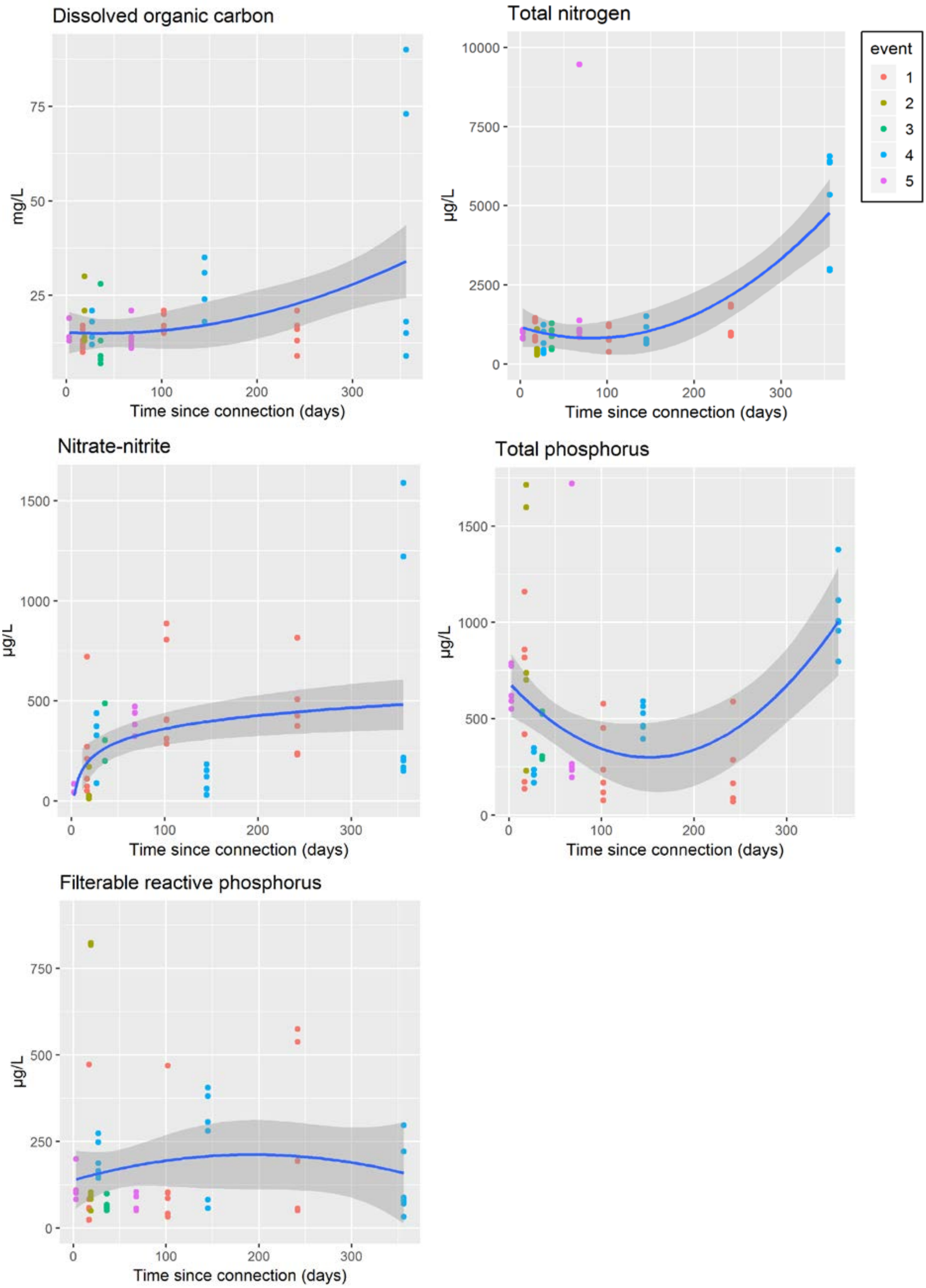

Figure E-11: Regressions between time since connection (days) and water quality (nutrient) indicators within the Warrego Channel zone.

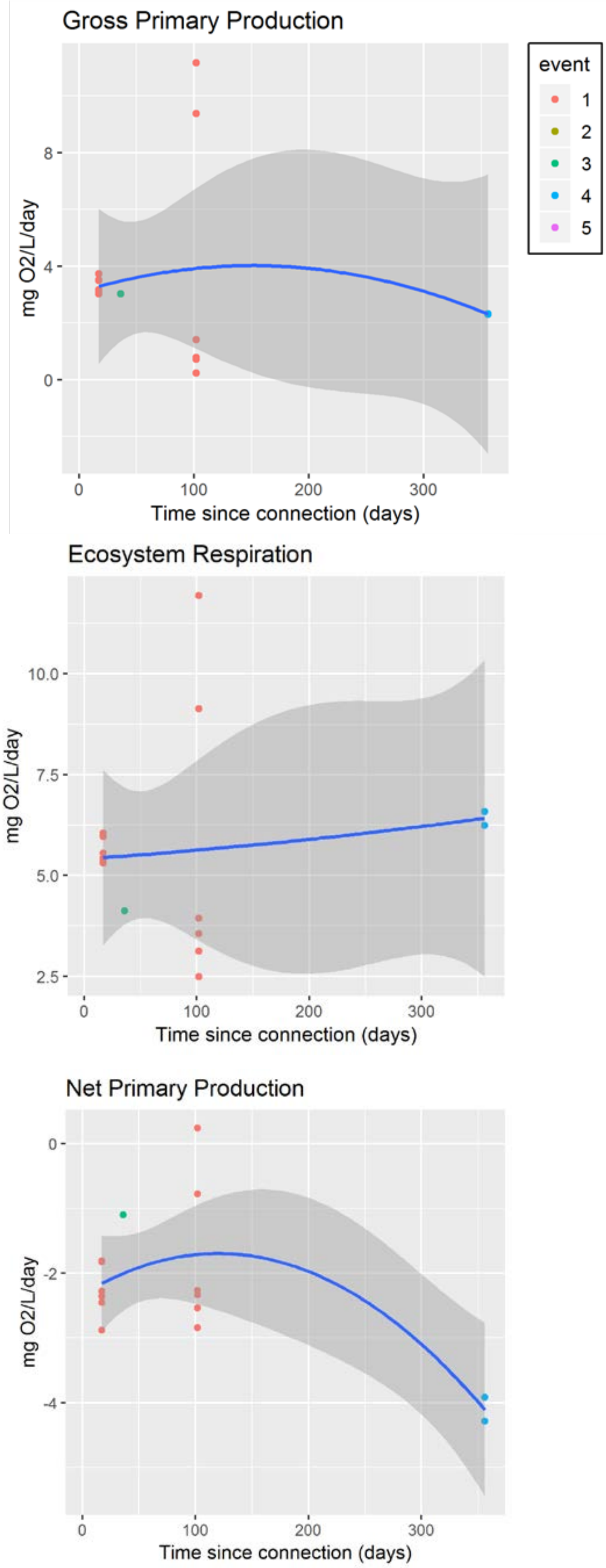

Figure E-12: Regressions between time since connection (days) and stream metabolism indicators within the Warrego Channel zone.

E.3.5 Western Floodplain zone

During the LTIM project water quality indicators were sampled in three out of five inundation events in the Western Floodplain zone (Figure E-2b). Time since inundation was calculated using days between when Boera gauge was above 2.26 m and the first day of the next sampling trip, to test the influence of three Western Floodplain inundation events in each water quality indicator. Increases in time since inundation in days represent the system proceeding through a water retention phase, contraction phase and then drying out.

Similar to overall water temperature records, the Western Floodplain zone temperature was higher in summer than in winter months as expected due to seasonal variation (Figure E-4). Environmental water did not contribute to change in water temperature in ten spots sampling.

In the Warrego Floodplain, pH values were generally alkaline and lower than those in the Darling River and Warrego Channel zones, as leachate humic acids derived from rewetted organic matter lowered the pH. There was a clear pattern in pH by event. In event 1 and 2, pH consistently exceeded the ANZECC guideline for up to 100 days since inundation (Figure E-13). In event 3, lower pH values were found after 100 days since inundation (Figure E-13). These event-based differences in pH were likely due to different antecedent flow conditions and the magnitude and duration of inundation events. This highlights the importance of long-term monitoring in highly dynamic system to allow event-based comparison. There was no strong predictable relationship between time since inundation and pH (Table E-7).

In the Western Floodplain, turbidity increased with increasing time since inundation with a predictable quadratic polynomial relationship (Figure E-13 and Table E-7). It is likely that with increasing time since connection, bioturbation by organisms such as fish and benthic macroinvertebrates contributed to these high values in smaller remnant habitats (Adámek & Maršálek, 2013).

Similar to overall conductivity records, the Western Floodplain zone conductivity was within the ANZECC and EHP water quality guidelines (Table E-4). Conductivity increased with increasing time since inundation with a predictable quadratic polynomial relationship (Figure E-13 and Table E-7). This pattern was observed in the 2016-17 water year, as evapoconcentration during the contraction phase caused conductivity to rise to extremely high concentrations just before the remnant pools dried.

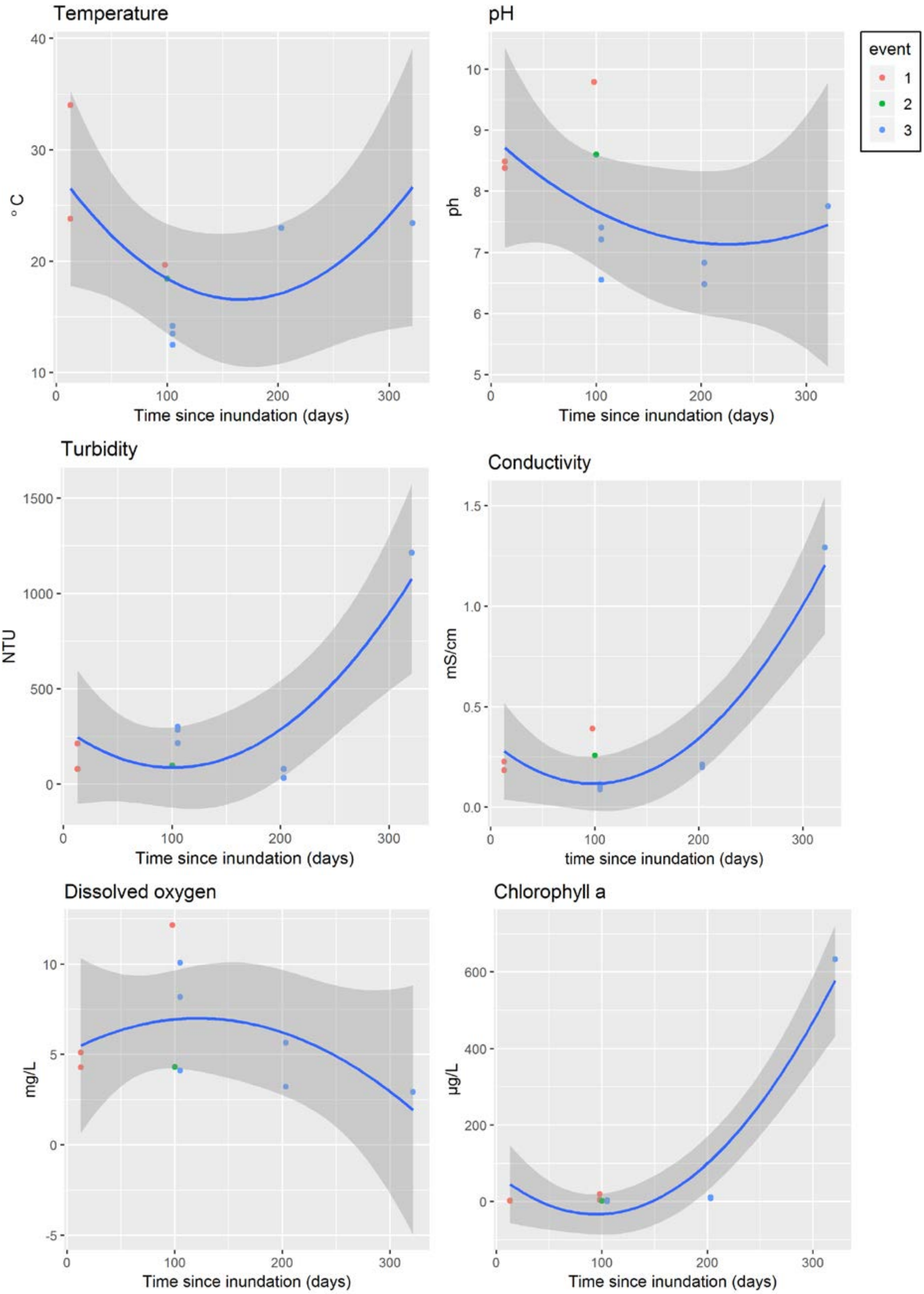

Figure E-13: Regressions between time since inundation (days) and water quality (chemistry) indicators within the Western Floodplain zone.

Dissolved oxygen levels were highly variable in the Western Floodplain zone, with no strong relationship with time since inundation (Figure E-13 and Table E-7). Dissolved oxygen concentrations below 5 mg/L were recorded in all three inundation events, with a wide range of days since inundation (Figure E-13). In event 1, low dissolved oxygen was recorded at the beginning of the event (less days since inundation) (Figure E-13), with the rewetting of *in situ* organic matter driving heterotrophic metabolism (Baldwin *et al*., 2013). In event 2, the single data point at 100 days since inundation was below 5 mg/L. In event 3, low dissolved oxygen concentrations were found between 100 and 300 days since inundation (Figure E-13). The lowest dissolved oxygen record was reported in March 2017, when sites receded to a disconnected small pool. These event-based differences in dissolved oxygen concentrations were likely driven by different antecedent flow conditions and the magnitude and duration of inundation events. No hypoxic event was observed within the project period.

Chlorophyll *a* concentrations increased with increasing time since connection, with a predictable quadratic polynomial relationship (Figure E-13 and Table E-7). The significant positive correlation was likely to be affected by a single record of exceptionally high concentration 633 µg/L at 300 days since inundation (Figure 13; March 2017), reflecting high algal concentration when the site receded to a disconnected small pool, and is associated with peaks in total nutrient concentrations.

Water column nutrient (DOC, TN, TP, NOx and FRP) concentrations were consistently higher than the ANZECC and EHP guideline values (Table E-4 and Figure E-14). Total nitrogen and total phosphorus concentrations increased with increasing time since inundation, with strong predictable relationships (Figure E-14 and Table E-7). This pattern has been consistently reported in the contraction period as flows receded, suggesting the internal recycling of nutrients from the sediment and water column. There was no strong predictable relationship between time since inundation and dissolved carbon and nutrients (Figure E-14 and Table E-7).

ER rates were generally higher than GPP rates, and NPP rates were predominantly heterotrophic which indicated the system was a carbon sink (Figure E-15). The major reason for heterotrophy in these systems was a low GPP rate and high ER rate (Figure E-15). Two net autotrophic records of 0.07 mg O_2/L/day and 9.76 mg O_2/L/day were found within the Coolibah woodland vegetation habitat in different events and at different times since inundation (Figure E-15). There was no strong predictable relationship between time since inundation and stream metabolism indicators (Table E-7).

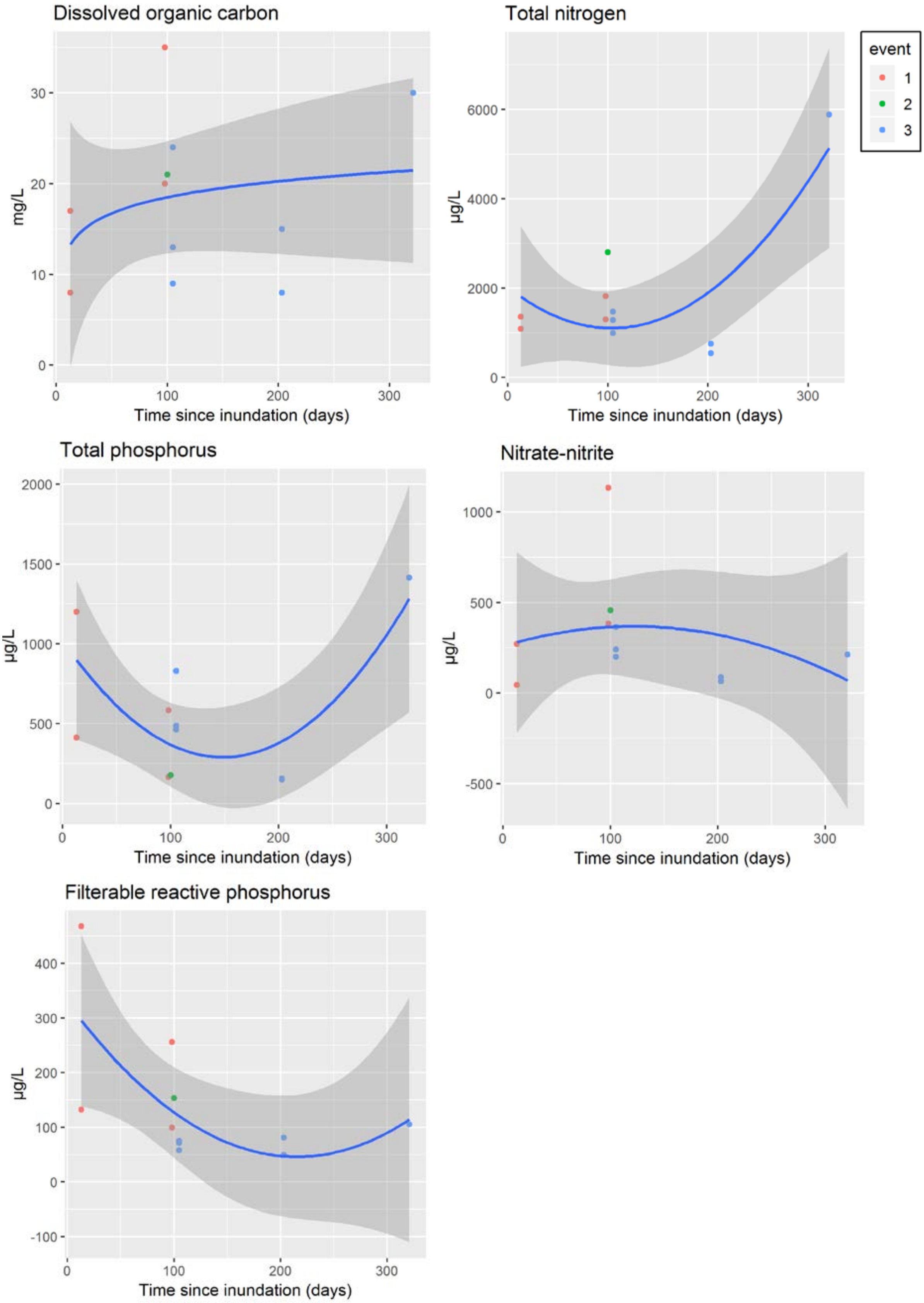

Figure E-14: Regressions between time since inundation (days) and water quality (nutrient) indicators within the Western Floodplain zone.

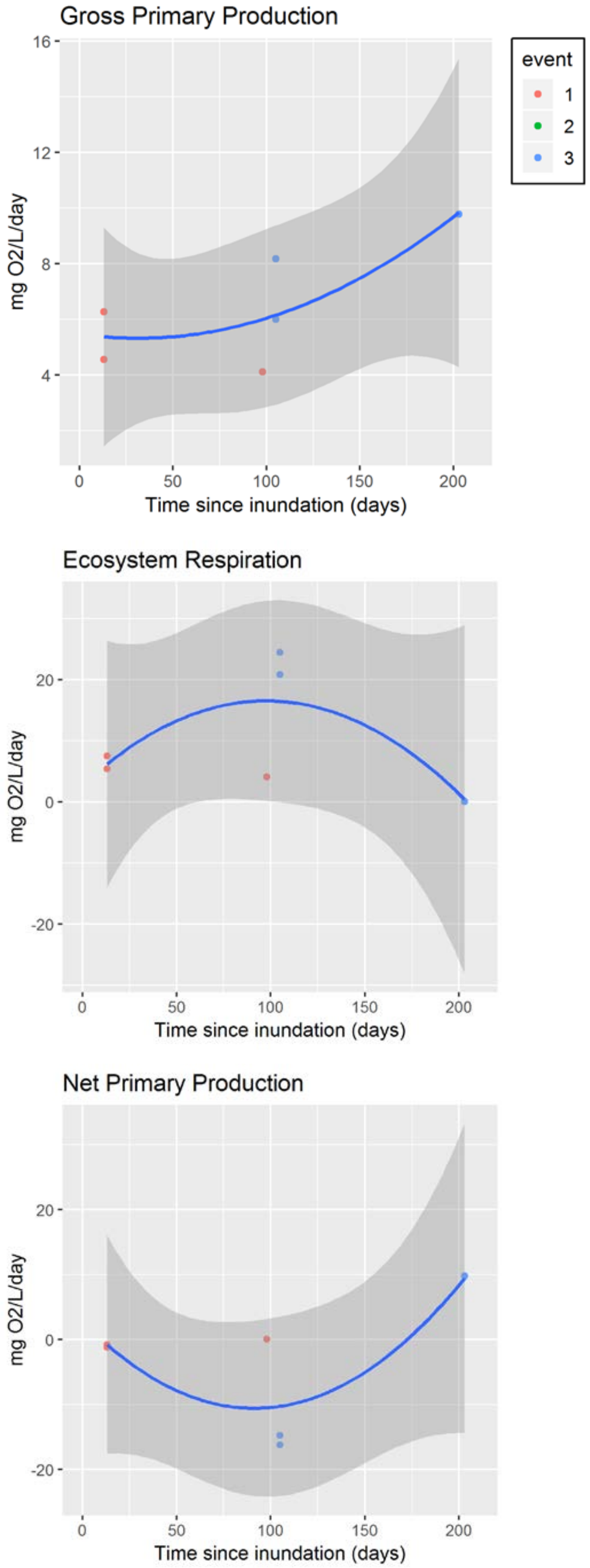

Figure E-15: Regressions between time since inundation (days) and stream metabolism indicators within the Western Floodplain zone.

E.4 Summary

Hydrology was found to be the primary driver of water quality patterns in all zones in the Warrego-Darling Selected Area during the project. Moreover, broader spatial (zone) water quality patterns were predominantly driven by catchment characteristics and landscape-scale processes, such as sediment and saline inputs.

Water temperature records were within the normal range and variation is attributed to seasonal patterns rather than flow or other environmental conditions. There was evidence, from *ad hoc* sampling, of thermal stratification in the deeper pools of the Darling River zone, but it was not enough to produce any harmful ecological impacts.

Improved pH values were found with an increase in flow variability and magnitude, augmented by environmental water events or from natural flow events due to dilution. In the Darling zone, significant improvement in pH levels were observed in the ‘wet year’ in 2016-17. In the Warrego zone, connection events improved pH that was maintained for up to 50 days from connection. The dilution effect for pH was less evident in the Western Floodplain zone, due to differences in antecedent flow condition and the magnitude and duration of inundation in each event. The pH values were consistently alkaline and occasionally exceed ANZECC guideline values.

Turbidity was naturally high and highly variable within the Warrego-Darling Selected Area. Turbidity increased with time since connection in the Warrego and Western Floodplain zone likely due to bioturbation by benthic organisms such as fish and benthic macroinvertebrates.

Conductivity levels were significantly higher in the Darling River than the Warrego Channel and Western Floodplain zones. In the Darling River, increased flow variability and magnitude augmented by environmental water lowered conductivity reflecting a dilution effect provided by higher discharge. In the Warrego Channel and Western Floodplain zones, conductivity increased with increasing time since connection due to evapoconcentration during the contraction phase.

Dissolved oxygen levels were highly variable with no strong relationship with hydrological factors. It is likely that seasonal change in temperature exerted a strong influence on dissolved oxygen. In the Warrego Channel and Western Floodplain zones, dissolved oxygen was extremely variable with increases in time since connection, reflecting differences in dissolved oxygen concentrations when sites were disconnected into pools. Low dissolved oxygen concentrations of below 5 mg/L were recorded but no hypoxic event was observed in LTIM records.

Chlorophyll *a* concentrations were consistently higher than the ANZECC guideline value and similar to the EHP guideline value. In the Darling River, discharge around 4,000 ML/d may inundate low lying in-channel features such as bars, and transport nutrients to stimulate primary production, measured as chlorophyll a concentrations. In the Warrego Channel and Western Floodplain, high levels of algal production in the water column tended to occur in the contraction phases and was positively associated with peaks in total nitrogen and phosphorus concentrations.

Five measured nutrient (DOC, TN, TP, NOx and FRP) concentrations were consistently higher than the ANZECC and EHP guideline values. In the Darling River, there was no strong predictable relationship with discharge.

Dissolved organic carbon, total nitrogen and nitrate-nitrite concentrations increased with increasing time since connection in the Warrego Channel zone, while total nitrogen and total phosphorus concentrations increased with increasing time since inundation in the Western Floodplain zone. It is suggested that the internal recycling of nutrients from the sediment and water column occurred in the contraction period as flows receded.

Stream metabolism was predominantly net heterotrophic with very few net autotrophic records. The major reason for heterotrophy in these systems was a low rate of gross primary production and high ecosystem respiration rates. Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which organic matter is colonised by microbes and fungi or consumed by detritivores. In the Warrego Channel and Western Floodplain zones, a shift from net heterotrophy to net autotrophy was driven by internal nutrient cycling boosting primary production with prolonged inundation and water retention in summer with high ambient water temperature.

Water quality monitoring should be undertaken regularly as an alert for potential water quality issues. In this case, the relationship between conductivity, turbidity and chlorophyll *a* concentrations need further investigation. Inter-annual hydrological variability and antecedent flow conditions could play an important role in water quality variability, highlighting the importance of long-term monitoring in a highly dynamic system to allow multi-year comparison.

E.5 References

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Appendix F Stream Metabolism

F.1 Introduction

The Category I Stream Metabolism indicator aimed to assess the contribution of Commonwealth environmental water to the improved water quality in the Darling River within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). As such this indicator is linked to Hydrology (River, Northern Tributaries) and Water Quality indicators. Two specific questions were addressed through this indicator in the Darling River zone during 2015-19:

- What did Commonwealth environmental water contribute to patterns and rates of primary productivity?
- What did Commonwealth environmental water contribute to patterns and rates of decomposition?

F.2 Methods

Stream metabolism indicators were monitored at two stations with permanent surface water in the Darling River. The Darling upstream site is located near Yanda homestead, and all Commonwealth environmental water derived in the upstream tributaries of the Darling Basin (except the Warrego River) passes through this reach (Figure F-1 and Table F-1). The Darling downstream station is downstream of the confluence of the Warrego and Darling Rivers, near Akuna homestead (Figure F-1). As such, the Darling downstream station is used to assess the influence of Warrego River flows on water chemistry of the Darling River.

Continuous monitoring of temperature (°C) and dissolved oxygen (% saturation) occurs at the Yanda and Akuna stations using Hydrolab DS5-X loggers set to read at 10-minute intervals. Each logger was mounted to a floating pontoon to ensure it was kept under the water but away from obstructions. All data was downloaded during each visit, or periodically by NPWS staff. Due to power supply problems, instrument failure at both sites, and the permanent loss of the instrument in the Darling upstream station, datasets were partly discontinuous, espetially in the first several years of the project.

From the 2016-17 water year, two additional PME miniDOT loggers were installed to monitor temperature and dissolved oxygen concentration: one logger was installed at microinvertebrates site Darling Pump (DARPUMP) to replace the lost Hydrolab DS5-X logger at the Darling upstream station, and another logger was placed in the Darling downstream station to ensure data continuity and comparability (Figure F-1). Each water quality variable was logged at 10-minute intervals. Photosynthetically active radiation (PAR) and barometric pressure were also logged at 10-minute intervals.

Daily rates of gross primary production (GPP), ecosystem respiration (ER) and net primary production (NPP) were calculated using the BASE2 modelling package (Grace *et al.* 2015). In 2017-18, a new metric was developed to estimate the amount of organic carbon produced per day per one-kilometre stream reach (kg C/km/day). This metric multiplied the daily rate of GPP (mg O_2/L/day) by the cross-sectional stream area (m^2) at the nearest gauge station with a conversion factor of 12/32 to convert oxygen gas (O_2) molecular mass to carbon (C) atomic mass. Water nutrient samples (Category I) are collected at approximately 6-weekly intervals throughout the project and analysed at the NATA accredited Environmental Analytical Laboratories at Southern Cross University (Table F-1).

Discharge data was collated from the Darling @ D/S Weir 19a (NSW425037) gauge for the Darling upstream station and Darling @ Louth (NSW425004) gauge for the Darling downstream station.

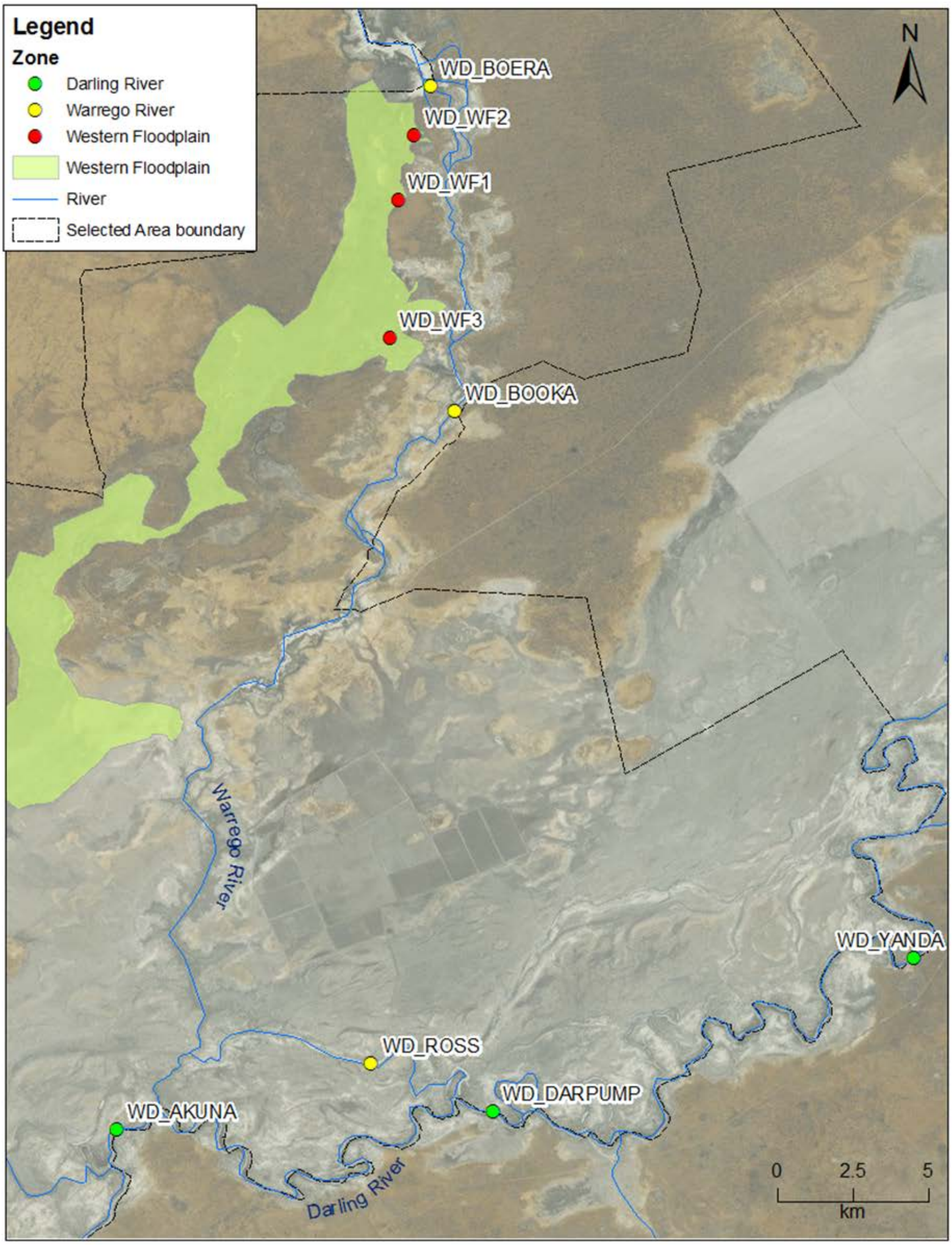


Figure F-1: Location of three long-term water quality monitoring stations (Cat I) in the Darling River within the Warrego-Darling Selected Area. WD_DARPUMP (2017-19) and WD_YANDA (2014-17) are the upstream stations and WD_AKUNA is the downstream station.

Table F-1: Category I Water Quality indicators measured two stations in 2015-19.

Indicators	Variables		Units	Code
Stream metabolism	i.	Gross Primary Production	mg O_2/L/day	GPP
	ii.	Ecosystem Respiration	mg O_2/L/day	ER
	iii.	Net Primary Production	mg O_2/L/day	NPP
Water nutrients	i.	Dissolved Organic Carbon	mg/L	DOC
	ii.	Total Nitrogen	mg/L	tn
	iii.	Total Phosphorus	mg/L	tp
	iv.	Nitrate-nitrite	mg/L	NOx
	v.	Ammonium	mg/L	-
	vi.	Filterable Reactive Phosphorus	mg/L	frp

Table F-2: Environmental water (EW) events in the Darling River during the LTIM Project (2014-19).

EW event	Water Year	Event	Start date	End date	Flow (ML)		
					Total	EW	EW%
1	2014-15	Event 1	1/02/2015	25/03/2015	37,390	9,593	25.7
2		Event 2	26/04/2015	7/06/2015	28,529	1,135	4.0
3	2015-16	Event 1	2/07/2015	30/10/2015	56,324	2,824	5.0
4		Event 2	2/11/2015	10/12/2015	12,589	428	3.4
5		Event 3	31/01/2016	25/03/2016	22,098	6,621	30.0
6	2016-17	Event 1	20/06/2016	30/07/2016	129,820	7,818	6.0
7		Event 2	2/08/2016	8/09/2016	171,909	3,102	1.8
8		Event 3	11/09/2016	25/12/2016	1,772,486	42,228	2.4
9		Event 4	21/04/2017	17/05/2017	44,161	16,101	36.5
10	2017-18	Event 1	14/10/2017	29/11/2017	50,514	21,669	42.9
11		Event 2	26/03/2018	29/04/2018	14,157	3,446	24.3
12		Event 3	25/05/2018	26/06/2018	13,385	13,332	99.6
13	2018-19	Event 1	23/04/2019	1/06/2019	23,364	2,624	11.2

F.3 Results and Discussion

Hydrological patterns

Throughout the LTIM project, 13 in-channel flow pulses containing environmental water were recorded and used to examine responses in water quality parameters (Table F-2 and Figure F-2). The contributions of environmental water in each in-channel flow pulse event ranged from 1.8% to 99.6%, and were sourced from various upstream tributaries (Table F-2; Appendix C). In the northern Murray-Darling Basin, seasonal variation also leads to higher long-term average annual rainfall during summer months and, therefore, higher hydrological variability in summer in contrast to the southern Basin.

The Darling River upstream and downstream stations exhibited similar discharge magnitudes, with a short time lag for the downstream station (Figure F-2). The magnitude of flow events in 2016-17 (‘wet year’; a bankfull event with peak flow around 39,000 ML/d; events 6, 7 and 8) was much higher than other years (‘dry year’), due to high rainfall in the upstream Barwon and Darling catchments. All other flow events were in-channel fresh events with peak flow of less than 5,000 ML/d (Table F-2). Water quality indicators were highly variable during the monitoring program in response to a large range of event volumes.

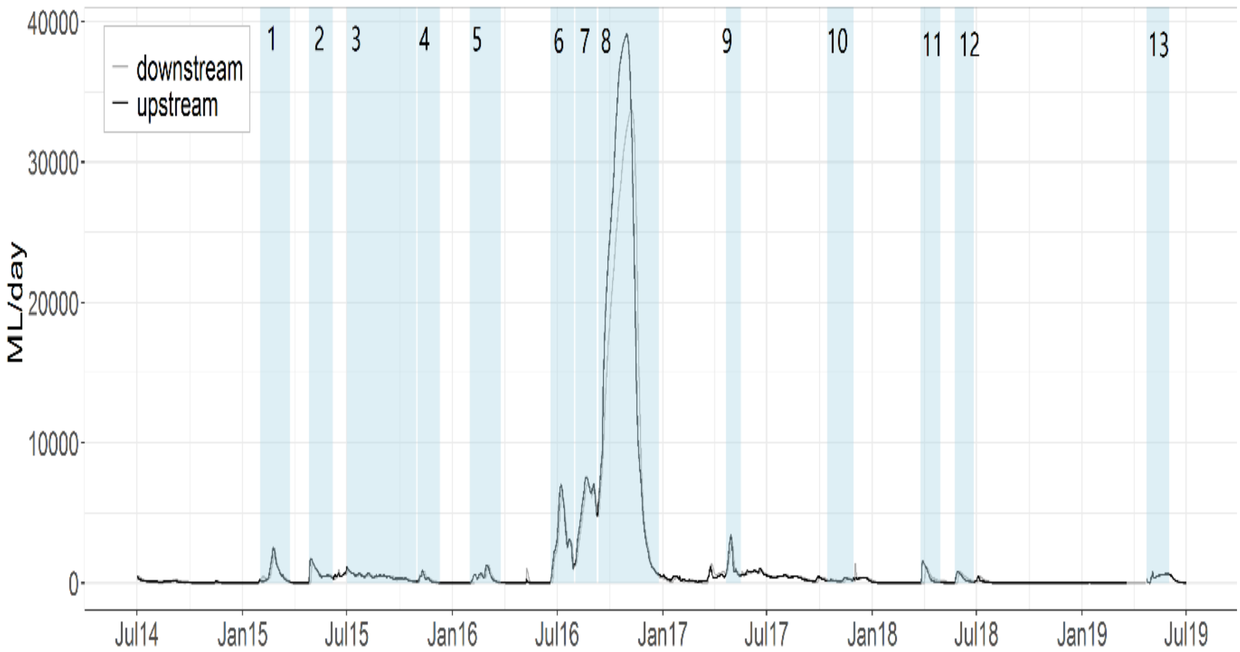


Figure F-2: Mean daily discharge (ML/d) at upstream station (Darling @ D/S Weir 19a (NSW425037)) and downstream station (Darling @ Louth (NSW425004)) with shaded areas representing 13 EW events details in Table F-2.

Stream metabolism regime

A total of 351 valid daily stream metabolism records were recorded from the Darling River stations. The low number of valid records was due to a low percentage of data that met the BASE model output requirements in the Standard Operating Procedure (Commonwealth of Australia, 2017). Stream metabolism rates were highly variable at both stations in the Darling River (Figure F-3 and Table F-3). The highest GPP and ER rates were recorded at the downstream station in March 2019, associated with high algal production and high total nitrogen concentrations in the water column during an extended low flow period.

Generally, the Darling River zone was a carbon sink during the project period (2014-2019), with more net carbon consumed than produced, reflected as negative NPP (Figure F-3). The major reason for heterotrophy in this system was consistently low rates of GPP, linked to low chlorophyll *a* concentrations, and high rates of ER, fuelled by dissolved organic matter and respiring algae (Figure F-3). Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which organic matter is colonised by microbes and fungi or consumed by detritivores that then fuel the invertebrate, fish and waterbird food webs (Kobayashi *et al.*, 2009).

GPP rates increased with increasing in-stream total nitrogen and chlorophyll *a* concentrations (Figure F-4). This positive correlation was mainly driven by high total nitrogen and chlorophyll *a* concentrations in two downstream records. GPP rates also increased with increasing temperature, with rates consistently above 5 mg/O_2/L/day when temperature was above 24 °C. Moreover, GPP rates were highly variable during base flow conditions and were constrained to below 5 mg/O_2/L/day when discharge was above 150 ML/d (Figure F-4). This means flow events generally led to a lower net carbon production. GPP rates also fell in higher turbidity from decreased light penetration. Above 100 NTU, GPP rates generally dropped to below 5 mg/O_2/L/day (Figure F-4). This indicates that primary production rates were predominantly affected by the decline in available light (Figure F-4; Appendix D), nutrient availability and in-stream temperature. Metabolism indicators appear to respond to change in specific thresholds in discharge, rather than following a linear trend. The relationship between discharge and turbidity, the effect of flocculation, and the complex interactions between conductivity, turbidity and chlorophyll *a* concentrations observed in the Warrego-Darling Selected Area need further investigation.

The Darling downstream station generally had lower metabolism rates than the upstream station when comparing all available records around similar periods (Figure F-3). Additional water quality sampling in the 2016-17 peak flow event showed a dilution effect in pH, conductivity, chlorophyll *a* and total nitrogen concentrations that was caused by Warrego River inflow during the connection event. The effect of Warrego–Darling connection on stream metabolism and water quality patterns needs further investigation, as the LTIM Project does not have similar temporally intensive data to compare the condition.

Table F-3: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each stream metabolism indicators at two stations between 2015 and 2019 within the Warrego-Darling Selected Area.

Indicator	Station	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
GPP	Up	0.00	1.42	4.57	7.66	26.19	154
	Down	0.02	0.55	1.83	6.02	35.93	197
ER	Up	0.03	1.60	7.06	16.67	47.03	154
	Down	0.00	0.40	2.90	7.81	115.30	197
NPP	Up	-23.23	-9.62	-0.98	0.79	25.23	154
	Down	-79.33	-3.70	-0.55	0.53	8.12	197

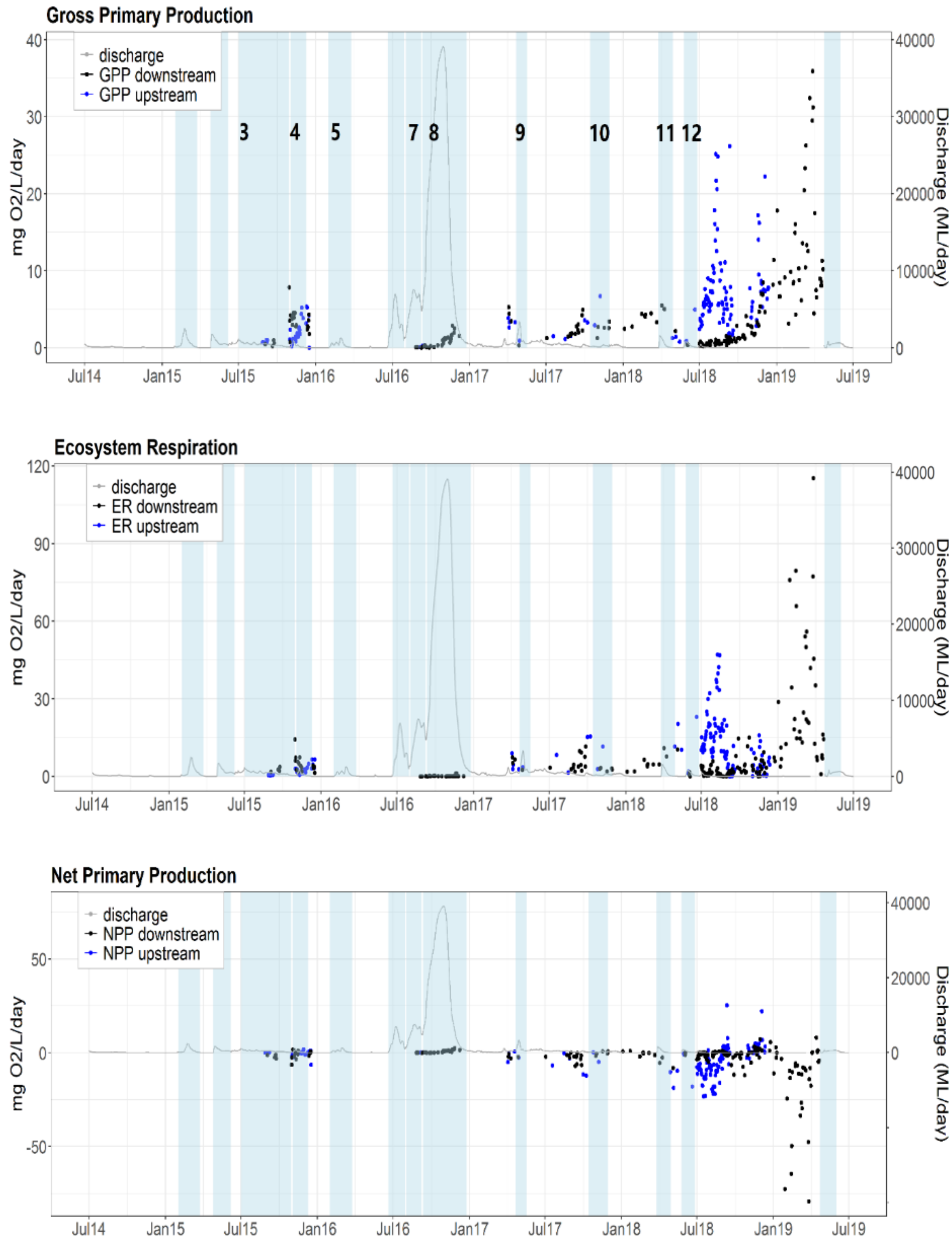


Figure F-3: Daily GPP, ER and NPP at two Darling River sites with black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station. Shaded areas representing 13 EW events details in Table F-2.

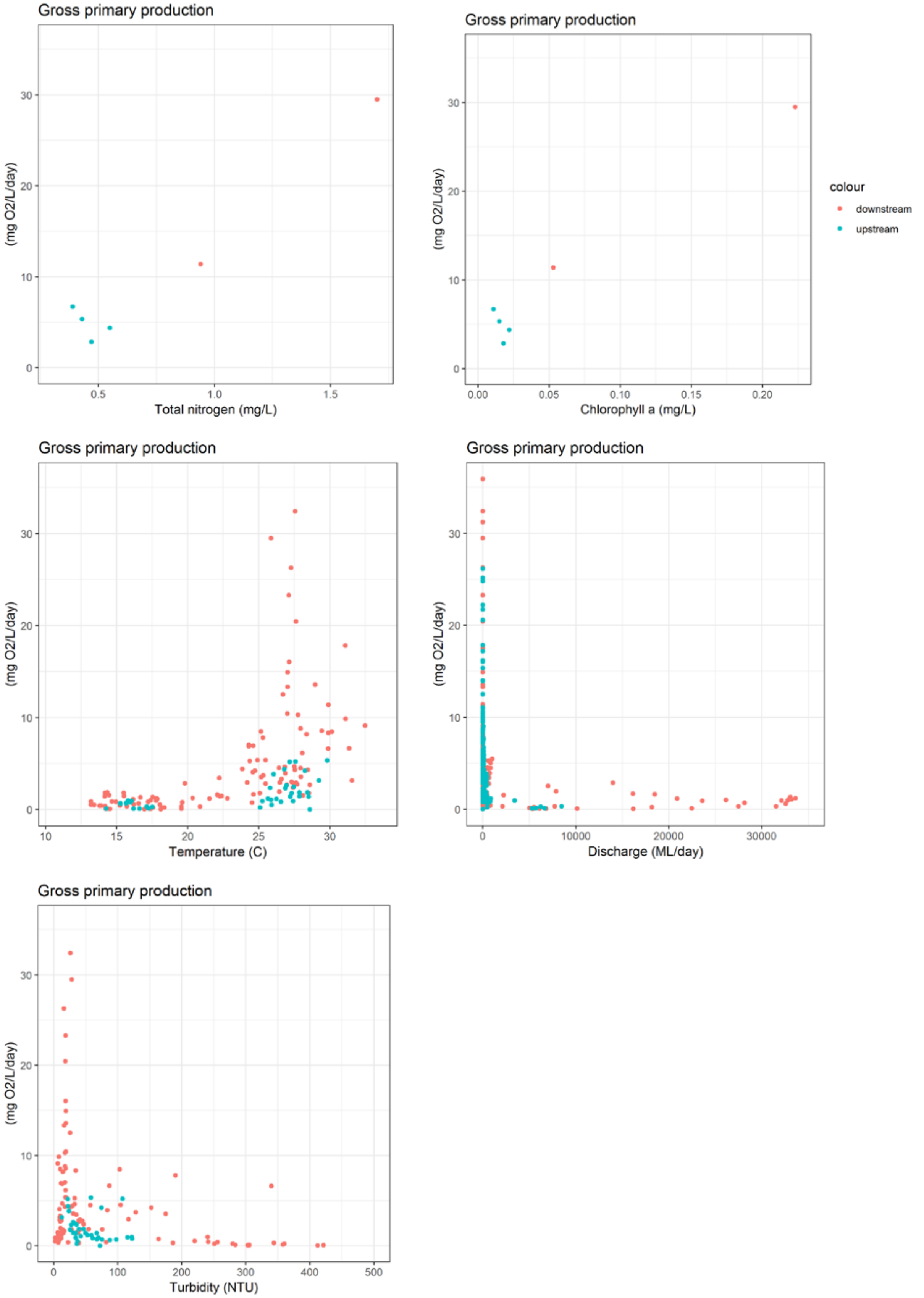
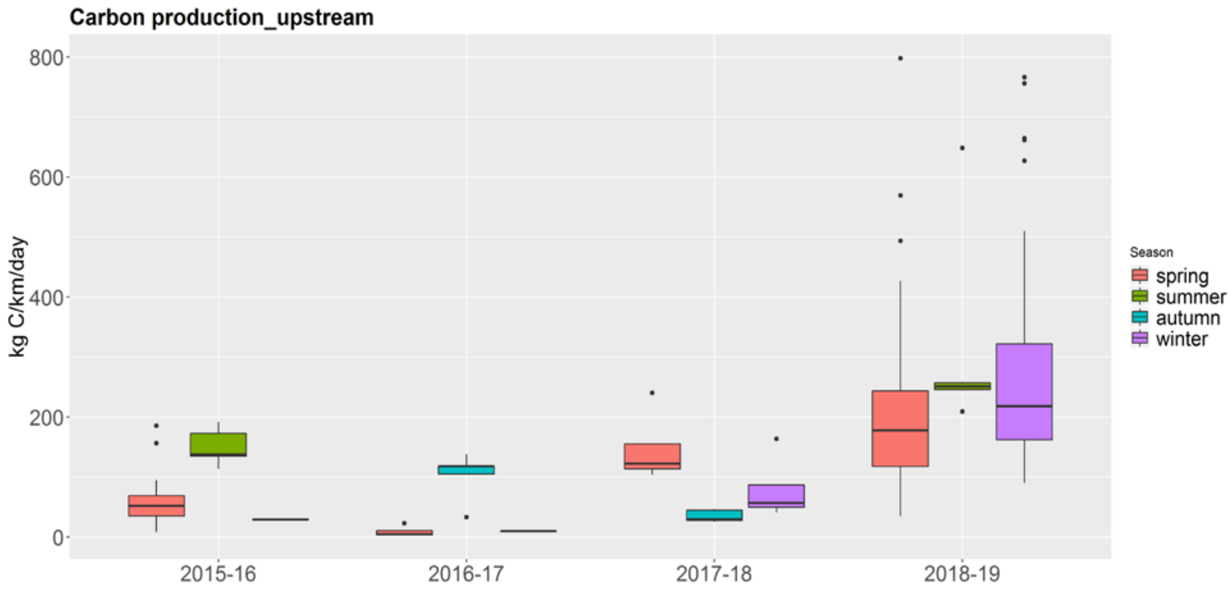


Figure F-4: Regressions between GPP and environmental variables within the Warrego-Darling Selected Area in 2015-19.

Carbon production

The estimated amount of carbon produced ranged from 3.2 to 1,000 kg C/km/day assuming 100% efficiency in the conversion of oxygen to carbon (Figure F-5). Seasonal change in temperature exerts a strong influence on carbon production with generally lower carbon production in winter (Figure F-5). In 2018-19, carbon production per unit area was higher than other years. Total carbon production during each event in the Warrego-Darling Selected Area was calculated using percentage of environmental water contribution of total flow (Table F-4 and Figure F-6). The Darling downstream station generally had higher carbon production than the upstream station due to larger channel volume, thus more carbon was produced (Table F-4). In 2015-17, there was less carbon produced from the environmental water contribution because the proportion of environmental water in those flow events was smaller (Figure F-6). In 2017-19 (events 10-13), more carbon production was supported by environmental water (Figure F-6).



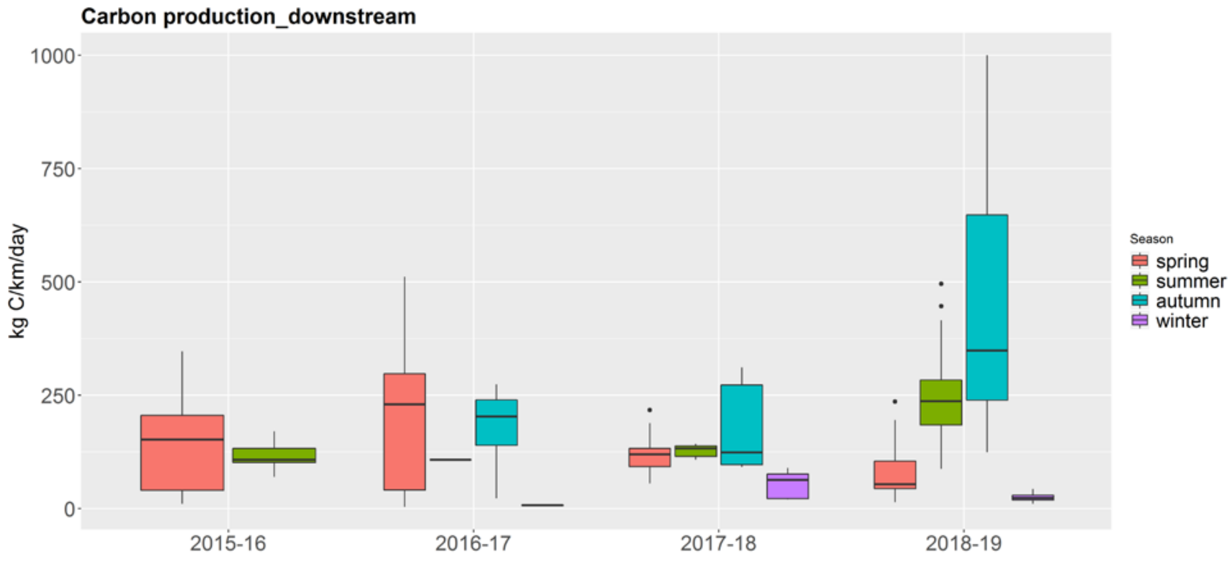


Figure F-5: Boxplot of carbon production within the Warrego-Darling Selected Area in 2015-19.

Table F-4: Average carbon production (kg C/km/day) of each environmental water (EW) event at two stations between 2015 and 2019 in the Warrego-Darling Selected Area.

EW event	Event	Upstream carbon production			Downstream carbon production		
		Total	EW contribution	n	Total	EW contribution	n
3	2015-16_EW1	30.64	1.53	7	26.58	1.33	4
4	2015-16_EW2	68.99	2.35	22	188.05	6.39	11
5	2015-16_EW3	-	-	-	-	-	-
6	2016-17_EW1	-	-	-	-	-	-
7	2016-17_EW2	5.62	0.1	3	6.06	0.11	3
8	2016-17_EW3	13.01	0.31	3	196.95	4.69	26
9	2016-17_EW4	33.28	12.13	1	22.61	8.24	1
10	2017-18_EW1	-	-		136.18	58.42	3
11	2017-18_EW2	-	-	-	292.25	71.13	2
12	2017-18_EW3	73.69	73.39	3	21.44	21.36	3
13	2018-19_EW1	-	-	-	283.65	31.85	1

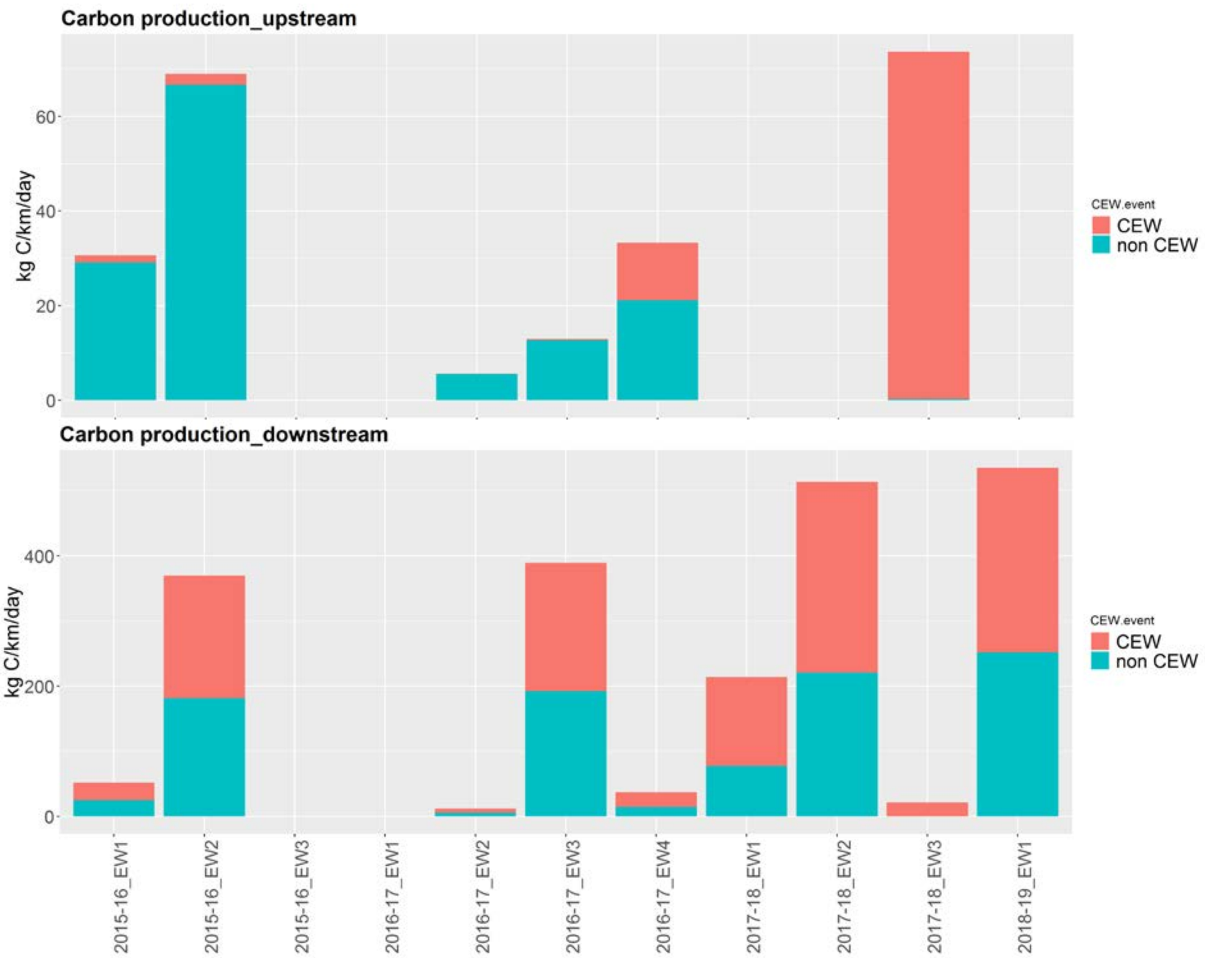


Figure F-6: Stalked boxplot of carbon production (kg C/km/day) of each environmental water (EW) event at two stations between 2015 and 2019 in the Warrego-Darling Selected Area.

Water nutrients

A total of 45 Category I water nutrient records (20 from upstream and 25 from downstream) were recorded from two Darling River stations (Table F-5). All nutrient concentrations were highly variable at both stations in the Darling River and were higher than the ANZECC guideline values on most occasions (Table F-5, Figure F-7 and Figure F-8).

All nutrient concentrations were highly variable during base flow and low flow conditions (discharge <500 ML/d; Figure F-9 and Figure F-10). The highest total nitrogen concentration occurred at the downstream station in March 2019, associated with high algal production in the water column during an extended low flow period after event 12. It is likely that increased total nitrogen was due to internal recycling of nutrients from the sediment and water column during the contraction period as flow receded. In contrast, the highest total and dissolved carbon and phosphorus concentrations were found at the downstream station in August 2016 during event 7, likely due to the delivery of carbon and phosphorus from inflow with increasing discharge. However, there was no clear correlation between the measured nutrient indicators and discharge. Nutrient indicators appear to respond to change in discharge thresholds, rather than following a linear trend. The relationship between water nutrients and discharge patterns need further investigation, as the LTIM project did not capture a wide range of discharge variability in Category I water nutrient samples.

Table F-5: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water nutrient indicators at two stations between 2015 and 2019 in the Warrego-Darling Selected Area.

Indicator (mg/L)	ANZECC (mg/L)	Station	Minimum	Percentile			Maximum	Number of samples
				20th	50th	80th		
Total Nitrogen	0.50	Up	0.390	0.464	0.545	0.680	0.860	20
		Down	0.310	0.456	0.520	0.796	1.700	25
Nitrate-nitrite	0.04	Up	0.000	0.000	0.003	0.007	0.390	20
		Down	0.000	0.000	0.000	0.007	0.154	25
Ammonium	0.02	Up	0.000	0.006	0.021	0.046	0.055	20
		Down	0.000	0.007	0.020	0.046	0.102	25
Total Phosphorus	0.05	Up	0.050	0.060	0.080	0.120	0.180	20
		Down	0.030	0.050	0.090	0.156	0.230	25
Filterable Reactive Phosphorus	0.02	Up	0.011	0.015	0.024	0.036	0.075	20
		Down	0.007	0.016	0.027	0.039	0.093	25
Dissolved Organic Carbon	-	Up	5.60	7.54	8.25	9.30	10.50	20
		Down	5.60	8.12	9.60	11.30	12.70	25
Chlorophyll *a*	0.005	Up	0.008	0.013	0.019	0.034	0.062	20
		Down	0.002	0.011	0.025	0.036	0.223	25

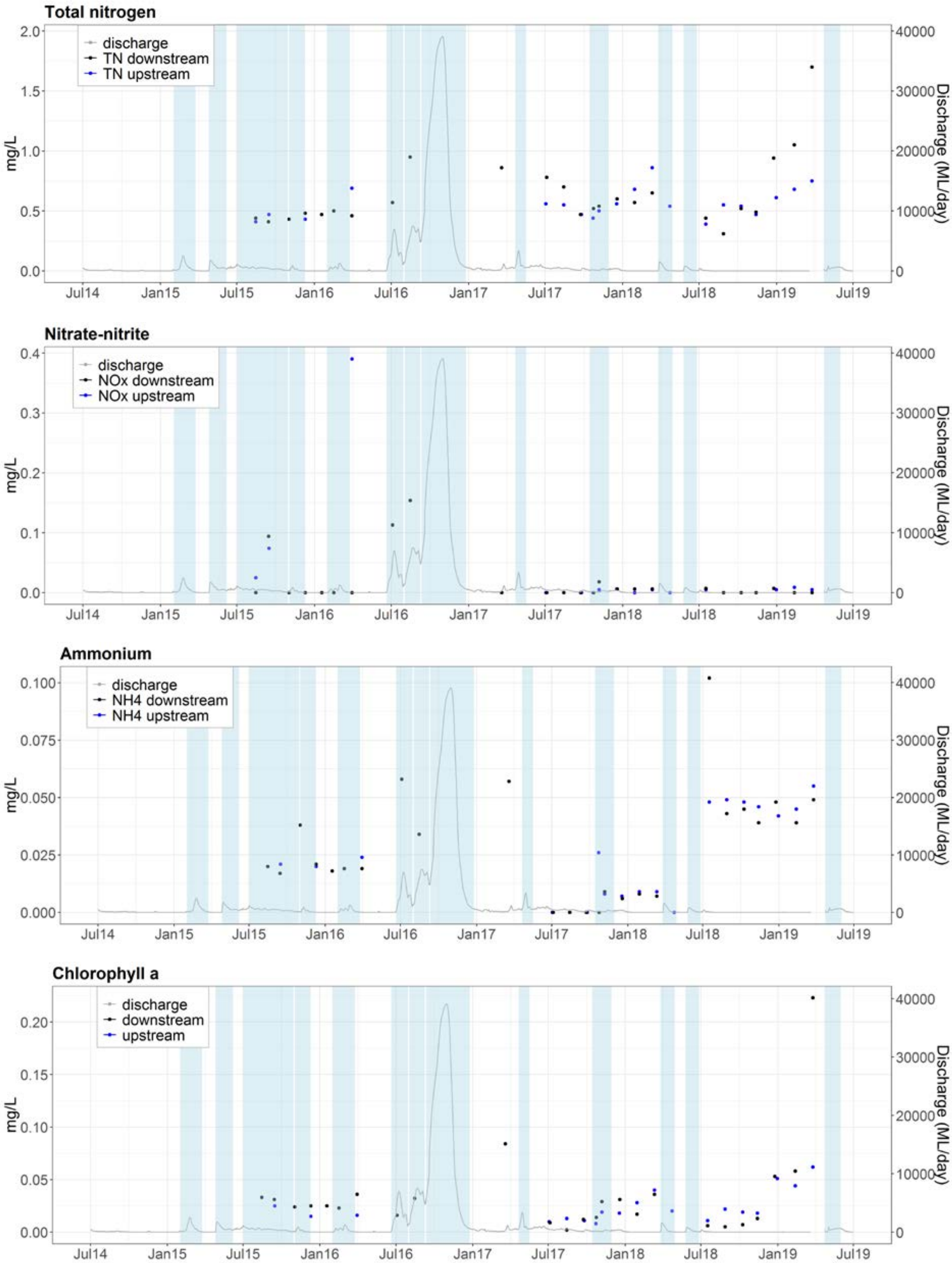


Figure F-7: Category I water nutrient concentrations at two Darling stations. Black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station.

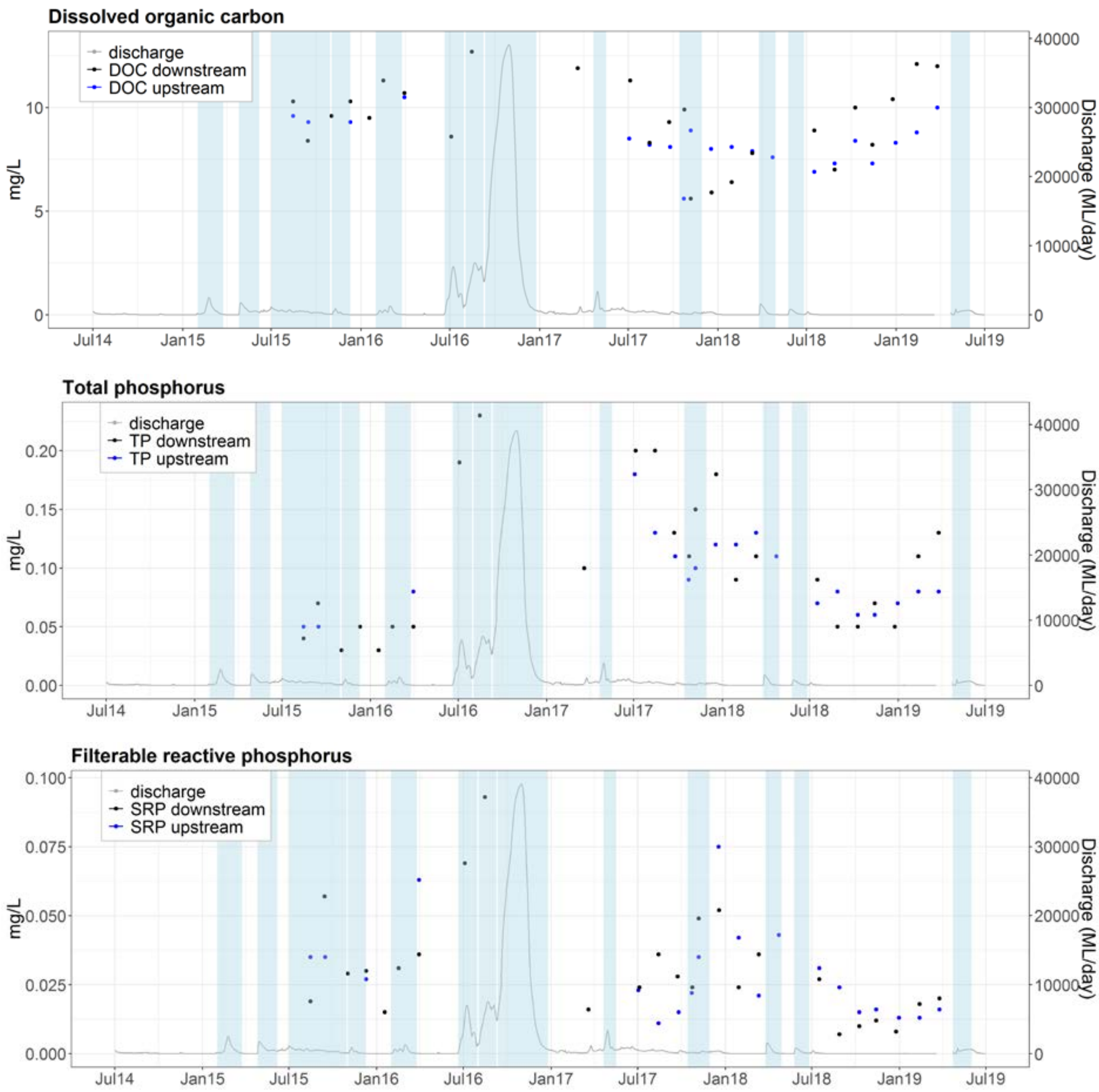


Figure F-8: Category I water nutrient concentrations at two Darling stations. Black line represents discharge at Darling @ D/S Weir 19a (NSW425037) near the upstream station.

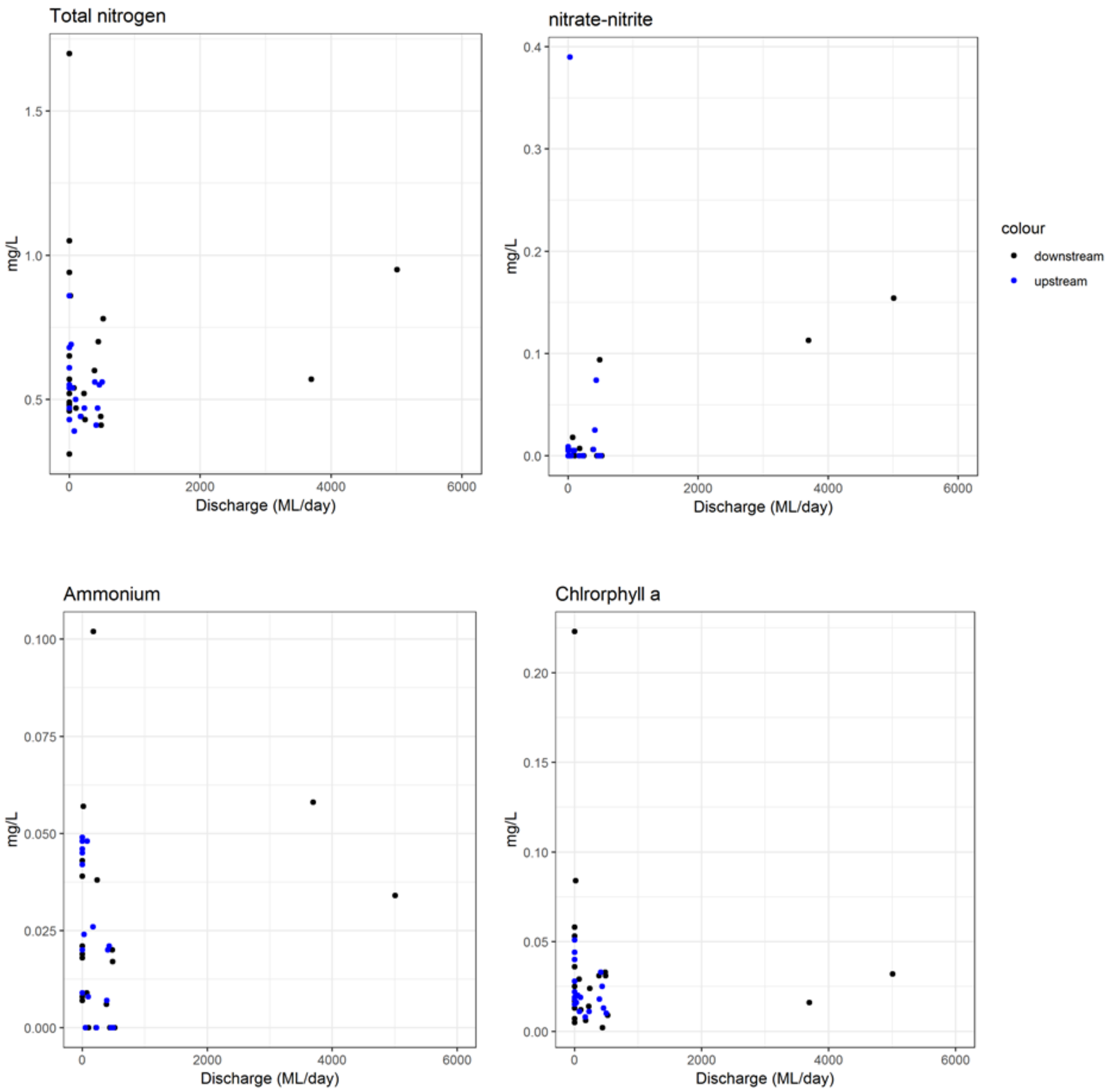


Figure F-9: Regressions between discharge and Category I water nutrient indicators in the Warrego-Darling Selected Area between 2015 and 2019.

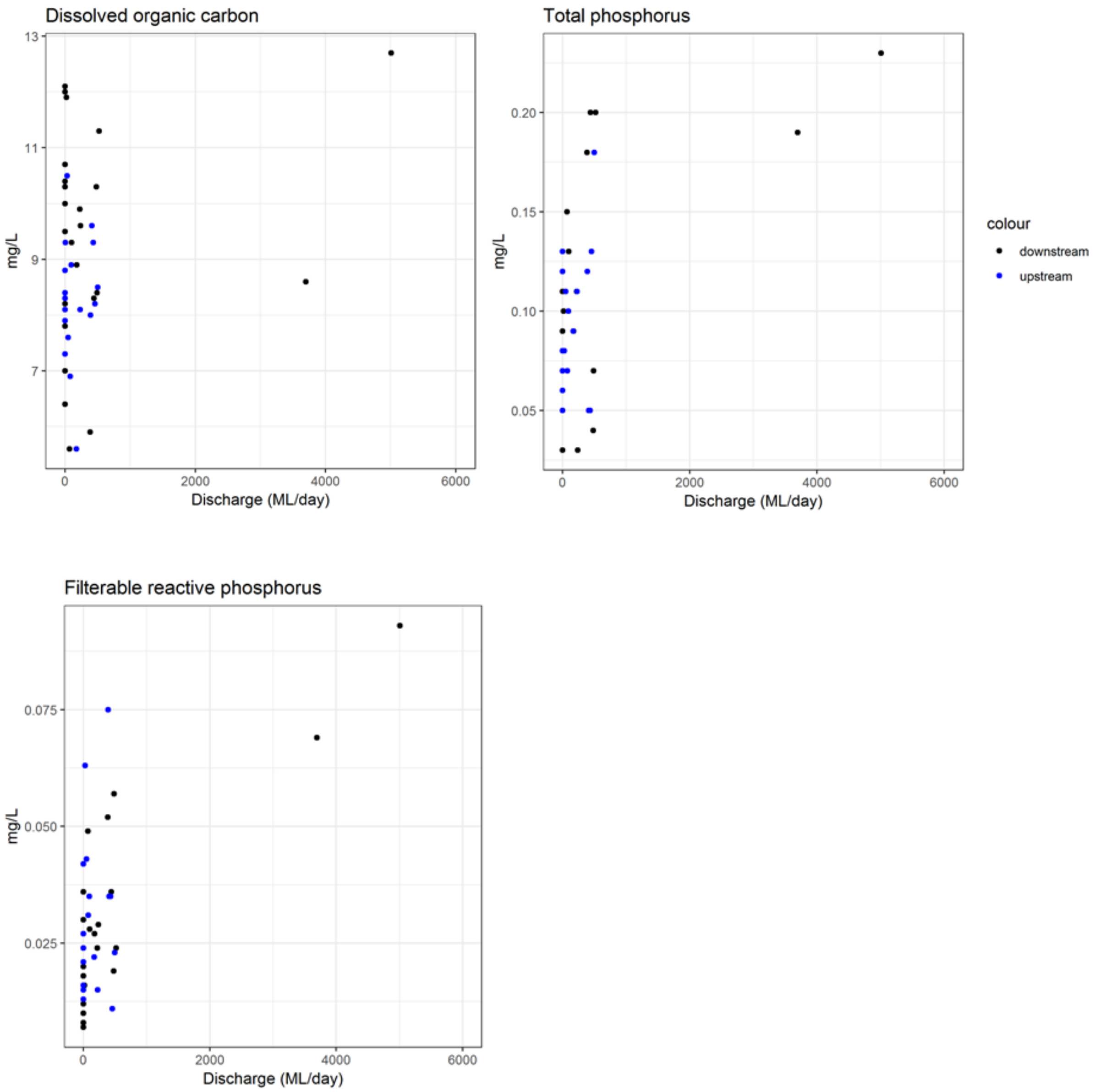


Figure F-10: Regressions between discharge and Category I water nutrient indicators in the Warrego-Darling Selected Area between 2015 and 2019.

F.4 Conclusion

Stream metabolism rates were highly variable at both stations in the Darling River. GPP rates increased with increasing in-stream total nitrogen and chlorophyll *a* concentrations. This reflects primary productivity rates that were predominantly driven by nutrient availability and temperature. On the other hand, increases in discharge and turbidity are likely to have limited GPP rates. It is proposed that metabolism indicators respond to discharge thresholds rather than following a simple linear trend. The relationship between discharge and turbidity, the effect of flocculation and complex interactions between conductivity, turbidity and chlorophyll *a* concentrations were observed. These interactions require further study under a range of flow conditions.

Generally, the Darling River zone was a carbon sink. The major reason for heterotrophy in this system was the low GPP rate and high ER rate. Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which organic matter is colonised by microbes and fungi or consumed by detritivores that then fuel the invertebrate, fish and waterbird food webs (Kobayashi *et al.,* 2009).

F.5 References

Commonwealth of Australia. 2017. Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area - 2016-17 Final Evaluation Report. Commonwealth of Australia: Commonwealth of Australia.

Kobayashi, T., Ryder, D. S., Gordon, G., Shannon, I., Ingleton, T., Carpenter, M., & Jacobs, S. J. (2009). Short-term response of nutrients, carbon and planktonic microbial communities to floodplain wetland inundation. Aquatic Ecology, 43(4), 843-858. doi:10.1007/s10452-008-9219-2

Appendix G Microinvertebrates

G.1 Introduction

The Microinvertebrate indicator aimed to assess the contribution of Commonwealth environmental water to microinvertebrate abundance and diversity within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). Several specific questions were addressed through this indicator in the 2015-19 project period:

- What did Commonwealth environmental water contribute to microinvertebrate productivity?
- What did Commonwealth environmental water contribute to microinvertebrate diversity?
- What did Commonwealth environmental water contribute to microinvertebrate community composition?
- What did Commonwealth environmental water contribute to connectivity of microinvertebrate communities in floodplain watercourses?

G.2 Methods

G.2.1 Field and laboratory methods

Microinvertebrates were sampled in association with Category III Water Quality (Appendix E) and Macroinvertebrate (Appendix H) indicators on eight sampling occasions between 2015 and 2018. Sampling sites were located across all three Warrego-Darling Selected Area Monitoring zones: Darling River, Warrego Channel and the Western Floodplain (Figure G-1).

Benthic microinvertebrates were haphazardly sampled by combining five cores (50 mm diameter x 120 mm long with 250 mL volume of water from immediately above the sediment surface) for each site. Replicates were separated by a minimum of 20 linear metres. The composite sample was allowed to settle for a minimum of 15 minutes and then the supernatant was poured through a 63 μm sieve. The retained sample was washed into a labelled jar and stored in ethanol (70% w/v with Rose Bengal stain) until laboratory analysis.

Pelagic microinvertebrates were sampled by haphazardly sampling 100 L of the water column at each site. Samples were poured through a plankton net (63 μm). Retained samples were stored in ethanol (70% w/v with Rose Bengal stain) until laboratory analysis. Samples were mixed thoroughly, and a sub-sample was sorted on a Bogorov tray under a stereo microscope at up to 400x magnification.

Microinvertebrate samples were identified in the laboratory to various taxonomic levels: Rotifer to Family, Cladocera to Family, Copepoda to Order, Anostracina to sub-Order, Ostracoda to Class, Collembolan and Oligochaeta to sub-Class, and Nematoda and Tardigrada to Phylum.

The volumes of the total samples were recorded, and sub-sample totals were scaled to each total sample volume and reported as microinvertebrate density (individual/L). Samples were stored in 70% ethanol with Rose Bengal for auditing purposes. Four microinvertebrate indices were measured: density, diversity, richness and community composition (Table G-1).

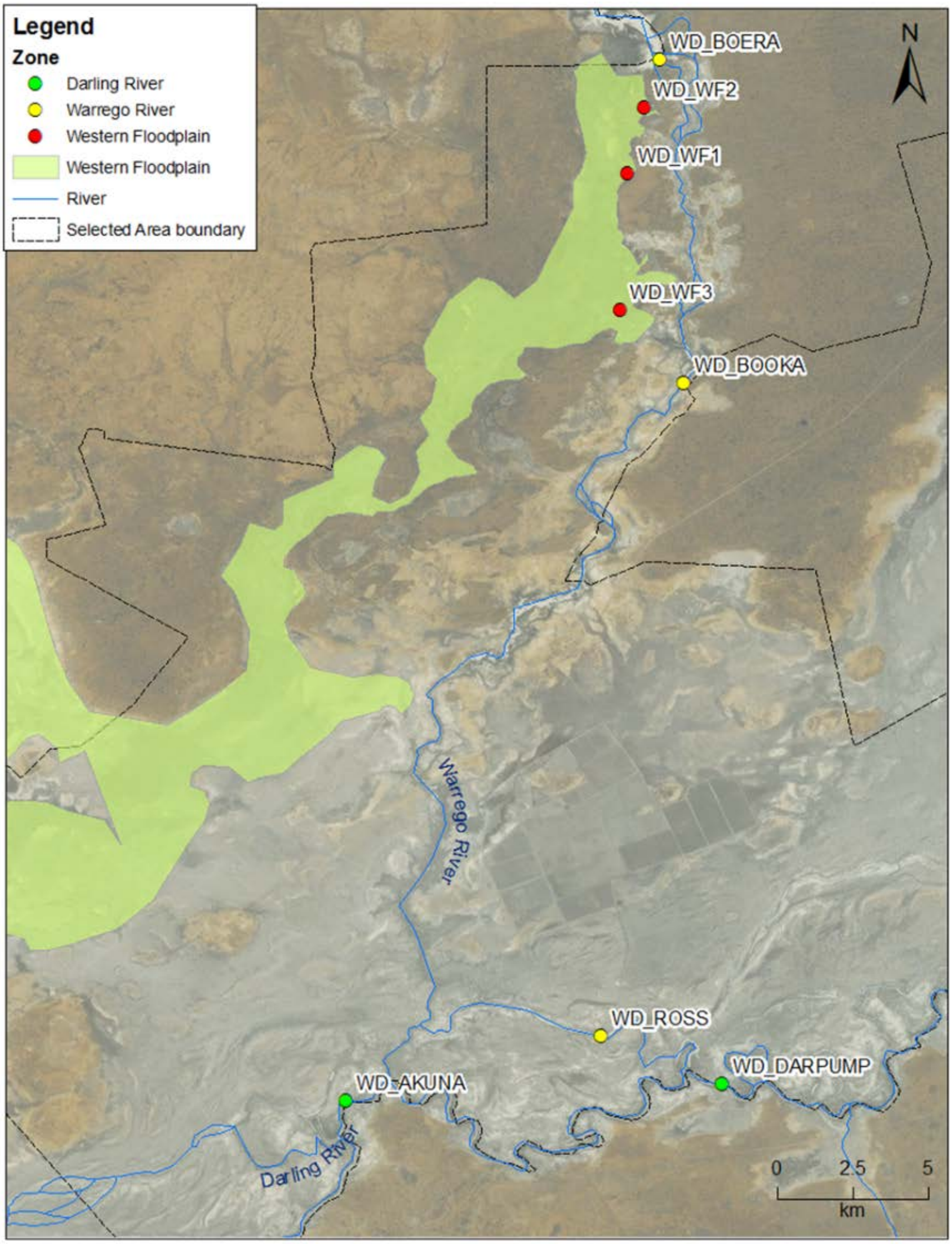


Figure G-1: Location of eleven microinvertebrate sites within the Warrego-Darling Selected Area.

Table G-1: Category III Microinvertebrate indicators measured in eight sampling occasion in 2015-18.

Indicators	Variables		Units	Code
Microinvertebrate	i.	Density	individual/L	N
	ii.	Diversity	-	H'
	iii.	Richness	-	S
	iv.	Community abundance (square root)	-	-

G.2.2 Microinvertebrate Diversity Indices

Shannon Weiner diversity index (H')

Diversity accounts for taxonomic richness and evenness. Evenness measures the relative abundance of different taxa in each sample to show how even the distribution is between all taxa present in a sample. The higher diversity in a sample, the 'more diverse' the sample. Shannon Weiner diversity was calculated in PRIMER v6.1.13 using the DIVERSE function.

Taxa richness (S)

Taxa richness is the number of microinvertebrate taxa identified in each sample. This index is used commonly in biodiversity monitoring programs and does not consider the abundances of the taxa or their relative abundance. The more taxa present in a sample, the 'richer' the sample. Taxa richness was calculated in PRIMER v6.1.13 using the DIVERSE function.

G.2.3 Explanatory factors

Spatial and temporal factors were used to test if microinvertebrate indicators were spatio-temporally dependent. Eleven sampling sites were analysed in three categories; **ZONE**: Darling River, Warrego Channel and the Western Floodplain (Table G-2). Eight sampling occasions were placed into three **YEAR** and two **SEASON** categories (i.e. summer from October to April and winter from May to September) (Table G-3).

Hydrological factors were used to test the influence of environmental water and natural flow events. In the Darling River zone, daily discharge (ML/d) data was collated from the WaterNSW gauge 425003 Darling at Bourke Town to find hydrological thresholds in each microinvertebrate indicator (Table G-3). In the Warrego Channel zone, connection events were identified when Boera Dam gates were opened to allow water to connect the three Warrego Channel sites. Time since connection was calculated using days between Boera gate opening (i.e. water flow to the Warrego Channel) and the first day of each sampling trip to test the influence of five Warrego connectivity events (Table G-3 and Figure G-2a). In the Western Floodplain zone, inundation events were identified when Boera Dam water levels were above 2.26 m on Boera gauge. Time since inundation was calculated using days between when Boera gauge was above 2.26 m (i.e. water over flow to the Western Floodplain) and the first day of each sampling trip to test the influence of three Western Floodplain inundation events (Table G-3 and Figure G-2b). Three continuous hydrological factors were further transformed into three categorical hydrological factors to infer patterns in statistical analyses.

Table G-2: Location of eleven microinvertebrate sites within the Warrego-Darling Selected Area (n=68 in each habitat). Map projection GDA94 Zone 55. Inundation condition Wet=sampled, Dry=no sample.

Sampling Zone	Site Name	Site Code	Easting	Northing	2015-16		2016-17			2017-18		
					WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
					Oct-15	Mar-16	Aug-16	Nov-16	Mar-17	Oct-17	Apr-18	Jun-18
Darling River	Akuna	AKUNA	340008	6634629	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Darling Pump	DARPUMP	350768	6635351	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
Warrego Channel	Boera Dam 1	BOERA1	348526	6669158	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Boera Dam 2	BOERA2	348720	6669094	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 1	BOOKA1	349357	6658461	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 2	BOOKA2	349835	6658024	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Ross Billabong 1	ROSS1	347281	6636893	Wet	Wet	Wet	Wet	Wet	Wet	Dry	Wet
	Ross Billabong 2	ROSS2	347242	6636926	Wet	Wet	Wet	Wet	Wet	Wet	Dry	Dry
Western Floodplain	Coolibah-Cooba-Lignum woodland	WF1	348083	6667550	Wet	Dry	Wet	Dry	Dry	Dry	Dry	Dry
	Coolibah open woodland	WF2	347848	6665662	Dry	Dry	Wet	Wet	Dry	Dry	Dry	Dry
	Lignum shrubland	WF3	347476	6660850	Dry	Dry	Wet	Wet	Wet	Dry	Dry	Dry

Table G-3: Explanatory (temporal, continuous hydrological and categorical hydrological) factors to infer Microinvertebrate patterns in statistical analyses.

Temporal factor				Hydrological factor (within each Zone)							
				Darling		Warrego			Western Floodplain		
Year	Sampling occasion	Month	Season	Discharge (ML/d)	Discharge category	Flow event	Time since connection (day)	Connection category	Flow event	Time since inundation (day)	Inundation category
2015-16	3	2015-10	summer	411	Base	1	242	100-299	2	100	retention
	4	2016-03	summer	51	Base	2	19	<50	-	-	-
2016-17	5	2016-08	winter	7,613	5,000-10,000	3	36	<50	3	105	during
	6	2016-11	summer	3,993	1,000-4,999	4	27	<50	3	203	during
	7	2017-03	summer	572	500-999	4	145	100-299	3	321	retention
2017-18	8	2017-10	summer	184	Base	4	356	>300	-	-	-
	9	2018-04	summer	47	Base	5	3	<50	-	-	-
	10	2018-06	winter	145	Base	5	68	50-99	-	-	-

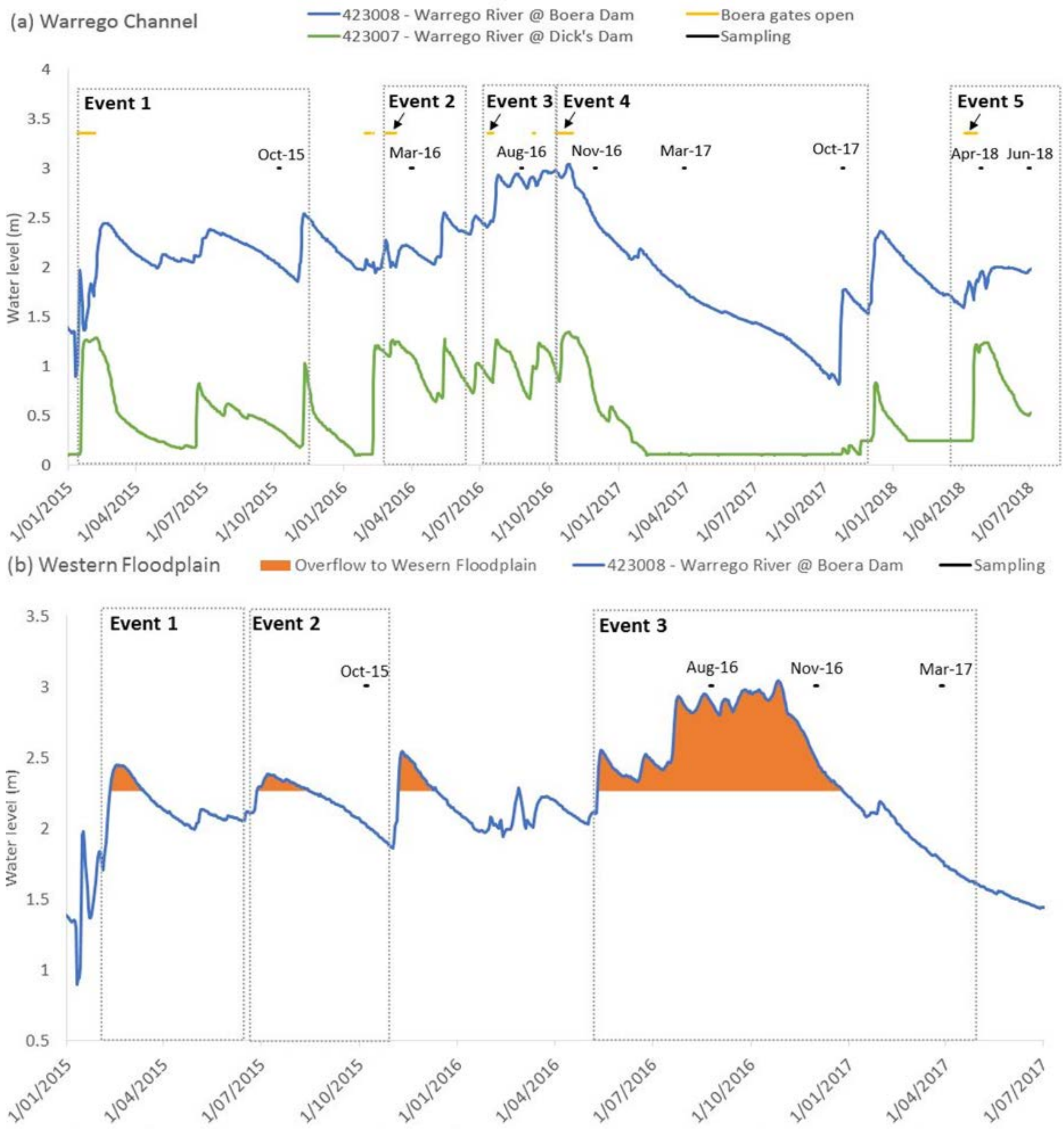


Figure G-2: Mean daily water level in (a) the Warrego Channel and (b) the Western Floodplain with flow events and sampling occasions.

G.2.4 Statistical methods

Two data sets by habitats

Benthic and pelagic microinvertebrate samples were analysed as separate datasets since different sampling methods were used for each habitat.

Summary statistics and water quality guidelines

The minimum, 20th, 50th (median) and 80th percentile and maximum values of each microinvertebrate indicator in eight sampling occasions between 2015 and 2018 were calculated in three zones within the Warrego-Darling Selected Area.

Regression

Relationships between microinvertebrate indicators (Table G-1) and continuous hydrological factors (Table G-3) were analysed using non-linear polynomial or logistic regression. In the Darling River zone, regression was used to explore the relationships between microinvertebrate indicators and discharge (ML/d). In the Warrego Channel zone, regression was used to explore the relationships between microinvertebrate indicators and time since connection (days). In the Western Floodplain zone, regression was used to explore the relationships between microinvertebrate indicators and time since inundation (days). Regression outputs of F-statistic, degrees of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

PERMANOVA

The permutational multivariate analysis of variance (PERMANOVA) routine was used to test differences in overall microinvertebrate attributes between spatial, temporal and categorical hydrological factors. This routine can analyse unbalanced experimental designs in an analysis of variance experimental design using permutation methods (Anderson, 2008). Up to 999 random permutations estimated the probability of p-values, with levels of significance reported as $p<0.05$. Where statistically significant differences were detected, pair-wise comparisons in PERMANOVA routine were used to determine the source of the significant differences. PERMANOVA analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

Three-way PERMANOVA was used to test the overall difference in microinvertebrate indicators between YEAR, SEASON and ZONE and their interactions. Within each zone, microinvertebrate patterns were mainly driven by different hydrological events and therefore were analysed separately. In the Darling River zone, one-way PERMANOVA was used to test the difference in microinvertebrate indicators between discharge categories. In the Warrego Channel zone, one-way PERMANOVA was used to test the difference in microinvertebrate indicators between connection categories. In the Western Floodplain zone, one-way PERMANOVA was used to test the difference in microinvertebrate indicators between inundation categories.

BIOENV

BIOENV analyses were used to examine eleven water quality indicators (Appendix E) and hydrological indicators (Table G-3) that were linked to the patterns of microinvertebrate indicators. BIOENV analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

nMDS and SIMPER

Non-metric multidimensional scaling ordinations (nMDS) were used to visualise community patterns and similarity percentages (SIMPER) were used to determine the taxa contributing to the observed community patterns. Community abundance data were square root transformed to stabilize variance and weigh the contributions of common and rare species and to improve normality (Clarke, 2001). A Bray-Curtis dissimilarity matrix was generated by rank correlating the community structure between samples. Then, nMDS output with stress values of less than 0.2 were considered appropriate for interpretation (Clarke, 2001). nMDS and SIMPER analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

G.3 Results and Discussion

G.3.1 **Overall**

Overall microinvertebrate density pattern

Across two habitats, three sampling zones and eight sampling occasions, microinvertebrate density ranged from 55 to 63,680 individuals/L (Table G-4). The densities of microinvertebrates recorded in this period were similar to those reported in previous studies from the Murray, the Ovens and the Macquarie Marshes floodplain river and wetland within the Murray-Darling Basin (Kobayashi *et al.* 2011; Ning *et al.* 2013).

Within the Warrego-Darling Selected Area, benthic habitat had higher microinvertebrate density than pelagic habitat (Figure G-3). Overall, the Western Floodplain had the highest microinvertebrate density, followed by the Warrego Channel with the lowest density in the Darling River (Figure G-3). The Western Floodplain displaying a higher density than other zones demonstrates that lateral floodplain connection stimulated microinvertebrate productivity. This secondary production measured as microinvertebrate density provides a basal food resources to fuel wetland foodwebs.

Table G-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of microinvertebrate density in eight sampling occasions between 2015 and 2018 calculated in three zones in the Warrego-Darling Selected Area.

Habitat	Zone	Minimum	Percentile			Maximum	Number of samples
			20th percentile	50th percentile	80th percentile		
Benthic	Darling	505	1,080	1,589	2,880	8,448	16
	Warrego	223	1,678	3,488	5,648	33,680	45
	WF	1,040	2,738	3,200	8,602	11,200	7
Pelagic	Darling	55	79	408	1,620	2,816	16
	Warrego	100	311	857	3,734	41,500	45
	WF	434	1,342	4,525	11,078	63,680	7

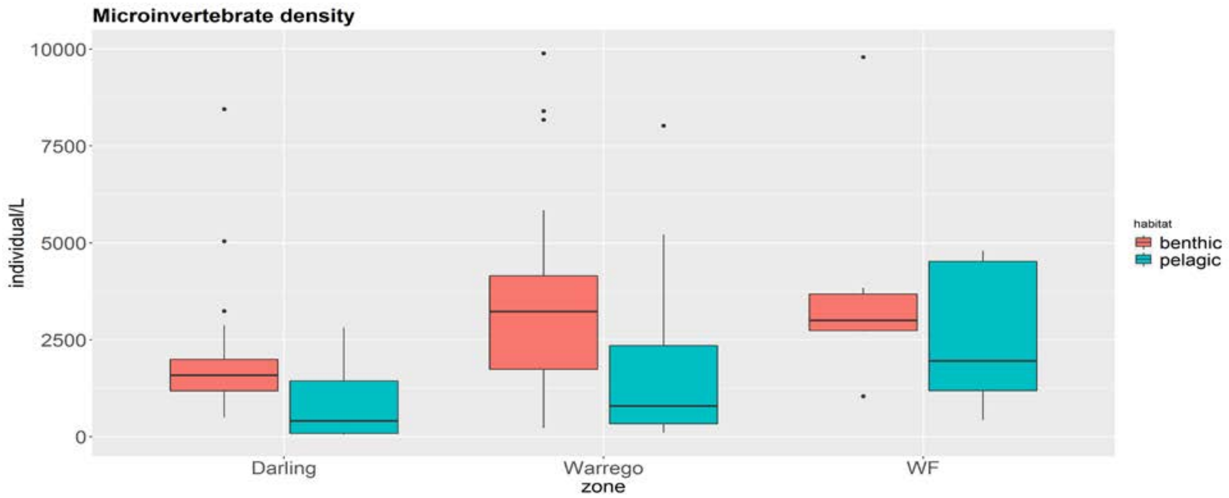


Figure G-3: Boxplot of microinvertebrate density among 136 samples in the Warrego-Darling Selected Area. Outliers to 63,680 individual/L not shown.

Overall microinvertebrate diversity pattern

A total of 35 microinvertebrate taxa were identified from 136 samples (68 samples from each habitat) collected from 2015-18 (Supplement A). Rotifers were the most abundant taxonomic group (68%), followed by Copepoda (17%), Cladocera (7.6%) and Ostracoda (3.4%). The 18 most abundant taxa (>1% in total abundance) comprised 95% of the total abundance with the most abundant taxa Family Brachionidae (37% of the total abundance). The other most abundant taxa were Copepod nauplii (12%), Order Bdelloida (6%) and Family Notommatidae (6%) that occurred in more than 58% of sites and sampling occasions.

Microinvertebrate taxonomic richness ranged from 4 to 21 and Shannon diversity index ranged from 0.47 to 2.45 (Table G-5). There was a distinct temporal pattern in microinvertebrate diversity and richness. Three-way PERMANOVA analyses showed a significant interaction between year and season in both benthic richness (Pseudo-F=7.25, d.f.=1, p=0.011), pelagic richness (Pseudo-F=15.52, d.f.=1, p=0.001) and pelagic diversity (Pseudo-F=6.16, d.f.=1, p=0.015) (Figure G-4). In 2016-17 winter, microinvertebrate richness and diversity were significantly higher than other groups (p<0.05), driven by higher richness and diversity in 2016-inundated samples.

The Western Floodplain had the highest microinvertebrate diversity, followed by the Warrego Channel and the lowest density in the Darling River. This spatial difference between zones highlights the importance of slower flow habitats such as waterholes and billabongs in the Warrego Channel and the Western Floodplain as microinvertebrate refuges and recruitment habitats to support long term diversity and abundance of microinvertebrate communities (Daryl *et al.* 2010; Nielsen & Watson, 2008).

Table G-5: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each microinvertebrate diversity indicators in eight sampling occasions between 2015 and 2018 were calculated in three zones within the Warrego-Darling Selected Area.

Variable	Habitat	Zone	Min	Percentile			Max	Number of samples
				20th percentile	50th percentile	80th percentile		
Richness	Benthic	Darling	7	10	13	14	15	16
		Warrego	7	11	13	16	18	45
		WF	11	11	12	13	15	7
	Pelagic	Darling	4	9	14	16	19	16
		Warrego	5	9	12	14	21	45
		WF	7	10	14	15	19	7
Diversity	Benthic	Darling	1.05	1.53	1.94	2.08	2.20	16
		Warrego	0.83	1.51	1.95	2.22	2.46	45
		WF	1.33	1.91	2.10	2.19	2.22	7
	Pelagic	Darling	0.47	1.21	1.83	2.04	2.18	16
		Warrego	0.54	1.36	1.62	1.84	2.16	45
		WF	0.50	1.41	1.76	2.05	2.15	7

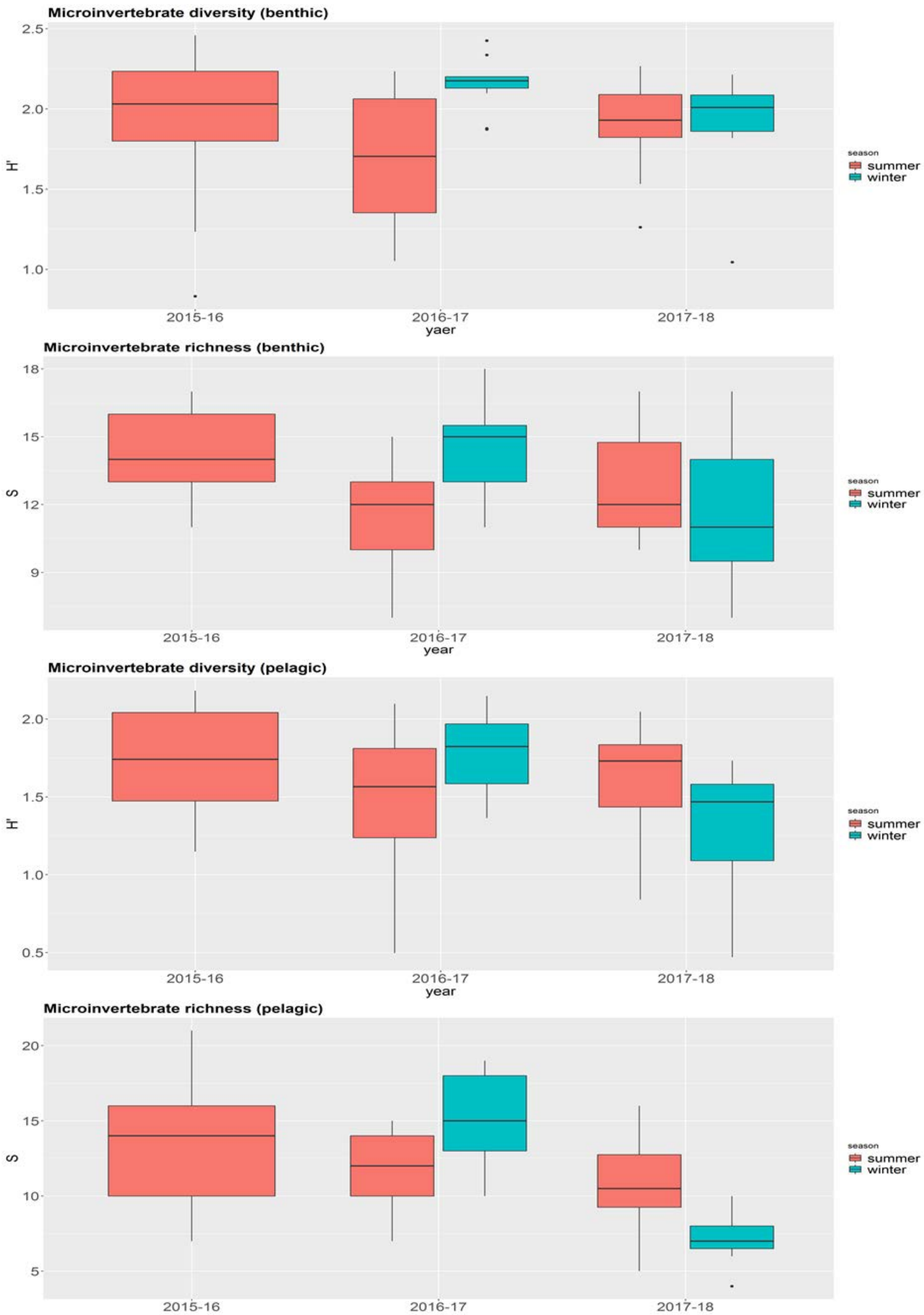


Figure G-4: Boxplot of microinvertebrate divrsity and richness among 136 samples in the Warrego-Darling Selected Area.

<u>Overall microinvertebrate community pattern</u>

Microinvertebrate taxonoimc composition (68 samples from each habitat) differed between benthic and pelagic habitats (Pseudo-F=26.026, p=0.001; Figure G-5a). This difference in habitat community composition is driven by the higher average abundance of benthic taxa such as F.Brachionidae, F.Notommatidae, O.Bdelloida and P. Nematoda and higher average abundance of pelagic taxa (Table G-6).

There was a distinct temporal pattern in microinvertebrate community composition (Figure G-5b and Figure G-5c). In the benthic habitat, a three-way PERMANOVA showed a significant year and season interaction (Pseudo-F=3.077, d.f.=1, p=0.002). In the pelagic habitat, a three-way PERMANOVA analysis showed a significant zone, year and season interaction (Pseudo-F=2.229, d.f.=1, p=0.013). These patterns reflect temporal and hydrological differences between the three zones exerting a strong influence on community compsition in both benthic and pelagic habitats (Figure G-5b and Figure G-5c).

Table G-6: Microinvertebrate taxa contributing most of the dissimilarities between benthic and pelagic habitats.

Taxa		Average abundance		Contribution%
		Benthic	Pelagic	
Benthic	F.Brachionidae	**23.0**	21.3	11.3
	nauplii	**20.4**	16.3	7.3
	F.Notommatidae	**16.0**	4.5	7.1
	O.Bdelloida	**14.8**	2.6	6.8
	P.Nematoda	**13.0**	0.7	6.5
	C.Ostracoda	**9.6**	0.3	4.5
	F.Chydoridae	**8.0**	0.9	4.2
	F.Lecanidae	**8.1**	1.0	3.9
	O.Cyclopoida	**9.1**	5.2	3.9
	F.Moinidae	**5.3**	4.9	3.8
	F.Macrothricidae	**5.7**	1.3	3.0
	O.Harpacticoida	**5.0**	0.8	2.5
	F.Daphniidae	**3.0**	2.9	2.4
	sC.Oligochaeta	**4.4**	0.2	2.2
Pelagic	F.Filiniidae	4.9	**8.6**	4.5
	F.Synchaetidae	2.9	**8.5**	4.1
	O.Calanoida	4.3	**6.3**	3.3
	F.Asplanchnidae	2.5	**6.4**	3.0
	F.Hexarthridae	2.0	**5.1**	2.7
	F.Gastropidae	1.4	**4.4**	2.1
	F.Sididae	1.5	**3.5**	1.9

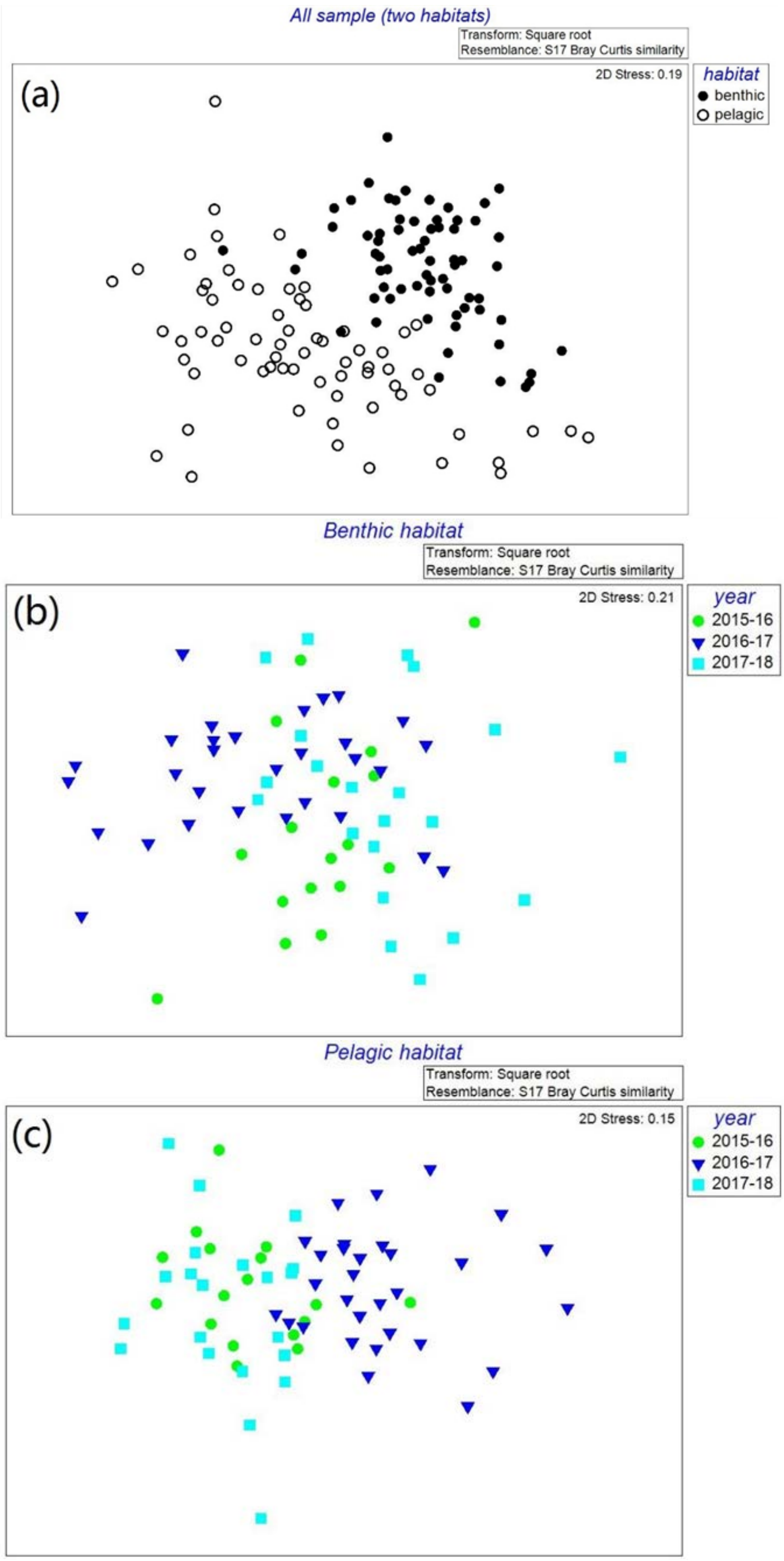


Figure G-5: nMDS ordination of microinvertebrate community composition among 136 samples in the Warrego-Darling Selected Area using community abundance (square root) dataset.

G.3.2 **Darling River Zone**

<u>Microinvertebrate density</u>

In the Darling River, discharge had a different effect on microinvertebrate density in both benthic and pelagic habitats. In the benthic habitat, there was no predictable relationship with discharge (Figure G-6 and Table G-7), and water nutrients and chlorophyll *a* concentrations were best correlated with benthic microinvertebrate density pattern (Table G-8). In the pelagic habitat, microinvertebrate density increased with increasing discharge in the Darling River up to 8,000 ML/d with a strong positive relationship (Figure G-6 and Table G-7). Discharge was the single environmental factor that best correlated with pelagic microinvertebrate density (Table G-8).

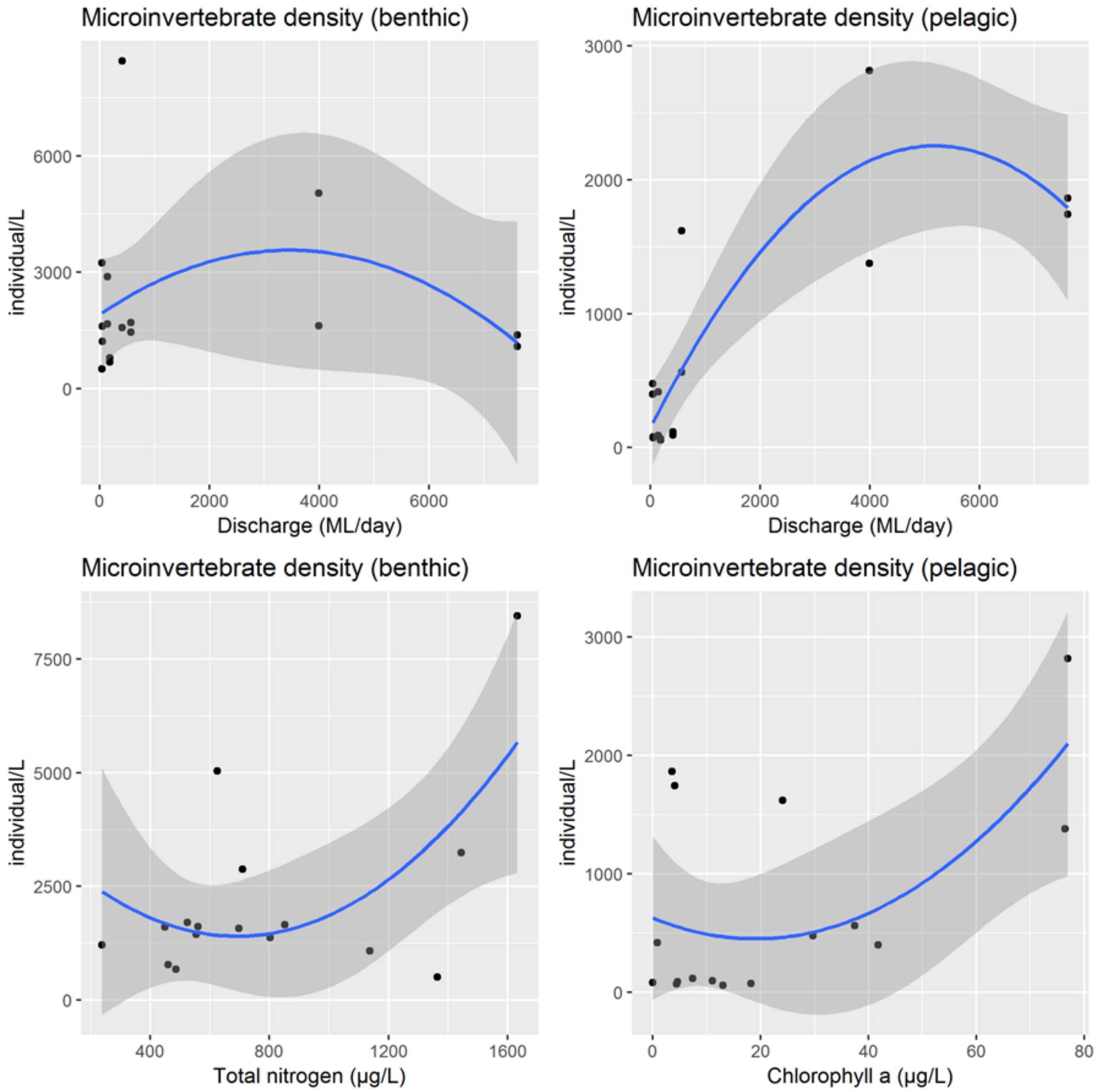


Figure G-6: Regression between microinvertebrate density and discharge and water quality (Cat III) indicators in the Darling River zone.

Table G-7: Summary of regression results between continuous hydrological factors and microinvertebrate indicators within the Warrego-Darling Selected Area in 2015-18. * represents significant results of p-value <0.05. 'poly' represents quadratic polynomial regression model and 'log' represents log regression model.

Habitat	Zone	Microinvertebrate indicator	Regression				
			F	d.f.	p-value	R^2	model
Benthic	Darling	Density	0.72	2,13	0.507	0.10	poly
		Diversity (Shannon diversity index)	0.24	2,13	0.792	0.04	poly
		Richness	2.81	2,13	0.097	0.30	poly
	Warrego	Density	2.24	2,42	0.120	0.10	poly
		Diversity (Shannon diversity index)	3.62	2,42	0.036	0.15	poly
		Richness	3.21	1,43	0.080	0.07	log
	Western Floodplain	Density	2.33	2,4	0.214	0.54	poly
		Diversity (Shannon diversity index)	17.81	2,4	0.010	0.90	poly
		Richness	0.04	2,4	0.965	0.02	poly
Pelagic	Darling	Density	20.27	2,13	0.000	0.76	poly
		Diversity (Shannon diversity index)	9.71	2,13	0.003	0.60	poly
		Richness	4.25	2,13	0.038	0.40	poly
	Warrego	Density	1.65	2,42	0.204	0.07	poly
		Diversity (Shannon diversity index)	3.77	2,42	0.031	0.15	poly
		Richness	6.43	1,43	0.015	0.13	log
	Western Floodplain	Density	145.40	2,4	0.000	0.99	poly
		Diversity (Shannon diversity index)	8.80	2,4	0.034	0.81	poly
		Richness	1.98	2,4	0.251	0.50	poly

Table G-8: Summary of BIOENV results of microinvertebrate indicators within the Warrego-Darling Selected Area. 'v' represents environmental indicators that highly correlated to microinvertebrate indicators.

Habitat	Zone	Microinvertebrate indicator	Rho	p	Water chemistry						Water nutrient					Hydrological indicator
					Temperature	pH	Turbidity	Conductivity	Dissolved oxygen	Chlorophyll *a*	Dissolved organic carbon	Total nitrogen	Total phosphorus	Nitrate-nitrite	Filterable reactive phosphorus	
Benthic	Darling	Density	0.411	0.550						v		v		v	v	
		Richness	0.461	0.110					v	v	v			v		
		Diversity	0.505	0.140						v		v				
		Community	0.471	0.004						v		v				
	Warrego	Density	0.331	0.040		v				v					v	
		Richness	0.241	0.010				v		v						
		Diversity	0.465	0.010						v			v		v	
		Community	0.436	0.001				v		v		v				
	Western Floodplain	Density	0.788	0.140								v	v			
		Richness	0.226	0.780					v							
		Diversity	0.749	0.130				v	v			v				
		Community	0.743	0.004	v											

Habitat	Zone	Microinvertebrate indicator	Rho	p	Water chemistry						Water nutrient					Hydrological indicator
					Temperature	pH	Turbidity	Conductivity	Dissolved oxygen	Chlorophyll *a*	Dissolved organic carbon	Total nitrogen	Total phosphorus	Nitrate-nitrite	Filterable reactive phosphorus	
Pelagic	Darling	Density	0.702	0.020												v
		Richness	0.542	0.010	v	v	v		v							
		Diversity	0.555	0.060			v		v	v				v	v	
		Community	0.317	0.024		v					v					
	Warrego	Density	0.374	0.030						v						
		Richness	0.18	0.270			v		v							
		Diversity	0.267	0.110		v				v	v					
		Community	0.401	0.001	v			v			v					
	Western Floodplain	Density	0.908	0.060						v						
		Richness	0.657	0.230			v		v		v					
		Diversity	0.818	0.140				v			v		v			
		Community	0.886	0.001	v	v				v				v	v	

Microinvertebrate diversity

Microinvertebrate diversity and richness had a weak correlation with discharge in both habitats (Table G-7 and Figure G-7). The largest in-channel pulse of around 40,000 ML/d (July 2016) reduced microinvertebrate richness for over a month following the flow peak, suggesting a lag effect of discharge on richness, potentially through limiting key resources required for recolonization and for successional processes to re-establish flow-prone taxa.

Microinvertebrate diversity and richness were highly correlated to multiple water quality and nutrient parameters in both habitats (Table G-8). Among all highly correlated parameters, microinvertebrate richness showed a strong decreasing trend with increased nitrate-nitrite concentration in benthic habitat and with increased dissolved oxygen concentration in pelagic habitat (Figure G-7), linked to poor water quality during the low flow period (Appendix E). This highlights that longitudinal flow pulses in the Darling River can improve water quality, in turn supporting a more diverse assemblage of microinvertebrate taxa especially in pelagic habitat, to create feeding opportunities for higher level consumers such as macroinvertebrates, frogs, fish, waterbirds and other aquatic vertebrates.

Microinvertebrate community

Community composition was significantly different between benthic (Pseudo-F=1.978, p=0.0004) and pelagic habitats (Pseudo-F=3.148, p=0.001; Figure G-8a and Figure G-9a). The Darling River benthic community composition was highly correlated to chlorophyll *a* and total nitrogen concentrations, and pelagic community composition was highly correlated to pH and dissolved organic carbon (Table G-8). The nMDS ordinations show chlorophyll *a* concentrations correlating to the higher discharge group (>500 ML/d) in both benthic and pelagic habitats (Figure G-8b and Figure G-9b), suggesting that microinvertebrate community composition was driven by increased primary production and higher abundance of rotifer Families Brachionidae and Synchaetidae as well as Copepod nauplii and Order Cyclopoida (Figure G-9d).

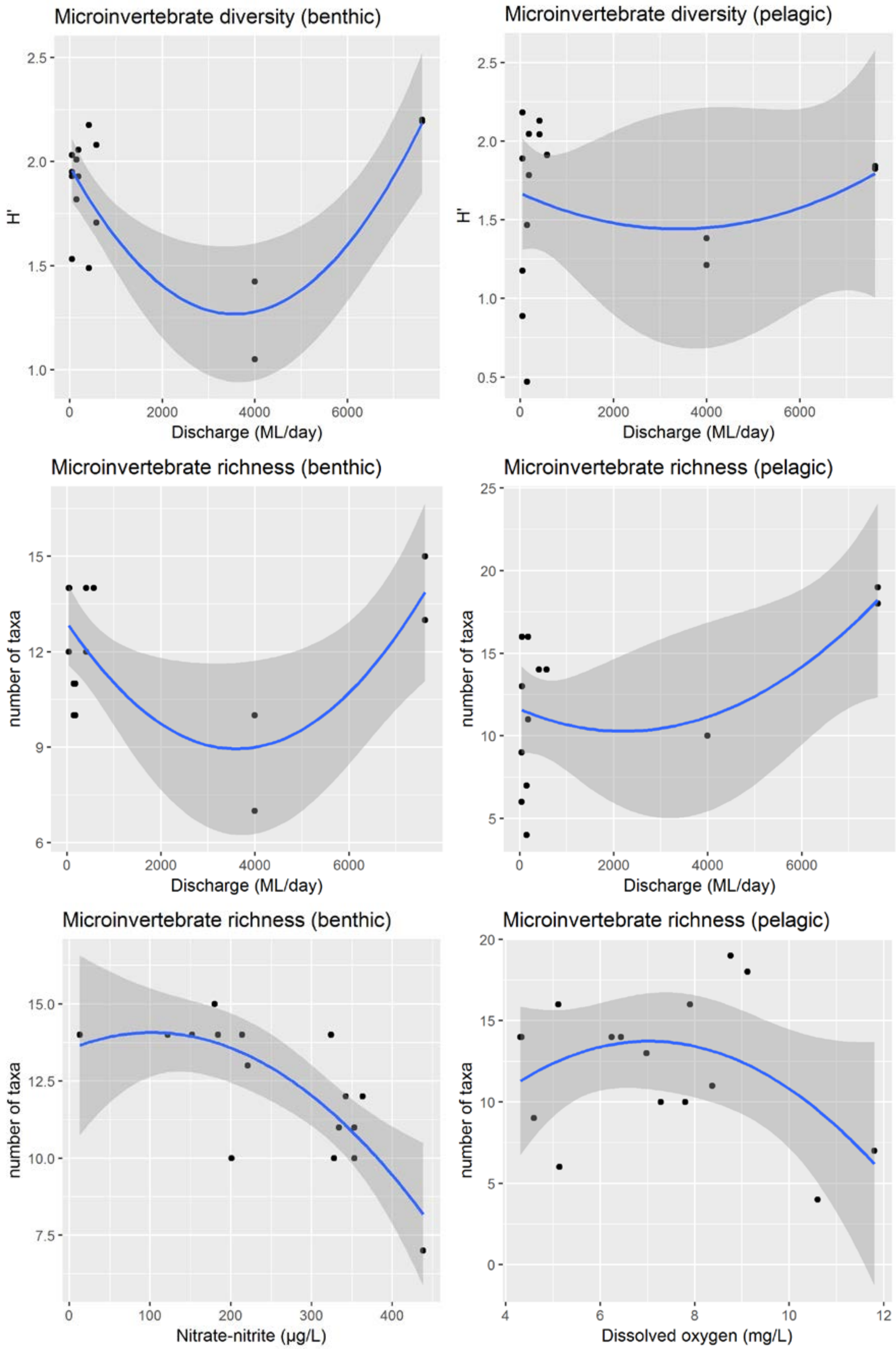


Figure G-7: Regression between discharge at Darling@Bourke Town gauging station (NSW425003) and chlorophyll *a* and microinvertebrate diversity in the Darling River zone.

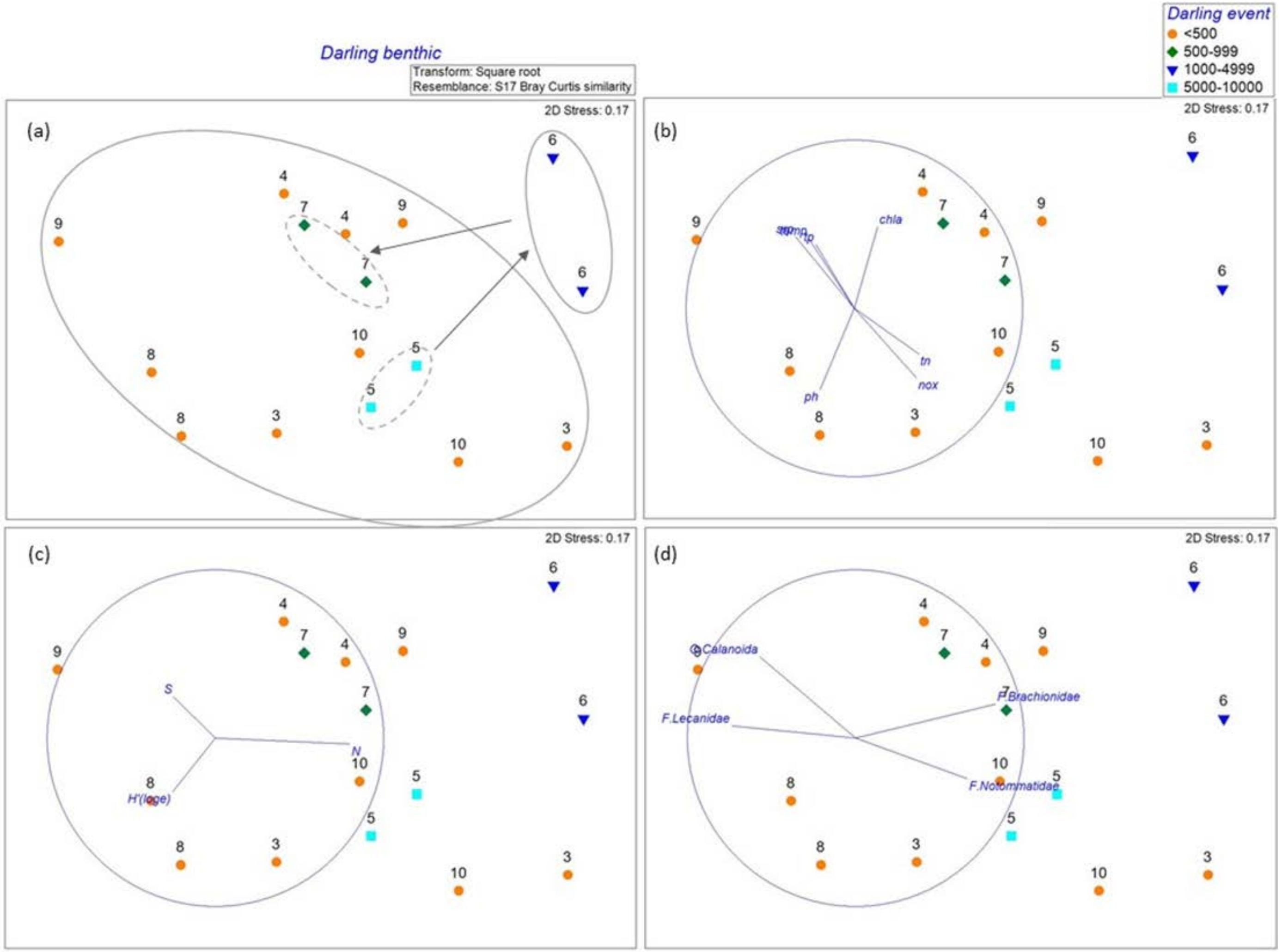


Figure G-8: nMDS ordinations of Darling River zone benthic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern. Numbers represent sampling occasion.

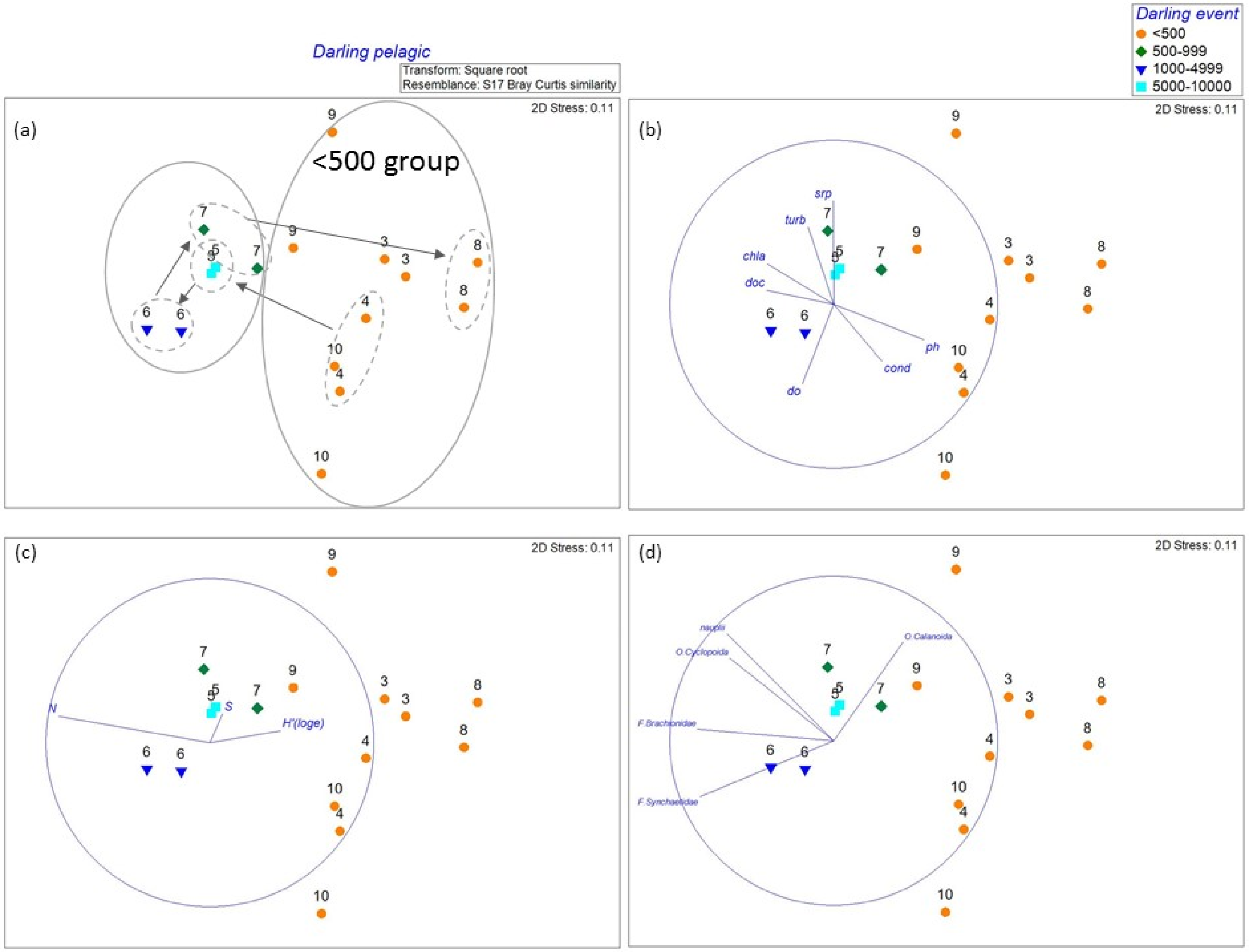


Figure G-9: nMDS ordinations of Darling River zone pelagic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern. Numbers represent sampling occasion.

G.3.3 Warrego Channel zone

Microinvertebrate density

Microinvertebrate density followed a boom and bust cycle with peak density found during contraction periods following connection events. In both benthic and pelagic habitats, microinvertebrate density appeared as a hump shape regression and decreased with increasing time since connection (Figure G-10). Warrego Channel benthic and pelagic density was highly correlated to chlorophyll *a* concentrations in both habitats (Table G-8 and Figure G-10), suggesting secondary production was stimulated by increased in water column primary production. However, there was no strong predictable relationship with time since connection because inundation duration varied between events (Table G-7).

Microinvertebrate diversity

Microinvertebrate diversity and richness peaked around 30-50 days following connection and then decreased with time since connection at both sites (Figure G-11). Diversity and richness were highly correlated to multiple water quality and nutrient parameters (Table G-8). Among all highly correlated parameters, benthic richness and pelagic diversity showed a strong decreasing trend with increases in conductivity and pH (Figure G-11). The cessation of upstream Warrego inflows and contraction to disconnected pools is linked to declining water quality and a reduction in more sensitive taxa.

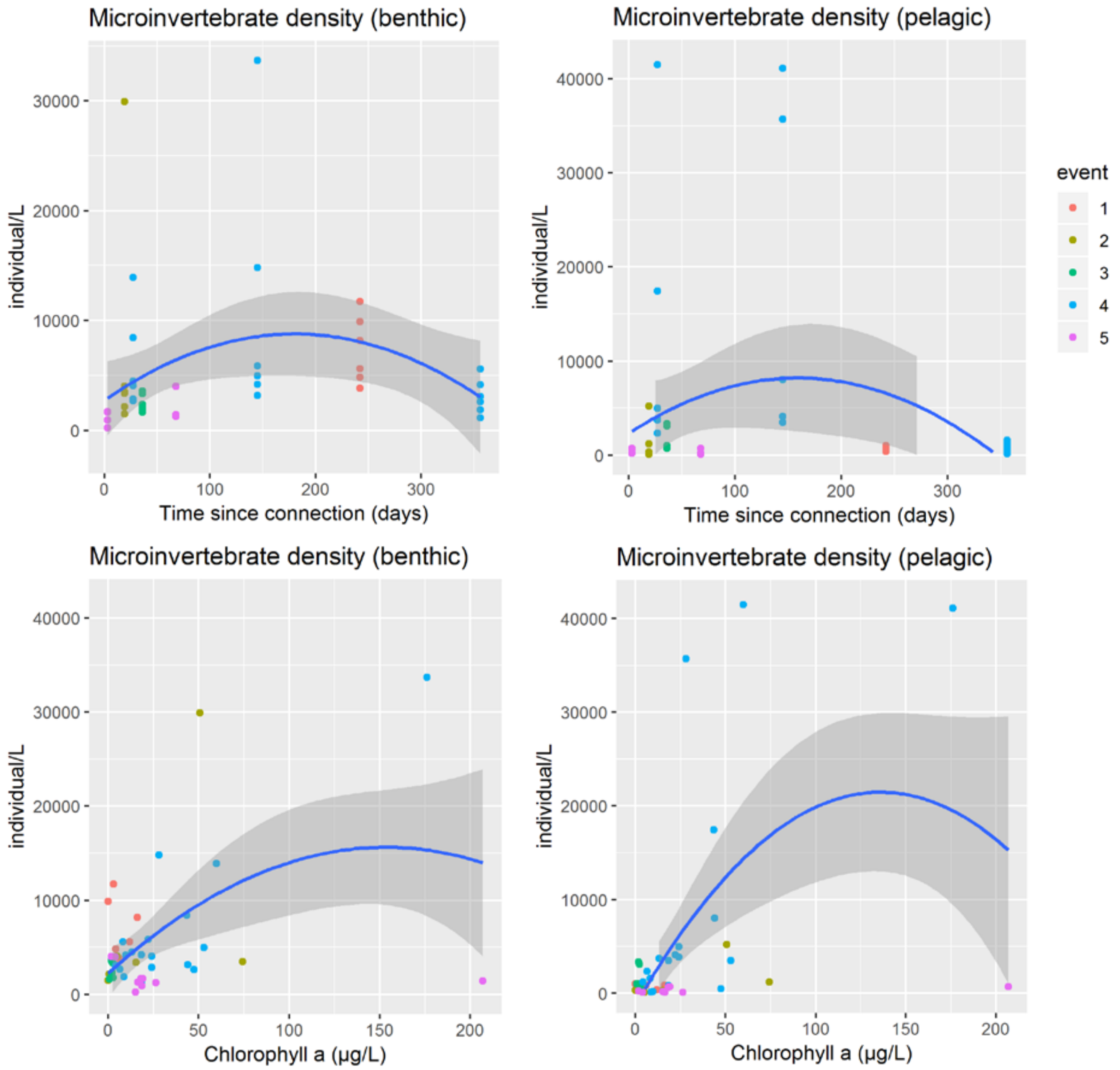


Figure G-10: Regression between microinvertebrate density and time since connection and chlorophyll *a* concentration in the Warrego Channel zone.

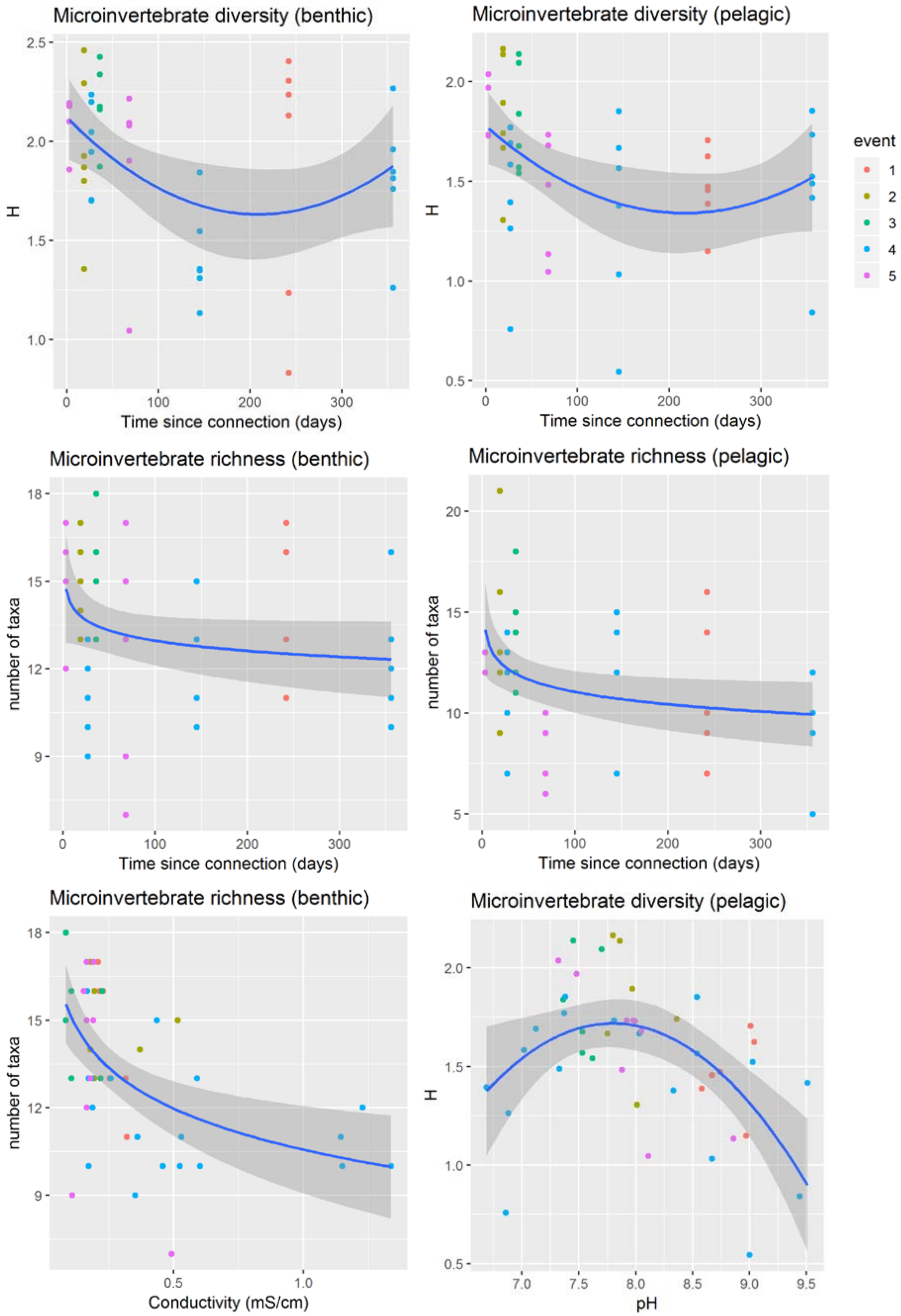


Figure G-11: Regression between microinvertebrate diversity, richness and time since connection and water quality indicators (Cat III) in the Warrego Channel zone.

Microinvertebrate community

Community composition was significantly different between the ‘time-since’ groups in both benthic (Pseudo-F=3.353, p=0.001) and pelagic habitats (Pseudo-F=4.496, p=0.001). All ‘time-since’ groups differed in the pelagic habitat (p<0.05, Figure G-12a and Figure G-13a), with community composition shifting along the time-since connection groups, regardless of event (Figure G-13a). Community composition in both habitats was highly correlated to multiple water quality parameters (Table G-8), with poor water quality during the contraction phase (>50 days’ time-since connection) leading to lower microinvertebrate diversity and richness (Figure G-12c and Figure G-13c).

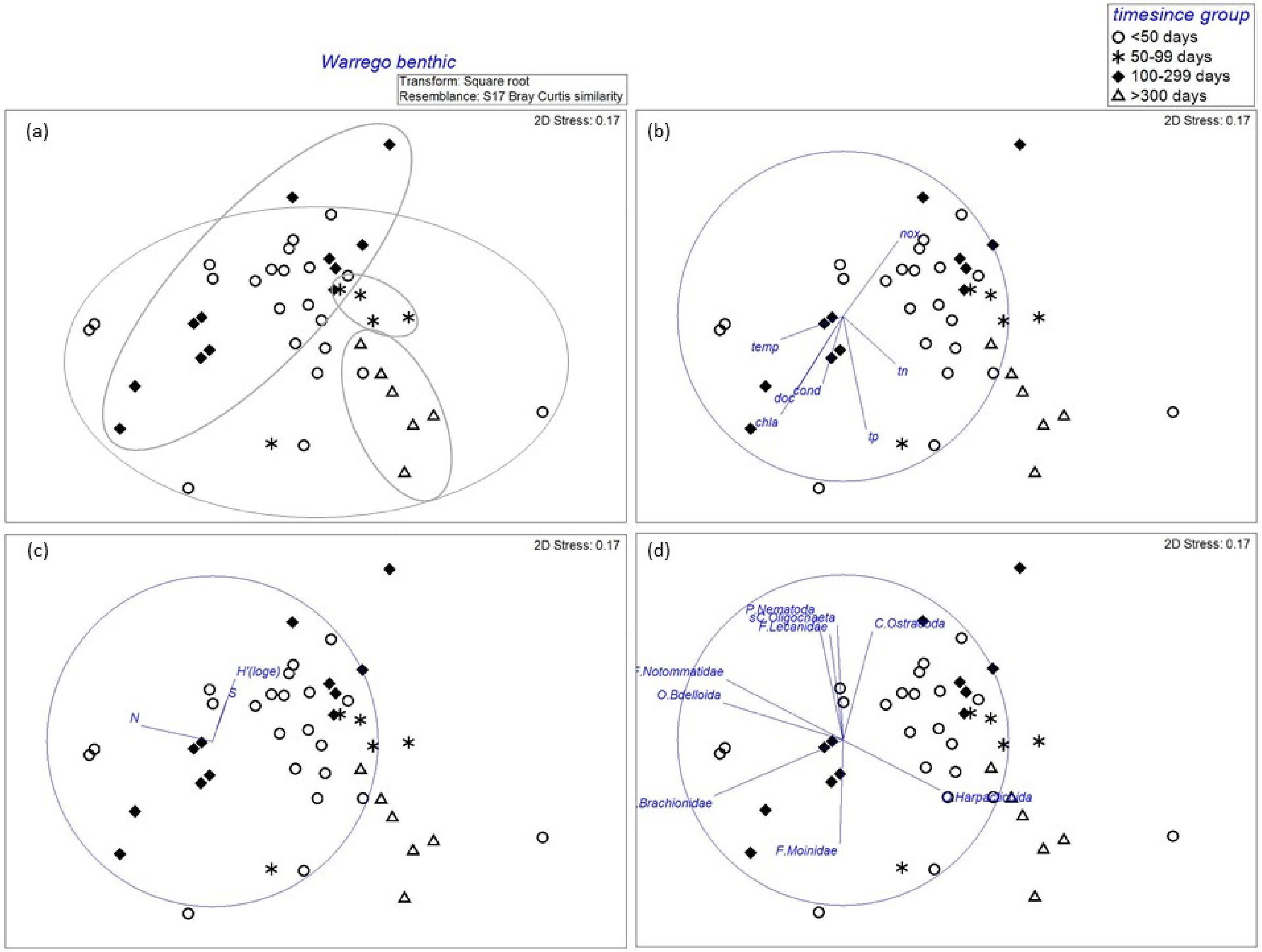


Figure G-12: nMDS ordinations of Warrego Channel zone benthic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern.

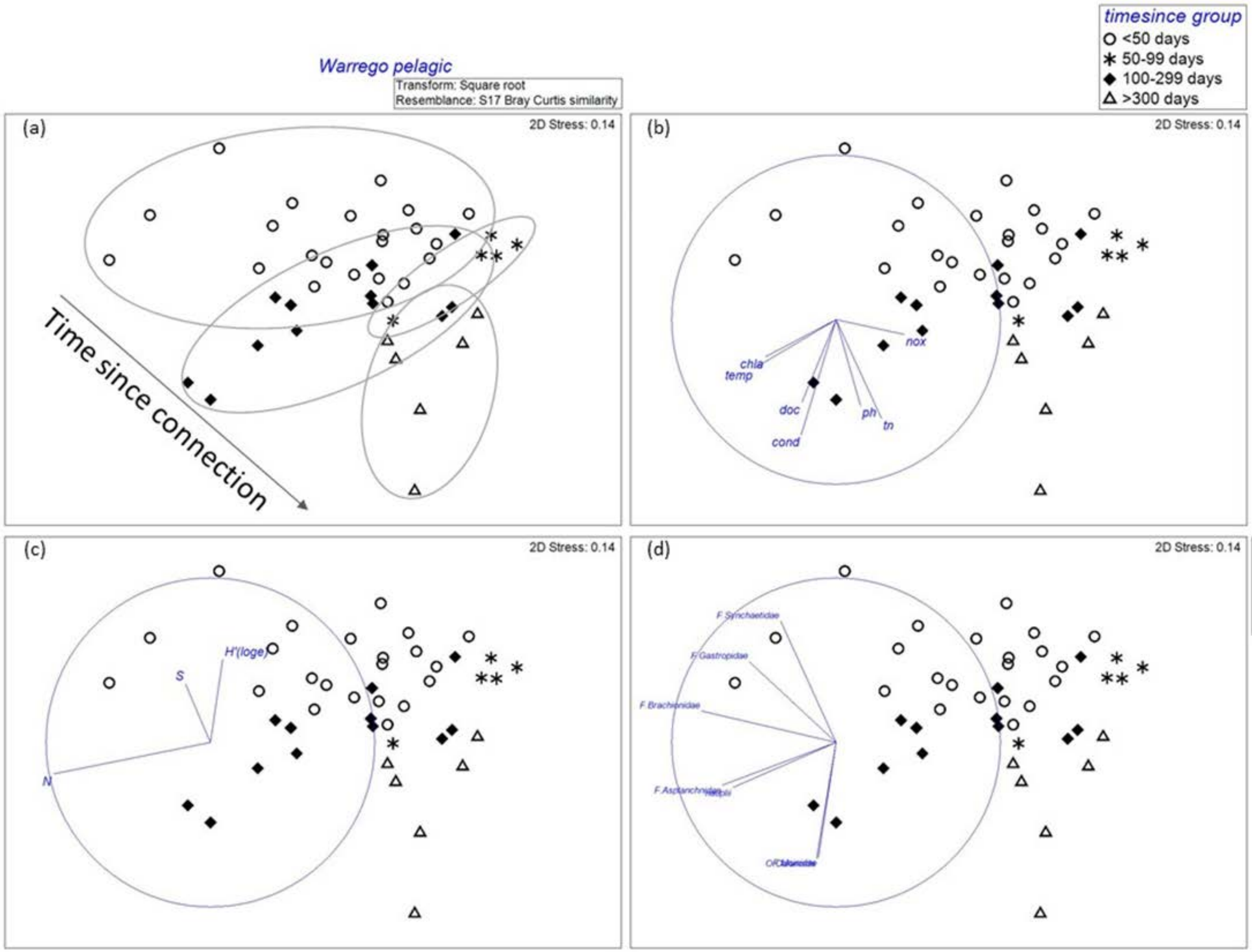


Figure G-13: nMDS ordinations of Warrego Channel zone pelagic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern.

G.3.4 Western Floodplain zone

Hydrology

During the LTIM Project, one microinvertebrate sample was collected in event 2 and six samples from three sampling occasions were collected in event 3 in the Western Floodplain (Figure G-2b and Table G-3). This report focuses on the largest inundation event (event 3) in July 2016, in which multiple samples were collected during the inundation and contraction cycle.

Three microinvertebrate sampling occasions captured the inundation cycle of this event. In August 2016 “during 1” sample in winter, an estimated 6.457 ML of inflows had spilled onto the Western Floodplain with 1,695 ha of the Floodplain inundated as at 13 August 2016 (Appendix B). Three sites were sampled representing different inundation frequencies (Table G-9). In November 2016 “during 2” sample, the floodplain connection had been over five months with steadily declining inflow. Two sites were sampled (WF1 sampled in August 2016 was dry). In March 2017 “retention” samples, the floodplain was in a contraction period with no inflow for the three previous months.

In the August 2016 “during 1” sampling occasion, Coolibah/Cooba woodland and Lignum wetland had similar pelagic and benthic microinvertebrate density, higher than the benthic density in the Coolibah woodland (Figure G-14). In the November 2016 “during 2” sampling occasion, density peaked in both habitats in the Coolibah woodland habitat and Coolibah/Cooba woodland habitat was dry (Figure G-14). Microinvertebrate density in the Lignum habitat sustained similar densities throughout inundation, reaching peak density in March 2017 “retention” period (Figure G-14). In summary, the three vegetation habitats displayed similar densities, but different maximum microinvertebrate densities were linked to differences in habitat availability and food resources.

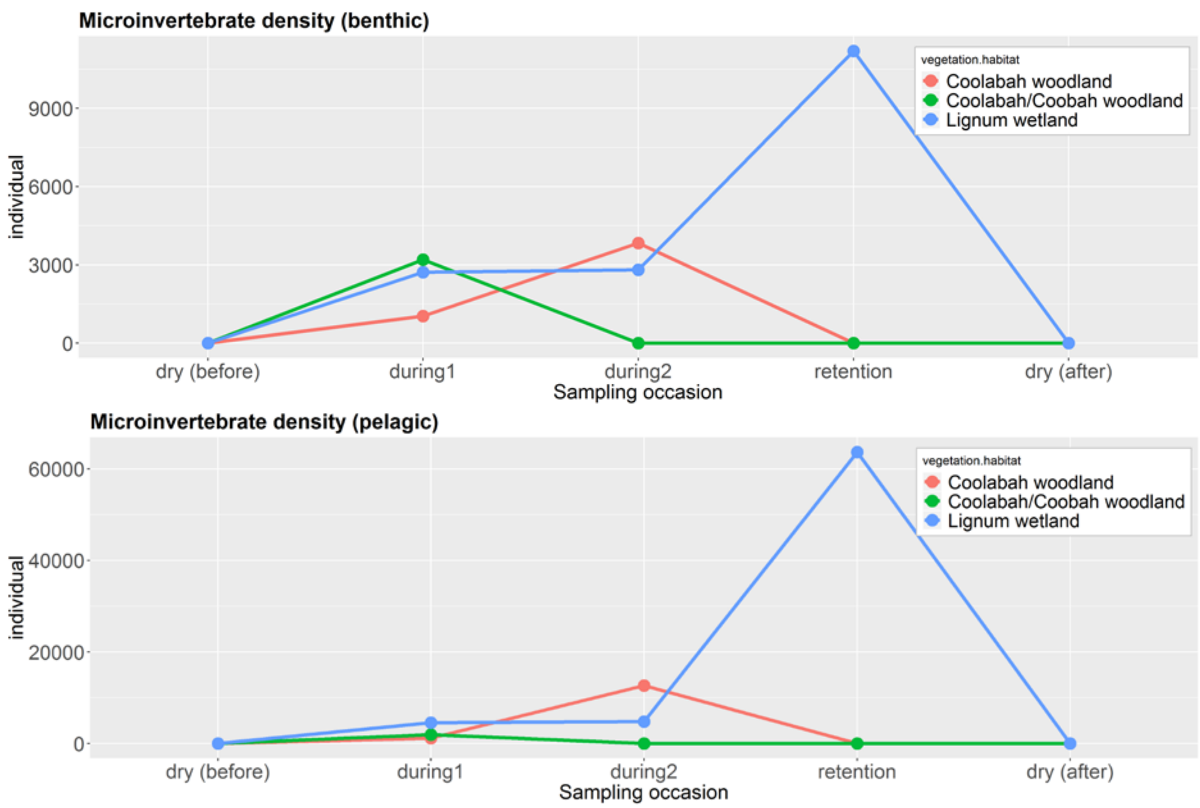


Figure G-14: Microinvertebrate density among six samples in the Western Floodplain from three sampling occasions in the largest-scale Western Floodplain inundation event in 2016-17.

There was strong positive relationship between pelagic microinvertebrate density and time since inundation (Table G-7 and Figure G-15). Microinvertebrate density was highly correlated to total nutrient concentrations in benthic habitats and to chlorophyll *a* concentration in pelagic habitats (Table G-9, Figure G-15). This suggests microinvertebrate density increases with time since inundation and peaks during the contraction period when higher total nutrients and chlorophyll *a* concentrations are present. In the Western Floodplain, peak microinvertebrate density was observed in the March 2017 “retention” sampling occasion when the system had contracted to disconnected pools with only Lignum habitats having surface water present (Table G-10).

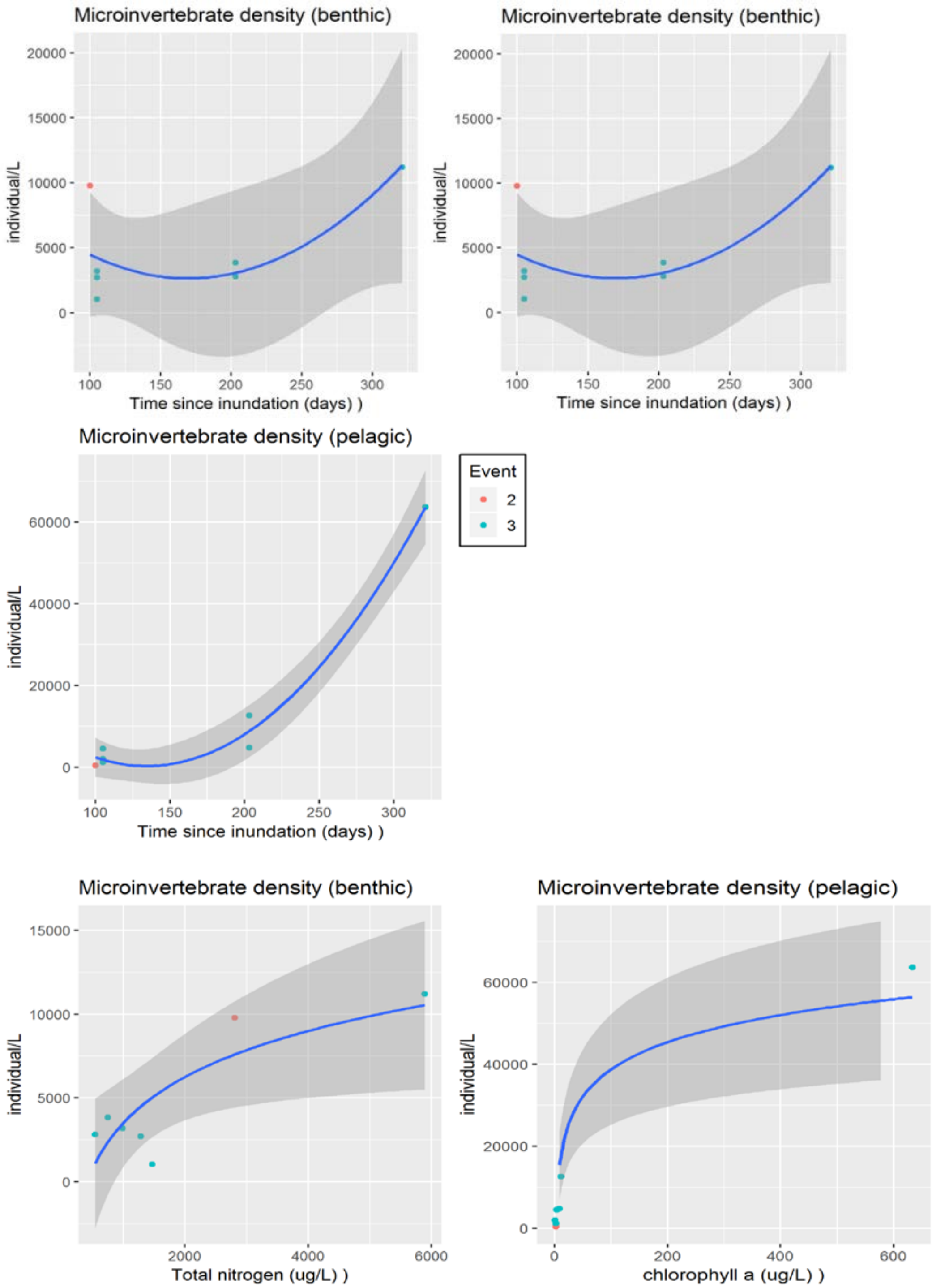


Figure G-15: Regression between microinvertebrate density and time since inundation water quality indicators (Cat III) in the Western Floodplain zone.

Table G-9: Whole-system scale microinvertebrate density (individual/m^2) among six samples in the Western Floodplain from three sampling occasions in the largest Western Floodplain inundation event in 2016-17.

Vegetation Community	During 1	During 2	Retention
	Aug-16	Nov-16	Mar-17
Coolibah/ Cooba woodland	990,000	-	-
Coolibah woodland	420,000	2,070,000	-
Lignum wetland	1,380,000	960,000	9,360,000
Total	2,780,000	3,020,000	9,360,000

Microinvertebrate diversity and richness showed similar patterns along the inundation and contraction cycle during the July 2016 event (Figure G-16). Maximum microinvertebrate diversity and richness were similar among the three vegetation habitats but at different points in the inundation cycle (Figure G-16). There was a strong negative relationship between microinvertebrate diversity and time since inundation in both habitats (Table G-7 and Figure G-17), highly correlated to multiple water quality and nutrient indicators (Table G-7). In particular, diversity in both habitats was negatively correlated to conductivity (Figure G-17).

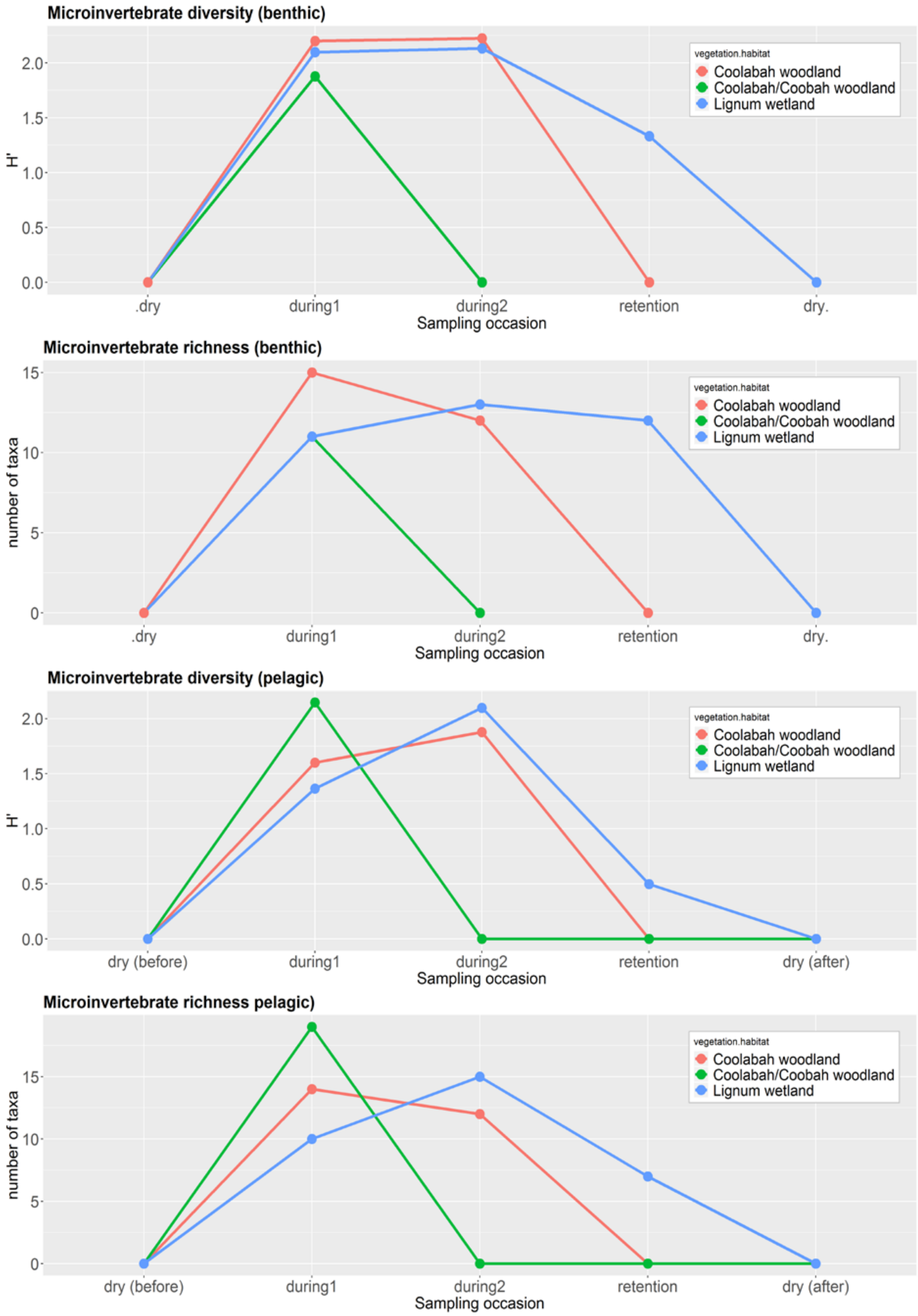


Figure G-16: Microinvertebrate diversity and richness among six samples in the Western Floodplain from three sampling occasions in the largest scale Western Floodplain inundation event in 2016-17.

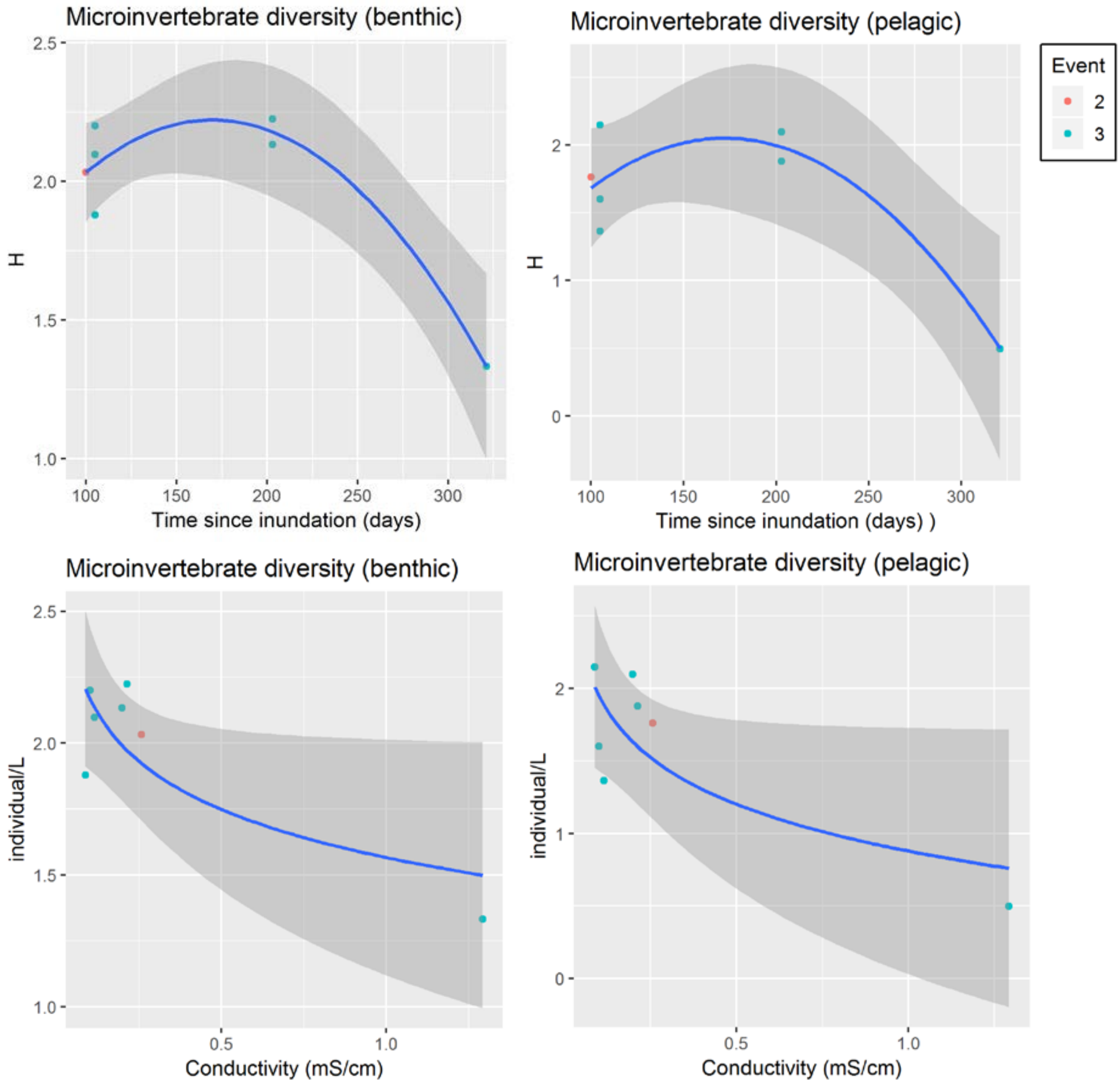


Figure G-17: Regression between microinvertebrate diversity, time since inundation and water quality indicators (Cat III) in the Western Floodplain zone.

Microinvertebrate community

In benthic habitats, community composition differed among the three vegetation habitats during the Aug-16 “during 1” sampling occasion (Figure G-18a). In the Nov-16 early summer “during 2” sampling, increased temperature and conductivity led to higher microinvertebrate abundance (Figure G-18b and Figure G-18c). Microinvertebrate community composition was similar among the three vegetation habitats in the Aug-16 “during 1” sampling occasion in pelagic habitats (Figure G-19a). The community shifted with time since inundation, regardless of vegetation habitats (Figure G-19a). In the Nov-16 early summer “during 2” sampling, increased temperature and conductivity led to higher microinvertebrate abundance (Figure G-19b and Figure G-19c). Similar to benthic habitat, pelagic microinvertebrate diversity decreased with water quality deterioration (Figure G-19c). Community composition was highly correlated to increased temperature, pH, chlorophyll *a,* and dissolved nutrients concentrations (Table G-8).

The temporal shift in community composition with time since inundation was driven by increasing abundance of rotifer Family Brachionidae, Family Filiniidae and Order Bdelloida, reflecting community succession and changes in resource availability in the system (Figure G-18d, Figure G-19d, Table G-10). In particular, a rotifer genus *Brachionus* known to tolerate various water quality conditions (Shiel, 1983) increased in abundance and dominated community in benthic and pelagic habitats in the “during 2” and “retention” phases.

Community composition was highly correlated to increased temperature in both habitats (Table G-8). Temperature seems to play a critical role in affecting water quality and determining the metabolic rates of organisms (primary producer and secondary producer), highlighting the potential ecological significance of the timing of flow events. In this case, the boom in microinvertebrate biomass did not occur immediately after inundation “during 1” (Geddes, 1984). Instead, the boom was delayed until warmer temperatures and increased rates primary production were evident. Inundation of channel and floodplain habitats during warmer periods may result in maximum diversity and density of microinvertebrates by providing an increased diversity of physical habitats and basal resources.

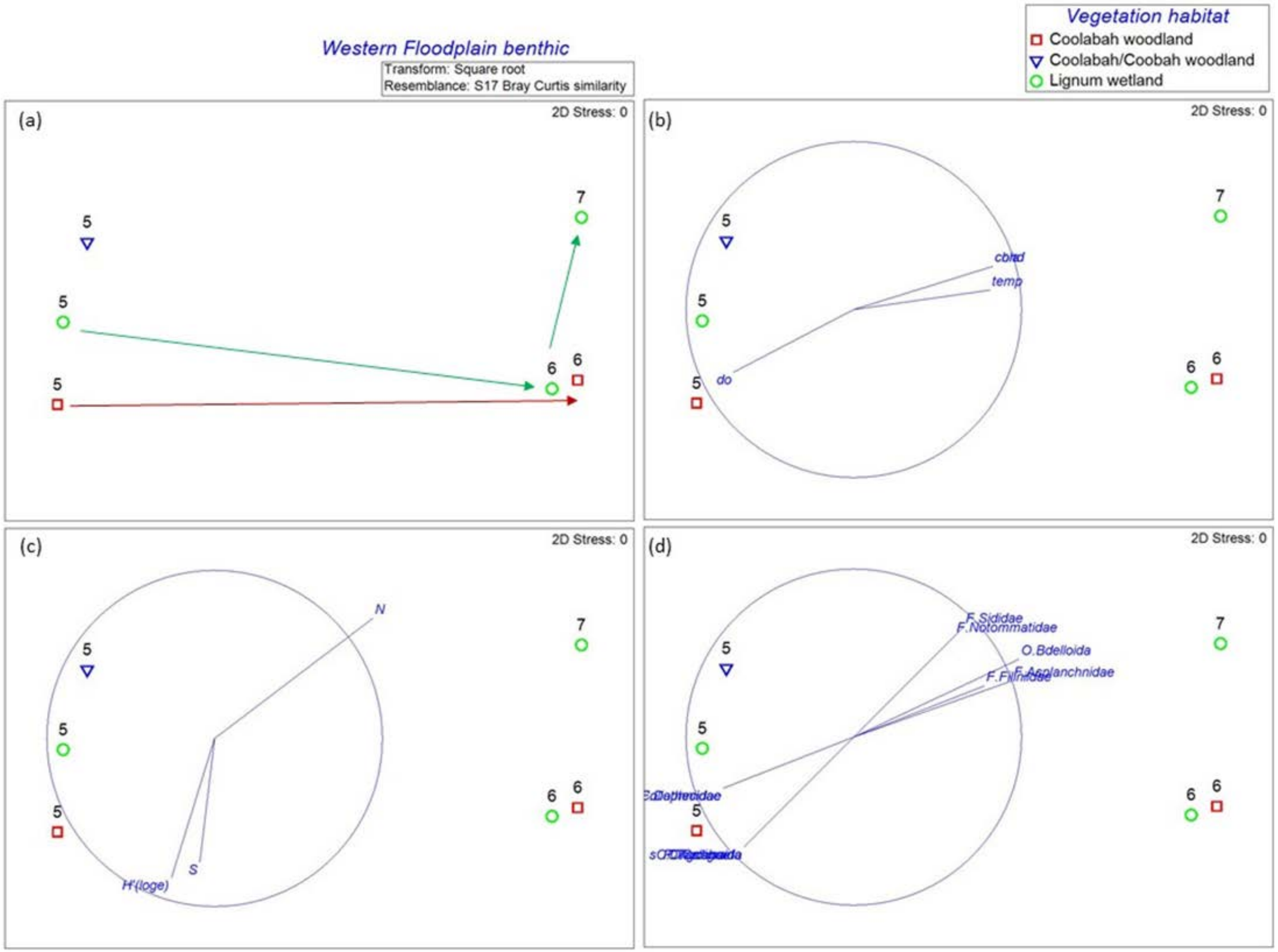


Figure G-18: nMDS ordinations of the Western Floodplain zone benthic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern.

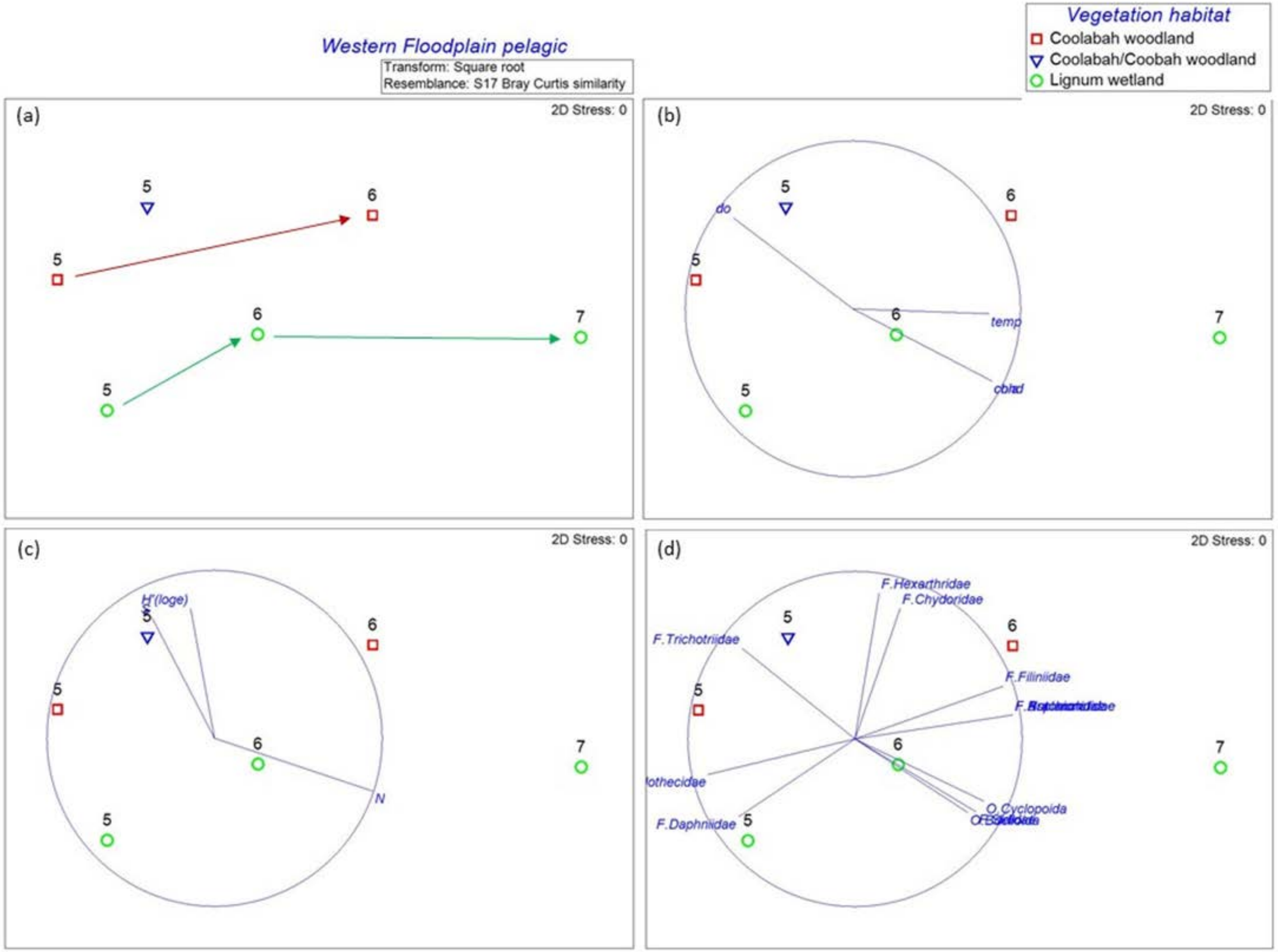


Figure G-19: nMDS ordinations of the Western Floodplain zone pelagic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables, (c) microinvertebrate univariate indicators and (d) microinvertebrate taxonomic composition data which underlie the community composition pattern.

Table G-10: Microinvertebrate taxa contributing most of the dissimilarities (SIMPER analysis) between sampling occasions based on abundance data. Bold numbers are the higher average abundance group.

Taxa	Average Abundance		Contribution%	Cumulative%
	Aug-16	Mar-17		
Benthic habitat				
G. *Brachionus*	2.92	**57.38**	20.9	20.9
O. Bdelloida	7.2	**31.86**	9.1	30.0
F. Filiniidae	1.41	**12.04**	4.1	34.1
C. Ostracoda	**9.81**	0.31	4.1	38.2
P. Tardigrada	**8.51**	0	3.6	41.8
P. Annelida	**6.63**	2.92	2.3	44.1
F. Moinidae	0	**15.98**	5.8	49.9
Pelagic habitat				
G. Brachionus	3.1	**72.6**	20.7	20.7
F. Moinidae	0.4	**22.6**	6.9	27.6
G. Keratella	13.8	**17.9**	6.6	34.2
F. Hexarthridae	3.9	**15.1**	6.4	40.6
F. Filiniidae	4.2	**18.4**	5.4	45.9
Copepod nauplii	**23.1**	22.3	5	50.9

G.4 Conclusion

Hydrology was the primary driver of microinvertebrate patterns in the Darling River zone, and within the modified dams (Warrego Channel zone) and floodplain wetlands (the Western Floodplain zone) of the Warrego-Darling Selected Area. Moreover, broader spatial (zone) microinvertebrate patterns were predominantly driven by water quality.

Across three sampling zones and eight sampling occasions, the densities of microinvertebrate recorded in this period were similar to those reported in the Murray River, Ovens River and the Macquarie Marshes within the Murray-Darling Basin (Kobayashi *et al*., 2011; Ning *et al*., 2013). The Western Floodplain had the highest average microinvertebrate density, followed by the Warrego Channel and the lowest density in the Darling River. Overall, flow acted as a resource that initiated a microinvertebrate boom and bust cycle, highlighting the benefits of environmental water for longitudinal connection of the Warrego Channel and lateral connection to the Western Floodplain. Microinvertebrate peak density was recorded during contraction periods and links to higher carbon and nutrients concentrations, suggesting secondary production was stimulated by increases in water column primary production. In the Darling River, pelagic microinvertebrate density increased with increasing discharge up to 8,000 ML/d. In the Warrego Channel, inundation duration, magnitude and antecedent conditions varied between events leading to a poorly defined relationship between time since inundation and microinvertebrates. In the Western Floodplain, the three vegetation habitats varied in maximum microinvertebrate density (carrying capacity) due to difference in inundation duration.

A total of 35 microinvertebrate taxa were identified from 136 samples (68 samples from each habitats). Rotifers were the most abundant taxonomic group, followed by Copepoda, Cladocera and Ostracoda. The Western Floodplain had the highest microinvertebrate diversity, followed by the Warrego Channel, while the lowest diversity in the Darling River. This spatial difference between zones highlights the importance of slower flow habitats, such as waterholes and billabongs in the Warrego Channel and the Western Floodplain, as microinvertebrate refuges to support diverse and abundant microinvertebrate communities.

There was a distinctive temporal pattern in microinvertebrate diversity and richness, with hydrology acting as the primary driver of microinvertebrate patterns. A high flow event in the Darling River reduced microinvertebrate richness, with over a month required to restore the richness and diversity of the microinvertebrate community. In the Warrego Channel, longitudinal flow events that included environmental water improved water quality, and in turn supported a more diverse assemblage of microinvertebrate taxa, offering a wider range of feeding opportunities for higher level consumers such as macroinvertebrates, frogs and fish. For example, the Warrego Channel microinvertebrate diversity and richness generally peaked around 30-50 days after connection and then decreased with increasing time since connection in both benthic and pelagic habitats. The cessation of upstream Warrego inflows and the contraction to disconnected pools was linked to declining water quality, which in turn led to the loss of microinvertebrates from the system.

Microinvertebrate taxonomic composition over the 5-year period showed significant differences between benthic and pelagic habitats. In the Darling River, community composition was significantly different between discharge groups with evidence that the <500 ML/d group was most different to all other discharge groups. In the Warrego Channel, pelagic microinvertebrate community composition shifted along the time since connection groups, regardless of the event size and antecedent conditions. After inundation of >50 days, poor water quality condition with higher nutrient concentrations in both habitats led to a reduction in microinvertebrate diversity. Microinvertebrate taxa with higher tolerance levels to various water quality condition appeared to dominate the community.

Temperature seems to play a critical role in affecting water quality and determining the metabolic rates of organisms (primary and secondary producers), highlighting the potential ecological significance of the timing of flow events. In the 2016-17 water year, initial inundation occurred in the cooler months leading to lower rates of primary production, and the contraction phase coincided with warmer summer months and increased rates of primary production in both the Warrego Channel and Western Floodplain. For example, the boom in microinvertebrate biomass did not occur immediately after inundation in the Western Floodplain, instead the boom was delayed until warmer temperatures and increased rates of primary production were evident. Inundation of channel and floodplain habitats during warmer periods may result in maximum diversity and density of microinvertebrates by providing an increased diversity of physical habitats and basal resources. Teasing apart the effects of inundation and season on microinvertebrates is complex, but the positive effects of prolonged inundation over warmer months is clear.

In the Warrego Channel, each connection event had different magnitude, duration and timing, as well as antecedent flow conditions. Therefore, it is challenging to understand the role of multiple hydrological factors. In the Western Floodplain, the three vegetation habitats have similar patterns in microinvertebrate response to boom and bust cycles within the same flow pulse event but showed different carrying capacity (maximum microinvertebrate density) due to inundation duration and availability of high quantity and quality carbon inputs from different vegetation habitats.

Supplement A: Microinvertebrate taxa collected within the Warrego-Darling Selected Area in 2015-18.

Taxa id	Class or sub-Class	Order	Family
Class Ostracoda			
C.Ostracoda	Ostracoda	-	-
Order Cladocera			
F.Moinidae	Branchiopoda	Cladocera	Moinidae
F.Chydoridae	Branchiopoda	Cladocera	Chydoridae
F.Macrothricidae	Branchiopoda	Cladocera	Macrothricidae
F.Daphniidae	Branchiopoda	Cladocera	Daphniidae
F.Sididae	Branchiopoda	Cladocera	Sididae
F.Bosminidae	Branchiopoda	Cladocera	Bosminidae
Class Copepoda			
nauplii	Copepoda	-	-
O.Cyclopoida	Copepoda	Cyclopoida	-
O.Calanoida	Copepoda	Calanoida	-
O.Harpacticoida	Copepoda	Harpacticoida	-
Phylum Rotifer			
F.Asplanchnidae	Monogononta	Ploima	Asplanchnidae
F.Brachionidae	Monogononta	Ploima	Brachionidae
F.Collothecidae	Monogononta	Flosculariacea	Collothecidae
F.Colurellidae	Monogononta	Ploima	Colurellidae
F.Conochilidae	Monogononta	Flosculariacea	Conochilidae
F.Epiphanidae	Monogononta	Ploima	Epiphanidae
F.Euchlanidae	Monogononta	Ploima	Euchlanidae
F.Filiniidae	Monogononta	Flosculariacea	Filiniidae
F.Flosculariidae	Monogononta	Ploima	Flosculariidae
F.Gastropidae	Monogononta	Ploima	Gastropidae
F.Hexarthridae	Monogononta	Flosculariacea	Hexarthridae
F.Lecanidae	Monogononta	Ploima	Lecanidae
F.Mytilinidae	Monogononta	Ploima	Mytilinidae
F.Notommatidae	Monogononta	Ploima	Notommatidae
F.Synchaetidae	Monogononta	Ploima	Synchaetidae
F.Testudinellidae	Monogononta	Ploima	Testudinellidae
F.Trichocercidae	Monogononta	Ploima	Trichocercidae
F.Trichotriidae	Monogononta	Ploima	Trichotriidae
O.Bdelloida	Digonanta	Bdelloida	-
Other taxonomic groups			
sC.Collembola	Collembola	Symphypleona	Sminthuridae
P.Nematoda	-	-	-
P.Tardigrada	-	-	-
sC.Oligochaeta	Oligochaeta	-	-
sO.Anostracina	Branchiopoda	Anostraca	-

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Appendix H Macroinvertebrates

H.1 Introduction

The Category III Macroinvertebrates indicator aimed to assess the contribution of Commonwealth environmental water to macroinvertebrate abundance and diversity within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). Specific questions were addressed through this indicator in the 2015-19 project period:

- What did Commonwealth environmental water contribute to macroinvertebrate productivity?
- What did Commonwealth environmental water contribute to macroinvertebrate diversity?
- What did Commonwealth environmental water contribute to macroinvertebrate community composition?

H.1.1 Environmental watering during the LTIM Project

Barwon-Darling and northern tributaries

Flows into the Darling River zone during the LTIM project were influenced by both unregulated and regulated environmental water (Appendix C). Over the project period, 12 flow events entered the Warrego-Darling Selected Area containing a environmental water contribution of between 1.8 – 99.6%. During 2014-15 one regulated flow out of the Gwydir river system and two unregulated flows containing environmental water flowed into the Warrego-Darling Selected Area. All three events were small in magnitude, being less than 1,500 ML/d at Louth, but did increase connectivity in the 2014-15 water year. Similarly, 2015-16 was another relatively dry year, characterised by three flow events of low magnitude. Environmental water contributions during this year ranged from 3.4 – 30%. In contrast, 2016-17 was characterised by one large flow event that occurred in late spring-summer and peaked at 33,700 ML/d at Louth. While only containing 2.4% environmental water, this flow inundated all available in-channel habitat along the Darling River zone. In addition to this, three other smaller inundation events occurred in 2016-17 containing between 2.4 –36.5% environmental water. 2017-18 was again a relatively dry year, with three small flow events providing connection through the Warrego-Darling Selected Area. The flow event in May-June 2016 was a targeted environmental flow called the Northern Connectivity Event, which was a combination of both state and Commonwealth water. This flow was delivered to re-connect the Barwon-Darling River and was also supported by pumping embargos along the length of the channel. This flow contained 99.6% environmental water when it flowed past the Warrego-Darling Selected Area.

Warrego River

In the Warrego River, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Warrego-Darling Selected Area have been sporadic over the LTIM Project (Figure H-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16, with flows refilling waterholes and providing a connection to the Darling River. The small flow event in January - March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, during June 2016 – February 2017.

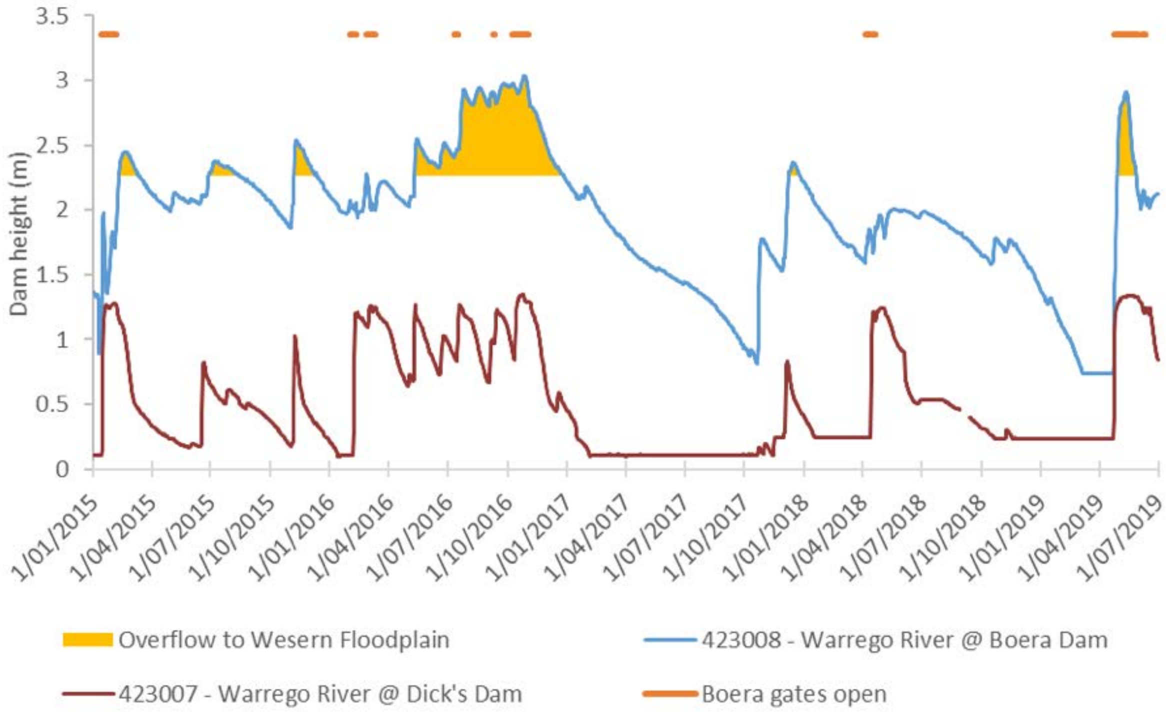

Figure H-1: Boera and Dicks Dam levels during the LTIM Project and flow to Western Floodplain and/or into lower Warrego Channels (gates open).

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, March - April 2018 and June 2018. Commonwealth environmental water made up 17.3% of the flow event during March - April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure H-1). During the flow event in March - April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River.

No flows were experienced through the lower Warrego River system during the majority of 2018-19 with levels receding in both Boera and Dicks Dams (Figure H-1). Widespread rainfall from a tropical depression in the upper Warrego catchment produced a flow event down the Warrego that entered the Warrego-Darling Selected Area in April 2019. The gates at Boera Dam were opened on 22 April 2019 and remained open for 40 days until the flow pulse had moved through the system. During this time 8,106 ML of environmental water was accounted against the Toorale Warrego River licence, which comprised 40% of the total flow.

H.2 Methods

H.2.1 Sampling methods

Macroinvertebrates were sampled in association with Category III Water Quality (Appendix E) and Category III Microinvertebrate (Appendix G) indicators on eight sampling occasions between 2015 and 2018. Sampling sites were located in three Sampling Zones within the Warrego-Darling Selected Area: Darling River, Warrego Channel and the Western Floodplain (Figure H-2).

Macroinvertebrate monitoring was conducted following the Standard Operating Procedures in Hale *et al.* (2013). Macroinvertebrate samples were identified in the laboratory to Family level, with the exception of Chironomidae that were identified to sub-Family level, Arachnida to Class level, Isopoda to Order level, and Collembola and Oligochaeta to sub-Order level. Six macroinvertebrate indicators were measured: density, diversity, richness, Signal score, salinity sensitivity index, and community abundance (Table H-1).

Table H-1: Category III Macroinvertebrate indicators measured in eight sampling occasion in 2015-18.

Indicators	Variables		Units	Code
Macroinvertebrate	i.	Density	Individual/m^2	N
	ii.	Diversity	-	H'
	iii.	Richness	-	S
	iv.	SIGNAL score	-	-
	v.	Salinity sensitivity index	-	-
	vi.	Community abundance (square root)	-	-

H.2.2 Macroinvertebrate diversity Indices

Shannon Weiner diversity index (H')

Diversity accounts for taxonomic richness and evenness. Evenness measures the relative abundance of different taxa in each sample to show how evenly each taxa are distributed between all taxa present in a sample. The higher diversity in a sample, the 'more diverse' the sample. Shannon Weiner diversity were calculated in PRIMER v6.1.13 using the DIVERSE function.

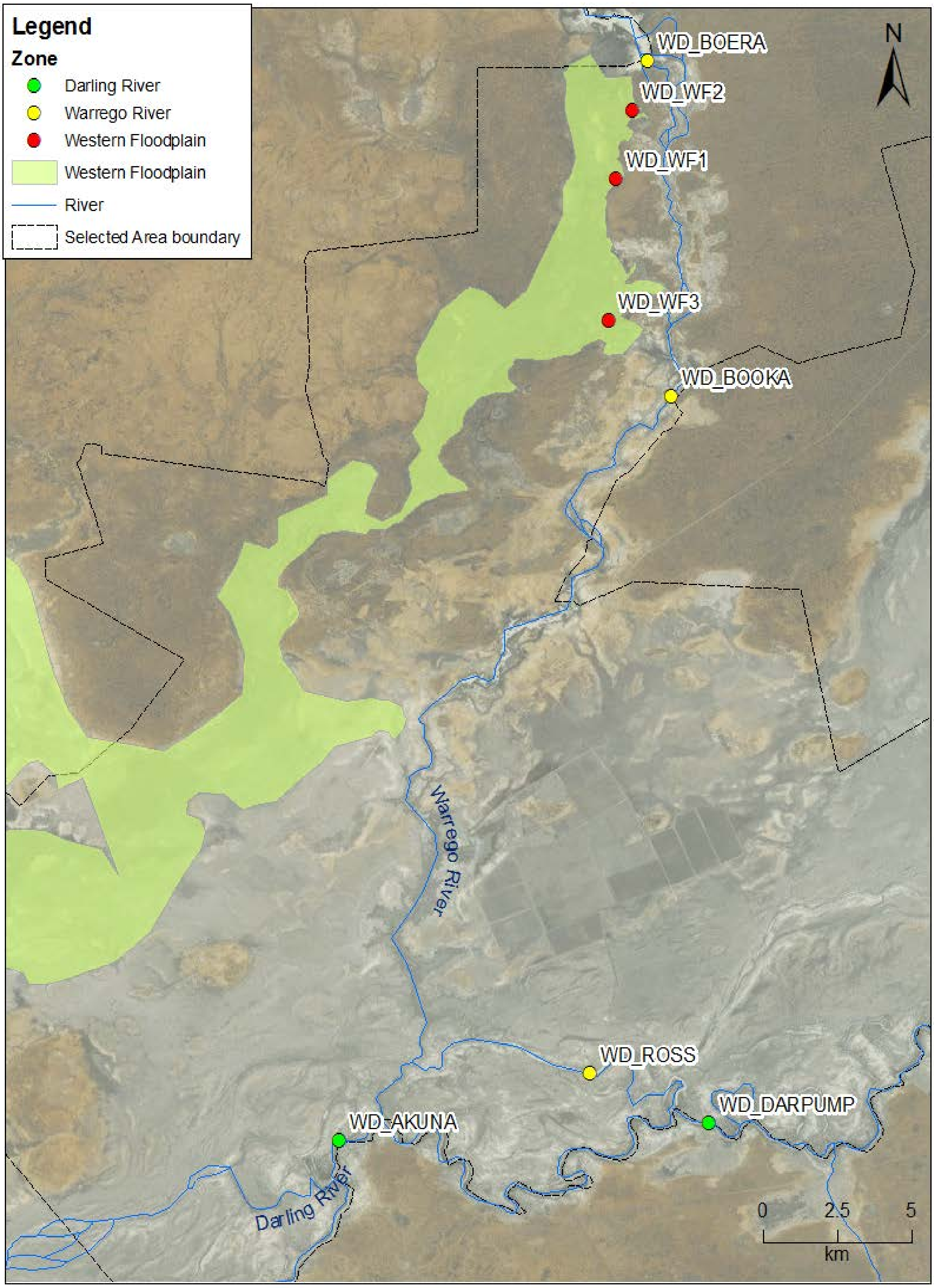

Figure H-2: Location of eleven macroinvertebrate sites within the Warrego-Darling Selected Area monitored during the LTIM Project.

Taxa richness (S)

Taxa richness is the number of macroinvertebrate taxa identified in each sample. This index is used commonly in biodiversity monitoring programs and does not take into account the abundances of the taxa or their relative abundance. The more taxa present in a sample, the 'richer' the sample. Taxa richness was calculated in PRIMER v6.1.13 using the DIVERSE function.

SIGNAL score

The SIGNAL (Stream Invertebrate Grade Number – Average Level) score in each sample was calculated using Family grades in SIGNAL version.2iv (Chessman, 2003). Macroinvertebrate taxa were assigned a sensitivity score from 1 (very tolerant) to 10 (very sensitive). The higher the SIGNAL score means that the macroinvertebrate community is more sensitive to most forms of pollution ('better health'). In the 2015-18 LTIM dataset, a total of 43 taxa (out of 47) had SIGNAL Family scores.

The SIGNAL score for each sample was calculated by averaging the sensitivity grades of all of the macroinvertebrate Families collected based on community abundance (presence/absence) dataset.

Salinity index

The macroinvertebrate salinity index of each sample was calculated using edge habitat salinity sensitivity scores (Horrigan *et al.* 2005). Individual macroinvertebrate taxa were assigned a sensitivity score of 1 (very tolerant), 5 (generally tolerant) or 10 (sensitive). The salinity index for each sample was calculated by averaging the sensitivity grades of all of the macroinvertebrate Families collected, with a higher salinity index meaning the macroinvertebrate community is more sensitive to salinity. In the LTIM dataset, a total of 34 taxa (out of 47) had a salinity sensitivity score available from Horrigan *et al.* (2005).

H.2.3 **Explanatory factors**

Spatial and temporal factors were used to test if macroinvertebrate indicators were spatially or temporally dependent. Eleven sampling sites were categorised into three **ZONES**: Darling River, Warrego Channel and the Western Floodplain (Table H-2). Eight sampling occasions were categorised into three **YEARS** and two **SEASONS** (i.e. summer from October to April and winter from May to September) (Table H-3).

Hydrological factors were used to test the influence of environmental water and other flow events. In the Darling zone, daily discharge (ML/d) data was collated from the WaterNSW gauge station 425003 Darling at Bourke Town to explore hydrological thresholds for macroinvertebrate indicators (Table H-3). In the Warrego zone, connection events were identified when Boera Dam gates were open to allow water from Boera Dam to connect to Warrego Channel sites. Time since connection was calculated using days between when Boera gate were opened (i.e. water flow to the Warrego Channel) and the first day of sampling to test the influence of five Warrego connectivity events (Table H-3 and Figure H-2a). In the Western Floodplain zone, inundation events were identified when Boera Dam water levels were above 2.26 m on the Boera gauge. Time since inundation was calculated using days between when Boera gauge was above 2.26 m (i.e. water overflow to the Western Floodplain) and the first day of sampling (Table H-3 and Figure H-3b). Three continuous hydrological factors were further transformed into three categorical hydrological factors to infer patterns. Hydrological conditions within the Warrego-Darling Selected Area during 2014-18 are described in details in Appendix A and Appendix B.

Table H-2: Location of eleven macroinvertebrate sites within the Warrego-Darling Selected Area measured over eight sampling occasions (n=68). Map projection GDA94 Zone 55. Inundation condition Wet=sampled, Dry=no sample.

Sampling Zone	Site Name	Site Code	Easting	Northing	2015-16		2016-17			2017-18		
					WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
					Oct-15	Mar-16	Aug-16	Nov-16	Mar-17	Oct-17	Apr-18	Jun-18
Darling River	Akuna	AKUNA	340008	6634629	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Darling Pump	DARPUMP	350768	6635351	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
Warrego Channel	Boera Dam 1	BOERA1	348526	6669158	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Boera Dam 2	BOERA2	348720	6669094	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 1	BOOKA1	349357	6658461	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Booka Dam 2	BOOKA2	349835	6658024	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet
	Ross Billabong 1	ROSS1	347281	6636893	Wet	Wet	Wet	Wet	Wet	Wet	Dry	Wet
	Ross Billabong 2	ROSS2	347242	6636926	Wet	Wet	Wet	Wet	Wet	Wet	Dry	Dry
Western Floodplain	Coolibah, Cooba, Lignum woodland	WF1	348083	6667550	Wet	Dry	Wet	Dry	Dry	Dry	Dry	Dry
	Coolibah open woodland	WF2	347848	6665662	Dry	Dry	Wet	Wet	Dry	Dry	Dry	Dry
	Lignum shrubland	WF3	347476	6660850	Dry	Dry	Wet	Wet	Wet	Dry	Dry	Dry

Table H-3: Explanatory (temporal, continuous hydrological and categorical hydrological) factors to infer Category III Macroinvertebrate patterns in statistical analyses.

Temporal factor				Hydrological factor (within each Zone)								
				Darling		Warrego			Western Floodplain		
Year	Sampling occasion	Month	Season	Discharge (ML/d)	Discharge category	Flow/ event	Time since connection (day)	Connection category	Flow/ event	Time since inundation (day)	Inundation category
2015-16	3	2015-10	summer	411	Base	1	242	100-299	2	100	retention
	4	2016-03	summer	51	Base	2	19	<50	-	-	-
2016-17	5	2016-08	winter	7613	5000-10000	3	36	<50	3	105	during
	6	2016-11	summer	3993	1000-4999	4	27	<50	3	203	during
	7	2017-03	summer	572	500-999	4	145	100-299	3	321	retention
2017-18	8	2017-10	summer	184	Base	4	356	>300	-	-	-
	9	2018-04	summer	47	Base	5	3	<50	-	-	-
	10	2018-06	winter	145	Base	5	68	50-99	-	-	-

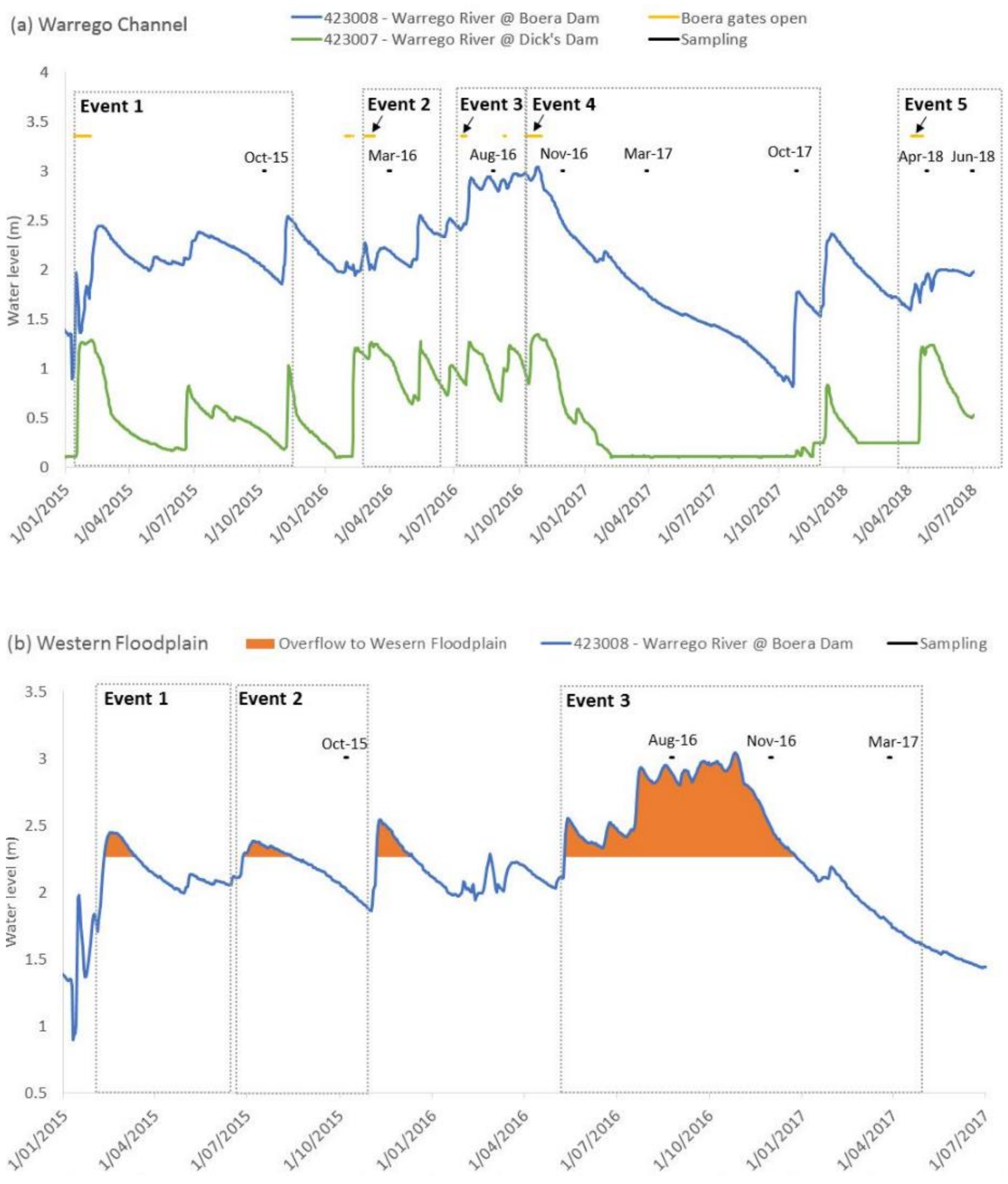

Figure H-3: Mean daily water level in (a) the Warrego Channel and (b) the Western Floodplain with flow events and sampling occasions.

H.2.4 **Statistical methods**

<u>Summary statistics and water quality guidelines</u>

The minimum, 20th, 50th (median) and 80th percentile and maximum values of each macroinvertebrate indicator on eight sampling occasions between 2015 and 2018 were calculated for the three zones within the Warrego-Darling Selected Area. The Warrego River index guideline values for macro-invertebrates in the Murray-Darling Basin in Queensland (Negus, 2013) are also indicated (Table H-5).

PERMANOVA

Permutational multivariate analysis of variance (PERMANOVA) was used to test differences in macroinvertebrate indicators between spatial, temporal and categorical hydrological factors. This routine can be used to analyse unbalanced experimental design in an analysis of variance experimental design using permutation methods (Anderson, 2008). Up to 999 random permutations estimated the probability of p-values, with levels of significance reported as $p<0.05$. Where statistically significant differences were detected, pair-wise comparisons in PERMANOVA routine were used to determine the source of the significant differences. PERMANOVA analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

Three-way PERMANOVA was used to test the overall difference in macroinvertebrate indicators between YEAR, SEASON and ZONE and their interactions. Within each zone, macroinvertebrate patterns were mainly driven by different hydrological events and therefore were analysed separately. In the Darling zone, one-way PERMANOVA was used to test the difference in macroinvertebrate indicators between discharge categories. In the Warrego zone, one-way PERMANOVA was used to test the difference in macroinvertebrate indicators between connection categories. In the Western Floodplain zone, one-way PERMANOVA was used to test the difference in macroinvertebrate indicators between inundation categories.

Regression

Relationships between macroinvertebrate variables (Table H-1) and continuous hydrological factors (Table H-3) were analysed using non-linear polynomial or logistic regression. In the Darling zone, regression was used to explore the relationships between macroinvertebrate indicators and discharge (ML/d). In the Warrego zone, regression was used to explore the relationships between macroinvertebrate indicators and time since connection (days). In the Western Floodplain zone, regression was used to explore the relationships between macroinvertebrate indicators and time since inundation (days). Regression outputs of F-statistic, degree of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

BIOENV

BIOENV analyses were used to examine eleven water quality indicators (Appendix E) and hydrological indicators (Table H-3) that were linked to the patterns of macroinvertebrate indicators. BIOENV analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

nMDS and SIMPER

Non-metric multidimensional scaling ordinations (nMDS) were used to visualise community patterns and similarity percentages (SIMPER) and determine the taxa contributing to the observed community patterns. Community abundance data were square root transformed to stabilize variance and weigh the contributions of common and rare species to improve normality (Clarke, 2001). A Bray-Curtis dissimilarity matrix was generated by rank correlating the community structure between samples. The nMDS output with stress values of less than 0.2 were considered appropriate for interpretation (Clarke, 2001). nMDS and SIMPER analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

H.3 Results

H.3.1 **Overall patterns**

Overall macroinvertebrate density pattern

Across three sampling zones and eight sampling occasions, macroinvertebrate density ranged from 11 to 1064 Individual/m^2 (Table H-4). A three-way PERMANOVA analysis showed a significant difference (Pseudo-F=8.372, d.f.=2, p=0.001), where three zones had significantly different macroinvertebrate density ($p<0.05$). Overall, the Western Floodplain had the highest macroinvertebrate density, followed by the Warrego Channel and the Darling River (Figure H-4). This spatial difference between zones in macroinvertebrate density reflects spatial and hydrological differences between the three zones exerting a strong influence on macroinvertebrate density and providing a basal food resource to support floodplain wetland food webs.

Table H-4 : The minimum, 20th, 50th (median) and 80th percentile and maximum values of macroinvertebrate density in eight sampling occasions between 2015 and 2018 were calculated in three zones within the Warrego-Darling Selected Area.

Zone	Minimum	Percentile			Maximum	Number of samples
		20th	50th	80th		
Darling	15	25	43	95	115	16
Warrego	11	68	149	334	1,064	45
WF	96	297	331	652	939	7

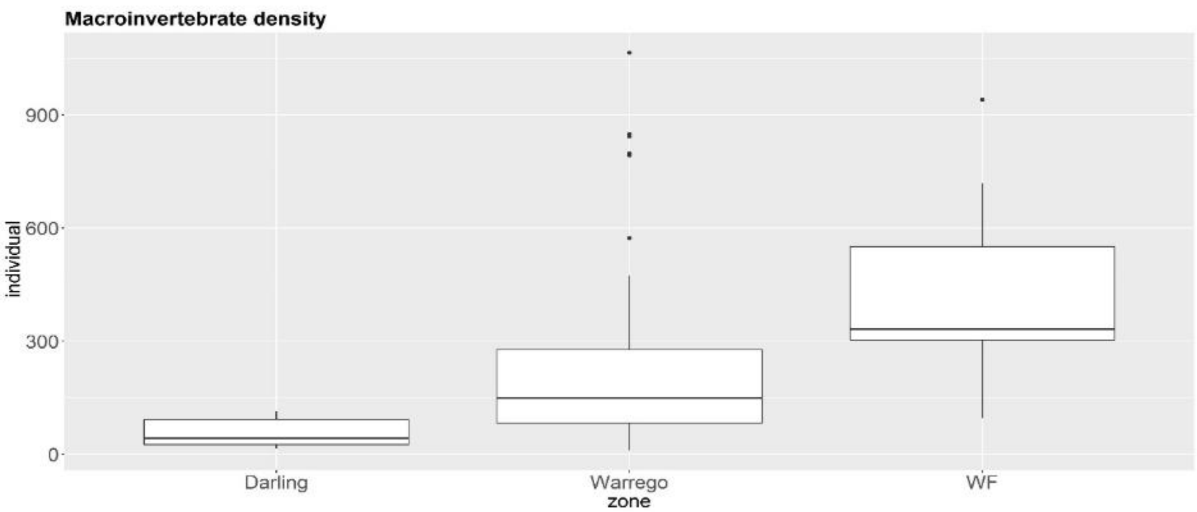

Figure H-4: Boxplot of macroinvertebrate density (individual/m^2) among 68 samples in the Warrego-Darling Selected Area from eight sampling occasions in 2015-18.

Overall macroinvertebrate diversity pattern

A total of 47 macroinvertebrate taxa were identified from 68 samples collected from 2015-18 (Supplement A). The 12 most abundant taxa (>1% in total abundance) comprised 93% of the total abundance, with the most abundant Family being Corixidae (30% of the total abundance). The other most abundant taxa were Family Notonectidae (21%), sub-Family Chironomidae (16%) and sub-Family Tanypodinae (5%) that occurred in more than 49% of sites and sampling occasions.

Macroinvertebrate taxonomic richness ranged from 2 to 17 and Shannon diversity index ranged from 0.35 to 2.34 (Table H-5). A significant difference in macroinvertebrate richness was found between zones (Pseudo-F=6.7195, d.f.=2, p=0.004), with the Darling zone having significantly lower taxa richness than the other two zones (p=0.008, Figure H-5). The Western Floodplain had the highest taxa richness and diversity, and lowest salinity index and SIGNAL score, linked to the presence of diverse vegetation habitats and basal resources that in turn support a more diverse assemblage of macroinvertebrate taxa (Figure H-5).

Table H-5: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each macroinvertebrate diversity indices in eight sampling occasions between 2015 and 2018 were calculated in three zones within the Warrego-Darling Selected Area.

Zone	Variable	Min	Percentile			Max	Number of samples
			20th	50th	80th		
Darling	Diversity (H')	0.37	0.72	1.03	1.54	2.13	16
	Richness	3	5	6	9	16	16
	salinity index	3.67	4.11	5.00	5.00	5.00	16
	SIGNAL score	2.33	2.83	3.00	3.30	3.67	16
Warrego	Diversity (H')	0.35	0.66	1.28	1.81	2.34	45
	Richness	2	6	8	12	17	45
	salinity index	2.33	4.00	4.50	5.00	6.36	45
	SIGNAL score	1.83	2.65	3.09	3.40	3.92	45
WF	Diversity (H')	0.53	1.14	1.46	1.58	1.83	7
	Richness	8	8	11	13	15	7
	salinity index	3.40	3.70	4.20	4.56	5.14	7
	SIGNAL score	2.63	2.71	2.73	2.96	3.00	7
Warrego (Qld guideline)	Richness	-	17	-	27	-	21
	salinity index	-	3.65	-	4.21	-	21
	SIGNAL score	-	3.21	-	3.5	-	21

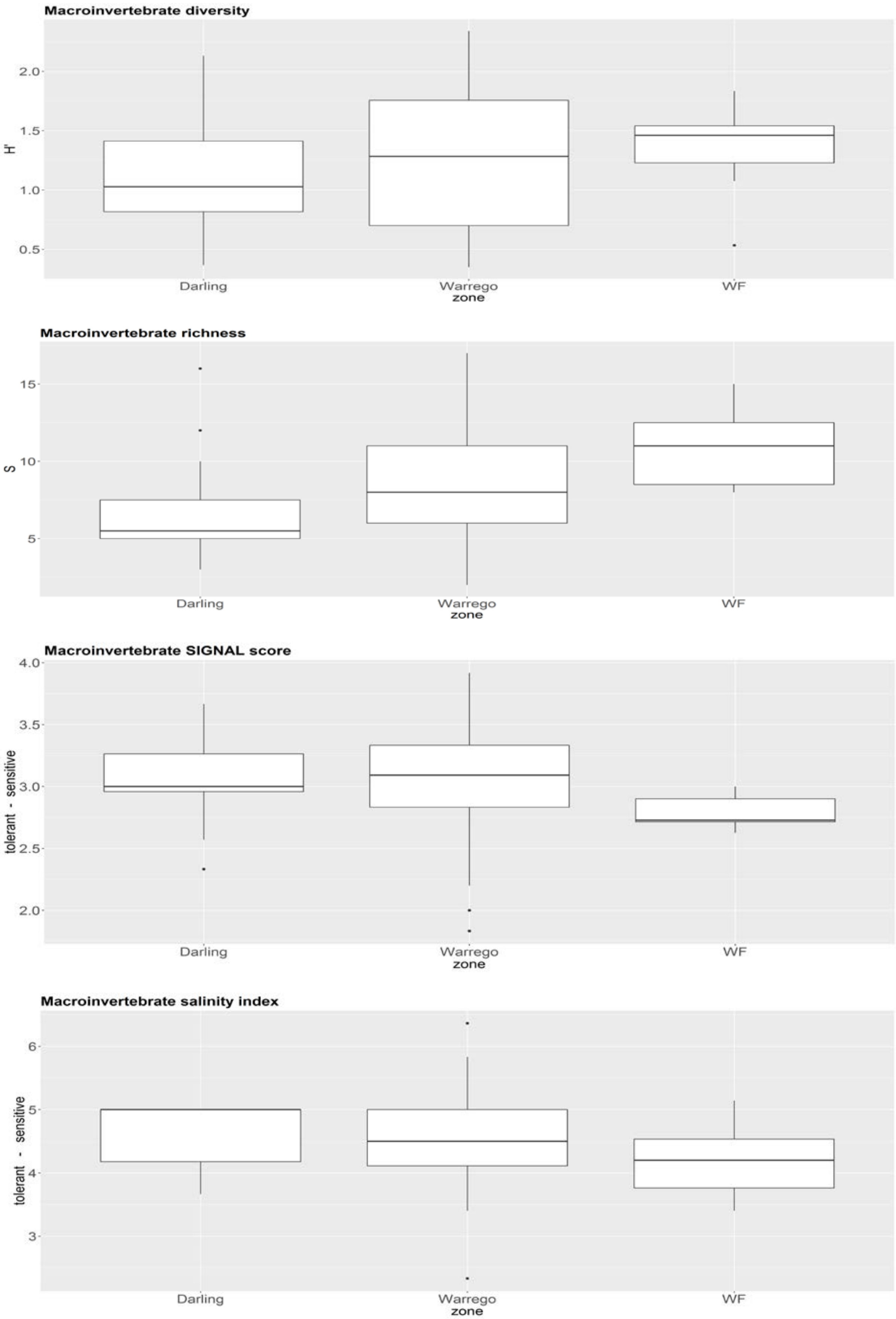

Figure H-5: Boxplot of macroinvertebrate diversity indices in the Warrego-Darling Selected Area from eight sampling occasions.

Overall macroinvertebrate community pattern

Macroinvertebrate taxonomic composition from 2015-18 showed strong spatial patterns (Figure H-6), with a significant interaction between zone, season and year, reflecting spatial, temporal and hydrological differences between three zones (Pseudo-F=2.56, d.f.=1, p=0.01).

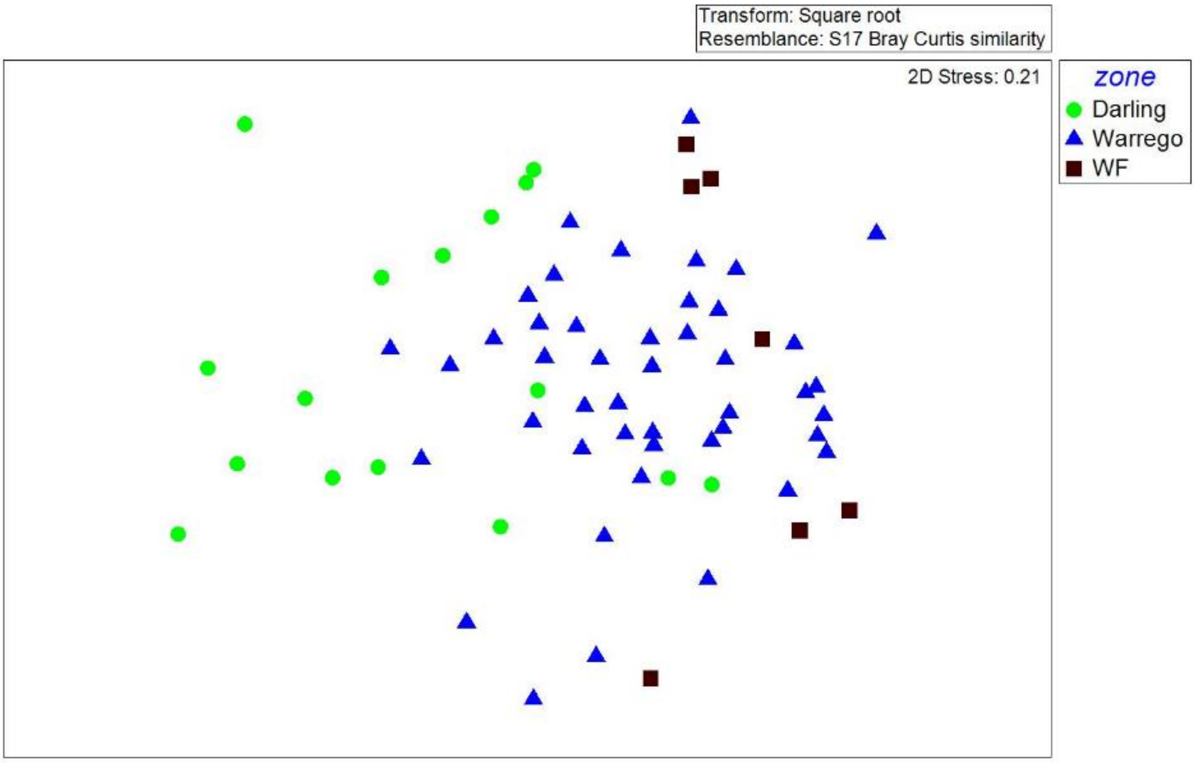

Figure H-6: nMDS ordination of macroinvertebrate community composition among 68 samples in the Warrego-Darling Selected Area from eight sampling occasions using community abundance (square root) dataset.

H.3.2 Darling River zone

Darling zone macroinvertebrate density

Macroinvertebrate density decreased with increasing discharge in the Darling River up to 8,000 ML/d (Figure H-7). This suggests that flow acted as a disturbance to initiate macroinvertebrate replacement and there may have not been enough time for re-colonising for these flow-loving taxa to re-establish (Chessman, 2009). However, there was no strong relationship with discharge (Table H-6). Dissolved organic carbon, pH and total phosphorus were best correlated with macroinvertebrate density (Table H-7), with many studies showing that macroinvertebrates can tolerate different ranges of pH and nutrients (Courtney & Clements, 1998; Petrin, Laudon, & Malmqvist, 2007).

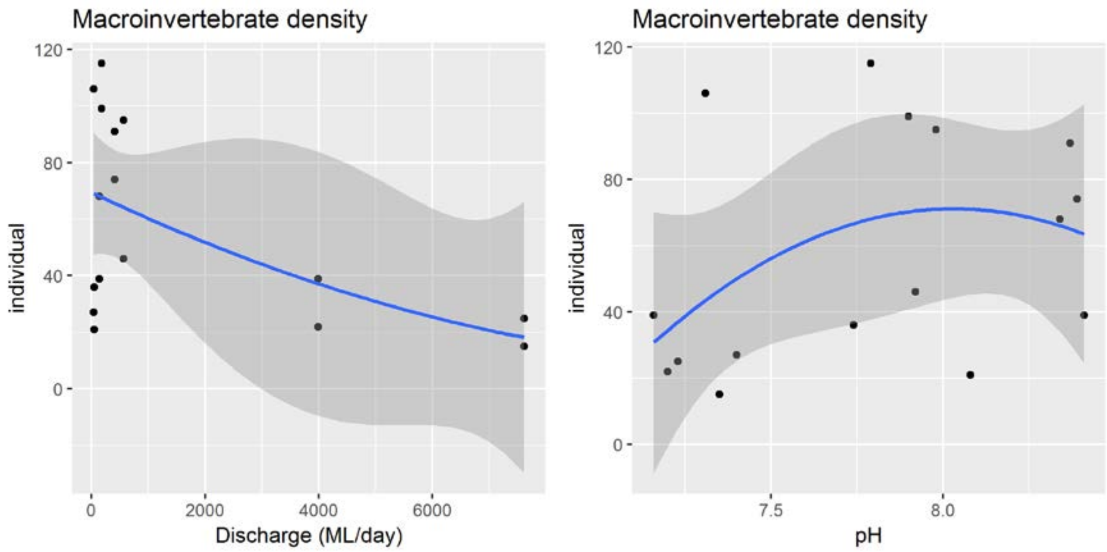

Figure H-7: Regression between macroinvertebrate density (individual/m^2) and discharge and pH in the Darling River zone.

Darling zone macroinvertebrate diversity

All macroinvertebrate diversity indices showed no clear relationships with discharge (Figure H-8 and Table H-6). Macroinvertebrate diversity and richness peaked in March 2017 when the Darling River experienced base flow conditions with discharge around 550 ML/d, with five months elapsed since the bank full event in October 2017. This reflects the longer term influence of flow disturbance in the Darling zone that macroinvertebrate taxonomic diversity and richness had recovered when the system had returned to low or base flow conditions.

Chlorophyll *a* was best correlated with diversity and filterable reactive phosphorus was best correlated with richness (Table H-7). However, there was no strong relationship between macroinvertebrate diversity and these water quality indicators (Figure H-8).

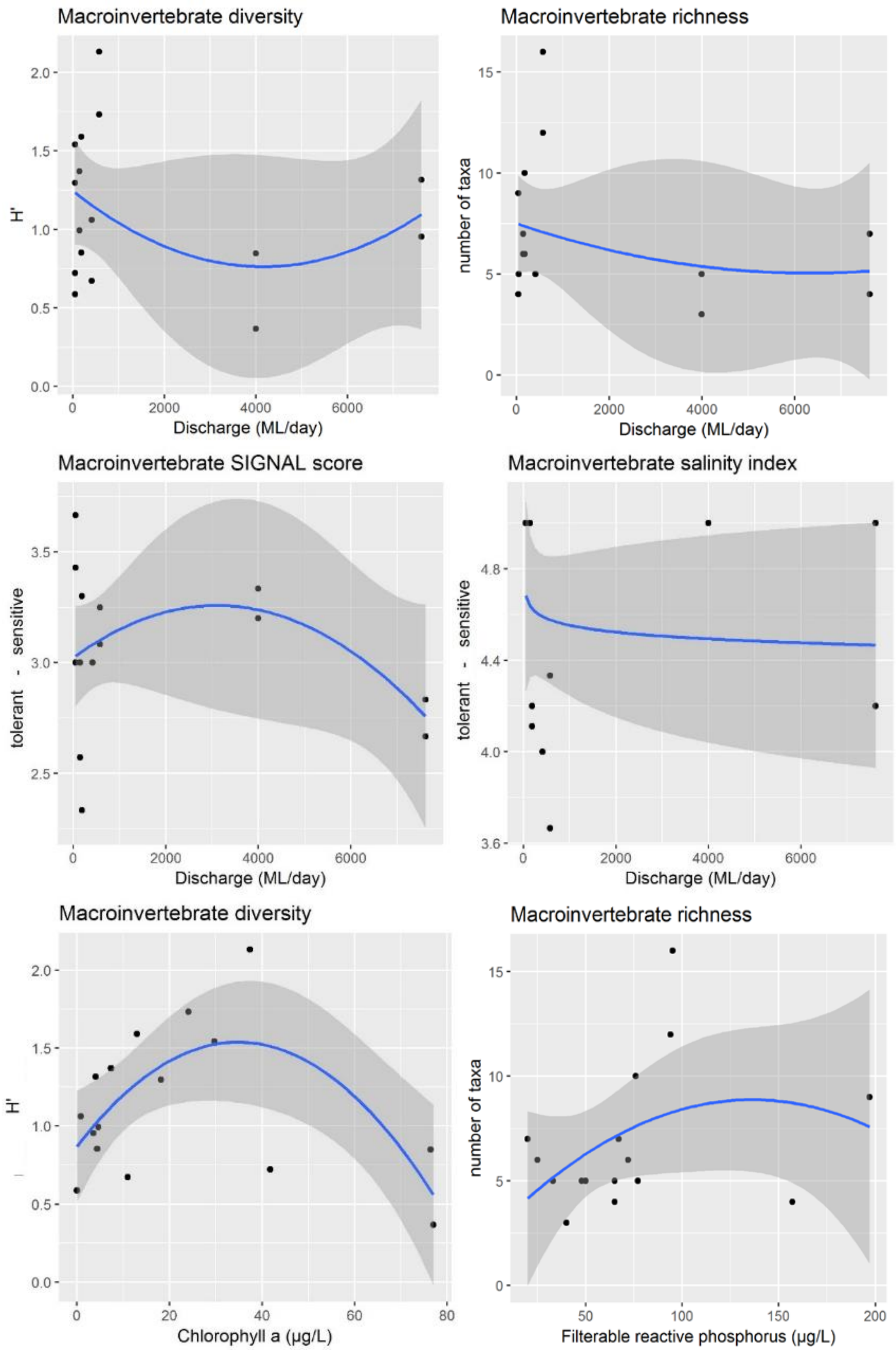

Figure H-8: Regression between macroinvertebrate diversity indices and discharge and water quality indicators (Cat III) in the Darling River zone.

Table H-6: Summary of regression results between continuous hydrological factors and macroinvertebrate indicators within the Warrego-Darling Selected Area. * represents significant results of p-value <0.05. 'poly' represents quadratic polynomial regression model and 'log' represents log regression model.

Zone	Macroinvertebrate indicator	Darling				
		F	d.f.	p-value	R^2	model
Darling	Density	2.57	2,13	0.11	0.28	poly
	Diversity (Shannon diversity index)	0.74	2,13	0.50	0.10	poly
	Richness	0.52	2,13	0.60	0.07	poly
	SIGNAL score	1.14	2,13	0.35	0.15	poly
	Salinity sensitivity score	0.35	1,14	0.56	0.02	log
Warrego	Density	2.50	2,42	0.09	0.11	poly
	Diversity (Shannon diversity index)	19.86	2,42	***0.00****	0.49	poly
	Richness	7.27	2,42	***0.00****	0.26	poly
	SIGNAL score	10.67	2,42	***0.00****	0.34	poly
	Salinity sensitivity score	0.34	2,42	0.71	0.02	poly
Western Floodplain	Density	0.29	2,4	0.62	0.05	log
	Diversity (Shannon diversity index)	0.59	2,4	0.60	0.23	poly
	Richness	1.02	2,4	0.44	0.34	poly
	SIGNAL score	14.45	2,4	***0.01****	0.88	poly
	Salinity sensitivity score	0.79	2,4	0.51	0.28	poly

Table H-7: Summary of BIOENV results of macroinvertebrate indicators within the Warrego-Darling Selected Area. 'v' represents environmental indicators that highly correlated to macroinvertebrate indicators.

Zone	Macroinvertebrate indicator	Rho	p	Water chemistry						Water nutrient					
				Temperature	pH	Turbidity	Conductivity	Dissolved oxygen	Chlorophyll *a*	Dissolved organic carbon	Total nitrogen	Total phosphorus	Nitrate-nitrite	Filterable reactive phosphorus	Hydrological indicator
Darling	Density	0.307	0.29		v					v		v			
	Richness	0.204	0.88											v	
	Diversity	0.227	0.68						v						
	SIGNAL score	0.642	0.03			v			v	v				v	v
	Salinity sensitivity score	0.050	0.99	v	v					v					
	Community composition	0.310	0.14	v	v				v					v	
Warrego	Density	0.420	0.01	v				v		v		v			
	Richness	0.230	0.09	v	v		v								
	Diversity	0.422	0.01		v				v						v
	SIGNAL score	0.459	0.01	v	v			v			v		v		
	Salinity sensitivity score	0.166	0.26	v	v				v	v			v		
	Community composition	0.236	0.09		v	v						v			
Western Floodplain	Density	0.486	0.51										v	v	
	Richness	0.542	0.27							v				v	
	Diversity	0.188	0.93	v											
	SIGNAL score	0.477	0.39	v									v		
	Salinity sensitivity score	0.056	0.99										v		
	Community composition	0.736	0.15	v	v									v	

Darling zone macroinvertebrate community

Community composition was significantly different between discharge groups (Pseudo-F=2.13, $p<0.01$) with evidence that the <500 ML/d group was most different from 1,000-5,000 ML/d group ($p<0.05$, Figure H-9a). It means that macroinvertebrate community composition was predominantly driven by hydrological conditions. Higher macroinvertebrate density and diversity was recorded in the low discharge group (<500 ML/d), as disturbance is the major mechanism controlling macroinvertebrate abundance (Figure H-9c).

Community composition was also highly correlated with temperature, pH, chlorophyll *a,* and filterable reactive phosphorus (Table H-7). A higher abundance of the pollution tolerant midge larvae, Chironominae, in the <500 ML/d group was linked with higher pH and conductivity caused by evapoconcentration during the Darling River contraction period (Figure H-9b and Figure H-9d). The high abundance of the mayfly Caenidae were also found in this <500 ML/d group (Figure H-9d), likely because their body shape is more adapted to low flow conditions. On the other hand, larger and highly mobile macroinvertebrate such as Atyidae shrimp and Palaemonidae shrimp had higher abundance in higher flow conditions (>1,000 ML/d) (Figure H-9d).

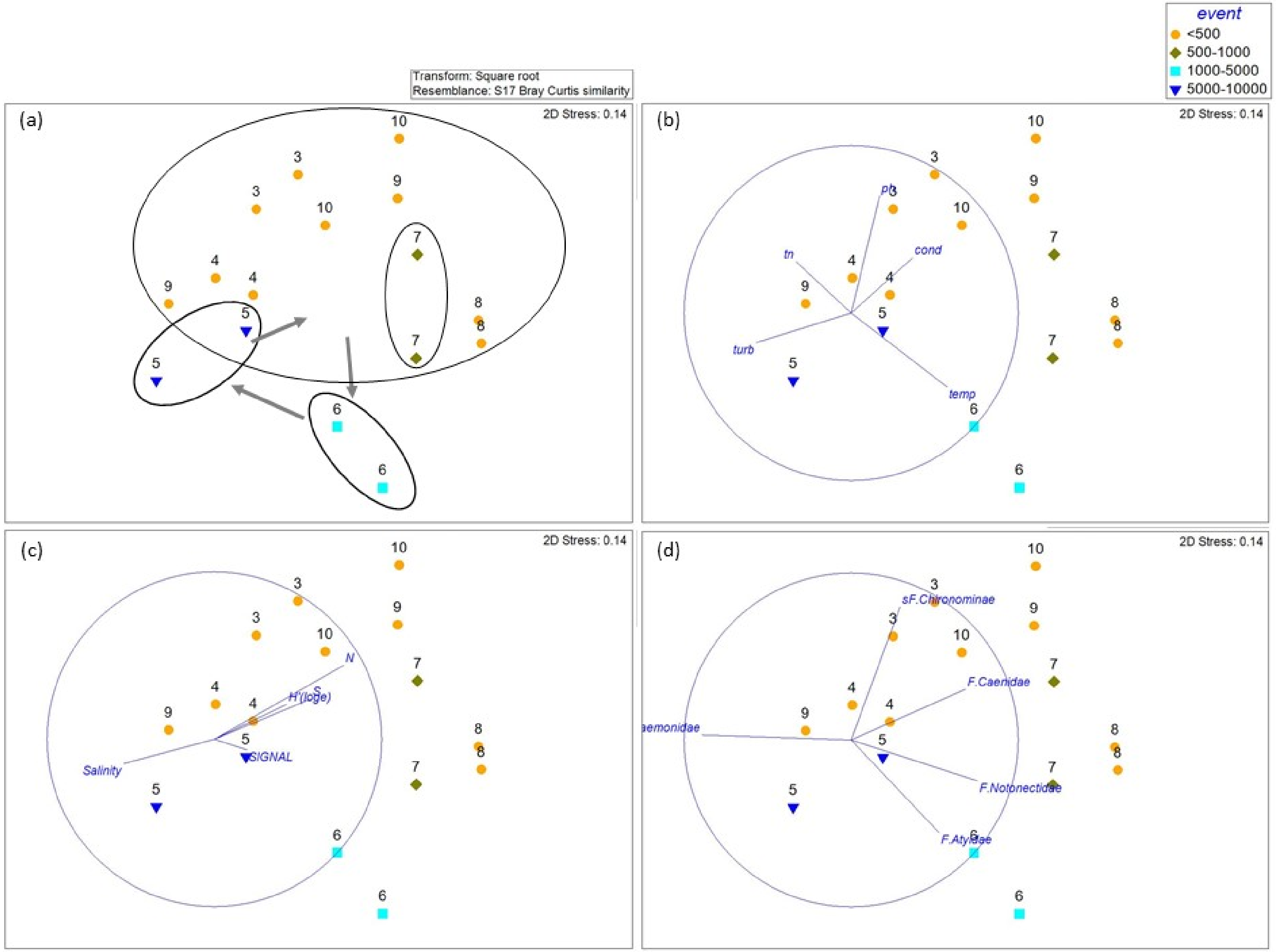

Figure H-9: nMDS ordinations of Darling River zone macroinvertebrate community composition using community abundance (square root) dataset with vectors of (b) environmental variables (normalised data, Spearman correlation), (c) macroinvertebrate univariate indicators (normalised data, Spearman correlation) and (d) macroinvertebrate taxonomic composition data (Spearman 0.7) which underlie the community composition pattern. Numbers represent sampling occasion.

H.3.3 **Warrego Channel zone**

Warrego hydrology

Macroinvertebrates were sampled in five out of seven connection events in the Warrego Channel zone (Figure H-3a). Time since connection was calculated using days between when Boera gates were open (i.e. water flow to the Warrego Channel) and the first day of sampling to test the influence of five Warrego connectivity events (Table H-3). Increase in time since connection in days represents the system moving towards a water retention phase, contraction phase and then dry.

Macroinvertebrate density

Macroinvertebrate density increased with increasing time since connection (Figure H-10). Temperature, dissolved oxygen, dissolved organic carbon and total phosphorus concentrations were best correlated with macroinvertebrate density (Table H-7). In particular, macroinvertebrate density increased with increasing total phosphorus concentration (Figure H-10). This finding suggests macroinvertebrate density increased with time since connection and peaked in the contraction period associated with higher carbon and total nutrient concentrations. However, there was no relationship between macroinvertebrate density and time since connection because inundation duration varied between events (Table H-6).

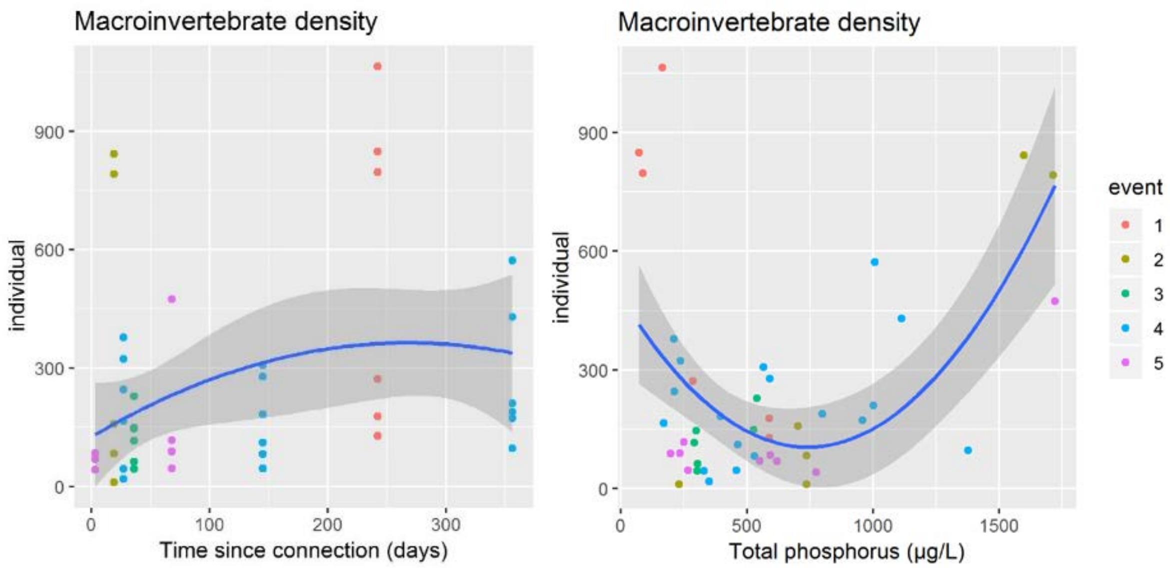

Figure H-10: Regression between macroinvertebrate density (individual/m²) and time since connection and total phosphorus in the Warrego Channel zone.

Macroinvertebrate diversity

Four macroinvertebrate diversity indicators generally peaked around 30 to 50 days since connection and then decreased with increasing time since connection, regardless of events (Figure H-11). There were strong negative relationships between diversity, richness, SIGNAL score and time since connection (Table H-6). Higher diversity and richness were found during the wettest phases.

Water quality and water nutrients were highly correlated with macroinvertebrate diversity (Table H-7), with diversity decreasing with increasing pH, and SIGNAL score decreasing with increasing total nitrogen concentration (Figure H-11). This matches the finding in Category III water quality, which identifies a deterioration in water quality when time since connection was more than 50 days driven by evapoconcentration and internal recycling of nutrients (Appendix E).

This highlights that longitudinal connection events in the Warrego Channel improve water quality, increase habitat diversity and basal resources that in turn, support more diverse assemblages of macroinvertebrate taxa. More diverse macroinvertebrate communities offer a wider range of feeding opportunities for higher level consumers such as frogs, fish, waterbirds and other aquatic vertebrates.

Macroinvertebrate community

Community composition was significantly different between time-since connection groups (Pseudo-F=3.34, p=0.0001), with the macroinvertebrate community composition shifting with time since connection, regardless of events (Figure H-12a). In particular, significant dissimilarity was found between <50 days and >300 days groups (p=0.0001, Figure H-12a). It means that macroinvertebrate community composition was predominantly driven by hydrological conditions, measured as time since connection.

Community composition was highly correlated to increased pH, turbidity and total phosphorus concentration along a time since connection gradient (Table H-7). Improved water quality in early connection phases (<50 days group) linked to higher richness, diversity and abundance in sensitive Families such as Leptoceridae and Physidae (Figure H-12b, c and d). After a prolonged inundation time (>50 days), the system shifted to a poorer water quality condition with higher pH, turbidity and total phosphorus concentrations that in turn recorded lower macroinvertebrate diversity and richness (Figure H-12b). In a poor water quality condition with longer time since connection, pollution tolerant Families including Corixidae and Chironomidae dominated the community (Figure H-12d).

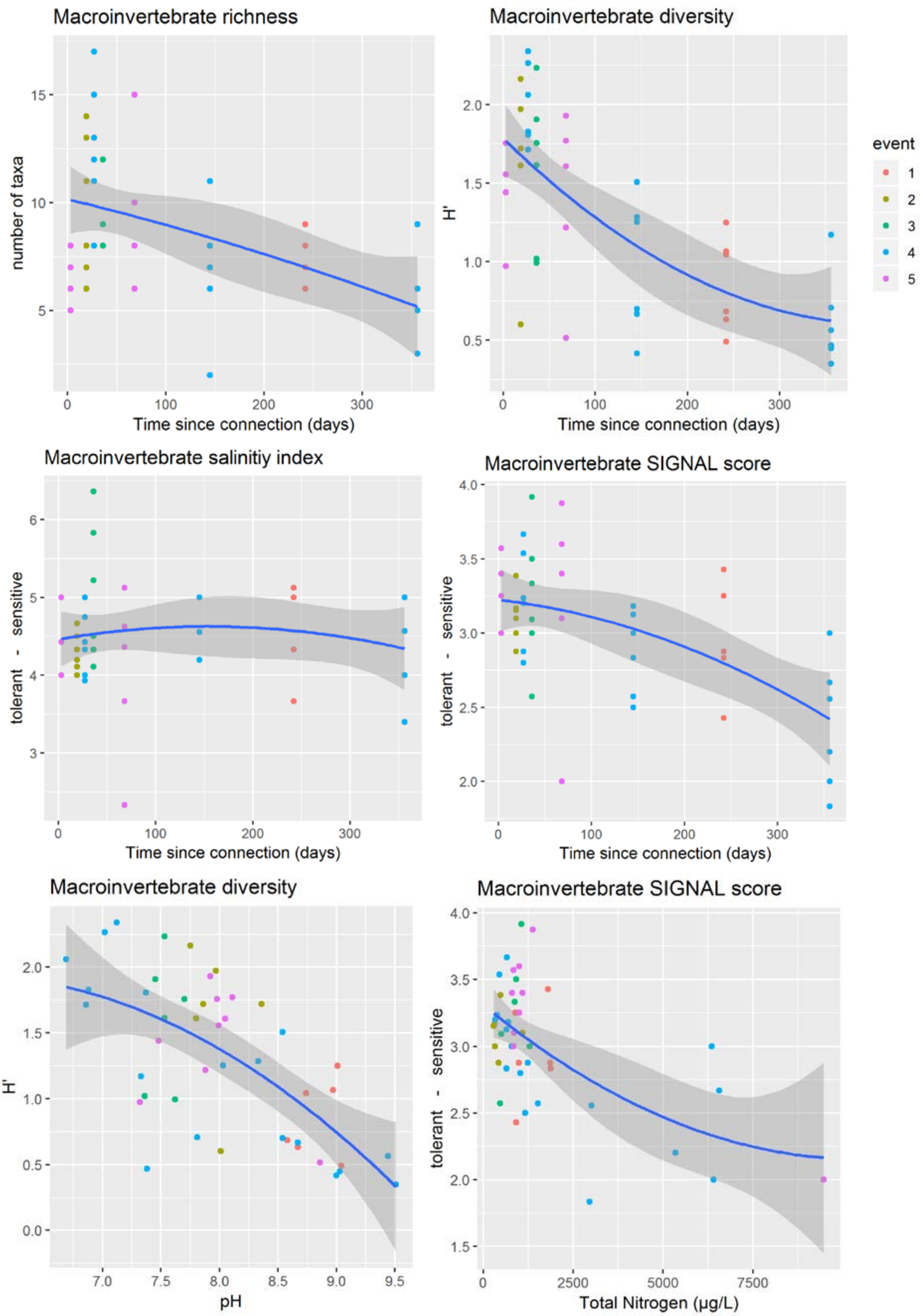

Figure H-11: Regression between macroinvertebrate diversity indices and time since connection and water quality indicators (Cat III) in the Warrego Channel zone.

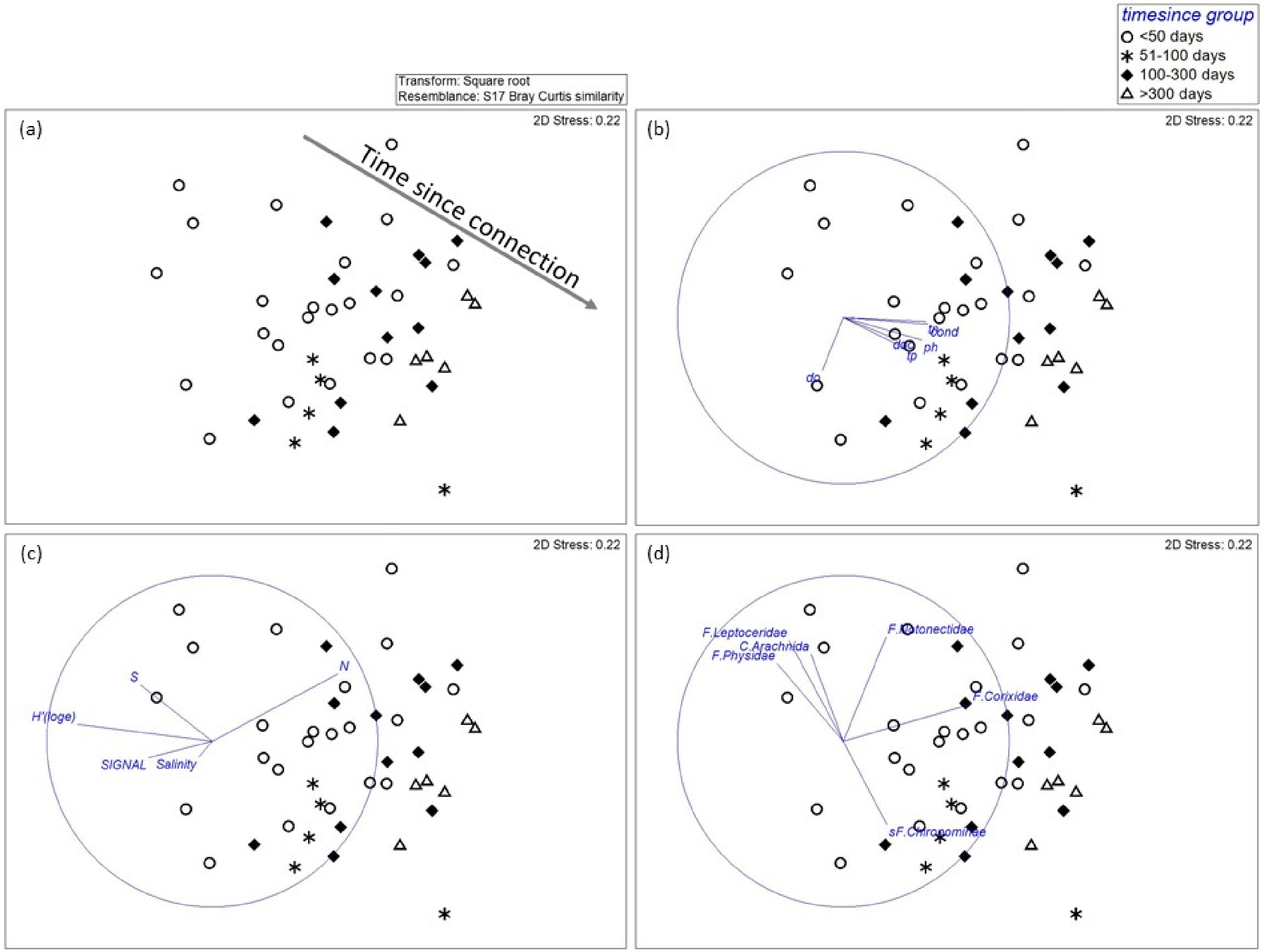

Figure H-12: nMDS ordination of Warrego Channel zone macroinvertebrate community composition using community abundance (square root) dataset with vectors of (b) environmental variables (normalised data, Spearman correlation), (c) macroinvertebrate univariate indicators (normalised data, Spearman correlation) and (d) macroinvertebrate taxonomic composition data (Spearman 0.7) which underlie the community composition pattern.

H.3.4 Western Floodplain zone

Western Floodplain hydrology

Time since inundation was calculated using days between the Boera gauge measuring above 2.26 m (i.e. water over flow to the Western Floodplain) and the first day of sampling. This was to test the influence of three Western Floodplain inundation events. During the LTIM Project, one macroinvertebrate sample was collected in event 2 and six samples from three sampling occasions were collected in event 3 in the Western Floodplain (Figure H-3b and Table H-3). This report focuses on the largest inundation event (event 3) in July 2016, in which multiple samples were collected during the inundation and contraction cycle.

Three macroinvertebrate sampling occasions captured the inundation cycle of this event. In August 2016 “during 1”, an estimated 6.457 ML of inflows had spilled onto the Western Floodplain with 1,695 ha of the Floodplain inundated on 13 August 2016 (Appendix C). Three sites were sampled to represent different inundation frequencies. In November 2016 “during 2” sample, the Western Floodplain had been connected for over five months with steadily declining inflow. Two sites were sampled (WF1 sampled in August 2016 was dry). In March 2017 “retention” samples, the Western Floodplain was in a contraction period with no inflow for the three previous months (Appendix C).

Macroinvertebrate density

In event 3, the Western Floodplain inundation was triggered by lateral connection between the Warrego Channel and the Western Floodplain from May 2016. In August 2016 “during 1” sampling, Coolibah woodland and Coolibah/Cooba woodland had similar peaks in macroinvertebrate density of around 300 individuals/m^2, which was lower than the density in Lignum habitats (approx. 400 individuals/m^2) (Figure H-13). In November 2016 “during 2” sampling, Coolibah woodland density reduced to around 100 individuals and Coolibah/Cooba woodland habitat was dry, and macroinvertebrate density in Lignum habitats reached a peak density above 700 individuals/m^2. In May 2017 “retention” phase, Lignum was the only habitat with standing surface water with a macroinvertebrate density reduced to around 300 individuals/m^2. In summary, the three vegetation habitats had similar responses to the flow pulse but varied in habitat inundation duration, leading to different maximum macroinvertebrate densities.

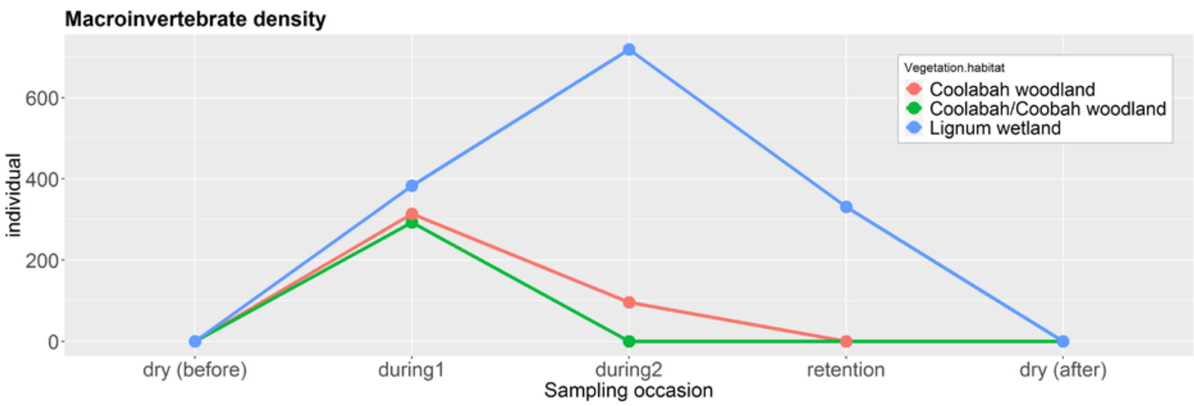

Figure H-13: Macroinvertebrate density (individual/m^2) among six samples in the Western Floodplain from three sampling occasions in the largest scale Western Floodplain inundation event in 2016-17.

Macroinvertebrate density was highly correlated to dissolved inorganic nutrients (Table H-7). Macroinvertebrate density increased with increasing dissolved inorganic nutrients (nitrate-nitrite and filterable reactive phosphorus) concentrations, regardless of event (Figure H-14). There was no predictable relationship with time since inundation (Table H-6). Overall, the highest density was recorded in the contraction phase in summer. The highest densities were also linked to higher water carbon and nutrients concentrations and subsequently highest chlorophyll *a* concentrations, as well as peak microinvertebrate densities.

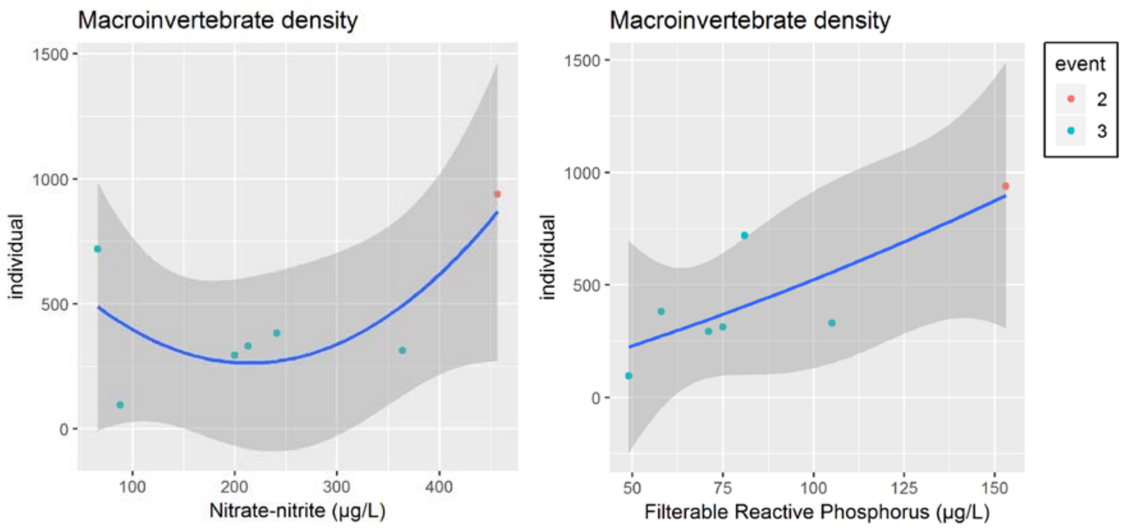

Figure H-14: Regression between macroinvertebrate density (individual/m^2) and water quality indicators (Cat III) in the Western Floodplain zone from four sampling occasions in 2014-18.

<u>Macroinvertebrate diversity</u>

In the Western Floodplain, four diversity indices showed similar patterns throughout the inundation and contraction cycle in the July 2016 event (Figure H-15). Maximum macroinvertebrate taxonomic richness was similar among the three vegetation habitats but in different sampling occasions. In Coolibah and Coolibah/Cooba woodland habitats, macroinvertebrate peak richness occurred in August 2016 “during 1” sampling, while in the Lignum habitat peak richness was in November 2016 “during 2” sampling (Figure H-15).

Macroinvertebrate diversity indices were highly correlated to multiple water quality and nutrients parameters (Table H-7). In particular, macroinvertebrate diversity was positively correlated to temperature and SIGNAL score and negatively correlated with inorganic nitrogen (Figure H-16). Macroinvertebrate diversity peaked during the wettest period around 100 days since inundation and decreased with time since inundation accompanied by water quality deterioration. However, there was no strong predictable relationship with time since inundation (Table H-6).

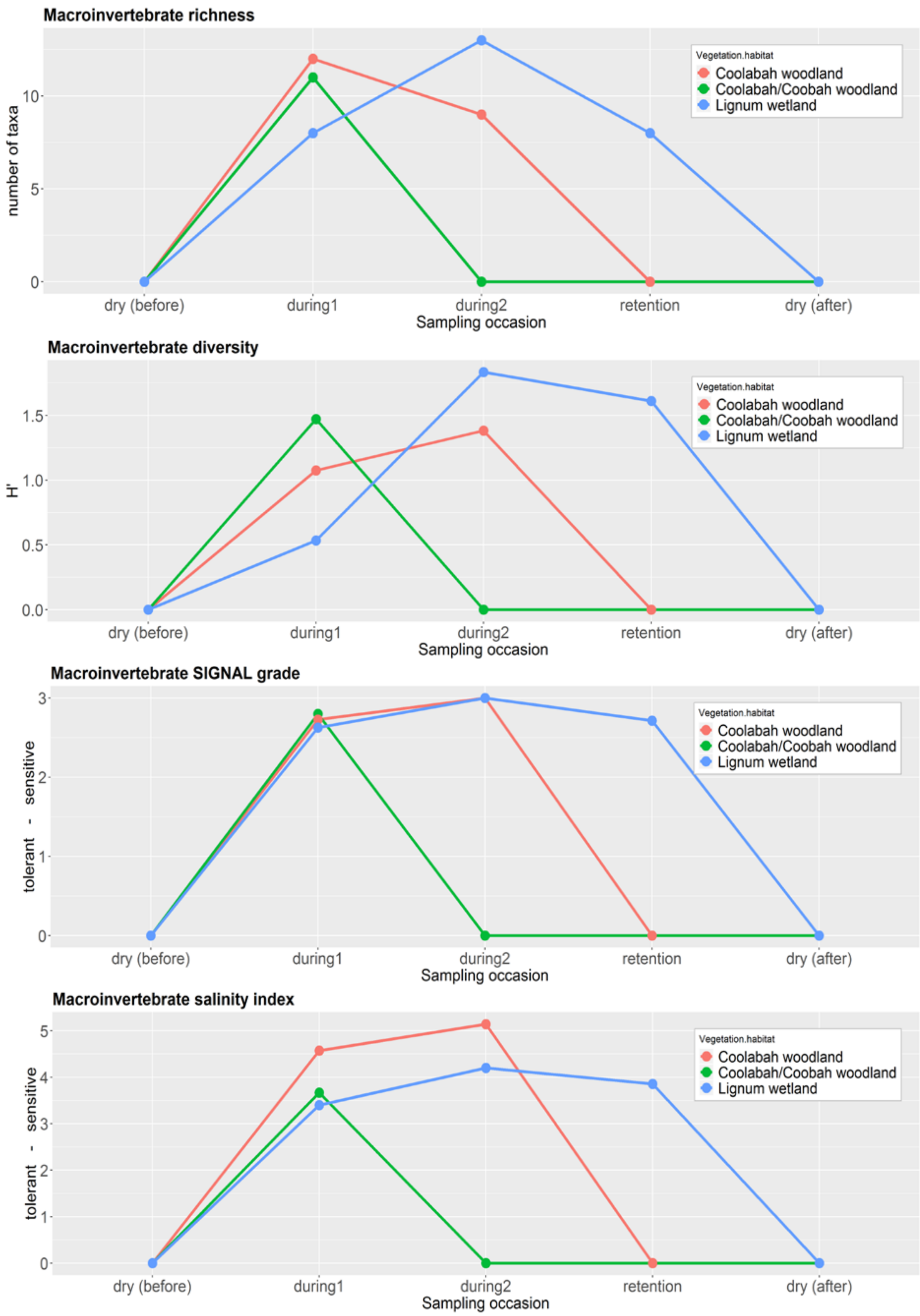

Figure H-15: Macroinvertebrate diversity indicators among six samples in the Western Floodplain from three sampling occasions in the largest scale Western Floodplain inundation event in 2016-17.

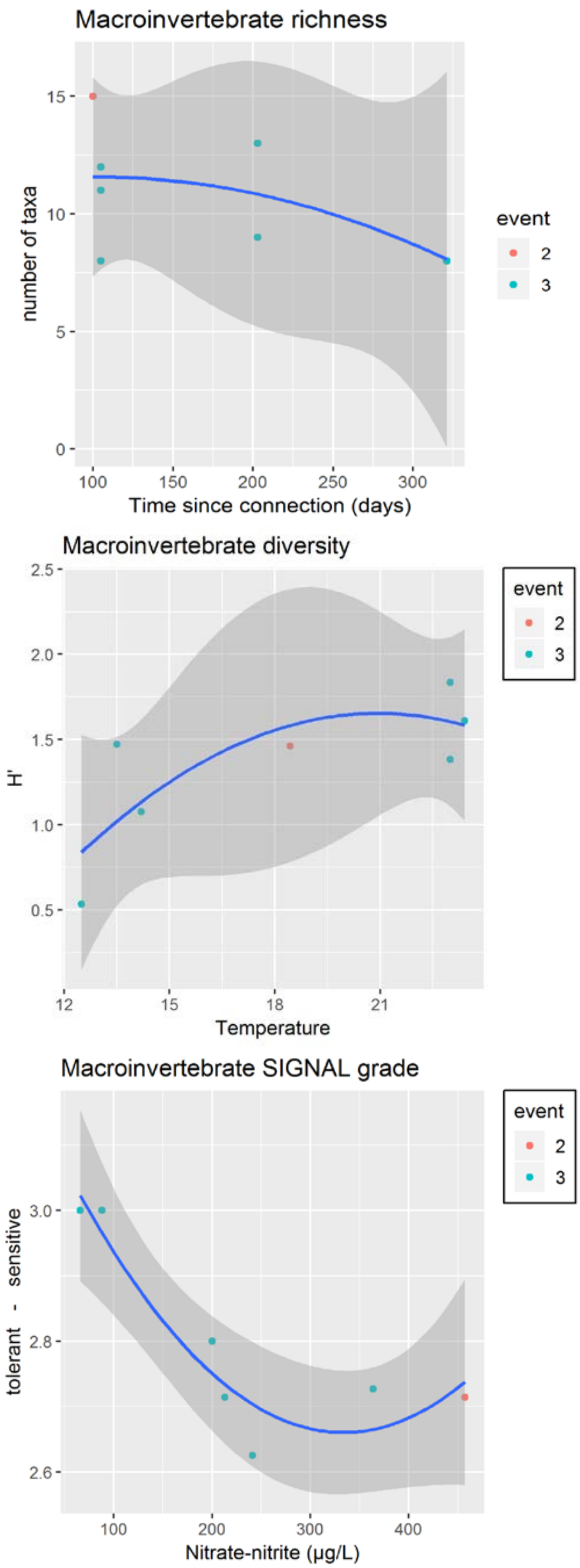

Figure H-16: Regression between macroinvertebrate diversity indicators and time since inundation and water quality indicators (Cat III) in the Western Floodplain zone.

Macroinvertebrate community

Macroinvertebrate community composition was similar among the three vegetation habitats in August 2016 “during 1” sampling (Figure H-17a). Typical early coloniser taxa from Order Diptera (flies) such as Culicidae, Ephydridae, Podonominae and Chironominae colonised the newly wetted floodplain habitats (Table H-8). These taxa have mobile adult stages that are capable of travelling long distances to lay eggs in temporary inland waters (Bilton, *et al.* 2011). Moreover, non-biting larval midges (Chironominae) were reported widespread in inland waters because of their drought resistant eggs that hatched once flows resume (Bilton et al., 2001).

In the November 2016 early summer “during 2” sampling, increased temperature and chlorophyll *a* concentrations were aligned to higher diversity (Figure H-17b and c). Higher abundance in sensitive Families such as caddis fly (Leptoceridae) and mayfly larvae (Baetidae) were found (Figure H-17d). Moreover, predatory macroinvertebrate such as dragonfly larvae (Coenagrionidae) and beetle larvae (Dytiscidae) occurred in higher abundances in summer periods, suggesting a food web that can support higher feeding functional macroinvertebrate groups (Table H-8 and Figure H-17d).

In May 2017 “retention” samples, the Floodplain was in the contraction period, with only the deeper Lignum habitats inundated. Macroinvertebrate diversity decreased with water quality deterioration (Appendix E). Taxonomic richness fell from 13 taxa to 8 taxa that are very tolerant to pollution including Corixidae, Notonectidae and Dytiscidae (Table H-8 and Figure H-16d). These three Families are able to breathe atmospheric air so they are more tolerant to low dissolved oxygen (Robson et al., 2011). Community composition was highly correlated to increased temperature, pH and SRP (Table H-7).

Table H-8: Macroinvertebrate taxa contributing most of the dissimilarities (SIMPER results) among six samples in the Western Floodplain from three sampling occasions in the largest scale Western Floodplain inundation event in 2016-17.

Taxa	Average abundance		
	during 1	during 2	retention
sF.Chironominae	**14.58**	1.50	6.08
F.Culicidae	**6.66**	0	0
sF.Podonominae	**1.58**	0	0
F.Ephydridae	**2.10**	0	0
F.Leptoceridae	0.33	**11.37**	0
F.Coenagrionidae	0	**8.43**	0
F.Baetidae	0	**5.24**	0
F.Corixidae	2.13	6.14	**11.70**
F.Dytiscidae	2.84	1.80	**7.00**
F.Notonectidae	1.85	3.96	**7.94**

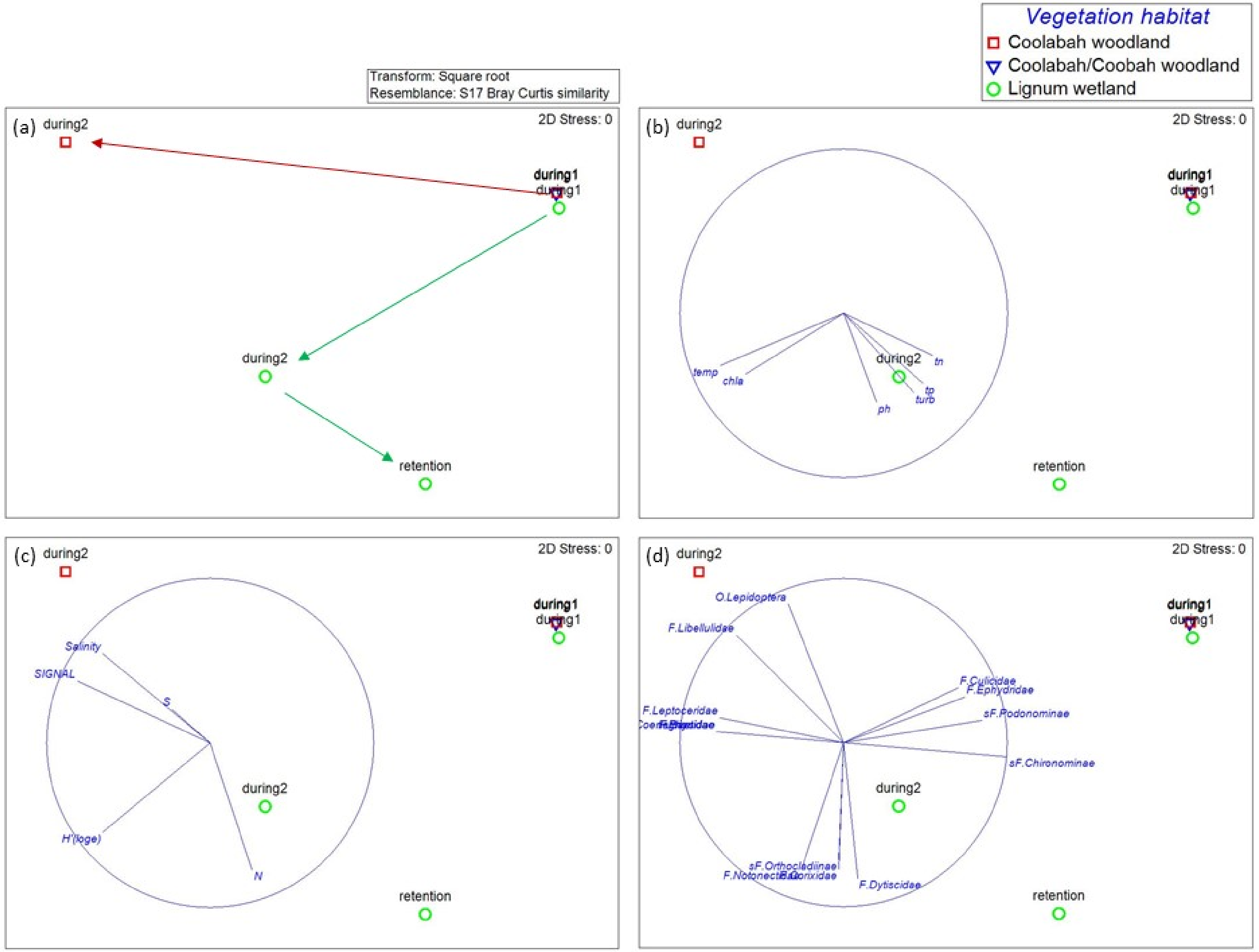

Figure H-17: nMDS ordination of the Western Floodplain zone macroinvertebrate community composition using community abundance (square root) dataset with vectors of (b) environmental variables (normalised data, Spearman correlation), (c) macroinvertebrate univariate indicators (normalised data, Spearman correlation) and (d) macroinvertebrate taxonomic composition data (Spearman 0.7) which underlie the community composition pattern

H.4 Discussion

Hydrology was the primary driver of macroinvertebrate patterns in the Darling River zone, and within the modified dams (Warrego Channel zone) and floodplain wetlands (the Western Floodplain zone) of the Warrego-Darling Selected Area. Moreover, broader spatial (zone) macroinvertebrate patterns were predominantly driven by water quality.

Across three sampling zones and eight sampling occasions, the Western Floodplain had the highest average macroinvertebrate density, followed by the Warrego Channel and the Darling River. In the Warrego Channel and Western Floodplain, flow acted to deliver resources that initiated macroinvertebrate recruitment. Macroinvertebrate density increased with time since flow and peaked in the contraction period associated with higher carbon, nutrient and chlorophyll *a* concentrations. The Western Floodplain consistently had the highest macroinvertebrate density, highlighting the importance of lateral connection from Boera Dam to stimulate macroinvertebrate productivity and provide basal food resources to support wetland food webs. In contrast, flow acted as a disturbance in the Darling River zone that decreased macroinvertebrate density.

The Western Floodplain had the highest taxa richness and diversity, linked to the presence of diverse vegetation habitats and basal resources that in turn support a more diverse assemblage of macroinvertebrate taxa. In the Warrego Channel and Western Floodplain, macroinvertebrate diversity peaked during the wettest periods (Warrego around 30-50 day since connection and Western Floodplain peaked around 100 days since inundation) due to improved water quality triggered by flow events. More diverse macroinvertebrate communities offer a wider range of feeding opportunities for higher level consumers such as frogs, fish, waterbirds and other aquatic vertebrates. Following this peak, diversity decreased with time since connection/ inundation accompanied by a deterioration in water quality.

Macroinvertebrate taxonomic composition showed strong links to hydrology. In the Darling River, community composition was significantly different between discharge groups with evidence that the <500 ML/d group was most different from the 1,000-5,000 ML/d group. Since the Darling River has less variable flow regimes when compared with the Warrego Channel and the Western Floodplain, macroinvertebrate taxa with highly mobile traits and body shape more adapted to flow had higher abundances in higher discharges. In the Warrego Channel, community composition consistently shifted with time since connection. A similar community composition pattern was observed in the Western Floodplain but varied between vegetation habitats. In both zones, macroinvertebrate taxa with higher pollution tolerant ability appeared to have higher abundance with increased time since connection/ inundation.

In the Warrego Channel, each connection event had a different magnitude, duration and timing, as well as antecedent flow conditions. It is therefore challenging to tease apart multiple hydrological factors within the existing dataset at this stage. In the Western Floodplain, communities within the three vegetation habitats responded similarly to inundation but recorded different maximum macroinvertebrate densities driven by habitat and resource availability. Macroinvertebrate SIGNAL score had a stronger predictable relationship with hydrology than macroinvertebrate salinity index or PET richness in all zones. This suggests the usefulness of SIGNAL score and the insights it could provide on the mechanisms driving patterns in macroinvertebrate communities.

H.5 Conclusion

The composition of macroinvertebrate communities within the Warrego-Darling Selected Area differed between monitoring zones, with the Western Floodplain showing the highest taxa richness, density and diversity, associated with more diverse habitats and increased basal resources. Sites within the Warrego River zone showed intermediate levels of taxa richness, density and diversity, with the Darling River having the least. Temporal patterns in macroinvertebrate community composition were driven by both hydrological connection and water quality. Positive responses in macroinvertebrates were observed following hydrological connection in the Western Floodplain and Warrego River, whereas flow events acted as a stressor for macroinvertebrate communities in the Darling River. Species that were more tolerant of disturbance (either increased velocities or poor water quality) appeared to do better in all zones, with the SIGNAL score measure showing a predictable relationship with hydrological factors. The findings from this indicator suggest that connection to the Warrego River and Western Floodplain is important to stimulating booms in diverse macroinvertebrate communities, which likely form important food resources for frogs, birds, fish and other aquatic consumers.

Supplement A: Macroinvertebrate taxa collected in the Warrego-Darling Selected Area in 2015-18.

Taxa ID	Class or sub-Class	Order	Family	SIGNAL	Salinity index
C.Arachnida	Arachnida	IF	IF	✗	✓
F.Aeshnidae	Insecta	Odonata	Aeshnidae	✓	✓
F.Ancylidae	Gastropoda	Hygrophila	Ancylidae	✓	✓
F.Atyidae	Malacostraca	Decopoda	Atyidae	✓	✓
F.Baetidae	Insecta	Ephemeroptera	Baetidae	✓	✓
F.Caenidae	Insecta	Ephemeroptera	Caenidae	✓	✓
F.Calocidae	Insecta	Trichoptera	Calocidae	✓	✗
F.Ceratopogonidae	Insecta	Diptera	Ceratopogonidae	✓	✓
F.Chrysomelidae	Insecta	Coleoptera	Chrysomelidae	✓	✗
F.Coenagrionidae	Insecta	Odonata	Coenagrionidae	✓	✓
F.Corduliidae	Insecta	Odonata	Corduliidae	✓	✓
F.Corixidae	Insecta	Hemiptera	Corixidae	✓	✓
F.Culicidae	Insecta	Diptera	Culicidae	✓	✓
F.Dolichopodidae	Insecta	Diptera	Dolichopodidae	✓	✗
F.Dytiscidae	Insecta	Coleoptera	Dytiscidae	✓	✓
F.Ecnomidae	Insecta	Trichoptera	Ecnomidae	✓	✓
F.Ephydridae	Insecta	Diptera	Ephydridae	✓	✗
F.Gerridae	Insecta	Hemiptera	Gerridae	✓	✓
F.Gomphidae	Insecta	Odonata	Gomphidae	✓	✓
F.Gyrinidae	Insecta	Coleoptera	Gyrinidae	✓	✓
F.Haliplidae	Insecta	Coleoptera	Haliplidae	✓	✗
F.Hydraenidae	Insecta	Coleoptera	Hydraenidae	✓	✓
F.Hydrochidae	Insecta	Coleoptera	Hydrochidae	✓	✗
F.Hydrophilidae	Insecta	Coleoptera	Hydrophilidae	✓	✗
F.Hydropsychidae	Insecta	Trichoptera	Hydropsychidae	✓	✓
F.Hydroptilidae	Insecta	Trichoptera	Hydroptilidae	✓	✓
F.Leptoceridae	Insecta	Trichoptera	Leptoceridae	✓	✓
F.Libellulidae	Insecta	Odonata	Libellulidae	✓	✓
F.Mesoveliidae	Insecta	Hemiptera	Mesoveliidae	✓	✓
F.Notonectidae	Insecta	Hemiptera	Notonectidae	✓	✓
F.Palaemonidae	Malacostraca	Decopoda	Palaemonidae	✓	✓
F.Parastacidae	Malacostraca	Decopoda	Parastacidae	✓	✓
F.Physidae	Gastropoda	Hygrophila	Physidae	✓	✗
F.Sciomyzidae	Insecta	Diptera	Sciomyzidae	✓	✗
F.Scirtidae	Insecta	Coleoptera	Scirtidae	✓	✓
F.Simuliidae	Insecta	Diptera	Simuliidae	✓	✓
F.Tabanidae	Insecta	Diptera	Tabanidae	✓	✓
F.Tipulidae	Insecta	Diptera	Tipulidae	✓	✓
F.Veliidae	Insecta	Hemiptera	Veliidae	✓	✓
O.Isopoda	Malacostraca	Isopoda	IF	✗	✗

Taxa ID	Class or sub-Class	Order	Family	SIGNAL	Salinity index
O.Lepidoptera	Insecta	Lepidoptera	Pyralidae	✓	✓
sC.Collembola	sC.Collembola	Symphypleona	Sminthuridae	×	×
sC.Oligochaeta	sC.Oligochaeta	IF	IF	×	✓
sF.Chironominae	Insecta	Diptera	sF.Chironominae	✓	×
sF.Orthocladiinae	Insecta	Diptera	sF.Orthocladiinae	✓	✓
sF.Podonominae	Insecta	Diptera	sF.Podonominae	✓	×
sF.Tanypodinae	Insecta	Diptera	sF.Tanypodinae	✓	✓

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Appendix I Ecosystem Type

I.1 Introduction

The Ecosystem Type indicator contributes to the broader scale evaluation of Commonwealth environmental water's influence on ecosystem diversity. While primarily designed to inform at larger basin scales, information on the types of ecosystems influenced by Commonwealth environmental water is also useful at the Selected Area scale. Several specific questions were addressed by monitoring Ecosystem Type within the Junction of the Warrego and Darling Rivers Warrego-Darling Selected Area (Warrego-Darling Selected Area) during the LTIM project (2014-2019):

- What did Commonwealth environmental water contribute to sustainable ecosystem diversity?
- Were ecosystems to which Commonwealth environmental water was allocated sustained?
- Was Commonwealth environmental water delivered to a representative suite of Ecosystem Types?

I.1.1 Environmental watering during the LTIM project

<u>Warrego River and Western Floodplain</u>

Unlike other Selected Areas, most environmental water is not specifically delivered to the Warrego-Darling Selected Area, rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Warrego-Darling Selected Area have been sporadic over the LTIM Project (Figure I-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16 and flows refilled waterholes and connected to the Darling River. The small flow event in January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, during June 2016 to February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, March to April 2018 and June 2018. Commonwealth environmental water made up 17.3% of the flow event during March and April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure I-1). During the flow event in March and April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River

<u>Barwon-Darling and northern tributaries</u>

Flows into the Darling River zone during the LTIM Project have been influenced by both unregulated and regulated environmental water (Appendix C).

Over the first four years of the project, 12 flow events have entered the Warrego-Darling Selected Area containing a environmental water contribution of between 1.8% to 99.6%. During 2014-15 one regulated flow out of the Gwydir river system and two unregulated flows containing environmental water flowed into the Warrego-Darling Selected Area. All three events were small in magnitude being less than 1,500 ML/d at Louth but did increase connectivity in the 2014-15 water year. Similarly, 2015-16 was another relatively dry year, characterised by three flow events of low magnitude. Environmental water contributions during this year ranged from 3.4% to 30%. In contrast, 2016-17 was characterised by one large flow event that occurred in late spring-summer which peaked at 33,700 ML/d at Louth. While only containing 2.4% environmental water, this flow inundated all available in-channel habitat along the Darling River zone. In addition to this, three other smaller inundation events occurred in 2016-17 containing between 2.4% to 36.5% environmental water. 2017-18 was again a relatively dry year, with three small flow events providing connection through the Warrego-Darling Selected Area. The flow event in May and June 2018 was a targeted environmental flow called the Northern Connectivity Event, which was a combination of both state and Commonwealth water. This flow was delivered to re-connect the Barwon-Darling River and was also supported by pumping embargos along the length of the channel. This flow contained 99.6% environmental water when it flowed past the Warrego-Darling Selected Area.

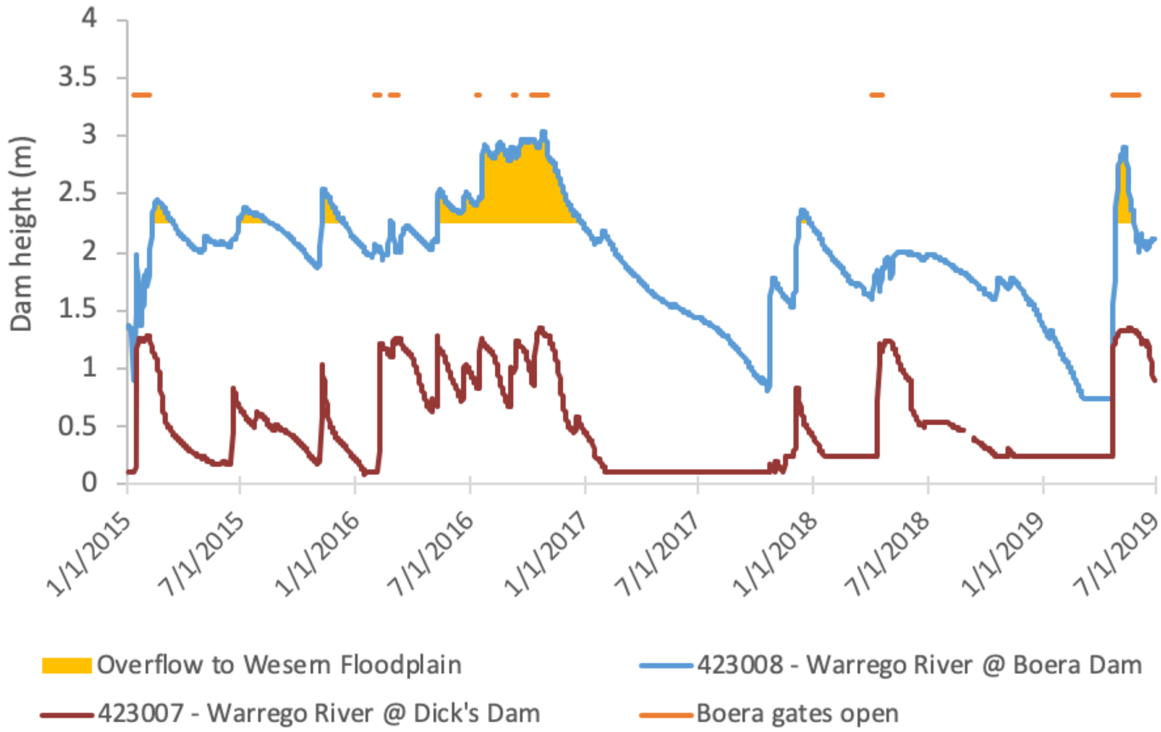

Figure I-1: Gauge heights in Boera and Dick's dams and periods of connection down the lower Warrego Channel in 2015-2018. Sampling dates, overflow to Western floodplain and dates of Boera gates being opened are shown.

I.2 Methods

Existing ANAE GIS layers (Brooks *et al.* 2013) have limited coverage within the Warrego-Darling Selected Area, being restricted to some sections of the Western Floodplain and the Darling River channel. Within this dataset, the whole Western Floodplain was classified as one ecosystem type (Pt2.2.1: Temporary sedge/grass/forb floodplain marsh), which is not representative of the true diversity of ecosystem types found on the floodplain. To gain a more representative understanding of ecosystem type inundation during the project, several data sources were utilised. For the Western Floodplain zone, the existing vegetation map produced by Gowans *et al.* (2012) was reclassified into ecosystem types based on field assessment of LTIM survey sites using a dichotomous key (Brooks *et al.* 2013). This resulted in six identified ecosystem types including an 'unclassified' grouping which included floodplain areas that could not be confidently classified into an ecosystem type. For the Warrego Channel zone, the extent of dams in the Warrego-Darling Selected Area was digitised and this was used to provide an assessment area of the 'Lt2.1: Temporary lake' ecosystem type within the network. The remaining channel network area was classed as 'Rt1.4: Temporary lowland stream', and the length of this ecosystem type that was inundated was calculated from a pre-defined stream network layer (Commonwealth of Australia 2017). In the Darling River zone, the existing ANAE GIS layer was used to calculate the area of the Rt1.4: Temporary lowland stream ecosystem type inundated.

In each water year, the maximum inundated area in each monitoring zone was calculate from inundation extents recorded at various times throughout each year, using Landsat imagery as outlined in Appendix Hydro (Warrego). Multiple images across each year were combined to give a total inundation extent for the year. These layers were assessed for continuity of inundation from the top of the system and any inundation that was not obviously related to river flows (e.g. rainfall) was removed. The resultant annual inundation layers were intersected by the ANAE layers for each monitoring zone to provide a total area or length of each ecosystem type inundated each year.

I.3 Results

Western floodplain zone

Four floodplain ecosystem types were inundated on the Western Floodplain over the duration of the project, and one lacustrine type (Table I-1). F2.2 Lignum Shrubland floodplain was the most inundated type during the project with maximum inundation of 1,594.22 ha recorded in the 2016-17 water year. F1.10 Coolibah woodland and forest floodplain was also commonly inundated (9.47 ha to 724.67 ha) and significant areas of F2.4 Shrubland floodplain were inundated during 2016-17 (1,525.56 ha) and 2018-19 (165.51 ha). Smaller areas of F1.11 River Cooba woodland floodplain (0.79 ha to 35.55 ha) and LT2.2 Temporary floodplain lake with aquatic beds (0.02 ha to 4 ha) were inundated during the Project.

Table I-1: Ecosystem types inundated within the Western Floodplain zone over the project.

Ecosystem Type	Hectares Inundated (% of total)				
	2014-15	2015-16	2016-17	2017-18	2018-19
F1.10 Coolibah woodland and forest floodplain	12.77 (27.4)	108.78 (20.4)	724.67 (18.4)	9.47 (50.6)	97.47 (13.4)
F1.11 River Cooba woodland floodplain	3.56 (7.6)	65.28 (12.3)	78.42 (2)	0.79 (4.2)	35.55 (4.9)
F2.2 Lignum Shrubland floodplain	30.09 (64.7)	333.01 (62.5)	1,594.22 (40.5)	7.69 (41.1)	424.44 (58.3)
F2.4 Shrubland floodplain	0 (0)	21.11 (4)	1,525.56 (38.8)	0.37 (2)	165.51 (22.7)
LT2.2 Temporary floodplain lake with aquatic beds	0.02 (0)	4 (0.8)	4 (0.1)	0.02 (0.1)	4 (0.6)
Unclassified	0.09 (0.2)	0.61 (0.1)	8.17 (0.2)	0.36 (1.9)	0.59 (0.1)
Total	**46.53**	**532.79**	**3,935.05**	**18.70**	**727.57**

Warrego River zone

One Lacustrine and one Riverine ecosystem type were identified within the Warrego River zone. Maximum inundation of both ecosystem types was achieved in the 2016-17 water year, with 916.14 ha of Lt2.1: Temporary lake, and 79.17 km length of Rt1.4: Temporary lowland stream inundated (Table I-2). This constituted 92% and 68% of these ecosystem types in this zone respectively. In all years, at least 50% of the total lake area, and 33% of the total channel network was inundated, with the largest differences in lake area occurring in Ross Billabong (Figure I-5).Table I-2: Area and length of ecosystem types inundated within the Warrego River zone over the project.

Ecosystem type	2014-15	2015-16	2016-17	2017-18	2018-19
Lt2.1: Temporary lake in ha (% of total)	544.44(55)	505.49(51)	916.14(92)	467.31(47)	697.85(70)
Rt1.4: Temporary lowland stream in km (% of total)	51.93(44)	38.10(33)	79.17(68)	51.07(44)	62.9(54)

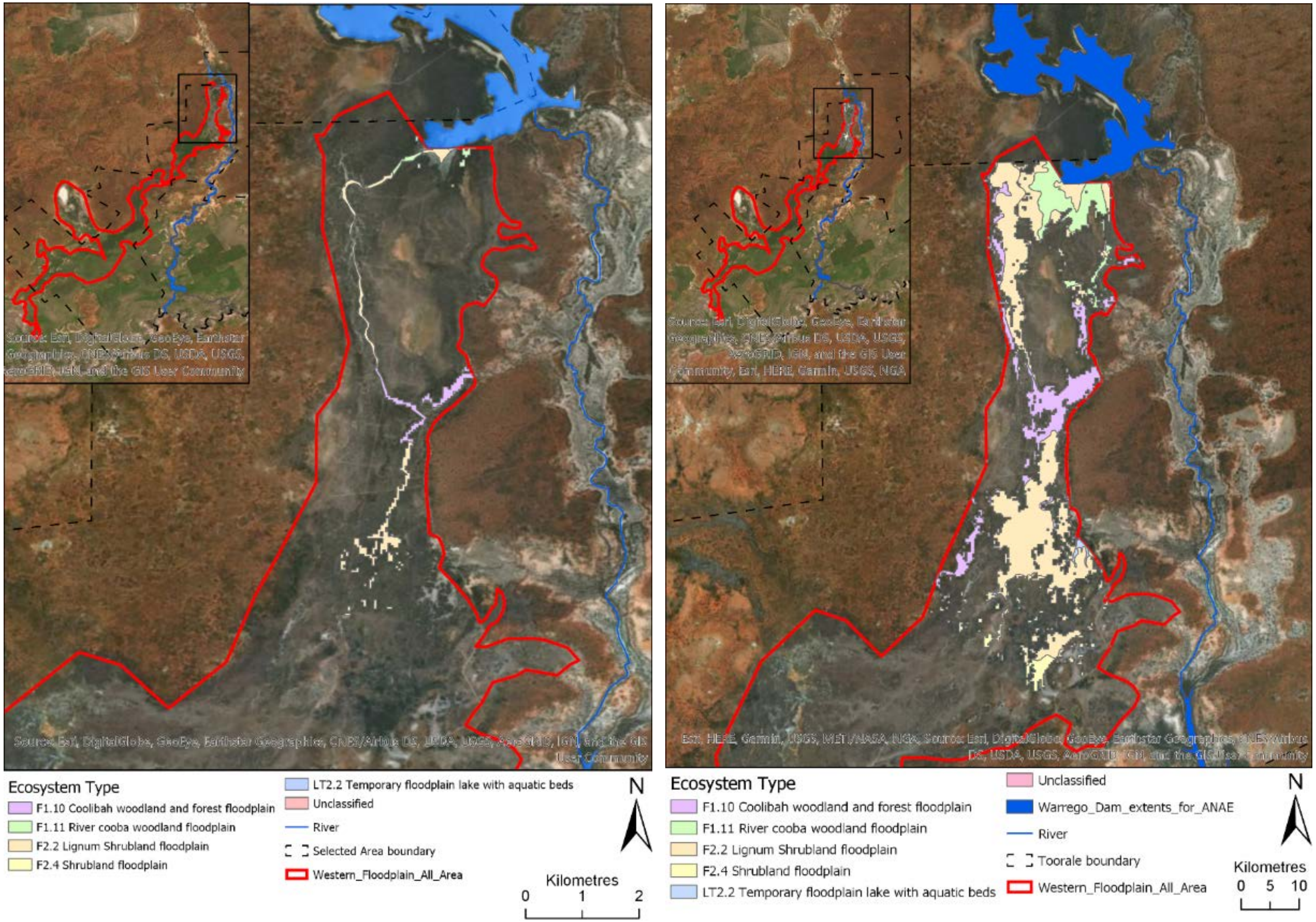

Figure I-2: Ecosystem type inundation extent within years 1 (left) and 2 of the LTIM Project (right).

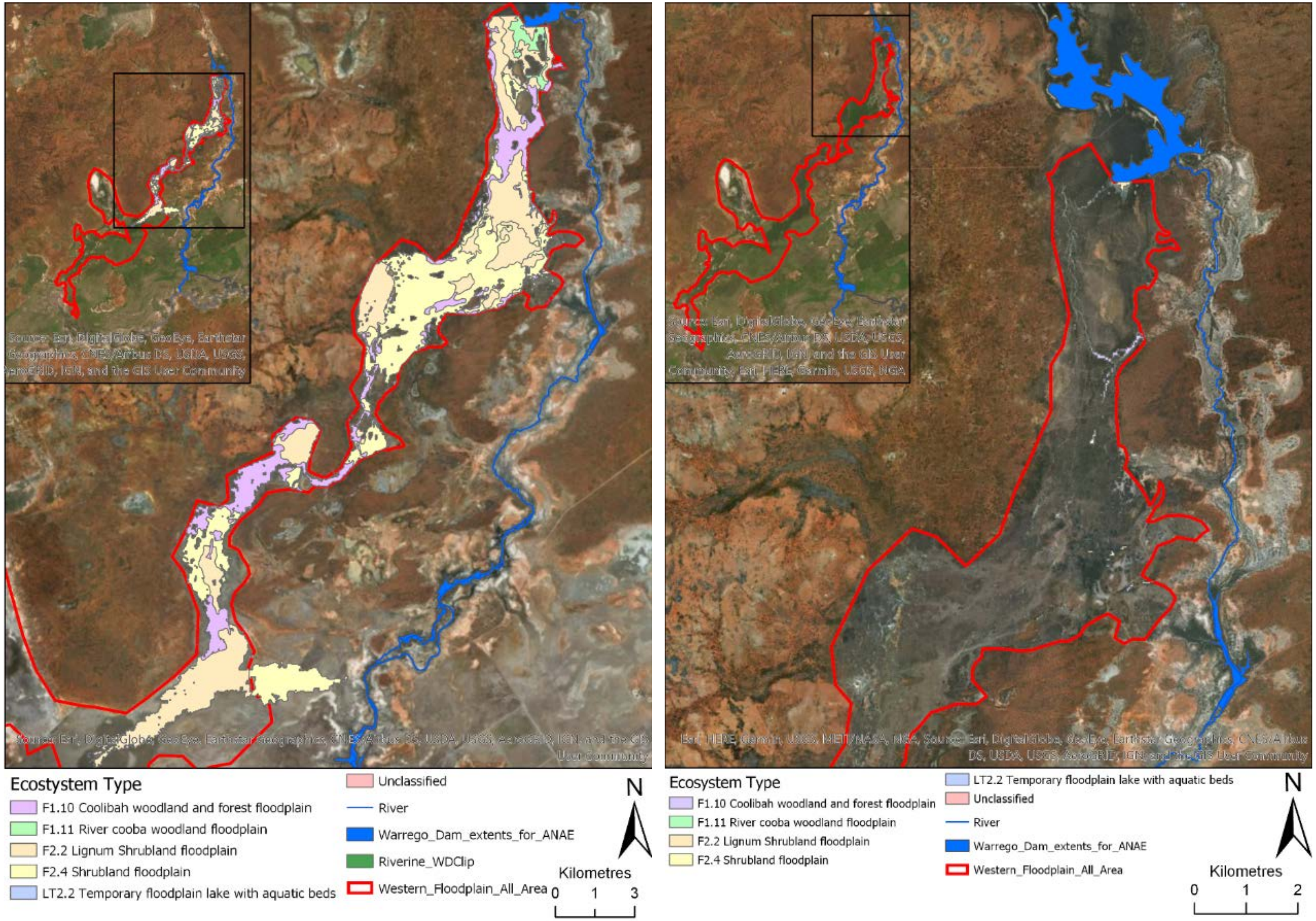

Figure I-3: Ecosystem type inundation extent within years 3 (left) and 4 of the LTIM Project (right).

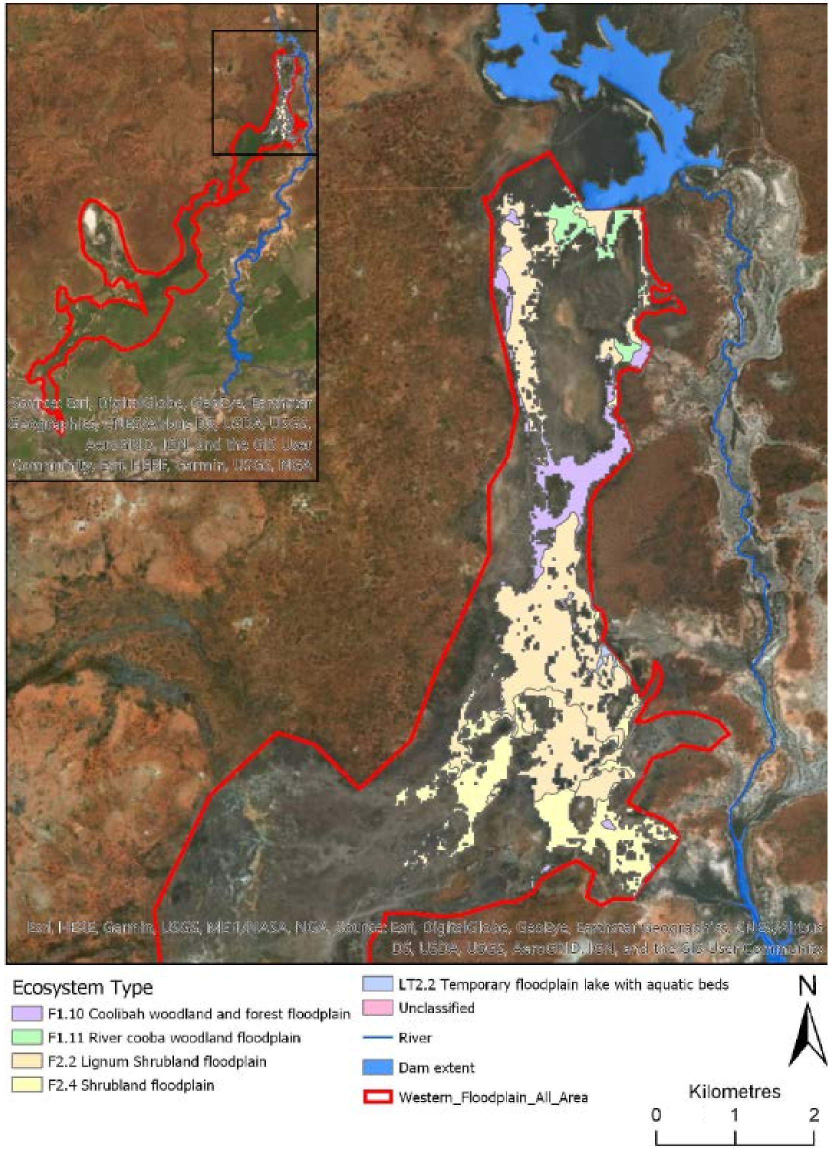

Figure I-4: Ecosystem type inundation extent within final year of the LITM Project.

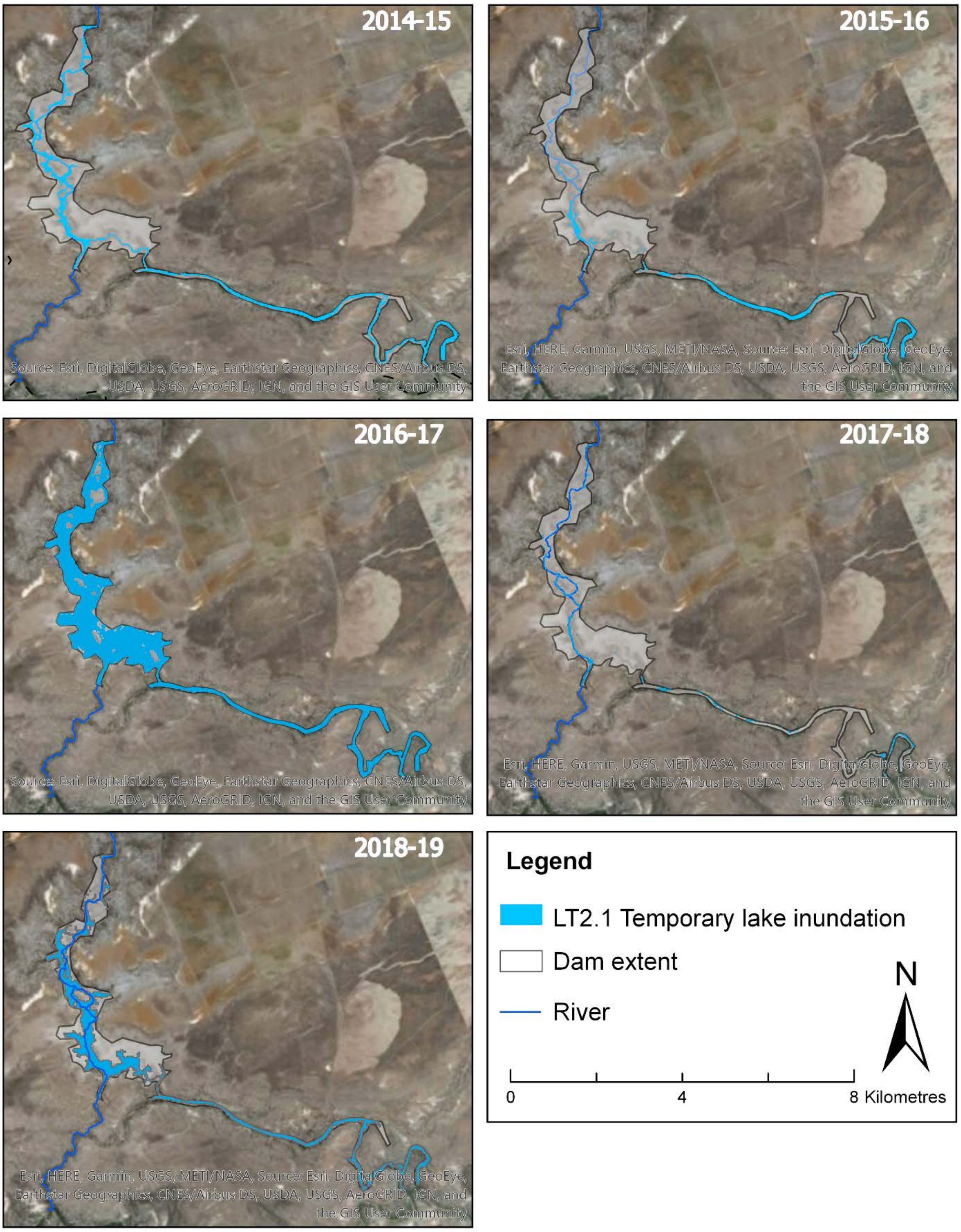

Figure I-5: Inundation of the LT2.1 Temporary Lake ecosystem type at Ross Billabong.

Darling River zone

The greatest area of Rt1.4: Temporary lowland stream inundated within the Darling River zone during the project was 326.51 ha in 2017-18, which made up 89.37% of the total mapped ecosystems in this zone. The 2016-17 water year also experienced a large inundation event of this ecosystem type with an area of 326.49 ha and 89.36% of the total mapped ecosystems being inundated. The smallest inundation event for the mapped ecosystem types occurred in the 2018-19 water year, with 284.09 ha being inundated, which made up 77.76% of the mapped ecosystem types in the area (Table I-3).

Table I-3: Ecosystem type inundated areas of the Darling River zone over the course of the project.

Water Year	Ecosystem Type	Area Inundated	% of mapped Ecosystem types	Total Flow (ML)
2014-15	Rt 1.4: Temporary lowland stream	288.17	78.87	87,589.86
2015-16	Rt 1.4: Temporary lowland stream	324.12	88.71	98,842.36
2016-17	Rt 1.4: Temporary lowland stream	326.49	89.36	235,155.23
2017-18	Rt 1.4: Temporary lowland stream	326.51	89.37	93,049.82
2018-19	Rt 1.4: Temporary lowland stream	284.09	77.76	29,118.33

I.4 Discussion

A total of 7 ecosystem types were inundated over the duration of the LTIM Project within the Warrego-Darling Selected Area. A greater diversity of floodplain types was inundated, however, significant areas of both channel and lake types were also inundated.

Maximum inundation in all monitoring zones was achieved during the 2016-17 water year, and this included significant contributions of Commonwealth environmental water. Flow onto the Western Floodplain during 2014-15 inundated 5 ecosystem types as a result of Commonwealth environmental water including floodplain shrubland types and temporary floodplain lakes which provide ideal habitat for waterbirds and frogs (Appendix M; Appendix L) and supports diverse and abundant invertebrate populations (Appendix G; Appendix H). Similarly, management decisions made by the Commonwealth Environmental Water Office (in consultation with the NSW National Parks and Wildlife Service and the Kurnu-Barkindji Joint Management Committee) on the operation of Boera Dam increased the inundation of channel and lake ecosystem types in the Warrego River zone during 2016-17, 2017-18 and 2018-19. In the Darling River zone, environmental water from upstream tributaries contributed to the inundation of the temporary lowland stream ecosystem type in in all years apart from 2018-19 (Appendix C).

In conclusion, Commonwealth environmental water and its management within the Selected Area, maintained a diversity of ecosystem types throughout the LTIM Project.

I.5 References

Brooks, S., Cottingham, P., Butcher, R, and Hale, J. 2013. *Murray-Darling aquatic ecosystem classification: Stage 2 report*. Peter Cottingham & Associates report to the Commonwealth Environmental Water Office and Murray-Darling Basin Authority, Canberra.

Commonwealth of Australia. 2015. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling Rivers Selected Area*, Canberra.

Appendix J Vegetation Diversity

J.1 Introduction

The vegetation communities of the Warrego River Western Floodplain primarily consist of stands of coolibah (*Eucalyptus coolabah*), black box (*Eucalyptus largiflorens*) and Lignum (*Duma florulenta*) that have adapted to increased inundation patterns due to water management structures on Toorale (Hale *et al.* 2008; Capon 2009). Compared with communities in other Northern Basin catchments, vegetation on the Western Floodplain is in relatively good condition (Hale *et al.* 2008). As a result, these communities represent a significant target for Commonwealth environmental water within the Junction of the Warrego and Darling rivers Selected Area (Warrego-Darling Selected Area). The LTIM project aimed to investigate the contribution of Commonwealth environmental water to floodplain vegetation diversity, condition and extent. The monitoring of vegetation diversity was used to address two key questions:

- What did Commonwealth environmental water contribute to vegetation species diversity?
- What did Commonwealth environmental water contribute to vegetation community diversity?

J.1.1 **Environmental watering during the LTIM Project**

Unlike other Selected Areas, most Commonwealth environmental water is not specifically delivered to the Warrego-Darling Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Selected Area have been sporadic over the LTIM Project (Figure J-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16 and flows refilled waterholes and connected to the Darling River. The small flow event in January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, during June 2016 – February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, from March to April 2018 and in June 2018. Commonwealth environmental water made up 17.3% of the flow event during March to April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure J-1). During the flow event in March to April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River.

Boera water levels rose above the Western Floodplain connection point during April to June 2019. This was after the last vegetation survey in March 2019.

Historically, rainfall in the Warrego-Darling Selected Area is summer-dominated, however, rainfall has been variable over the LTIM Project period (Figure J-2). During the 2014-15 water year, rainfall was above average in August, December, and February-April. During 2015-16 rainfall was above average in November and June, with the June 2016 being the highest recorded monthly rainfall of the project (110 mm; Figure J-2). The 2016-17 water year was a relatively wet year with above average rainfall in

August, September, October, January, May and June. This was the only year of the project that had an annual rainfall greater than average (389 mm compared to historical average of 355 mm). Monthly rainfall in 2017-18 exceeded the historical average in October – December and March. The 2018-19 water year was the driest year of the project (annual total 205 mm), but falls were above average in August, October and November (Figure J-2).

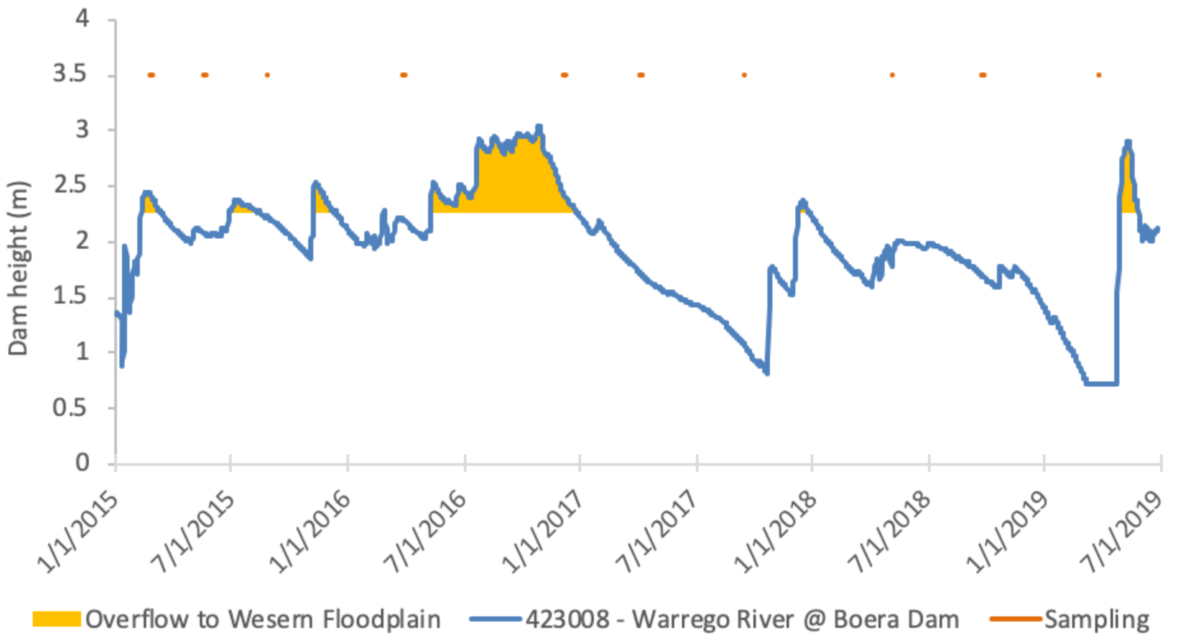

Figure J-1: Boera Dam levels during the project and flow to Western Floodplain.

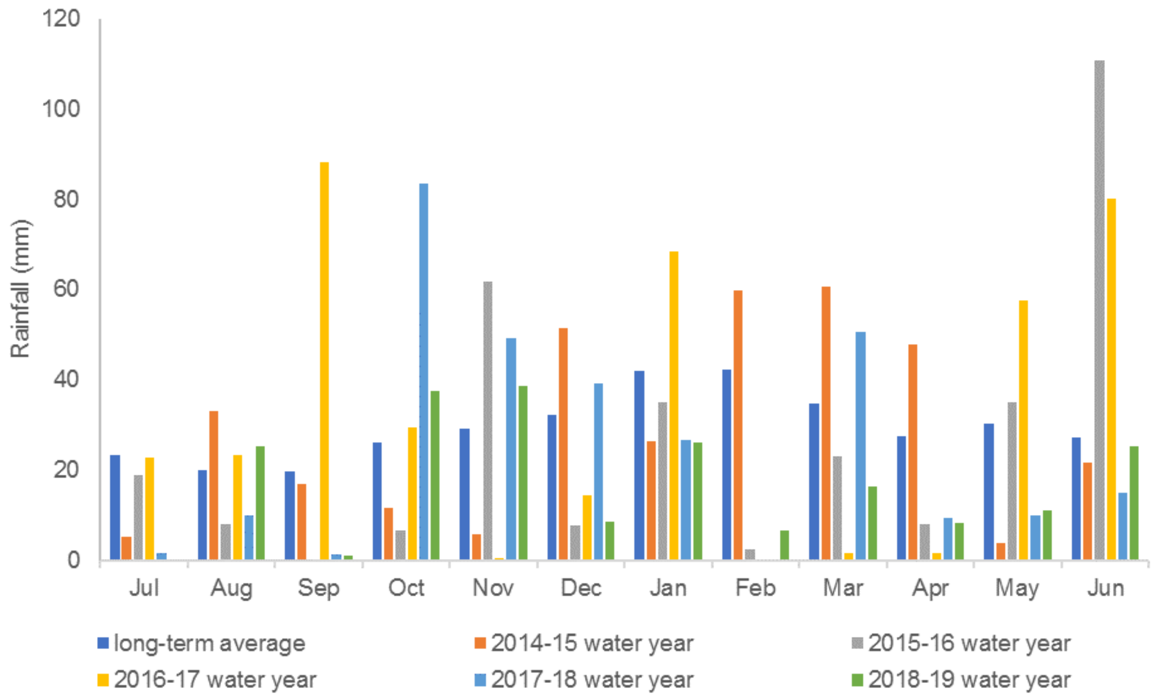

Figure J-2: Monthly rainfall at Bourke Airport from July 2014 to June 2019 compared to the long-term mean (Source: BoM, 2019a).

J.2 Methods

J.2.1 2015- 19 water years

Twenty-four plots were monitored at eight locations on the Western Floodplain over the course of the LTIM Project (Figure J-3; **Error! Reference source not found.**). Plots were located within four broad wetland vegetation communities that experienced different inundation frequencies. All sites that were inundated, were inundated at least once by Commonwealth environmental water in 2016-17. The plots were monitored on ten occasions from February 2015 to March 2019 (Table J-2). Vegetation surveys were undertaken following the standard vegetation diversity method (Commonwealth of Australia 2015; Hale *et al.* 2013), where vegetation diversity, structure and cover were recorded within each 0.04 ha plot. Environmental variables including the extent of inundation were also noted.

Species richness and total vegetation cover data were analysed using Poisson regression analysis to investigate the influence of sampling time and vegetation community on these measures. Total vegetation cover for each plot was calculated by adding together the cover of lower and mid strata types, therefore, it was possible to get >100% total cover. Both native and exotic species were included in this analysis.

To further explain changes in diversity, individual species were grouped into four functional groups (Brock and Casanova 1997):

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

Changes in these functional groups were compared between survey times using Poisson regression analysis to test for differences between respective groups.

To further understand the relationship between inundation and plant response, time since last inundation at each site was determined using satellite imagery (Appendix B) for each survey event. These data were then used to develop four categories of inundation (Inundation Period):

- Recent – (0-90) days since site was last inundated (565 instances);
- Frequent – (91- 520) days since site was last inundated (506 instances);
- Infrequent – (521 – 1,254) days since site was last inundated (1,220 instances); and
- Rare – (1,659 – 8,310) days since site was last inundated (651 instances).

Changes in vegetation community composition over all survey times were investigated using multivariate nMDS plots with differences between inundation, duration dry, survey time and vegetation community assessed using PERMANOVA in Primer 6. For nMDS analyses that had large numbers of data points, the 'distance among centroids' function was used to group the data by the appropriate factor to aid interpretation.

Table J-1: Sites surveyed for vegetation diversity across the LTIM Project. Sampling event number corresponds to those provided in Table J-2. Inundation Categories - Re = Recent, Fr = Frequent, In = Infrequent, Ra = Rare. Map projection GDA94 Zone 55.

Sites	Vegetation Community	Eastings	Northings	Sampling Event (Inundation category)									
				S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
WD1.1	Coolibah-River Cooba-Lignum woodland	6668758	347881	In	In	In	Re	Re	Re	Fr	Fr	In	In
WD1.2	Coolibah-River Cooba-Lignum woodland	6668663	347818	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD1.3	Coolibah-River Cooba-Lignum woodland	6668610	347776	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD2.1	Coolibah-River Cooba-Lignum woodland	6667219	347814	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD2.2	Coolibah-River Cooba-Lignum woodland	6667195	347764	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD2.3	Coolibah-River Cooba-Lignum woodland	6667165	347675	In	In	In	Ra	Ra	Ra	Ra	Ra	Ra	Ra
WD3.1	Chenopod shrubland	6658750	343962	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD3.2	Chenopod shrubland	6658762	343840	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD3.3	Chenopod shrubland	6658822	343729	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD4.1	Chenopod shrubland	6660934	347121	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD4.2	Chenopod shrubland	6661041	347292	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD4.3	Chenopod shrubland	6660788	347285	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD5.1	Coolibah woodland wetland	6654363	341209	In	In	In	Ra	Re	Re	Fr	Fr	In	In
WD5.2	Coolibah woodland wetland	6654290	341161	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD5.3	Coolibah woodland wetland	6654320	341268	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD6.1	Coolibah woodland wetland	6665179	347247	Re	Fr	Fr	Re	Re	Re	Fr	Fr	In	In
WD6.2	Coolibah woodland wetland	6665221	347382	Re	Re	Re	Re	Re	Re	Fr	Fr	In	In
WD6.3	Coolibah woodland wetland	6665082	347402	Re	Fr	Fr	In	In	Ra	Ra	Ra	Ra	Ra
WD7.1	Lignum shrubland wetland	6668699	347679	Re	Re	Re	Re	Re	Re	Fr	Fr	In	In

Sites	Vegetation Community	Eastings	Northings	Sampling Event (Inundation category)									
				S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
WD7.2	Lignum shrubland wetland	6668693	347608	Re	Re	Re	Re	Re	Re	Fr	Fr	In	In
WD7.3	Lignum shrubland wetland	6668627	347613	Re	Re	Re	Re	Re	Re	Fr	Fr	In	In
WD8.1	Lignum shrubland wetland	6667685	348087	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD8.2	Lignum shrubland wetland	6667780	348055	In	In	In	Ra	Re	Fr	Fr	Fr	In	In
WD8.3	Lignum shrubland wetland	6667585	348039	In	In	In	Ra	Re	Re	Fr	Fr	In	In

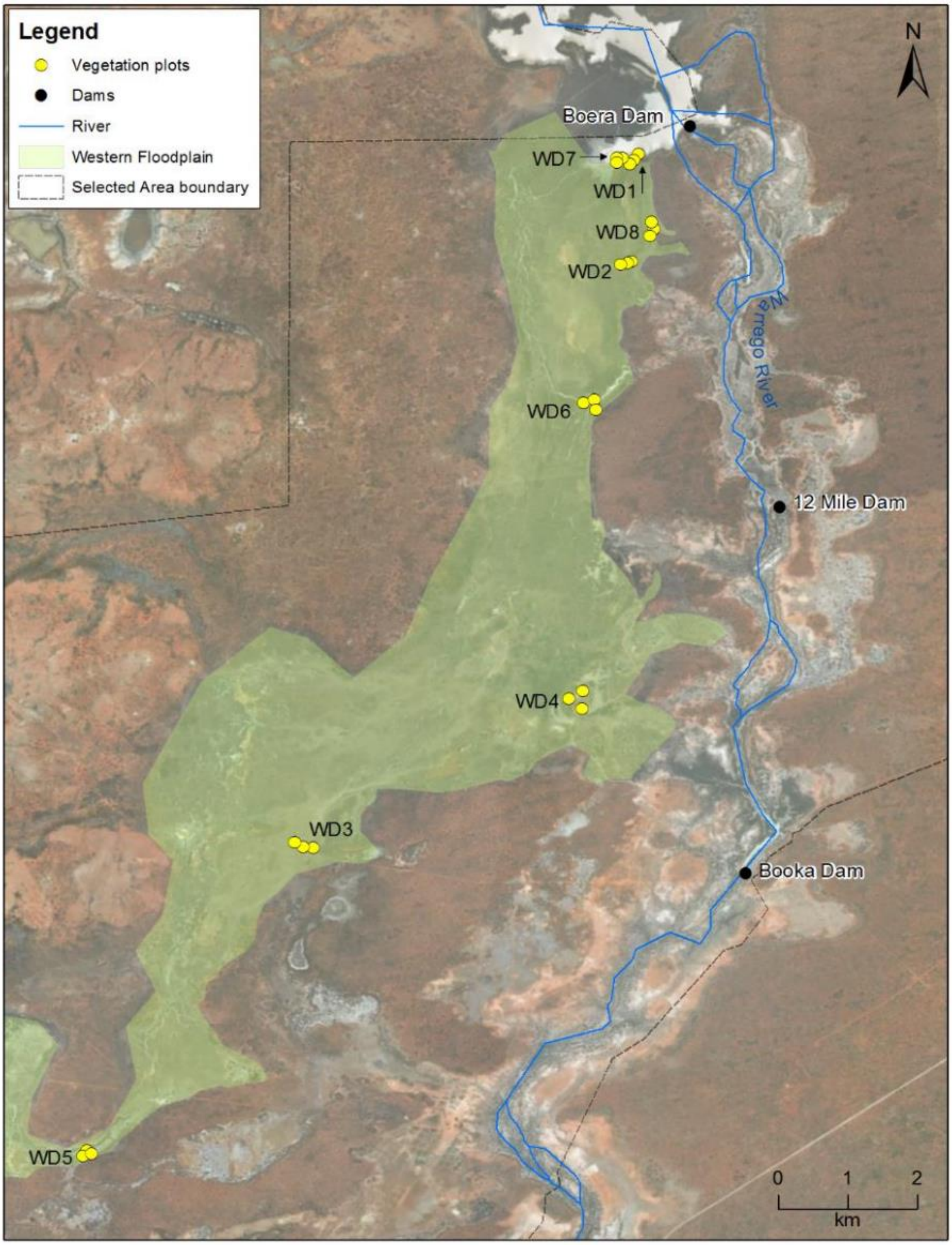

Figure J-3: Location of vegetation monitoring sites in the Western Floodplain zone.

Table J-2: Timing of vegetation diversity survey events during the project.

Survey Event	Season	Date
S1	Summer_2015	24-26 February 2015
S2	Autumn_2015	19-21 May 2015
S3	Spring_2015	25-27 August 2015
S4	Autumn_2016	30-31 March 2016
S5	Spring_2016	6-8 December 2016
S6	Autumn_2017	4-5 April 2017
S7	Spring_2017	14-15 September 2017
S8	Autumn_2018	8-9 May 2018
S9	Spring_2018	24-26 September 2018
S10	Autumn_2019	25-27 March 2019

Seedling height classes were recorded over the course of the project and means analysed to study tree recruitment rates within the River Cooba and Coolibah vegetation communities following standard vegetation methods (Commonwealth of Australia 2015; Hale *et al.* 2013). Tree recruitment data collected from the 0.04 ha quadrat was analysed at sites WD1 and WD2, whilst the 0.1 ha quadrat was examined at sites WD5 and WD6.

J.3 Results

J.3.1 Species richness

A total of 273 species from 49 Families and four assigned functional groups were recorded within vegetation plots across all monitoring periods (Table J-3).

Table J-3: Species count of the Functional Groups recorded over the course of the project.

Functional Group	Species Count	Common species
AmR	5	*Marsilea drummondi, Paspalum distichum, Ludwigia peploides, Bergia trimera*
AmT	17	*Duma florulenta, Acacia stenophylla, Eleocharis* spp. *Juncus* spp.
Tda	60	*Eucalyptus coolabah, Paspalidium jubiflorum, Stellaria angustifolia, Persicaria prostrata*
Tdr	176	*Schlerolaena* spp. *Dysphania pumilio, Centaurea melitensis, Chenopodium* spp.

Mean species richness per site was highest during spring 2015 (20.50 ± 4.67 species) and lowest during autumn 2019 (8.42 ± 5.03 species) survey periods (Figure J-4). Species richness differed significantly between vegetation communities (p=<0.05), with Other Shrub (16.32 ± 6.88) recording the highest mean species richness, followed by River Cooba (13.58 ± 6.12), Lignum (13 ± 6.68) and Coolibah (11.27 ± 6.62).

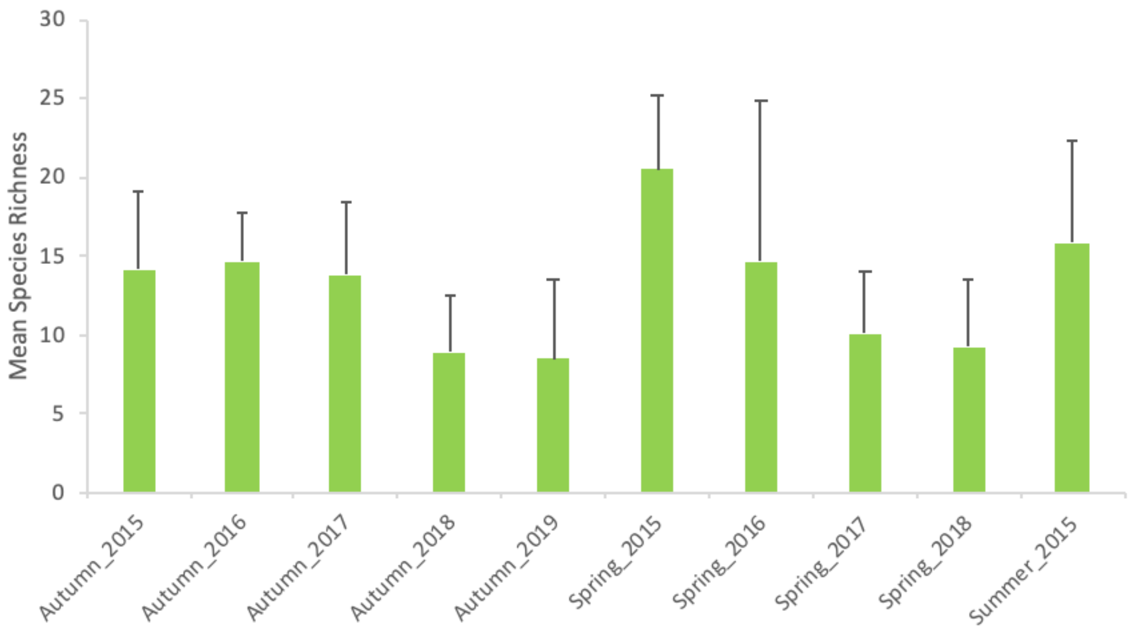

Figure J-4: Mean species richness across all survey periods.

Species richness was significantly influenced by the inundation categories (p<0.05), with the Recent category containing the highest mean value (17.21 ± 7.36), followed by Rare (14 ± 5.45), Infrequent (13.19 ± 6.88) and Frequent (10.25 ± 4.64).

A significant interaction was observed between inundation categories and vegetation communities ($p<0.05$), with the Recent category being significantly higher than other categories within River Cooba sites (17.09 ± 6.40 species, $p<0.05$). Species richness in the Rare (11.77 ± 7.92) and Recent (13.93 ± 5.88 species) inundation categories were significantly higher than Frequent (6.93 ± 5.39 species) and Infrequent (6.05 ± 4.56 species) sites within the Coolibah Woodland community ($p<0.05$). Frequently inundated sites (11.43 ± 5.33 species) contained significantly lower species richness than both Infrequent (17.30 ± 5.32 species) and Recent (22.25 ± 10.79 species), but not Rare sites (15.67 ± 2.06 species) within the Other Shrub vegetation community ($p<0.05$). Water did not influence species richness to the same degree within Lignum sites, with no significant differences being observed across inundation categories ($p>0.05$).

Functional group species richness also exhibited trends when grouped by Inundation Period. Functional groups AmR, AmT and Tda recorded their highest mean species richness within the Recent category, with richness then decreasing across the other categories for these functional groups. The Tdr Functional group did note a decrease between the Recent and Frequent categories, although richness increased within the Infrequent, and continued to increase and record its greatest value in the Rare category (7.24 ± 3.98, Figure J-5).

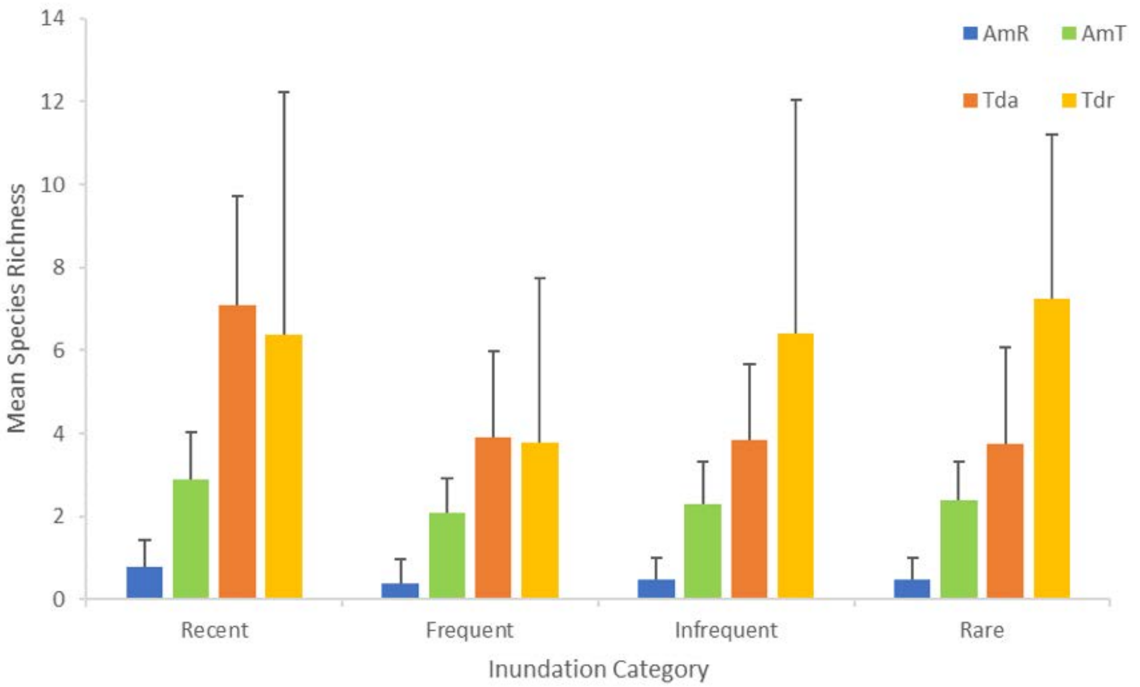

Figure J-5: Mean Species Richness of Functional groups when categorized by the Duration Dry groupings.

The response of Functional group species richness to Inundation Period varied between the four vegetation communities. The AmR Functional group generally decreased in species richness between the Recent and Rare categories. This trend was most obvious within the Other Shrub vegetation community. Although the Lignum community had a slight increase in mean richness (+0.14). AmT richness varied between vegetation communities, with the Other Shrub and River Cooba communities generally declining over the Inundation categories. In contrast, Coolibah and Lignum decreased between the Recent and Frequent categories but increased to their highest recorded levels in the Rare category. Tda species richness decreased from Recent through to the Rare category in all vegetation communities. There was an initial decrease in Tdr between Recent and Frequent, then it increased in the Infrequent and Rare categories for all four vegetation communities (Figure J-6).

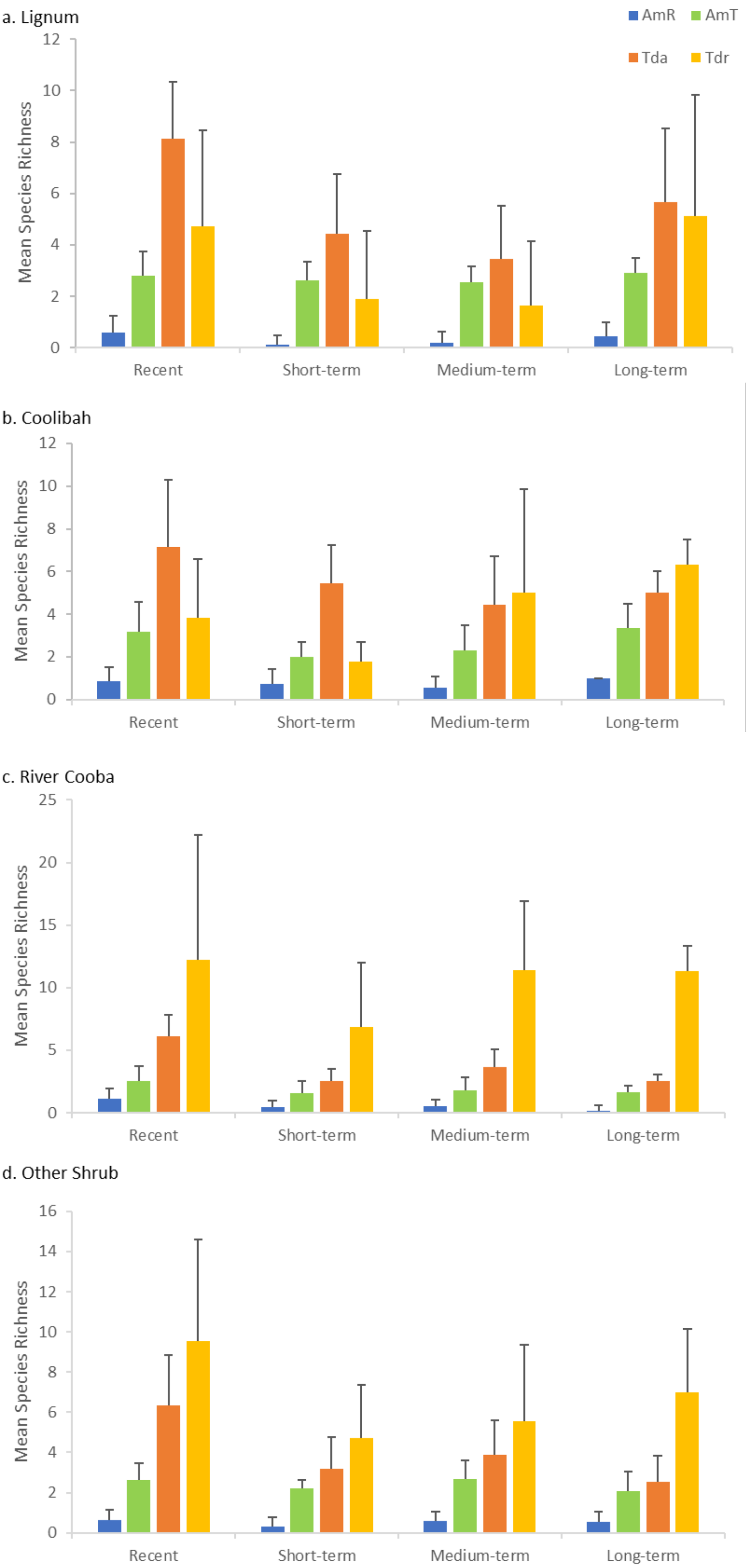

Figure J-6: Mean functional group species richness per site of the inundation categories recorded at the four vegetation communities; a. Lignum, b. Coolibah, c. River Cooba, d. Other shrub.

J.3.2 **Vegetation cover**

The spring-2016 sampling period (80.21 ± 32.35%) had the highest mean vegetation cover per site during the monitoring period, whilst autumn-2019 (19.29 ± 15.03%, Figure J-7) had the lowest. The high total cover percentage in spring-2016 can be strongly linked to the extended period of floodplain inundation preceding the spring-2016 sampling period, which inundated all monitoring plots except sites WD2.3 and WD6.3. Vegetation cover varied signficantly between vegetation communities ($p<0.05$), with River Cooba sites having the highest mean (48.67 ± 27.41%), followed by Lignum (41.62 ± 24.35%), Other Shrub (37.83 ± 26.86%) and Coolibah (25.53 ± 24.35%).

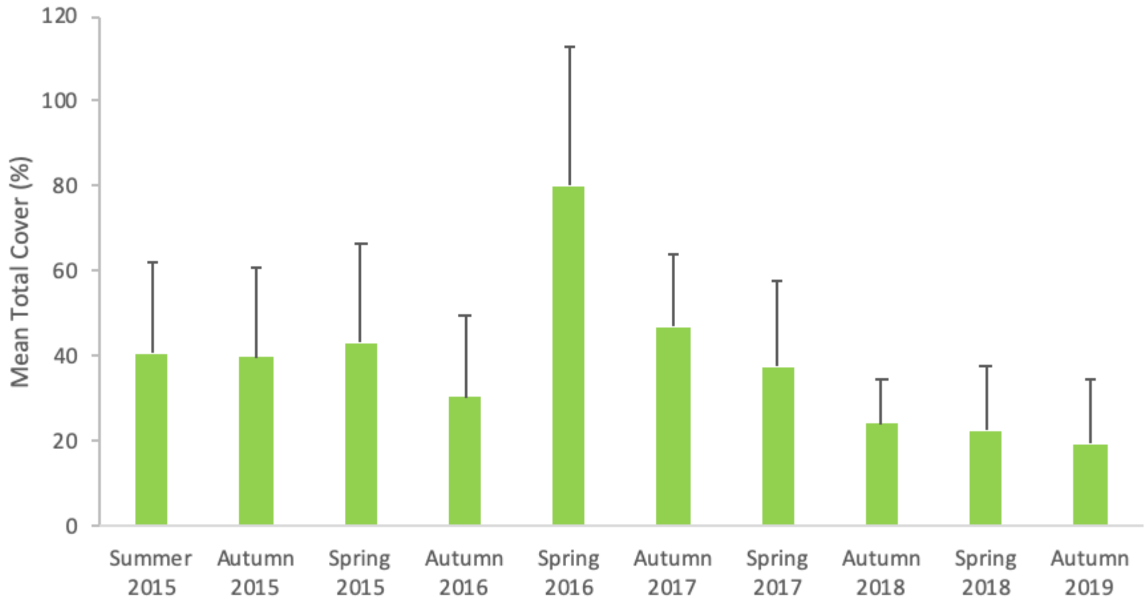

Figure J-7: Mean Total Cover per site at the different sampling periods over the course of the LTIM Project.

Total cover was also significantly influenced by the Inundation Period categories with a decrease in total cover observed as inundation frequency decreased ($p<0.05$). The Recent grouping contained the highest mean cover (55.86 ± 32.06%), followed by Frequent (34.45 ± 17.27%), Infrequent (33.83 ± 22.99%) and Rare (27.82 ± 22.33%).

A significant interaction was observed between inundation categories and vegetation communities ($p<0.05$), with recently inundated sites recording significantly higher cover within both the Other Shrub (90.13 ± 22.53%) and River Cooba (74.64 ± 33.75%) communities than the other inundation categories ($p<0.05$). Whilst both Recent (47.07 ± 21.39%) and Frequent (29.93 ± 18.06%) sites within the Coolibah woodland community recorded significantly higher means than Infrequent (10.05 ± 10.40%) and Rare sites (16 ± 5.98%; $p<0.005$). Water did not influence species cover to the same degree within Lignum sites, with no significant differences being observed across inundation categories ($p>0.05$).

Functional group cover also exhibited predictable trends when grouped by Inundation Period. AmR, AmT, and Tda groups generally declined in cover as inundation frequency decreased, with the Tda group displaying the sharpest fall between the Recent and Frequent categories (-69.45%) followed by AmR (-67.61%). The Tdr group initially declined in mean total cover between the Recent and Frequent category (-50.74%), although increased within the Infrequent category and then appears to stabilise with the Rare category, which had similar results (Figure J-8).

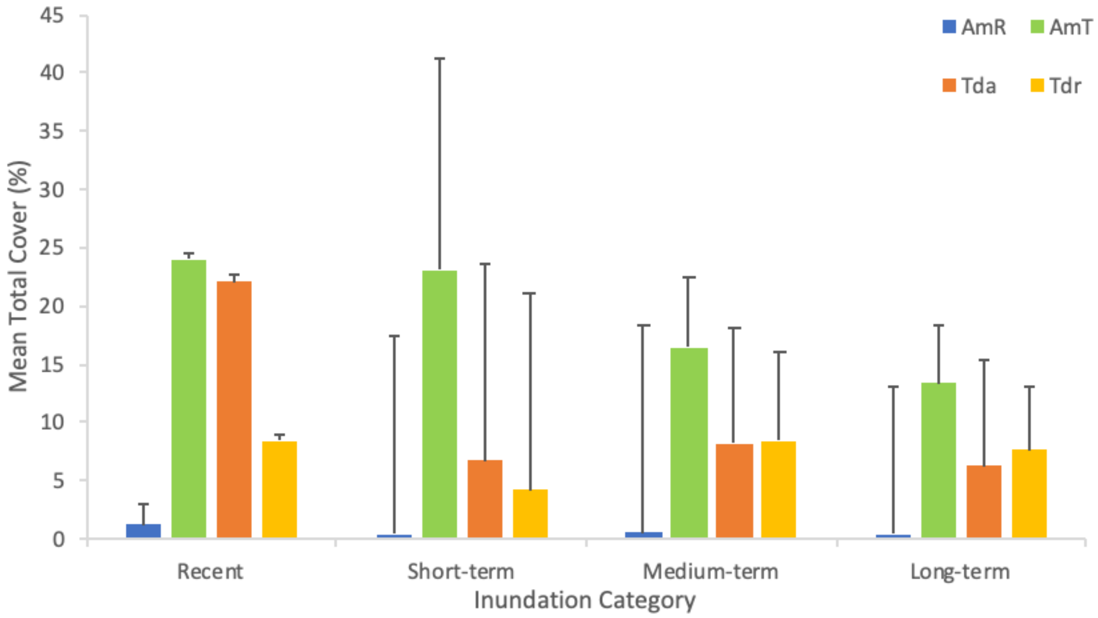

Figure J-8: Mean Total Cover per site of Functional groups when categorized by the Inundation categories.

The response of Functional group total cover to Inundation Period also varied between the four vegetation communities. The AmR group generally reduced with decreasing inundation within each vegetation community. The Other Shrub community recorded the highest mean total cover of AmR within the Recent category (2.13 ± 1.64%). AmT mean cover reduced as Inundation Period decreased at all communities except Lignum, which increased over this period. The Tdr functional group recorded its greatest total cover within the Recent category, with decreases being observed over the other categories within all vegetation communities. Whilst Tdr showed an initial decrease between the Recent and Frequent categories, then increased in the Infrequent and Rare categories across all vegetation communities (Figure J-9).

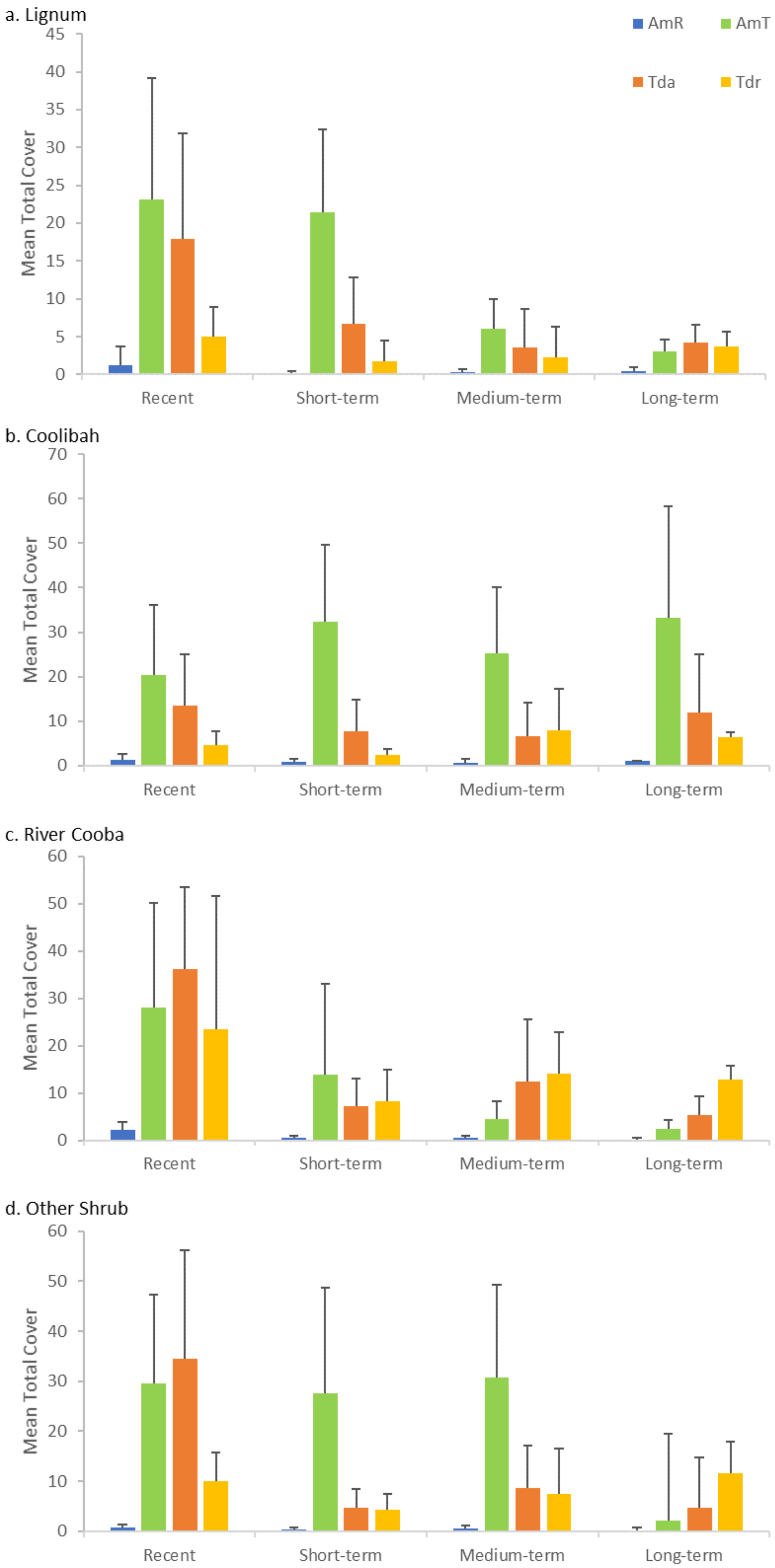

Figure J-9: Mean Total Cover per site of the Inundation categories recorded at the separate vegetation communities; a. Lignum, b. Coolibah, c. River Cooba, d. Other Shrub.

J.3.3 Vegetation composition

Vegetation composition was further assessed using multivariate analyses of species abundance data. PERMANOVA analysis confirmed significant differences between sample periods, vegetation communities, Inundation Period categories and Functional groups ($p<0.005$). The nMDS plot shows separation between data grouped by sampling period with a tendency for sampling periods from summer-2015 to spring-2016 to group together and post spring-2016 to group together (Figure J-10). Further pairwise tests concluding that all periods were significantly different ($p<0.05$), except for autumn-2018 and spring-2018 ($p=0.36$).

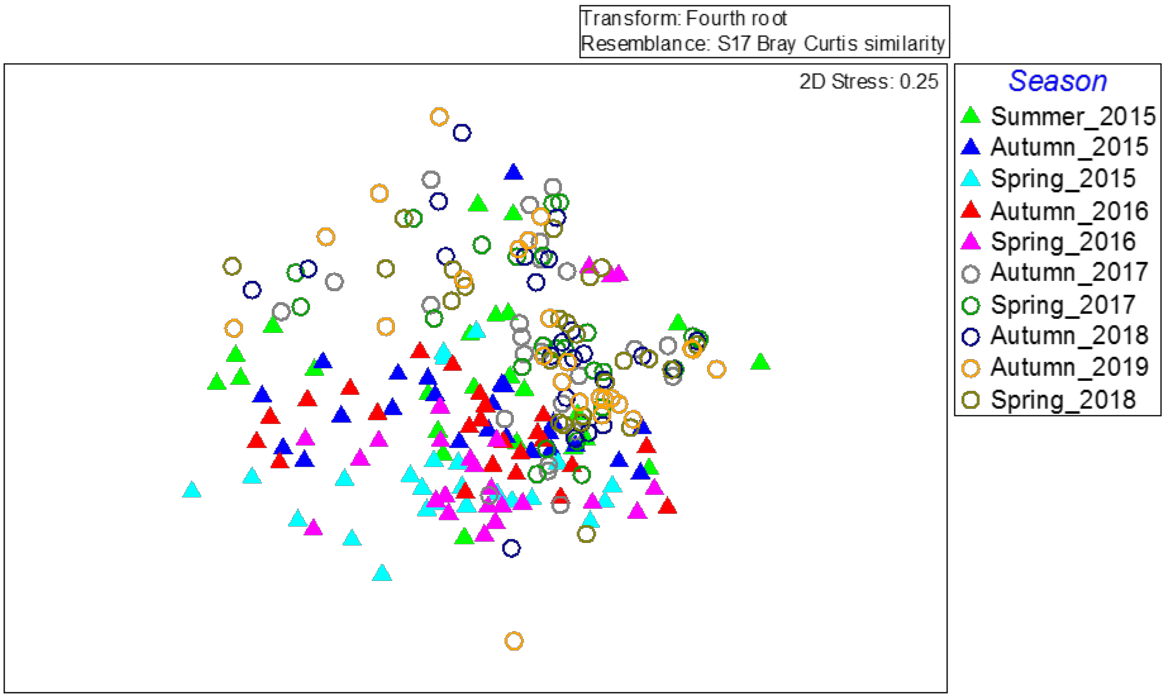

Figure J-10: nMDS plot of species composition data when grouped by Sampling Period.

SIMPER analysis indicated dissimilarity in lower/mid storey species when samples were grouped by sampling period. Lignum contributed the most across all sample periods. Warrego Grass (*Paspalidium jubiflorum)* and *Eleocharis* sp., both increased in spring-2016. This coincided with the largest inundation event of the project. Both species then decrease as sampling period progressed, with *Eleocharis* sp. dropping out of the four dominant species by autumn-2019 (Table J-4).

Table J-4: Contribution and mean cover% of the top four lower and mid-story species recorded across sample periods.

Sample Period	Species (func group)	Mean Cover (%)	Contribution (%)
Summer_2015	*Duma florulenta (AmT)*	19.79	18.75
	Juncus (AmT)	1.30	9.96
	Alternanthera denticulate (Tda)	1.00	7.28
	Marsilea drummondii (AmR)	1.13	6.84
Autumn_2015	*Duma florulenta (AmT)*	19.65	19.07
	Stellaria angustifolia (Tdr)	1.18	9.05

Sample Period	Species (func group)	Mean Cover (%)	Contribution (%)
	Paspalidium jubiflorum (Tda)	4.13	8.55
	Marsilea drummondii (AmR)	1.06	8.00
Spring_2015	*Duma florulenta (AmT)*	16.29	14.24
	Stellaria angustifolia (Tdr)	7.40	10.55
	Senecio runcinifolius (Tdr)	1.00	5.08
	Marsilea drummondii (AmR)	1.00	4.88
Autumn_2016	*Duma florulenta (AmT)*	16.29	18.21
	Einadia nutans (Tdr)	1.00	9.90
	Paspalidium jubiflorum (Tda)	2.41	8.65
	Eleocharis pallens (AmT)	1.25	7.28
Spring_2016	*Duma florulenta (AmT)*	17.32	16.23
	Stellaria angustifolia (Tdr)	11.22	13.14
	Lachnagrostis filiformis (Tda)	12.79	9.93
	Paspalidium jubiflorum (Tda)	5.50	8.73
Autumn_2017	*Duma florulenta (AmT)*	12.10	20.39
	Paspalidium jubiflorum (Tda)	6.72	18.83
	Eleocharis (AmT)	21.00	14.15
	Persicaria prostrata (Tda)	3.07	6.17
Spring_2017	*Duma florulenta (AmT)*	17.10	26.80
	Eleocharis (AmT)	18.75	18.90
	Paspalidium jubiflorum (Tda)	3.16	13.72
	Asperula gemella (Tda)	1.29	7.26
Autumn_2018	*Duma florulenta (AmT)*	14.57	33.63
	Paspalidium jubiflorum (Tda)	1.89	15.43
	Persicaria prostrata (Tda)	2.21	9.53
	Eleocharis (AmT)	5.92	8.89
Spring_2018	*Duma florulenta (AmT)*	12.27	35.26
	Paspalidium jubiflorum (Tda)	1.3	15.43
	Eleocharis (AmT)	3.66	8.68
	Persicaria prostrata (Tda)	2.3	4.45
Autumn_2019	*Duma florulenta (AmT)*	10.9	37.41
	Paspalidium jubiflorum (Tda)	1.21	10.96
	Persicaria prostrata (Tda)	2.79	9.85
	Cynodon dactylon (Tda)	1.11	3.76

Species composition varied when grouped by the Inundation Period categories (Figure J-11). The Recent and Frequent categories grouped more closely together, while the Infrequent category contained the widest spread of the data. Pairwise tests concluded the Recent category was significantly different from all other categories ($p<0.05$), and a significant difference was observed between the Frequent and Rare categories ($p<0.05$). Whilst no significant difference was found between the Infrequent and Rare combination ($p=0.211$).

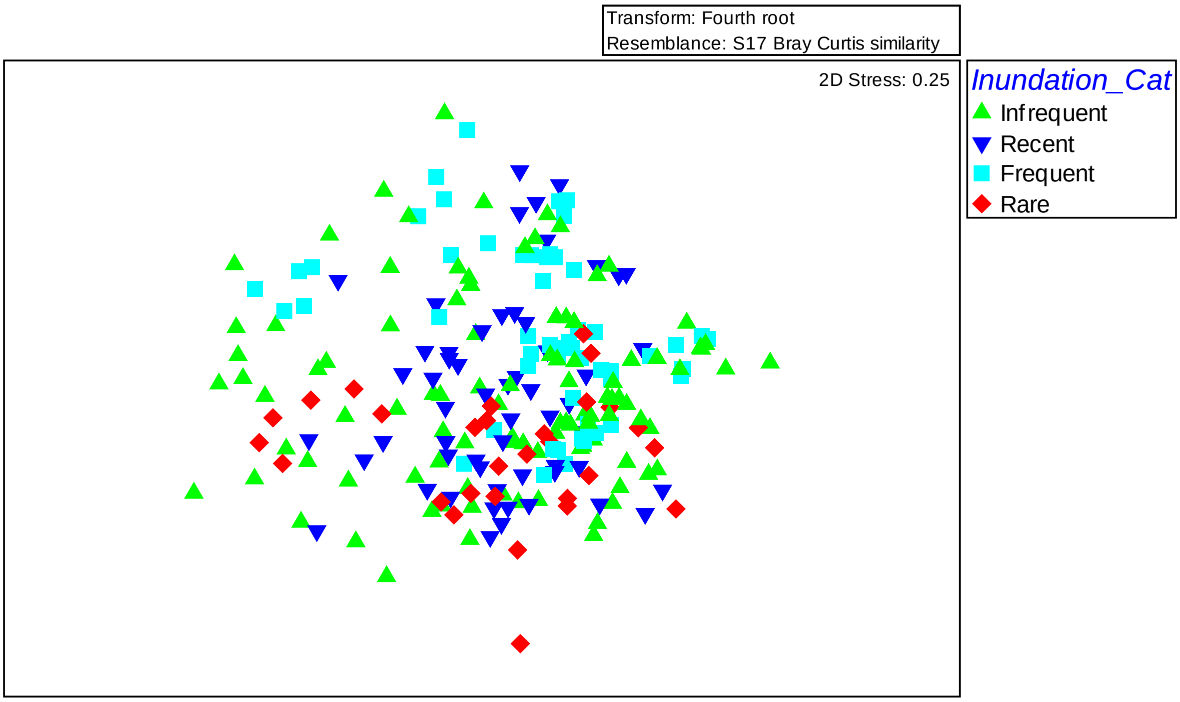

Figure J-11: nMDS plot of species composition data when grouped by Inundation Category.

SIMPER analysis noted variation in lower/mid storey species when grouped by the Inundation Period categories. All four categories indicated that Lignum had the highest contribution of the species, with Rare having the lowest (34.56%). Warrego Grass contributed highly to all categories with its mean being greatest during the Recent inundation category (4.18%), then declining with drier inundation categories. *Eleocharis* sp., contributed to 5.15% within the Recent category, peaked in the Frequent category (21.17%), but was absent in the Infrequent and Rare categories. Species from the *Schlerolaena* genus, which grow on sandy soils in dry habits, contributed highly to the Rare inundation category species composition, with *Sclerolaena birchii* recording the highest of the genus (4.55%,Table J-5).

Table J-5: Contribution and mean cover% of the top four lower and mid-storey species recorded in each of the Inundation categories.

Inundation Category	Species (func group)	Mean Cover%	Contribution (%)
Recent	*Duma Florulenta (AmT)*	14.15	48.46
	Paspalidium jubiflorum (Tda)	6.96	7.46
	Stellaria angustifolia (Tdr)	8.16	6.10
	Eleocharis pallens (AmT)	17.13	5.15
Frequent	*Duma Florulenta (AmT)*	15.25	43.08
	Eleocharis sp. *(AmT)*	16.00	21.17
	Paspalidium jubiflorum (Tda)	3.32	9.54
	Persicaria prostrata (Tda)	2.64	5.19
Infrequent	*Duma Florulenta (AmT)*	17.29	53.95
	Paspalidium jubiflorum (Tda)	2.9	5.22
	Persicaria prostrata (Tda)	4.2	4.31
	Marsilea drummondii (AmR)	1.06	2.14
Rare	*Duma Florulenta (AmT)*	13.64	34.56
	Paspalidium jubiflorum (Tda)	1.95	8.77
	Sclerolaena birchii (Tdr)	1.24	4.55
	Persicaria prostrata (Tda)	2.31	3.31

Functional group species composition was then grouped by Inundation Period categories. Categories appeared to vary within each functional group (Figure J-12). PERMANOVA analysis confirmed significant differences within the AmT, Tda and Tdr groups ($p<0.005$). Further pairwise tests revealed significant differences between the Recent/Rare ($p=0.029$) and Frequent/Rare ($p=0.001$) combinations within the AmT functional group. Species composition of the Recent category varied the most compared to other periods within the Tda Functional Group, with significant differences being noted between the Recent/Frequent ($p=0.002$) and Recent/Infrequent ($p=0.002$) combinations. Likewise, the Recent Inundation Period category within the Tdr functional group showed the greatest variation with the following significant differences being recorded (Recent & Infrequent; Recent & Rare; $p=0.001$). Although the AmR functional group showed some variation between inundation categories (Figure J-12a), the low number of observations within this group invalidated statistical tests.

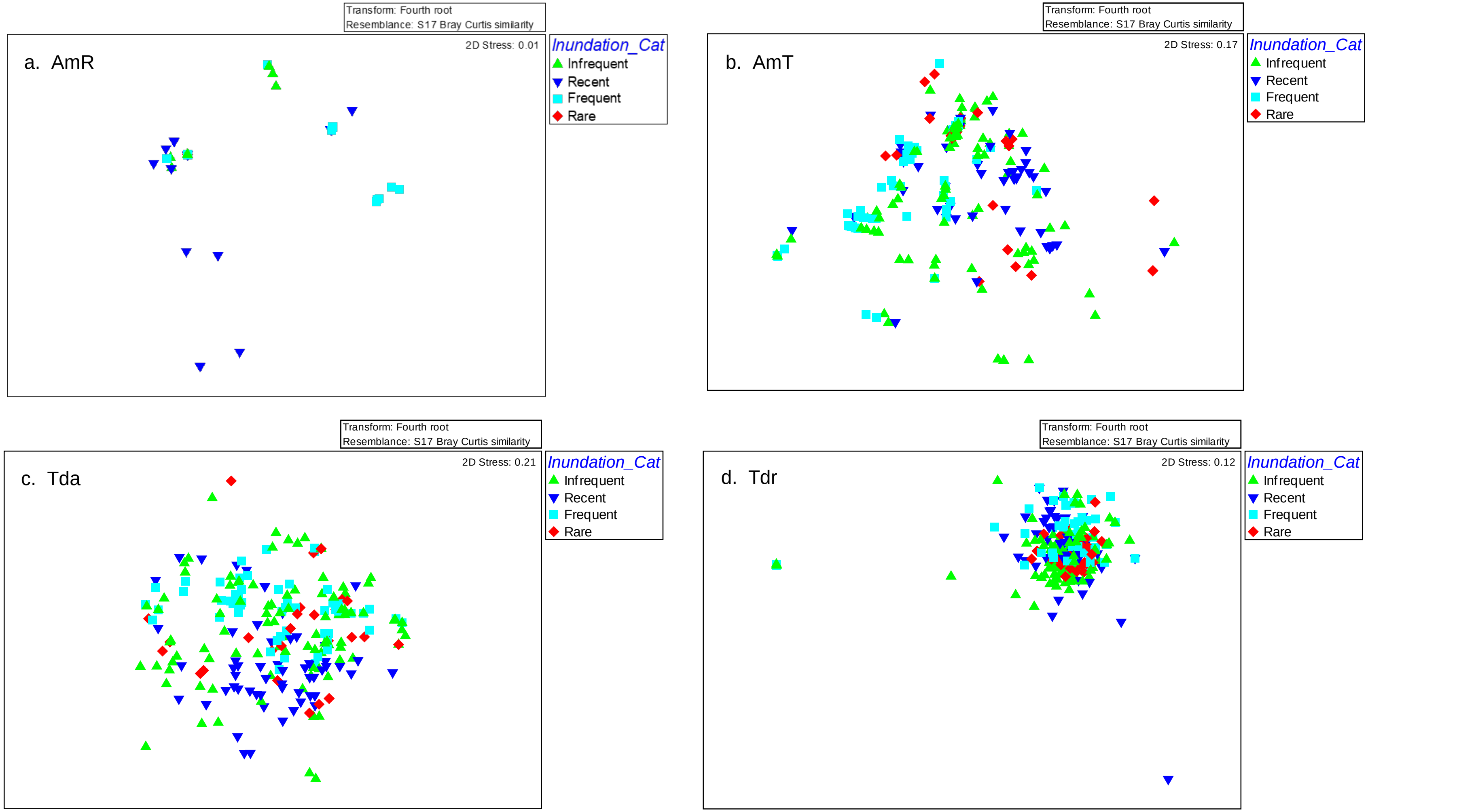

Figure J-12: nMDS plots of Functional Group species composition data when grouped by Duration Dry Period (a. AmR; b. AmT, c. Tda, d. Tdr).

J.3.4 Tree Recruitment

Average tree recruitment measured within River Cooba and Coolibah vegetation plots was calculated for three separate age classes across all sample periods (Figure J-13–Figure J-16). No clear trends were observed within the recruitment data of River Cooba for WD1 and WD2. Although a large number of individuals sized (0.2-0.5 m) occurred in spring-2015 at WD1 (26 ± 45.03 individuals), the same plants were absent the following year with only a small proportion developing into the (0.5-1.3 m) class (Figure J-13). WD2 showed reduced recruitment compared to WD1, although all age classes had initial increases from baseline surveys, until they peaked during the 2016-17 water year. By autumn-2019, abundances in the 0.2-0.5 m, 0.5-1.3 m age classes had returned to baseline means, whereas the upper class (1.3-3 m) remained elevated (+2.66 individuals, Figure J-14). At WD5, Coolibah recruitment was highest within the lower age class (0.2-0.5 m) at WD5 (86.33 ± 84.81 individuals) in autumn-2015. However, these plants failed to develop into the upper size class and had died off by autumn-2018 (Figure J-15). Similar results were noted at WD6 with a large recruitment event of Coolibah, recorded in autumn-2015, although these plants failed to establish and had died off by spring-2016 (Figure J-16).

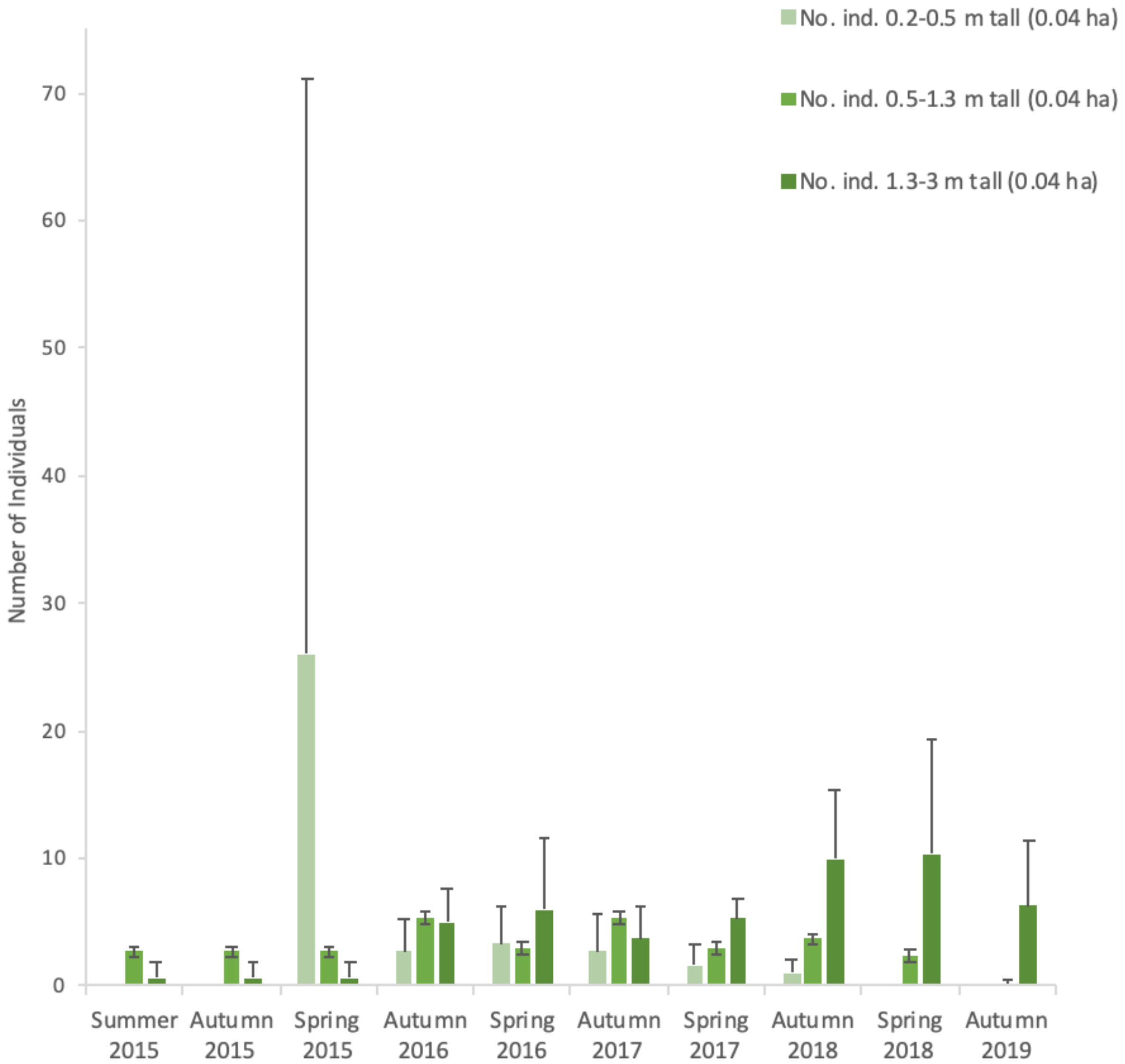

Figure J-13: Mean River Cooba recruitment at WD1 across all sample periods.

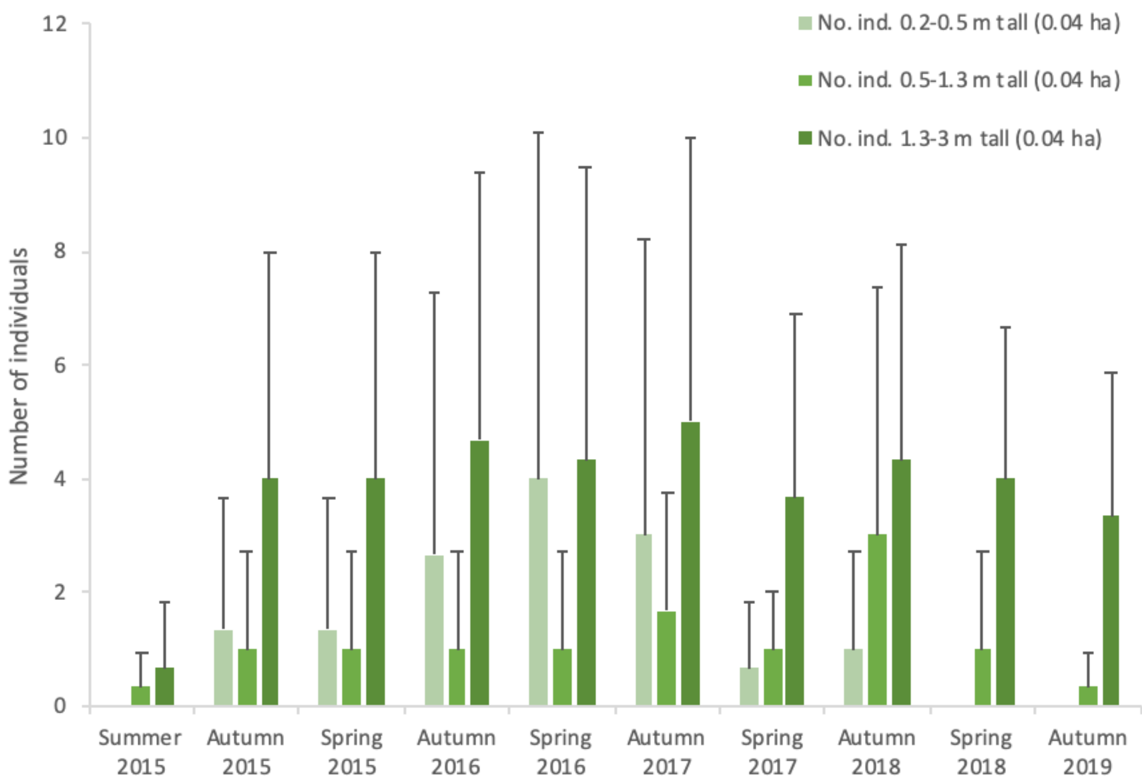

Figure J-14: Mean River Cooba recruitment at WD2 across all sample periods.

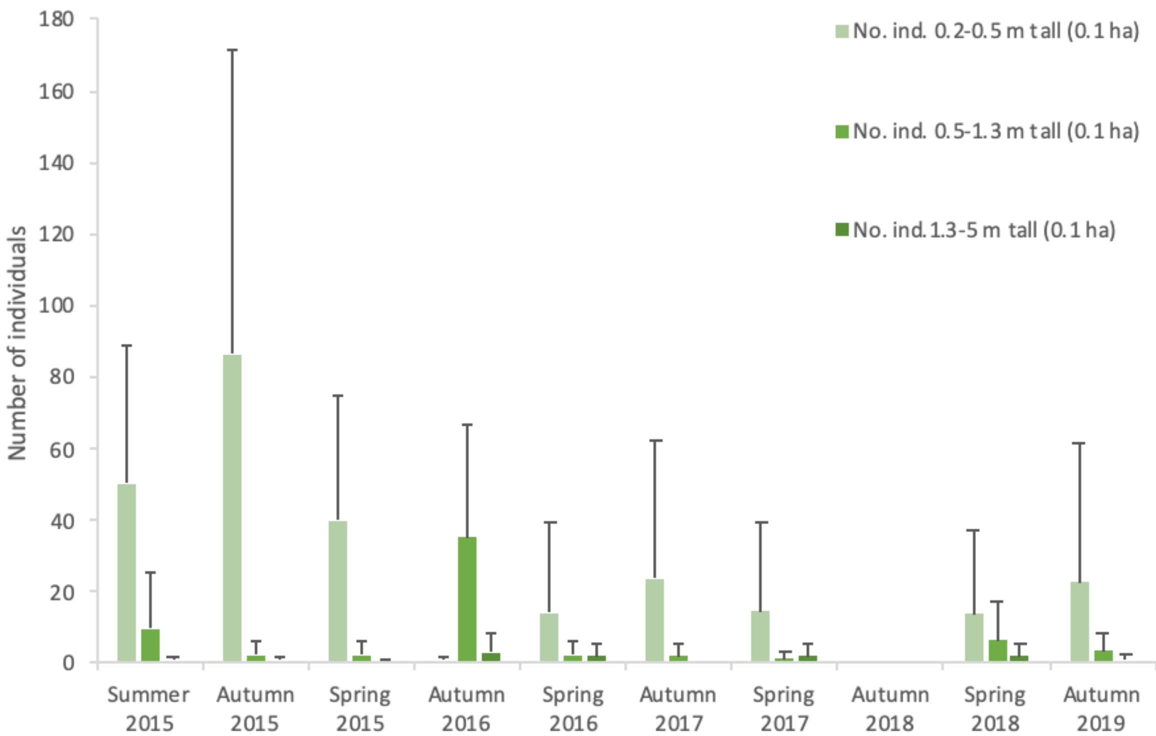

Figure J-15: Mean Coolibah recruitment at WD5 across all sample periods.

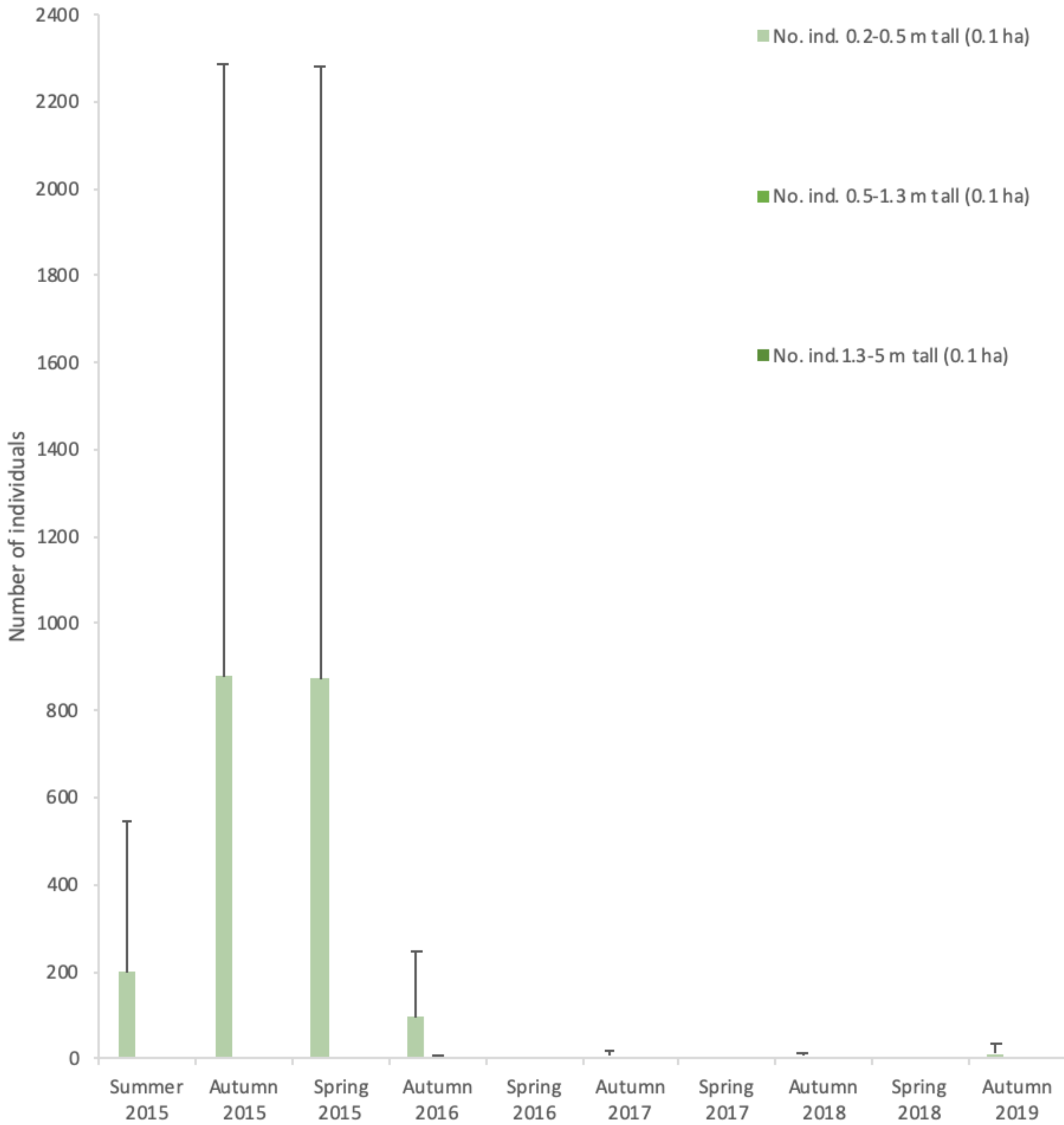

Figure J-16: Mean Coolibah recruitment at WD6 across all sample periods.

J.4 Discussion

Over the duration of the project, vegetation diversity on the Western Floodplain responded significantly to inundation, with the highest mean species richness and cover occurring at recently inundated sites. Seasonal patterns in vegetation diversity were less evident with responses more a reflection of the intermittent wetting and drying of the floodplain provided by connection with the Warrego River. The lowest levels of both vegetation species richness and cover coincided with the dry period experienced during the final two years of the project (Figure J-4, Figure J-7).

Commonwealth environmental water contributed 61% of the largest inundation event recorded within the LTIM Project (Spring-2016). It was in this year that mean vegetation cover was highest (Figure J-7), and amphibious species such as Blown Grass (*Lachnagrostis filiformis*) and Spike-Rush began to emerge as dominant species within the landscape (Table J-4, Figure J-17). The condition of Lignum, a more permanent wetland species, was also observed to improve during this time. However, the prolonged dry period during the final two years of the project reduced Lignum condition, with the plant appearing lifeless by autumn-2019 (Figure J-18). According to Casanova 2015, Lignum can remain essentially dormant, surviving via a persistent rootstock for up to 10 years. Observations from the floodplain following the most recent inundation event in April-May 2019, suggests Lignum has again improved in condition (Figure J-19). This highlights the ability of this species to recover following an extensive dry period on the Western Floodplain (≈ 950 days). Although, a high frequency of floods of short duration will optimise condition and reproduction of Lignum (Casanova, 2015).

Overall species Functional groups displayed predictable trends during the project, with amphibious species responding positively to inundation. Whereas, the terrestrial plants recorded more consistent results, with little change being observed between inundation categories. However, when analysed within the different vegetation communities, separate communities were found to uniquely influence these groups. The Lignum community produced more consistent total cover results over the inundation categories, with minor fluctuations being observed in either the amphibious or terrestrial plants between inundation categories. Whilst both the woodlands and other shrublands, experienced large declines in cover as time since inundation increased (Figure J-9). It is believed that the position of these communities in the landscape plays a large role in determining the influence of inundation on vegetation diversity. Lignum communities being situated in lower parts of the floodplain are often inundated for longer, inhibiting growth of other species that often thrive in the other communities following inundation. In contrast, the more prominent drying phases accompanied by lower soil moisture experienced within the woodlands result in the sharp declines of lower and mid storey vegetation cover.

Sporadic Coolibah and River Cooba recruitment occurred over the course of the project. In most cases, a higher recruitment rate was observed between periods of inundation and in years of higher rainfall. Very little recruitment was observed within the prolonged dry period in the final two years of the project. Few seedlings appeared to progress to the later stage of development and no clear distinction was observed between water availability and sustained growth once seedlings had become established. Seedling and sapling death may be attributed to competition for resources and grazing by both feral and native fauna on the floodplain.

Figure J-17: Spike Rush and Blown Grass dominating the landscape following the 2016 inundation event.

Figure J-18: Condition of Lignum observed at plot 8.3 during spring 2016 (top) and autumn 2019 (bottom).

Figure J-19: Condition of Lignum observed at plot 8.3 during July 2019.

J.5 Conclusion

The condition of vegetation communities on the Western Floodplain is driven by inundation, which has been enhanced by Commonwealth environmental water and water management. Maximum vegetation species richness and cover were observed in spring 2016 following the most widespread floodplain inundation to occur in the project. This inundation event-maintained vegetation communities until spring 2017, with dry conditions following this causing significant declines in richness and cover of vegetation communities until the last sampling in early 2019. Recent observations suggest a positive response of the vegetation on the floodplain once again, following inundation in April to May 2019. These fluctuations in vegetation condition are typical of floodplain systems that experience infrequent and unpredictable inundation. Recruitment of floodplain tree species was sporadic during the project, with limited evidence of succession from seedling to sapling at most locations. Grazing and competition for resources are likely drivers of this poor recruitment level.

J.6 References

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Appendix K Fish (River)

K.1 Introduction

The fish assemblages of the Warrego Valley are considered to be in a generally degraded condition. The Sustainable Rivers Audit (SRA) integrates three primary indicators of fish assemblage condition (*Expectedness, Nativeness,* and *Recruitment*) to produce an overall *Fish Index* (SR-FI) rating. In the SRA No. 2 assessment, the Warrego Valley scored an overall rating of ‘Very Poor’ for the Lowland zone and ‘Very Poor’ for the Slopes zone, primarily a reflection of the ‘Very Poor’ rating for Recruitment across the entire valley (Murray-Darling Basin Authority 2012). However, indicators relating to native fish diversity and the extent to which pre-European fish assemblages remained intact were more positive. In particular, the Warrego Valley attained a ‘Good’ rating for *Nativeness* (the proportion of total abundance, biomass, and species present that are native) although a relatively high total biomass of alien species was still captured, particularly common carp (*Cyprinus carpio*). Whilst more positive, the number of native species observed during sampling for the SRA No. 2 program differed somewhat from that expected under a pre-European reference condition. In summary, the SRA No. 2 program found that the contemporary presence of native species characteristic of the Warrego’s pre-European fish assemblages was outweighed by an apparent paucity of recent fish reproduction.

The aim of the current section of the Junction of the Warrego and Darling River Systems (Warrego-Darling Selected Area) LTIM Project was to assess the effects of Commonwealth environmental water on fish abundance, biomass and community health within the Warrego-Darling Selected Area (upstream of the confluence of the Darling and Warrego Rivers). Several specific questions were posed in relation to this indicator:

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

K.1.1 Environmental watering during the LTIM Project (fish survey periods)

Unlike other Selected Areas, most environmental water is not specifically delivered to the Warrego-Darling Selected Area, rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Warrego-Darling Selected Area have been sporadic over the LTIM Project (Figure K-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16 and flows refilled waterholes and connected to the Darling River. The small flow event in January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, during June 2016 to February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, from March to April 2018 and in June 2018. Commonwealth environmental water made up 17.3% of the flow event during March to April 2018.

Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure K-1). During the flow event in March-April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River.

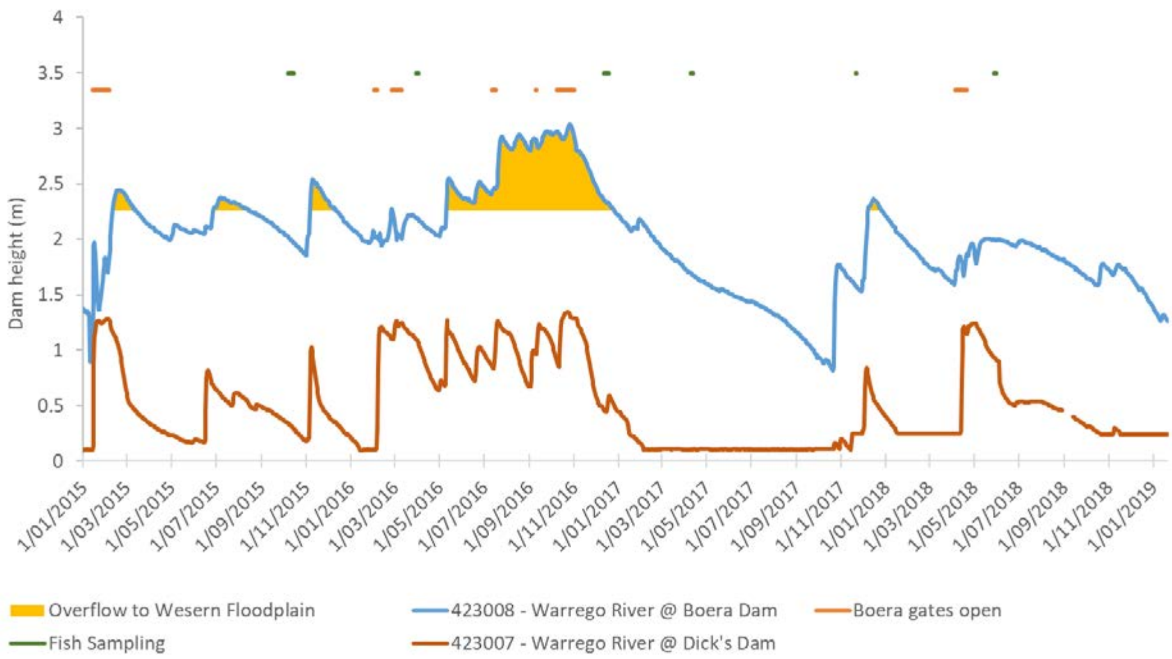

Figure K-1: Gauge heights in Boera and Dick's dams and periods of connection down the lower Warrego Channel in 2015-2018. Sampling dates, overflow to Western floodplain and dates of Boera gates being opened are shown.

K.1.2 Previous monitoring

There have been limited studies of the fish communities within the Warrego Valley, particularly across the lower sections of the system. In one of the few reported surveys, Balcombe *et al.* (2006) sampled the fish assemblages in 15 waterholes distributed among four reaches of the upper Warrego in Queensland between October 2001 and April 2002. As with the current study, sampling encompassed periods before and after flow events. All up, ten native species from eight Families, and three alien species from two Families were sampled. The most abundant and widespread species, under all conditions, was the bony herring (*Nematalosa erebi*). Hyrtl's tandan (*Neosilurus hyrtlii*) was also in high abundance, as was golden perch (*Macquaria ambigua*) (Balcombe *et al.* 2006).

As with many dryland rivers, fish assemblages in the upper Warrego were characterised by marked variations in abundance (Balcombe *et al.* 2006). For example, bony herring, spangled perch (*Leiopotherapon unicolor*) and the alien species', common carp and goldfish (*Carassius auratus*), underwent an 8,500% decline in abundance in three waterholes over the course of the Balcombe *et al.* (2006) two-year study. In contrast, Hyrtl's tandan underwent a 4,150% increase in abundance across the same three waterholes over the same period.

The difference in fish abundance was hypothesized to primarily reflect habitat attributes at the waterhole scale (Balcombe *et al.* 2006). In particular, fish abundances were higher in relatively broad, shallow waterholes featuring in-stream woody debris and overhanging vegetation, and lower in deeply-incised waterholes, although the latter provide important drought refuges for large-bodied fish species (Balcombe *et al.* 2006).

To what extent the patterns in fish assemblages observed by Balcombe *et al.* (2006) persist in the river's lowland zones (i.e. the current study sites) are unclear. It is apparent the river's channel morphology across the lower Warrego varies markedly from the headwaters (i.e. above Cunnamulla in south-western Queensland), possibly resulting in differences in fish assemblages.

Random and sporadic sampling by Fisheries NSW between 2004 and 2014 across the lower reaches of the Warrego catchment within NSW (as part of the SRA and the Carp Hotspots programs), returned catches of 12 species in varying abundances. Species sampled included nine natives and three exotics. Within the boundaries of the Warrego-Darling Selected Area, two of the species sampled upstream by Balcombe *et al.* (2006) were not caught at all; freshwater catfish (*Tandanus tandanus*) and Australian smelt (*Retropinna semoni*). However, a small number of the endangered native silver perch (*Bidyanus bidyanus*) were caught at Dick's Dam, which is located at the lower end of the Warrego-Darling Selected Area.

K.2 Methods

K.2.1 Sampling sites

The Warrego River is considered intermittent and ephemeral across the lower sections of the system, ending in a series of swamps and natural and artificial water storages immediately upstream of the Warrego-Darling junction. Data was collected from five sites over six sampling events from the lower Warrego River for Category III Fish River monitoring: Ross Billabong; Dick's Dam; Toorale Homestead; Booka Dam; and Boera Dam (Table K-1, Table K-2, Figure K-2). The lowest site (Ross Billabong) is approximately 5 km above the junction of the Warrego and Darling rivers, whilst the top site is approximately 45 km upstream of the junction of the two systems (Boera Dam) (Figure K-2). Due to low water levels in the Warrego system, only three of these five sites were sampled during Sample 4, those were Ross Billabong, Booka Dam and Boera Dam (Dick's Dam and Toorale Homestead not sampled) (Figure K-2, Table K-2). In Sample 5, Toorale Homestead and Boera Dam were sampled, whilst the three remaining sites were dry and were therefore not sampled (Ross Billabong, Dick's Dam and Booka Dam) (Figure K-2 & Figure K-3, Table K-2).

Of the five sample sites, four were artificial water storages, with Ross Billabong (Figure K-4) the only natural segment of the lower Warrego surveyed. Ross Billabong is around 4-5 km in length and has a maximum carrying volume of around 13,000 ML. The four artificial dams vary in size and capacity and were initially commissioned by Sir Samuel McCaughey in the late 19th century to help push water onto the western floodplain to improve grazing opportunities. The water at all sites and across all samples was highly turbid and relatively shallow, ranging up to a maximum depth of ~1m. In-stream habitat for fish was generally sparse, with small and the occasional large pieces of woody debris present at all sites, whilst fringing undercut banks were also present but again in low amounts. The substratum at all sites was dominated by mud, sand and silt. Most sites were fringed by a sparse riparian zone, dominated by large native trees such as river red gums (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*), as well as small numbers of a range of native shrubs <2 m in height.

Table K-1: Locations of sampling sites in the lower Warrego River used for LTIM Category III Fish River Warrego-Darling Selected Area assessment. NB* Electrofishing effort was dependent on water levels during each sample.

Site Name	River	Source	Latitude	Longitude	Altitude	Zone	Electrofishing Effort*
Ross Billabong	Warrego	LTIM CAT 3	-30.39029	145.40817	103	Lowland	Small boat
Dick's Dam	Warrego	LTIM CAT 3	-30.3163	145.36056	99	Lowland	Backpack/ Small boat
Toorale Homestead	Warrego	LTIM CAT 3	-30.27954	145.3788	98	Lowland	Backpack/ Small boat
Booka Dam	Warrego	LTIM CAT 3	-30.19054	145.43962	98	Lowland	Small boat
Boera Dam	Warrego	LTIM CAT 3	-30.1018	145.41962	104	Lowland	Small boat

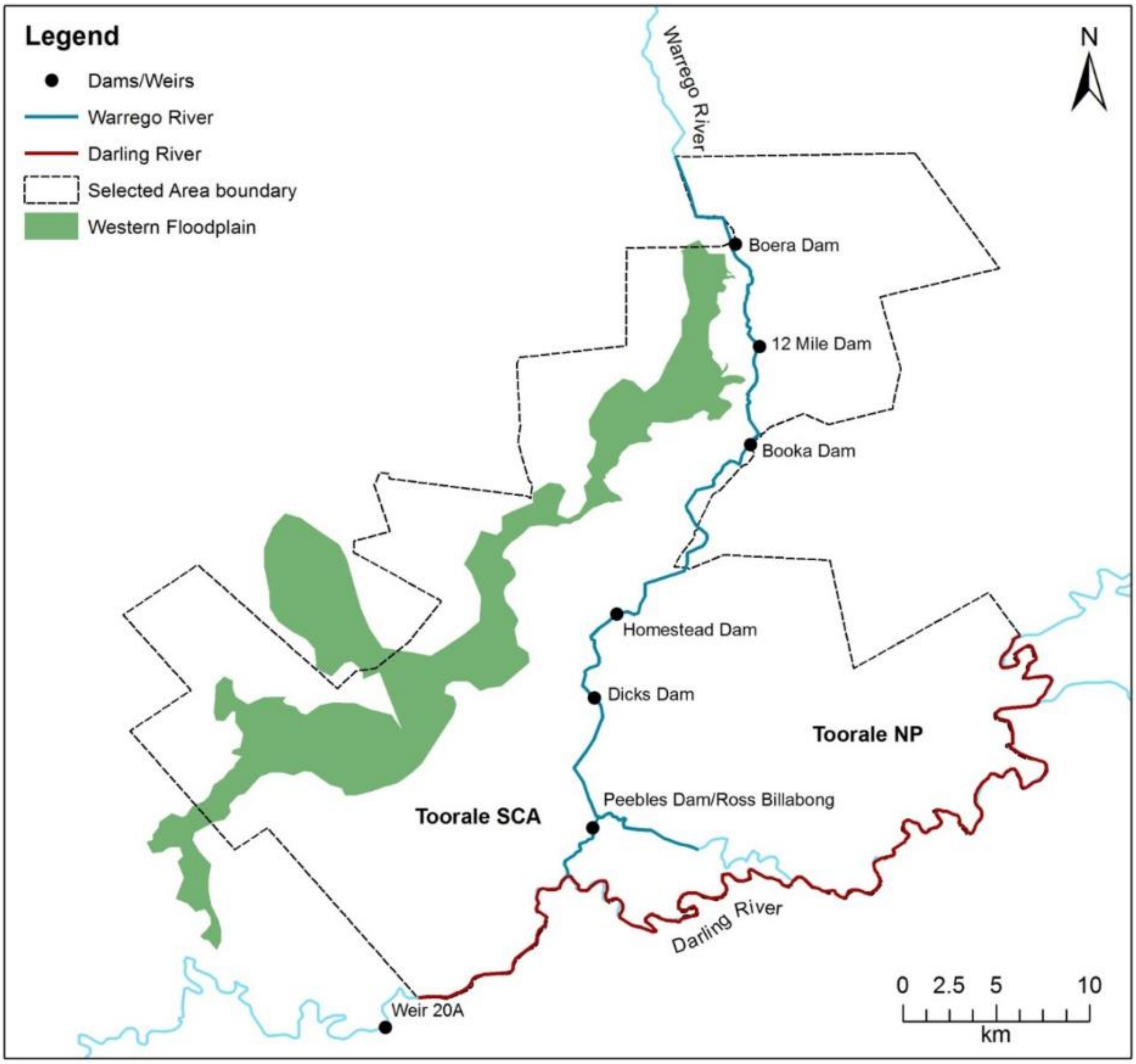

Figure K-2: Location of sampling sites in the lower Warrego River used for LTIM Category III Fish River Warrego-Darling Selected Area assessment.

Table K-2: Sampling dates for LTIM Category III Fish River Warrego-Darling Selected Area assessment.

Sampling event	Sampling dates	Number of sites with water
Sample 1	7-15 October, 2015	5
Sample 2	30 March-3 April, 2016	5
Sample 3	11-18 December, 2016	5
Sample 4	9-12 April, 2017	3
Sample 5	20-22 November, 2017	2
Sample 6	28-31 May, 2018	5

Figure K-3: Ross Billabong site on the lower Warrego River during Sample 5, November 2017.

Figure K-4: (a) Backpack electrofishing at Dick's Dam, November 2017 (b) and Ross Billabong during sampling in May 2018 (note low water levels).

K.2.2 Sampling protocols

Sampling effort at each site was a combination of electrofishing, baited and un-baited bait traps, small and large mesh fyke nets, and seine netting. Electrofishing was either by small boat (2.5 kW Smith-Root electrofisher unit), backpack (Smith-Root model LR20; Figure K-4a), or a combination of boat and backpack. Boat electrofishing involved 12 x 90 second operations, while backpack electrofishing consisted of 8 x 150 second operations. At sites where both boat and backpack sampling were required, the number of operations of each method used was proportional to the area of navigable versus wadable habitat. Boat electrofishing involved a series of ~10 sec power-on and power–off operations, with successive operations undertaken on alternate banks, whilst moving in an upstream direction. Backpack electrofishing involved sampling all areas accessible to the stationary operator, before they would progressively move upstream around ~3 m and repeat the process. All boat and backpack electrofishing was undertaken by two operators (Figure K-4a).

Bait traps (*n* = 10 unbaited, *n* = 5 baited, 'opera house' style) were deployed haphazardly throughout the sites in depths of 0.5 m to 1 m and soaked for up to two hours during electrofishing operations. Seine netting and fyke netting were undertaken on alternate days to electrofishing operations. Each seine operation involved one sampler remaining stationary on the bank, whilst the other dragged the net at full extension from bank to bank in a semi-circle motion; starting downstream of the stationary sampler and working upstream into the "flow". The seine net was 5 m in length, 1.8 m high and had 5 mm mesh. Three double wing small mesh (3 mm mesh) and three large mesh (19 mm) single wing fyke nets were set overnight for a minimum of 12 hrs.

All fish captured were identified, counted, and measured to the nearest mm; fork length (FL) for species with forked tails, and total length (TL) for all other species. If large numbers of a particular species were captured by a given gear type within a site, only the first 50 of that species were measured, with subsequent captures only being counted. Fish that escaped capture but that could be positively identified were recorded as "observed". Voucher specimens were retained for all species that could not be positively identified in the field.

K.2.3 Golden Perch Ageing

In order to determine the ages of juvenile golden perch within the lower Warrego River, samples were randomly and opportunistically collected during normal sampling from four of the five sites surveyed within the Warrego-Darling Selected Area; Dick's Dam, Toorale Homestead, Booka Dam and Boera Dam (Table 1). All samples were collected either by electrofishing or fyke netting. Following capture, fish were immediately euthanized using an overdose of clove oil, frozen and then transported to the Grafton Fisheries Centre for processing.

Otoliths were removed from specimens as described by Rowland (1998) for Murray cod (*Maccullochella peelii*). Once removed, otoliths were cleaned in warm water, dried and stored in individual labelled paper envelopes. Otoliths were then sent to Fish Aging Services (Queenscliff, Victoria) for processing.

The sagittal grind method was used to prepare otoliths to allow daily zone counts. All samples were read at 100X magnification using a Leica compound microscope illuminated with transmitted light. For each sample the reader recorded the following; the sample number, daily zone counts starting from the otolith margin and working in towards the primordium and the diameter of the first inner zone to ensure consistency.

To verify age estimates, otoliths were viewed independently by two readers without any prior knowledge of the length of the fish. No validation of age estimates was undertaken; however, previous studies have determined that daily increment counts were considered to represent the true age of juvenile golden perch (e.g. Anderson *et al.* 1992; Brown and Wooden 2007).

K.2.4 Data analyses

Fish community

All methods were combined for statistical analyses of the fish community data. Non-parametric multivariate analysis of variances (PERMANOVA) was used to determine if there were differences between the fish assemblages in abundance and biomass among samples (Table K-2) (PRIMER 6 & PERMANOVA; Anderson *et al.* 2008). Prior to analyses, the data were 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 differences were identified by PERMANOVA, pair-wise comparisons were then used to determine which groups differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities among groups.

Non-parametric Kolmogorov-Smirnov Z tests were used to determine if there were differences among samples in the size structures of the five more abundant large-bodied species present (golden perch, spangled perch, bony herring, Hyrtl's tandan and common carp). Data from all sites were combined for analysis, with samples of <20 individuals excluded. P-values were adjusted to account for increasing experiment-wise error rates associated with multiple comparisons (Ogle 2015).

Health Metrics

Reference Condition

The predicted pre-European fish community of the lower Warrego Basin was derived using the Reference Condition for Fish (RC-F) approach used by the Sustainable Rivers Audit (SRA) and NSW Monitoring, Evaluation and Reporting (MER) programs (Table K-3 &

Table K-4). The RC-F process uses historical and contemporary data, museum collections and expert knowledge to estimate the probability of collecting each species at any randomly selected site within an altitude zone prior to 1770 using the standard sampling protocol (Davies *et al.* 2008). Rare species were allocated a RC-F probability of capture of 0.1 (collected at 0 < 0.2 of samples), occasional species (collected at 0.21 < 0.7 of samples) an RC-F of 0.45 and common species (collected at 0.71 < 1.0 samples) an RC-F of 0.85 (RC-F scores being the median capture probability within each category) (Table K-3).

The definition of a recruit was derived using a similar process to that applied in the SRA and MER programs (Dean Gilligan unpublished data). For large-bodied and generally longer living species (>three years), an individual was considered to be a recruit if its body length was less than that of a one-year-old of the same species. For small-bodied and generally short-lived species that reach sexual maturity in less than one year, recruits were considered to be those individuals that were less than the species known average length at sexual maturity. The recruitment lengths used for both large- and small-bodied species were derived from published scientific literature or by expert opinion where published data was not available (

Table K-4).

Metrics, Indicators and the Overall Fish Condition Index.

Using the methods described by Robinson (2012), eight fish metrics were derived from the data collected at each site. The eight metrics were then aggregated to produce three fish condition indicators and these indicators were then used to derive an overall Fish Condition Index (SRA ndxFS). Metric and indicator aggregation was done using Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) using the rule sets developed by Davies *et al.* (2010).

The Expectedness Indicator ($SR\text{-}FI_e$) represents the proportion of native species that are now found within the basin, compared to that which was likely to have been historically present. The Expectedness Indicator is derived from two input metrics; the observed native species richness over 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 two metrics were aggregated using the Expectedness Indicator Expert Rule set (Carter 2012).

The Nativeness Indicator ($SR\text{-}FI_n$) represents the proportion of native versus alien fishes within the river. The Nativeness Indicator is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). The three metrics were aggregated using the Nativeness Indicator Expert Rule set (Carter 2012).

The Recruitment Indicator ($SR\text{-}Fi_r$) represents the recent reproductive activity of the native fish community within each altitude zone. The Recruitment Indicator is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (RC-F corrected), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). These metrics were aggregated using the Recruitment Indicator Expert Rule set (Carter 2012).

The three indicators were combined using the Fish Index Expert Rule set (Carter 2012) to calculate an overall Fish Condition Index (ndxFS). The Fish Index Expert Rules analysis is weighted as $SR\text{-}FI_e$ > $SR\text{-}FI_r$ > $SR\text{-}FI_n$. The output generated by the Expert Rules analysis is scaled between 0 and 100, with higher values representing a 'healthier' fish community. The index was then partitioned into five equal bands to rate the condition of the fish community; "Good" (81-100), "Moderate" (61-80), "Poor" (41-60), "Very Poor" (21-40), or "Extremely Poor" (0-20).

Table K-3: Native freshwater fish species predicted to have occurred in the lower Warrego River prior to European colonisation. Descriptions of predominance (occurrence) correspond to RC-F categories for the Murray-Darling Basin Sustainable Rivers Audit and are used to generate the fish condition metrics.

Species	Common name	Occurrence
Ambassis agassizii	olive perchlet	Occasional
Bidyanus bidyanus	silver perch	Occasional
Craterocephalus stercusmuscarum fulvus	unspecked hardyhead	Rare
Hypseleotris sp.	carp-gudgeon	Common
Leiopotherapon unicolor	spangled perch	Common
Melanotaenia fluviatilis	Murray-Darling rainbowfish	Common
Melanotaenia splendida tatei	desert rainbowfish	Rare
Mogurnda adspersa	southern purple-spotted gudgeon	Rare
Nematolosa erebi	bony herring	Common
Maccullochella peelii	Murray cod	Occasional
Macquaria ambigua	golden perch	Common
Neosilurus hyrtlii	Hyrtl's tandan	Occasional
Retropinna semoni	Australian smelt	Common
Tandanus sp.	freshwater catfish	Common

Table K-4: Sizes used to distinguish new recruits for species likely to be sampled in the lower Warrego River. Values represent the length at 1 year-of-age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)	Sampled during study	
		Adult	Juvenile
Native species			
olive perchlet	26 mm (Pusey *et al.* 2004)		
silver perch	75 mm (Mallen-Cooper 1996)		
unspecked hardyhead	38 mm (Pusey *et al.* 2004)		
carp gudgeon	35 mm (Pusey *et al.* 2004)	✓	✓
spangled perch	68 mm (Leggett & Merrick 1987)	✓	✓
Murray-Darling rainbowfish	45 mm (Pusey *et al.* 2004)	✓	✓
desert rainbowfish	38 mm (Pusey *et al.* 2004)		
S. purple-spotted gudgeon	40 mm (Pusey *et al.* 2004)		
bony herring	67 mm (Cadwallader 1977)	✓	✓
Murray cod	222 mm (Gavin Butler *unpub. data*)		
golden perch	75 mm (Mallen-Cooper 1996)	✓	✓
Hyrtl's tandan	130 mm (Pusey *et al.* 2004)	✓	✓
Australian smelt	40 mm (Pusey *et al.* 2004)	✓	
freshwater catfish	92 mm (Davis 1977)		

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)	Sampled during study	
		Adult	Juvenile
Alien species			
Common carp	155 mm (Vilizzi and Walker 1999)	✓	✓
Eastern mosquitofish	20 mm (McDowall 1996)	✓	✓
Common goldfish	127 mm (Lorenzoni *et al.* 2007)	✓	✓

K.3 Results

K.3.1 Abundance

In total, 9,517 fish were captured (n = 8,941) or observed (n = 576) across the six sampling rounds of the LTIM Fish River Warrego-Darling Selected Area assessment. Sample 3 had the highest total catch (n = 3,835) and Sample 5 the lowest (n = 482). The average ± S.E. total catch per sample was 1,586.2 ± 559.00 (Figure K-5).

There was a significant difference in the overall fish assemblage among all six samples ($Pseudo\text{-}F_{5,24}$ = 3.98, P = <0.01). Pair-wise comparisons revealed the dissimilarity was due to differences between: Sample 3 and Samples 1 (t = 1.99, P = 0.02), 2 (t = 2.12, P = 0.02), 5 (t = 3.92, P = 0.01) and 6 (t = 2.53, P = 0.01); Sample 5 and Samples 1 (t = 2.58, P = 0.01) 2 (t = 3.64, P = 0.01); and between Sample 2 and 6 (t = 1.91, P = 0.01).

SIMPER analysis suggested differences between Sample 1 and 3 were a result of a greater number of bony herring (contribution = 20.62%), Hyrtl's tandan (contribution = 16.35%) and Murray-Darling rainbowfish (contribution = 13.02%) in Sample 3. Contrastingly, differences between Sample 2 and 3 were a result of greater numbers of common carp (contribution = 20.33%), Hyrtl's tandan (contribution = 18.98%) and eastern mosquitofish (contribution = 12.69%) in Sample 3. Differences between Sample 1 and 5 were a result of greater number of spangled perch (contribution = 24.86%) and Hyrtl's tandan (contribution = 13.88%) in Sample 1 and greater numbers of common carp (contribution = 15.20%) in Sample 5. Bony herring (contribution = 26.21%) and spangled perch (contribution = 21.33%) numbers were the main contributors to differences between Sample 2 and 5, with higher numbers of both species collected in Sample 2. Differences between Sample 2 and 6 were as a result of lower numbers of bony herring (contribution = 29.76%) and spangled perch (contribution = 13.71%) and an increase in golden perch (contribution = 11.85%). Similarly, the differences between Sample 3 and 5 were as a result of lower fish numbers in Sample 5, with bony herring (contribution = 18.66%), spangled perch (contribution = 17.78%) and Hyrtl's tandan (contribution = 15.61%) the main contributors. Differences between Sample 3 and 6 were a result of higher numbers of fish collected in Sample 3 compared to Sample 6, with bony herring (contribution = 19.43%), Hyrtl's tandan (contribution = 16.51%) and spangled perch (contribution = 11.78%) the main contributors.

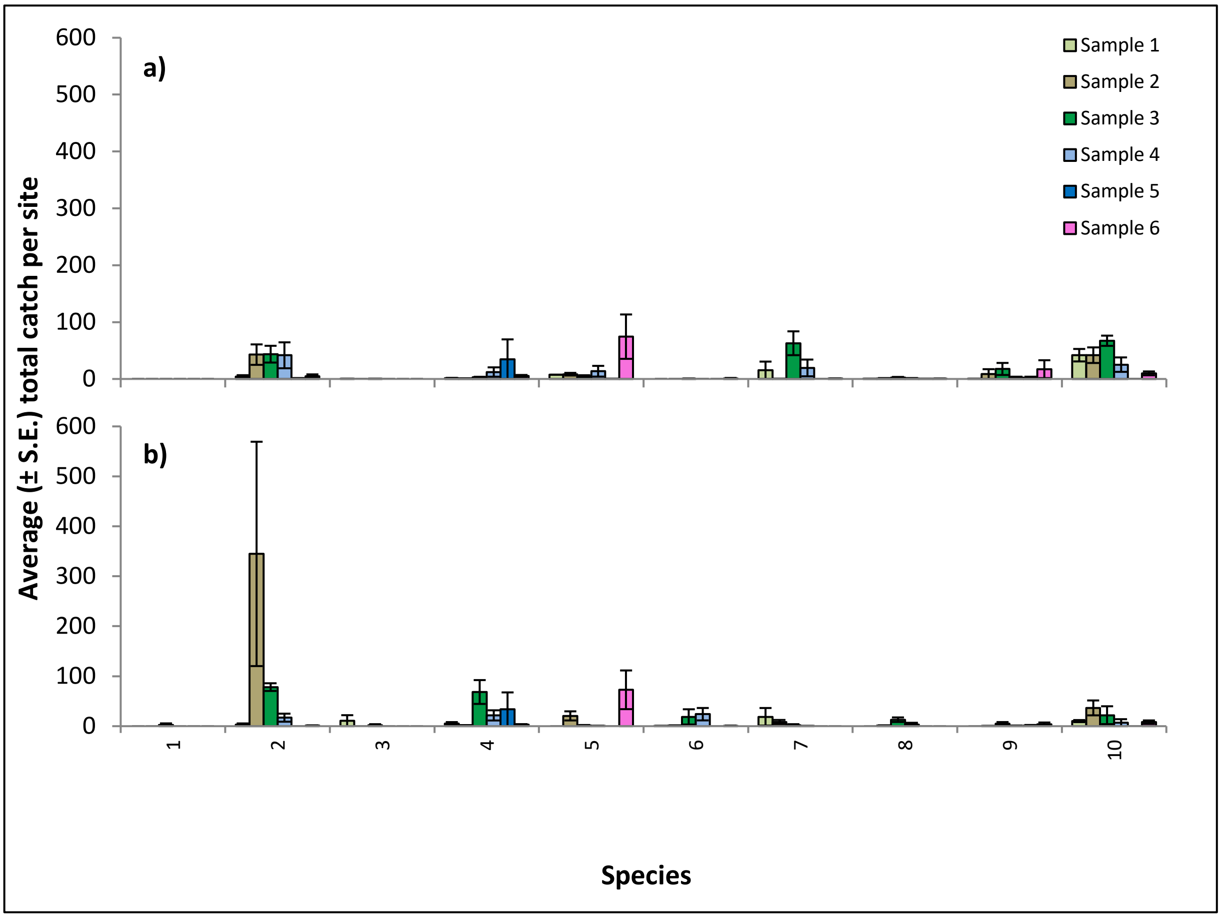

Figure K-5: Average total catch ± S.E. per site for non-juveniles (a) and juveniles (b) for all gear types combined for 10 fish species sampled in the lower Warrego River; October 2015 (Sample 1), April 2016 (Sample 2), December 2016 (Sample 3) and April 2017 (Sample 4), November 2017 (Sample 5) and May 2018 (Sample 6).

K.3.2 Biomass

Based on estimated and measured weights, a total of 174.7 kg of fish were collected across all six sampling occasions. Biomass was highest in Sample 3 at 55.6 kg and lowest in Sample 5 at 5.6 kg. The average ± S.E. biomass per sample was 29.12 ± 8.6 kg (Figure K-6).

There was a significant difference in the overall biomass of fish among samples ($Pseudo\text{-}F_{5,24}$ = 3.45, P = <0.01). Pair-wise comparisons revealed the dissimilarity was due to differences between: Sample 5 and Samples 1 (t = 2.96, P = 0.02), 2 (t = 3.46, P = 0.01) and 3 (t = 3.99, P = <0.01); and between Sample 3 and 6 (t = 1.71, P = <0.01) (Figure K-6).

SIMPER analysis suggested differences between Sample 1 and 5 were as a result of the higher abundance of spangled perch (contribution = 28.96%), common carp (contribution = 23.24%) and golden perch (contribution = 15.03%) in Sample 1 compared to Sample 5. Spangled perch (contribution = 28.25%), bony herring (contribution = 21.98%) and golden perch (contribution = 17.67%) were all lower in number in Sample 5 compared to Sample 2. Differences between Sample 3 and 5 were a result of less spangled perch (contribution = 24.59%), Hyrtl's tandan (contribution = 16.77%) and common carp (contribution = 16.60%) in the latter sample. Similarly, differences between Sample 3 and 6 were as a result of a lower biomass of spangled perch (contribution = 22.08%), Hyrtl's tandan (contribution = 19.44%) and bony herring (contribution = 16.22%) in Sample 6 compared to Sample 3.

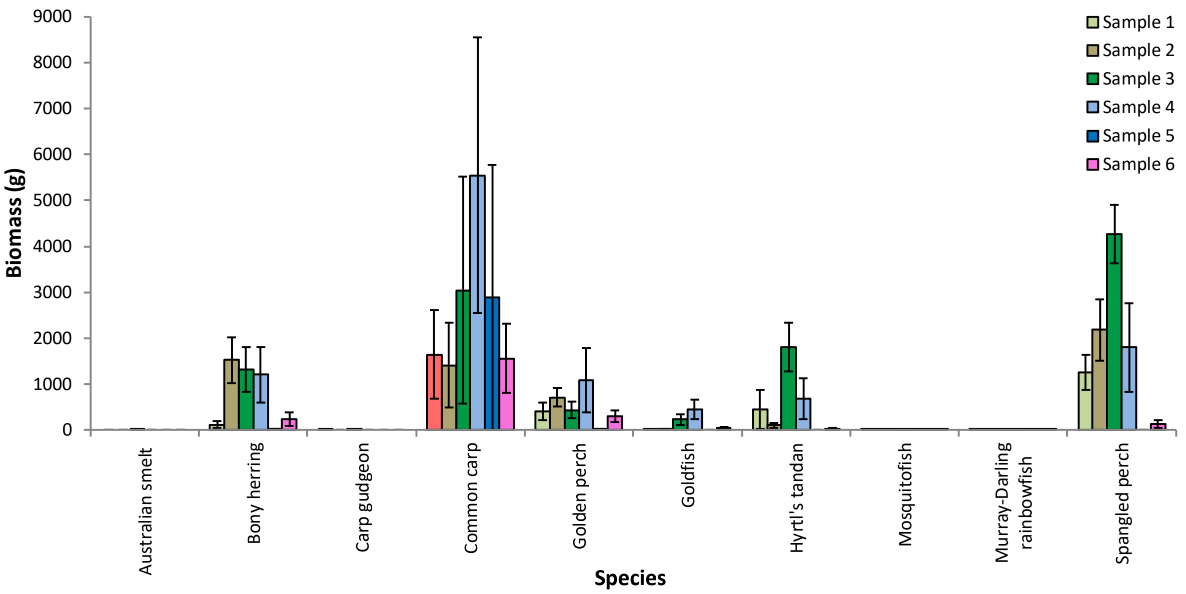

Figure K-6: Average biomass ± S.E. per site for the 10 fish species; October 2015 (Sample 1), April 2016 (Sample 2), December 2016 (Sample 3) and April 2017 (Sample 4), November 2017 (Sample 5) and May 2018 (Sample 6).

K.3.3 Length frequency

In general, there were significant differences in the length-frequency among the five more abundant species caught in the lower Warrego among most samples (golden perch, spangled perch, bony herring, Hyrtl's tandan and common carp) (Table K-5). There was also evidence of young-of-year among all five species, particularly in the earlier samples (1 to 4) (Figure K-7 & Figure K-8). For golden perch, the differences in length frequency distributions among samples was due to the increase in the number of larger individuals in Samples 3 and 4, and the increase in the numbers of young-of-year caught in Sample 2 (Figure K-7). Only one golden perch was collected in Sample 5 (151 mm TL), whilst the high numbers of juvenile fish caught in Sample 6 resulted in the differences between it and all the other samples (Figure K-7).

Similar to golden perch, the differences in the spangled perch population was largely dictated by the presence or absence of recruits (Figure K-7). For bony herring, there was a shift from a dominance of recruits in Samples 2 and 3, to greater numbers of individuals >100 mm FL in Sample 6 (Figure K-7). Hyrtl's tandan also experienced a distinct shift in population structure through time. In Sample 1 and 2, the population tended to be relatively symmetrical and was dominated by young-of-year individuals <130 mm TL. In Sample 3 and 4, very few young-of-year were caught, with the population dominated by adults. The species was absent in Sample 5 but a small number of individuals >130 mm was collected in Sample 6 (Figure K-7).

The small numbers of common carp in Sample 2 meant statistical comparisons between this sample and the other five samples could not be undertaken (Table 5). However, significant differences were detected between all other samples (Table 5). The population was dominated by recruits in Sample 5 (>97%) and this same trend was again evident in Sample 6 (Figure 8). Strong recruitment was also evident between Samples 2 and 3 and again between Samples 4 and 5 (Figure 8). Along with the large numbers of recruits present during a number of the samples, larger adult fish up to a maximum >600 mm FL and > 4 kg were also present in most samples.

Table K-5: Kolmogorov-Smirnov results of length frequency comparisons between the five most abundant fish species sampled; October 2015 (Sample 1), April 2016 (S Sample 2), December 2016 (Sample 3), April 2017 (Sample 4), November 2017 (Sample 5) and May 2018 (Sample 6). -- indicates <20 individuals were collected. Bold **indicates significant difference <0.05.**

Length Frequency Comparisons	Species (p-value)				
	Golden perch	Spangled perch	Bony herring	Hyrtl's tandan	Common carp
Round 1 & Round 2	**<0.001**	**<0.001**	**<0.001**	**<0.001**	--
Round 1 & Round 3	>0.999	>0.999	**0.002**	>0.999	**<0.001**
Round 1 & Round 4	>0.999	>0.999	0.122	>0.999	**0.019**
Round 1 & Round 5	--	--	--	--	**<0.001**
Round 1 & Round 6	**<0.001**	>0.999	**<0.001**	--	**0.002**
Round 2 & Round 3	**<0.001**	**<0.001**	**<0.001**	**<0.001**	--
Round 2 & Round 4	**<0.001**	**<0.001**	**<0.001**	**<0.001**	--
Round 2 & Round 5	--	--	--	--	--
Round 2 & Round 6	**<0.001**	**<0.001**	**<0.001**	--	--
Round 3 & Round 4	0.132	0.132	**<0.001**	0.132	**<0.001**
Round 3 & Round 5	--	--	--	--	**<0.001**
Round 3 & Round 6	**<0.001**	**<0.001**	**<0.001**	--	**0.003**
Round 4 & Round 5	--	--	--	--	**<0.001**
Round 4 & Round 6	**<0.001**	**<0.001**	**<0.001**	--	**<0.001**
Round 5 & Round 6	--	--	--	--	**<0.001**

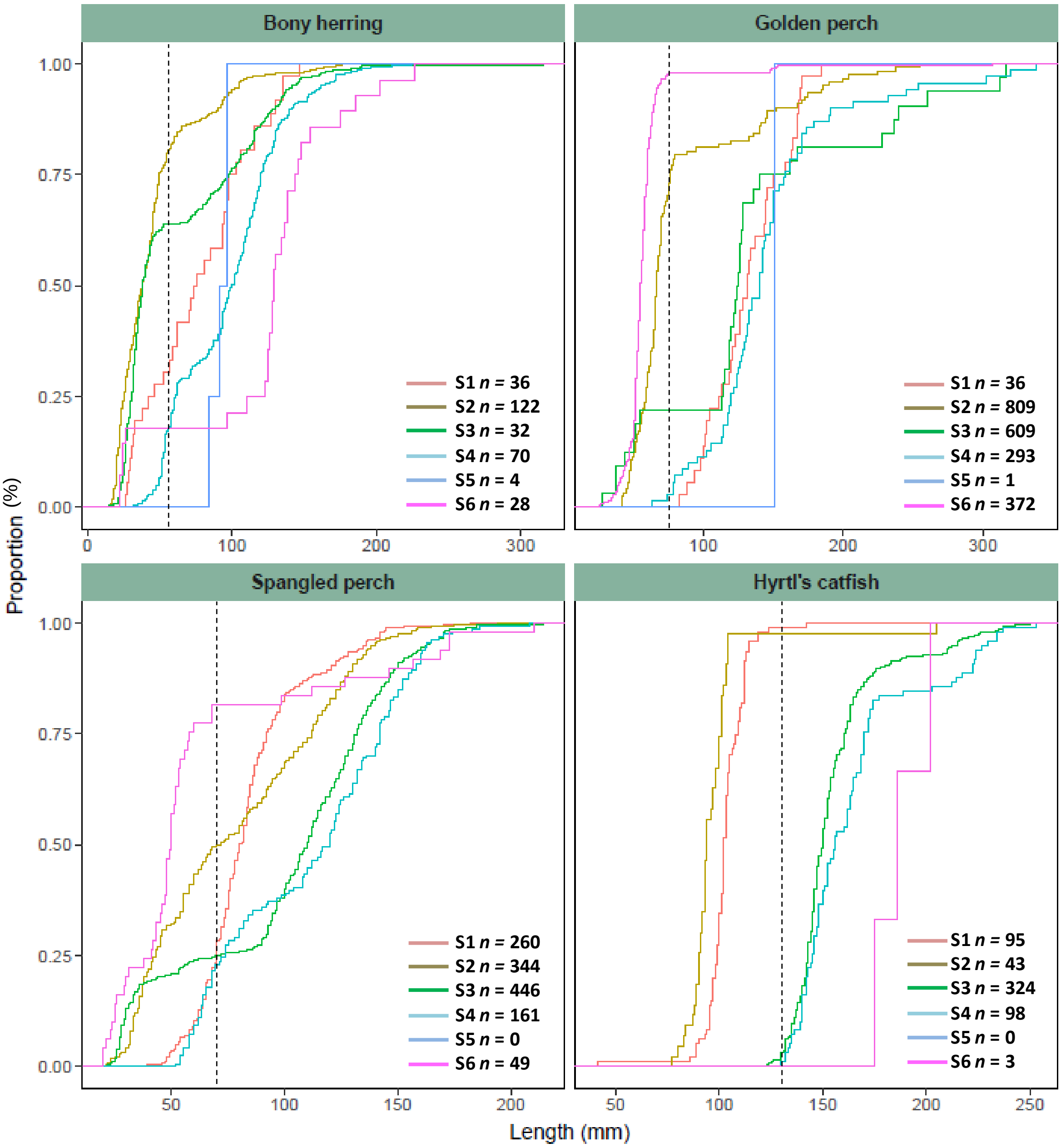

Figure K-7**: Length frequency distribution (proportion) of bony herring, golden perch, spangled perch, and Hyrtl's tandan sampled**; October 2015 (S1), April 2016 (S**2), December 2016 (S3), April 2017 (S4), November 2017 (S5) and May 2018 (S6). NB*. Dashed line is approximate length of one-year-old individual.**

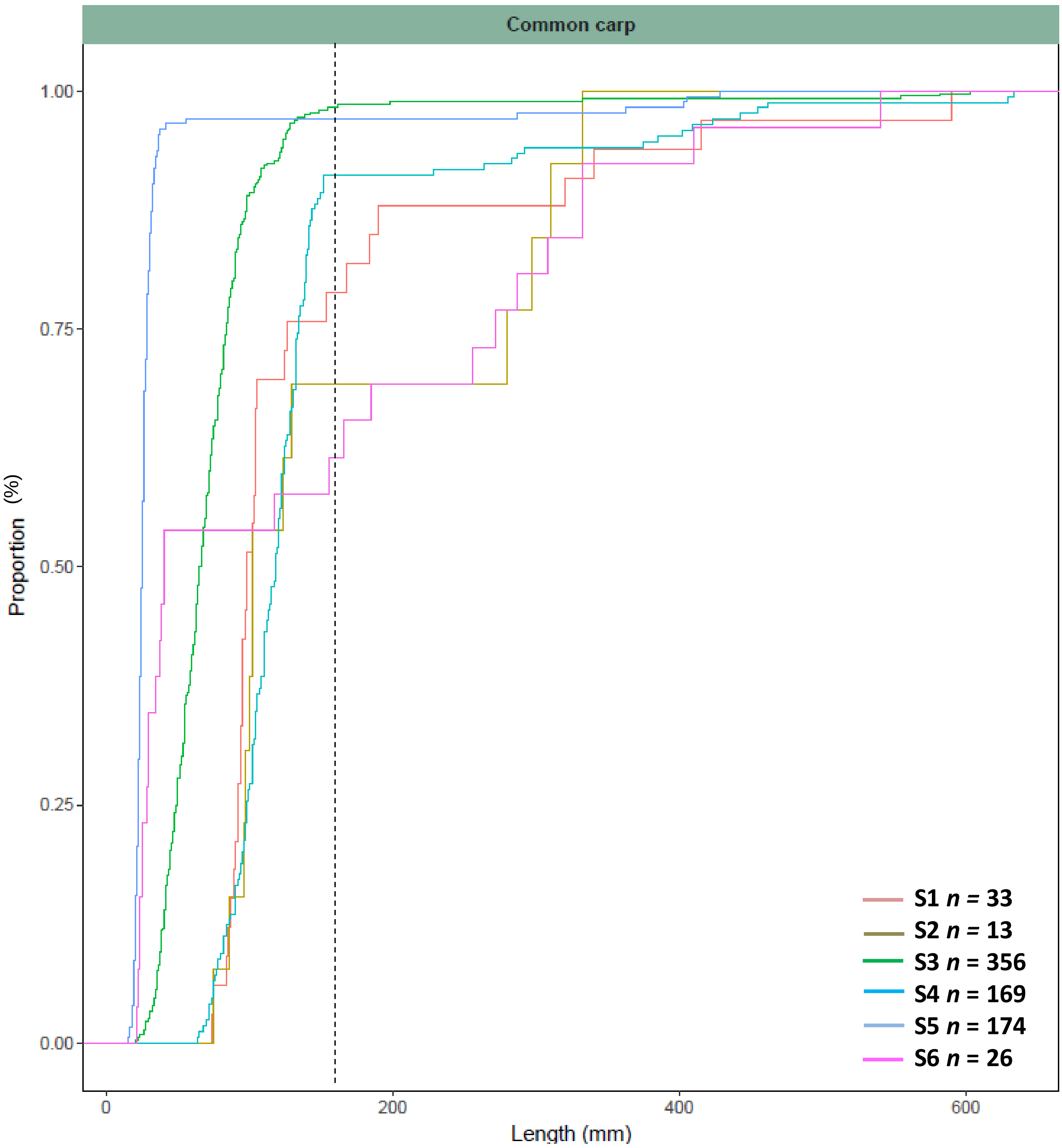

Figure K-8**: Length frequency distribution (proportion) of common carp sampled;** October 2015 (S1), April 2016 (S**2), December 2016 (S3), April 2017 (S4), November 2017 (S5) and May 2018 (S6). NB*. Dashed line is approximate length of one-year-old individual.**

K.3.4 Health Indicators

Expectedness

Of the 14 native fish species that have been previously sampled or were thought to have historically occurred in the Warrego (Table K-3), seven were caught at a minimum of one site across the study (

Table K-4). The seven native species not caught in any of the six samples were: olive perchlet, silver perch, unspecked hardyhead, desert rainbowfish, southern purple-spotted gudgeon, Murray cod, and freshwater catfish. Of these, three (unspecked hardyhead, desert rainbowfish and southern purple spotted gudgeon) were considered “rare” or “cryptic” meaning they are only likely to be collected in < 20% of sites sampled within a zone, and three (olive perchlet, silver perch and Murray cod) as “occasional” meaning they are only likely to be collected in 20-70% of sites within a zone (Robinson 2012). Freshwater catfish were considered as being “common” and “abundant” in the past and potentially should have been caught at a minimum of 70% of the sites sampled (Robinson 2012). Overall, Expectedness was highest in Sample 3 (60.2) and lowest in Sample 5 (3.9) (Figure K-9). The average ± S.E. Expectedness among samples was 28.7 ± 8.21.

Nativeness

Of the exotic species sampled, eastern mosquitofish, goldfish and common carp (Figure K-5 & Figure K-6) were caught in all six samples. Common carp increased in number considerably from Samples 1 to 4 and were the most abundant of the three exotic species in Sample 3 and Sample 4. In Sample 5, common carp (n = 460) was not only the most abundant of the exotic species but were also the most abundant species collected overall. However, common carp numbers declined between Sample 5 and Sample 6, with only 26 individuals collected in the later sample (Figure K-8).

Nativeness scores were the lowest across all six samples in Sample 5 at 5.28 but had recovered by Sample 6 to 51.54. The highest overall Nativeness score was in Sample 2 at 95.74 (Figure K-9). The average ± S.E. Nativeness score for all six samples was 60.20 ± 14.35, giving the lower Warrego an overall rating of “Poor” for Nativeness.

Recruitment

The Recruitment scores varied considerably among samples. The highest score was in Sample 2 at 96.6 (“Good”) and the lowest in Sample 5 at 0 (“Extremely Poor”). Overall, each sampling event showed either a considerable increase or a decrease in Recruitment values compared to the previous sample (Figure K-9).

Based on the individual metrics, in Samples 2, 3, 4 and 6, 100% of the native fish sampled were recruiting at a minimum of one site. Contrastingly, in Sample 1, 66% of the native fish sampled were recruiting at a minimum of one site. Few native fish and no recruits were collected in Sample 5. By number, recruits represented ~43%, ~72%, ~48%, ~27% and ~39% in Samples 1 to 4 and Sample 6 of the overall catch, respectively.

Whilst not considered in the calculation of the Recruitment indices, there was evidence of recruitment of all three exotic species sampled (Figure K-5). Mosquitofish, including recruits, were consistently caught across all samples, indicating regular breeding and recruitment. Similarly, the lengths of the goldfish collected also indicated regular recruitment for the species. In earlier Samples (1 and 2) all goldfish were under 1 year old (<127 mm), >99% of the catch in Sample 3 and Sample 4 were also below the recruit- cut-off length, and ~60% in Sample 5 and 6.

Common carp recruits (<155 mm) were collected across all six samples, and in most cases dominated the total catch of the species, representing 75%, 78%, 96%, 56%, 97% and 58% in Sample 1 to 6, respectively (Figure K-8).

Overall condition

The Overall Fish Condition (ndx-FS) scores varied among sites within samples, but more so between samples (Figure K-9). The average ± S.E. score for Overall Condition was highest in Sample 3, at 73.8 ± 3.97, and lowest in Sample 5, at 0.2 ± 0.20. The overall ratings for the Warrego-Darling Selected Area were “Very Poor”, “Poor”, “Moderate”, “Extremely Poor”, “Extremely Poor” and “Very Poor” for Samples 1 through 6 respectively (Figure K-9).

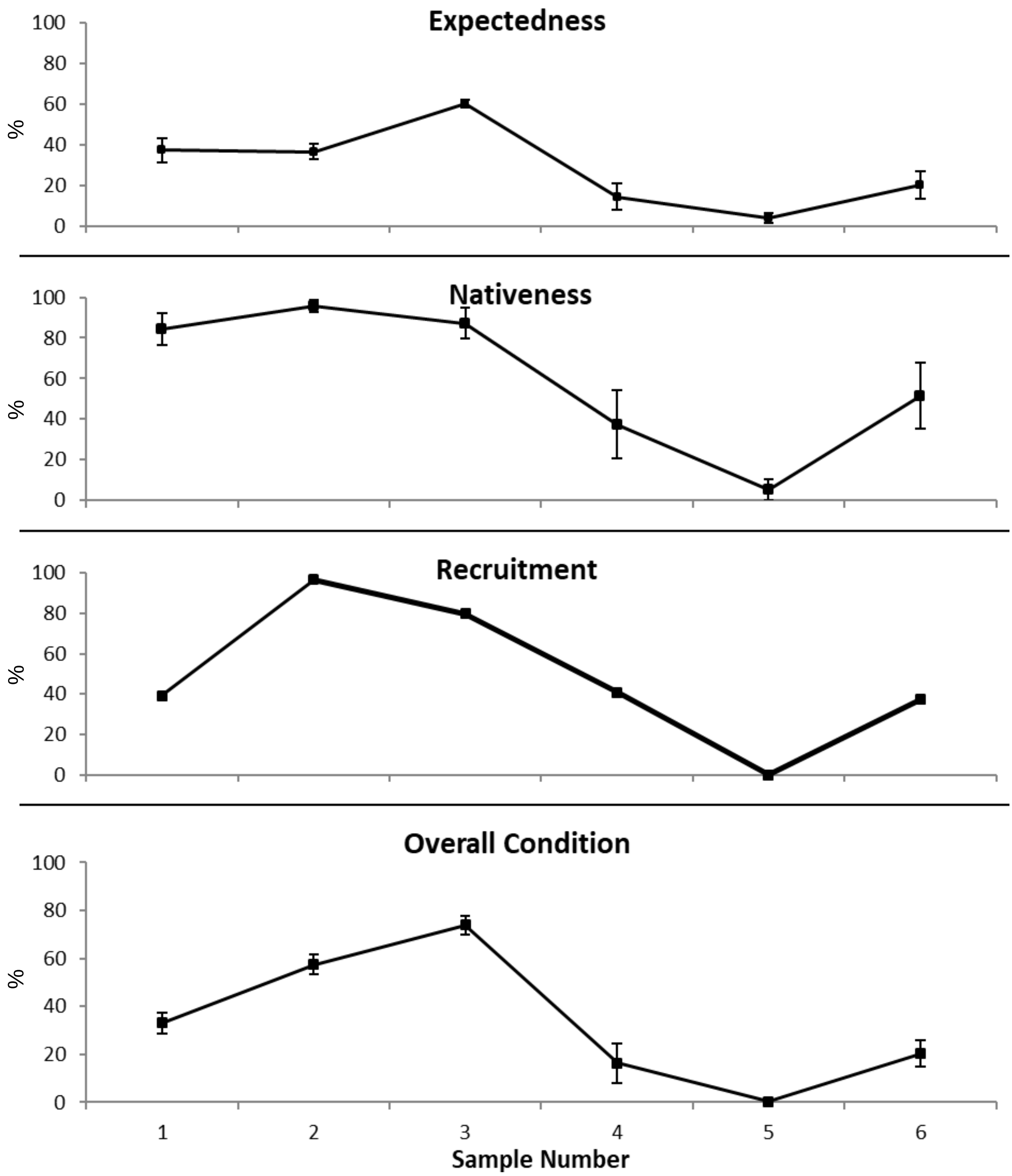

Figure K-9: Expectedness Nativeness, Recruitment and Overall Condition (ndxFS) values for fish at sites sampled; October 2015 (Sample 1), April 2016 (Sample 2), December 2016 (Sample 3), April 2017 (Sample 4), November 2017 (Sample 5) and May 2018 (Sample 6).

K.3.5 Golden Perch Ageing

A sub-sample of 124 juvenile golden perch was collected between 12/12/2016 and 30/5/2018 from Toorale Homestead Dam (*n* = 78), Dick's Dam (*n* = 36), Boera Dam (*n* = 5*)* and Booka Dam (*n* = 5) to determine age in days (Table 6). Fish ranged in length from 27 mm to 78 mm and weight from 0.25 g to 6.44 g (Table K-6). Ages ranged from 31 to 127 days (Figure K-10).

Based on back-calculated date-of-birth, golden perch captured in mid-December 2016 (mean estimated age: 66 days ± 0.6) were spawned between September and October 2016 (spring). This period coincided with substantial rainfall across south-west Queensland which resulted in a sizeable increase in flow in the Warrego River (Figure K-11; WaterNSW 2019). Similarly, the four individuals collected in April 2017 (mean estimated age: 119 days ± 2.89) were estimated to have been spawned in December 2016 (summer), also coinciding with a small rise in the Warrego (Figure K-11). Individuals collected in May 2018 (mean estimated age: 57 days ± 1.05) were estimated to have been spawned in March and April (autumn), coinciding with several rises in the Warrego over several weeks (Figure K-11).

Table K-6: Summary of golden perch (*Macquaria ambigua*) collected and aged from across the lower Warrego River, 2016-2018. For mean values sandard errors are shown in brackets.

Parameter	Value
Total golden perch collected	124
Length range (mm)	27-78
Mean length (mm)	55.98 (± 1.04)
Weight range (g)	0.25-6.44
Mean weight(g)	2.70 (± 0.12)

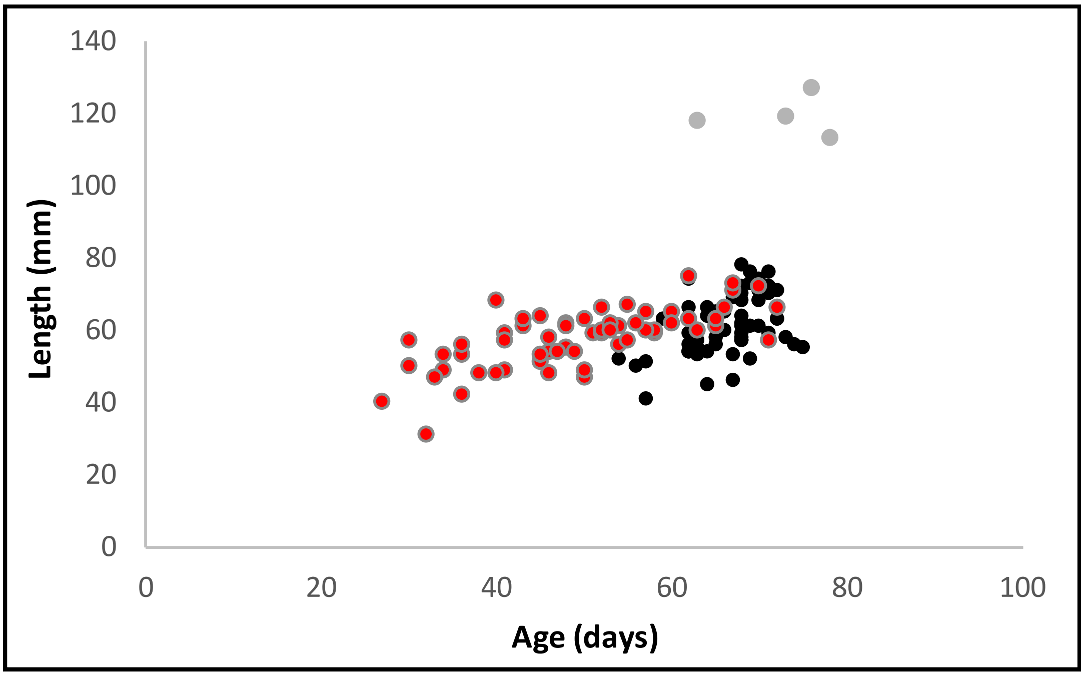

Figure K-10: Length-at-age of golden perch (*Macquaria ambigua*) collected from the Warrego River in 2016-2018. Black dots represent fish collected in Sample 3 (December 2016), grey dots represent fish collected in Sample 4 (April 2017) and red dots represent fish collected in Sample 6 (May 2018).

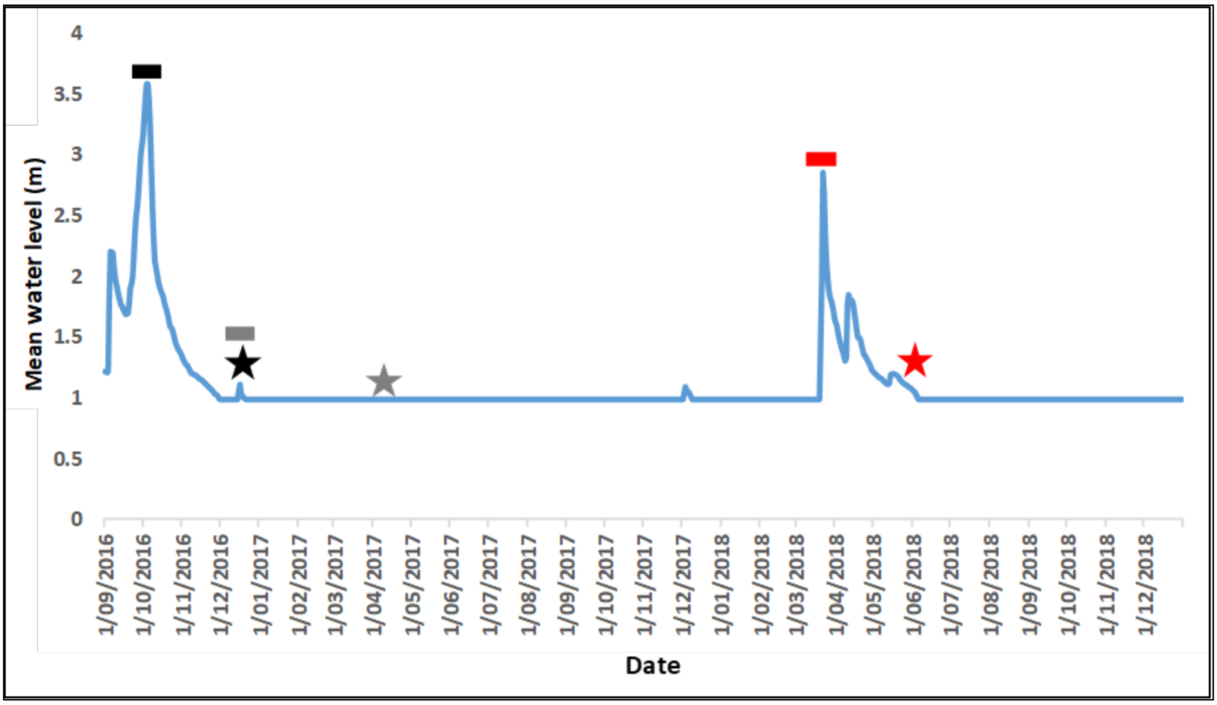

Figure K-11: Mean daily water level at Warrego River (Barringun No. 2 gauge) 1/9/2016 to 1/1/2019. Rectangles indicate approximate birth dates of back-calculated juvenile golden perch collected between December 2016 and May 2018. Stars indicate golden perch collection events. Shapes with the same colour indicate an association between a spawning event and collection of those fish.

Source: https://realtimedata.waternsw.com.au/ accessed: 2/4/2019.

K.4 Discussion

Stream drying is a common phenomenon that occurs naturally in many of the streams and rivers across the northern Murray-Darling Basin. 'Intermittent' or 'ephemeral' streams regularly experience dry periods, and this can be stressful for fish that reside within them and, in the worst case scenarios, can cause widespread mortality (Davey and Kelly 2007). The current study demonstrates the extent of environmental variability that fish can tolerate. Across the six sample rounds in the current study, the ability of fish to 'bounce back' and re-populate the Warrego system was observed in a number of instances. This was particularly apparent during Sample 6, following the extensive dry down experienced in the system around Sample 5, where all but two sites (Toorale Homestead and Boera Dam) had completely dried. Similarly, in earlier Samples (1 to 4), abundances and biomass of most species present fluctuated markedly between and among samples. The changes observed are most likely a reflection of an individual species' ability to cope and adapt to an environment where conditions can change rapidly. In general, those species that have wide ranging environmental tolerances to factors such as temperature, DO and pH are better able to handle the often rapid and wide-ranging changes in the surrounding abiotic conditions in semi-arid river systems like the lower Warrego (Katz and Freeman 2015; Kerezsy *et al.* 2013). In order for a species to endure, it must cope with disturbances such as the cessation of flows, long periods of drying, and in most cases, poor water quality. In the lower Warrego River, it is apparent that both the native and exotic fish species that persist clearly have these abilities.

Because of the ephemeral nature of the system, the fish species collected in this current study most likely reflect the long-term species diversity in the lower sections of the Warrego River. Several native fish species predicted to have occurred across the lower Warrego prior to European colonisation were not present in any of the six sampling events undertaken (Table K-3). However, several species predicted to have occurred in the past were considered to be "Rare" including unspecked hardyhead, desert rainbowfish and southern purple-spotted gudgeon (Table K-3) and as such may have always been intermittent inhabitants of the lower Warrego. A study by Balcombe *et al.* (2006) focusing on the upper and mid sections of the Warrego River did not detect any of these three species either, suggesting that they are truly rare in the Warrego, likely due to their lower resilience compared to the other species collected in the current study. Along with an ability to cope with extreme abiotic variability, to persist in environments like the lower Warrego, a species must also possess the ability to rapidly relocate as opportunity presents, allowing them to take advantage of more persistent refugia as the system dries. It also allows them to opportunistically access areas to take advantage of resources that may only be available for relatively short periods as they become intermittently available (Kerezsy *et al.* 2013). This type of resilience was evident among several species sampled in the current study including golden perch, spangled perch and bony herring. All three species are well known to be highly opportunistic in regard to moving on small and large flow events, both to colonise and establish populations in areas outside of their normal range or to move into intermittently wetted habitats (Ellis *et al.* 2015; Kerezsy *et al.* 2013; Balcombe *et al.* 2006). Additionally, these same three species all demonstrated the ability to recruit opportunistically during the current study (Figure K-7). The ability to rapidly recolonize and opportunistically recruit are two of the key factors why these species persist in the system and others do not.

The numbers of fish collected varied considerably for both native and exotic species throughout the current study. For example, following the dry period coinciding with Sample 5, Hyrtl's tandan were in low numbers during sample 6 (Figure K-7) compared to earlier samples (1 to 4) when they were relatively abundant. There was also no indication of Hyrtl's tandan recruitment in Sample 5 or 6 which reaffirms their classification as a "flow-dependent" species that requires major flooding in summer to bring about spawning and strong recruitment (Kerezsy *et al.* 2011). Contrastingly, spangled perch, bony herring and golden perch recruits were all collected in Sample 6 after being absent in Sample 5. Unlike Hyrtl's tandan, these three species have been shown to be "no-flow recruiters" in arid rivers like the Warrego, meaning that they can successfully breed and recruit during low or no flow periods (Kerezsy *et al.* 2011; Balcombe *et al.* 2006). Similarly, common carp recruits were captured in all six samples (Figure K-8) suggesting the ephemeral nature of the lower Warrego also suits this exotic species. In previous reporting, it was suggested that the lower Warrego may not be a constant source of common carp for the wider Darling but may be more of an opportunistic source when conditions are favourable (Commonwealth of Australia 2016). However, carp exhibit a range of dissimilar ecological characteristics that may allow a competitive edge over most local native fish species, even in dry environments (Koehn 2004). Common carp's ability to achieve high biomasses (Harris and Gehrke 1997), their broad physiological tolerances, high fecundity and longevity (>20 years) (Koehn *et al.* 2000; Brown *et al.* 2004; Driver *et al.* 2005; Stuart and Jones 2006) are all factors that have likely contributed to their success across the lower Warrego.

Based on the best available information, no golden perch restocking occurs within the study reach (NSW DPI Fish Stocking Database, unpublished data). As such, it can be assumed that the individuals aged in this current study were naturally spawned. The age estimates highlight that spawning can occur over several seasons and at different times of the year, indicative of an opportunist spawner. However, in all cases, golden perch spawned on 'river rises', particularly larger rises (Figure K-11). This finding is consistent with Koster *et al.* (2017) who concluded that golden perch spawning in the Goulburn River in south-eastern NSW was also related to higher flows.

In the Murray-Darling Basin, golden perch exhibit considerable variation in length-at-age (Anderson *et al.* 1992). This was also found in the current study (Figure K-10). The growth rates of golden perch found in this study are also similar to those observed in previous studies in the Darling River. Ebner *et al.* (2009) sampled golden perch 18 to 65 mm TL which ranged in age from 64 to 133 days.

The current study is the first age-and-growth study of golden perch from the population within the lower Warrego system. Further research is required that focuses on the exact source of these recruits to determine factors such as flow thresholds and the identification of critical breeding areas. Additionally, it is likely that golden perch recruits from the Warrego catchment are contributing to the wider Darling Basin golden perch population, further highlighting the need to understand the processes that are driving spawning and recruitment within the Warrego system.

K.5 Conclusion

Fish sampled in the current study demonstrated high levels of resilience by surviving and maintaining populations during the highly variable flow conditions experienced within the lower Warrego system over the last five years. The current study provides a valuable insight into how the lower Warrego functions and will help to improve the future management of the system for fish. The earlier sampling rounds showed how the system operates in a “boom” cycle with multiple species breeding, recruiting and growing during a relatively wet period. The later samples demonstrated the opposite extreme with the system switching to a “bust” cycle of drying and localized extirpations. Following the “bust” leading up to Sample 5, in Sample 6 as water again entered the system, recolonization and recruitment were apparent. For fish to persist across the lower Warrego regular managed flows are required to ensure survival first-and-foremost through refugia maintenance and also for fish to grow and breed. Whilst this is difficult due to the low amounts of environmental water available in the system, ensuring water is retained in at least some of the five waterholes at all the times should be considered a management priority. This will ensure that when reconnection of the system occurs as flows come through, there are founder populations present that can distribute and recolonize across the lower sections of the Warrego leading to breeding and recruitment in preparedness for the next drying phase.

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Appendix L Frogs

L.1 Introduction

Frogs are a widespread and important component of floodplain and river ecology and are sensitive to changes in hydrological regimes such as flood frequency, inundation period and seasonality of flows. River regulation has a profound impact on hydrological regimes both in the river channel and associated floodplains (Wassens and Maher 2011). Various components of the hydrological regime influence key habitat and population processes that affect frog communities, directly through influence on breeding and tadpole development times, and indirectly by structuring temporary and permanent habitat (Wassens and Maher 2011; Wassens *et al.* 2008; MacNally *et al.* 2009; Healey *et al.* 1997). Ongoing frog monitoring conducted as part of the Commonwealth LTIM Project is helping to build knowledge on how frog communities respond to inundation in the Junction of the Warrego and Darling Rivers Selected Area (Warrego-Darling Selected Area). Frog monitoring conducted during the 2018-19 water year represents the final seasonal monitoring for the LTIM Project. As such, this report highlights the results of the entire 5-year project.

The following specific questions were addressed through the monitoring of frog diversity in the Warrego-Darling Selected Area:

- What did Commonwealth environmental water contribute to frog populations?
- What did Commonwealth environmental water contribute to frog species diversity?
- What did Commonwealth environmental water contribute to frog survival?

L.1.1 Environmental watering during the LTIM Project (frog survey periods)

Unlike other Selected Areas, most environmental water is not specifically delivered to the Warrego-Darling Selected Area, rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Warrego-Darling Selected Area have been sporadic over the LTIM Project (Figure I-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16 and flows refilled waterholes and connected to the Darling River. The small flow event in January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area, during June 2016 to February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, March to April 2018 and in June 2018. Commonwealth environmental water made up 17.3% of the flow event during March to April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure I-1). During the flow event in March to April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River.

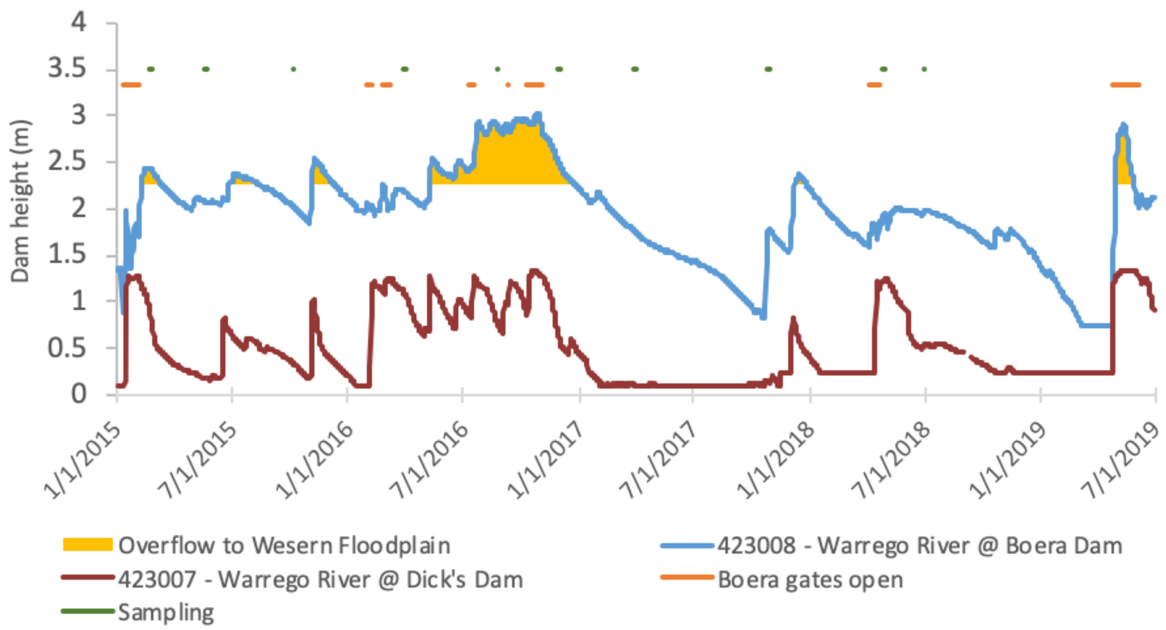


Figure L-1: Gauge heights in Boera and Dick's dams and periods of connection down the lower Warrego Channel in 2015-2018. Sampling dates, overflow to Western floodplain and dates of Boera gates being opened are shown.

L.2 Methods

Frog monitoring occurred on ten occasions at three sites in the Warrego River and one site on the Western Floodplain (Table L-1 & Table L-2, Figure L-2). Given the variable nature of flows in the Warrego River, surveys were undertaken on an event basis, timed to coincide with flow events down the system. Adult frogs were surveyed after dark by a two-person visual and audio survey (Commonwealth of Australia 2014). Survey times varied by site and date, therefore abundance is presented as catch per unit effort (CPUE) defined by the number of individuals per hour of survey. A spotlight was used to search for frogs along the wetland edge and surrounding terrestrial habitat. Audio surveys involved listening to distinct calls of resident frog species. All frogs observed were identified to species and counted.

Species richness, abundance (individuals/hr) and diversity measures based on observational data were analysed using Poisson regression analysis to investigate the influence of site (Channel sites; Booka Dam, Boera Dam, Ross Billabong, Floodplain site; Western Floodplain), sampling period (10 periods; Table L-2), and time since water connection factors. The time since water connection factor was calculated differently for the channel and floodplain sites. For channel sites (Boera Dam, Booka Dam, Ross Billabong), time since connection was calculated as the number of days between when the Boera Dam gates were shut, and the first day of sampling. Time since connection for the floodplain was calculated as the number of days between when water levels in Boera Dam dropped below the connection height to the Western Floodplain and the first day of sampling. Sites that were connected at the time of sampling were given a value of 0 days. The time since connection factor was applied in the modelling in two ways – as a continuous variable, and as a categorical variable with 4 levels. These categories are as follows:

- Recent-connection – 0 to 4 days since site was last connected (5 observations);
- Frequent-connection – 4 to 69 days since site was last connected (16 observations);
- Infrequent-connection – 69 to 303 days since site was last connected (12 observations); and
- Rare-connection – 303 to 550 days since site was last connected (6 observations).

Frog diversity was calculated in PRIMER using the Shannon Diversity Index (H') with natural logarithm (to the base *e*). In this index, a higher value indicates a higher diversity.

Non-metric multidimensional scaling (nMDS) analyses was used to represent patterns of community composition based on observational frog data. Fourth-root transformation was applied to density data prior to the calculation of resemblance matrices using Bray-Curtis similarities in PRIMER Version 6.1.13 (http://www.primer-e.com/). Sites with no observations were removed from the analysis. PEMANOVA tests were then performed to compare between survey period, site and time since water connection factors. SIMPER tests were performed to assess the dominant species associated with each data grouping.

Table L-1: Location of frog monitoring sites.

Monitoring Zone	Site Name	Site Type	Easting	Northing
Warrego River	Ross Billabong	Channel	347242	6636926
	Booka Dam	Channel	349835	6658024
	Boera Dam	Channel	348720	6669094
Western Floodplain	Western Floodplain	Floodplain	347802	6665756

Table L-2: Timing of the 10 sampling occasions for frog diversity over the project.

Sampling occasion	Dates
February 2015	23 – 27 February 2015
May 2015	4 – 8 May 2015
October 2015	7 – 10 October 2015
March 2016	29 March – 2 April 2016
August 2016	23 – 26 August 2016
November 2016	29 November – 2 December 2016
March 2017	27 – 30 March 2017
October 2017	24 – 27 October 2017
April 2018	25 – 28 April 2018
June 2018	29 June – 2 July 2018

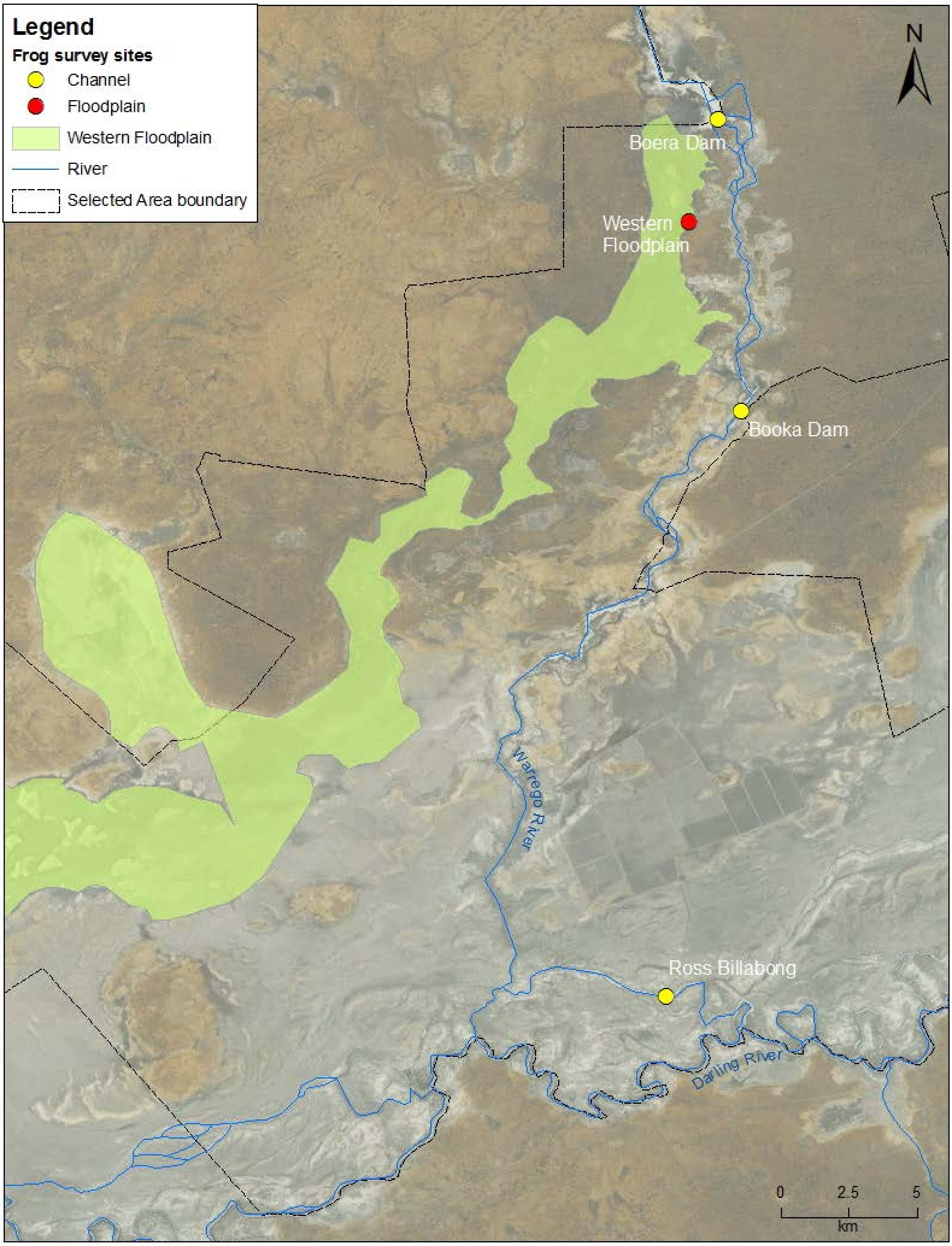


Figure L-2: Location of frog survey sites in the Junction of the Warrego-Darling Selected Area.

L.3 Results

A total of fourteen frog species were recorded in the Warrego-Darling Selected Area during the LTIM project (Table L-3 &Table L-4). None of the species present are listed as threatened under the NSW *Biodiversity Conservation Act 2016* (BC Act) or the Commonwealth *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act).

The spotted marsh frog (*Limnodynastes tasmaniensis*) was observed most frequently (eight occasions) across the monitoring period, followed by the barking marsh frog (*Limnodynastes fletcheri*) and green tree frog (*Litoria caerulea*) which were both observed on seven occasions. The barking marsh frog, green tree frog and spotted marsh frog were also the most abundantly recorded frogs, with 310, 155 and 120 individuals observed respectively (Table L-3 & Table L-4).

Booka Dam had the highest average species richness (3.2 ± 1.69 species), followed by Boera Dam (2.7 ± 1.77 species), Western Floodplain (2.3 ± 2.16 species) and Ross Billabong (1.3 ± 1.57 species). The difference between Booka Dam and Ross Billabong was significant ($p<0.05$). Sampling period was also a significant factor ($p<0.005$) with February 2015 (4.75 ± 0.96 species) and November 2016 (4.25 ± 1.26 species) having the highest average species richness of all survey periods (Figure L-3). Warrego sites had been recently connected (17 and 27 days previous for February 2015 and November 2016 respectively) during these events, and the Western Floodplain was connected on both occasions. Recent connection conditions indicated the highest average species richness results (3.2 ± 2.0 species), followed by Frequent-connection (2.4 ± 2.1 species), Infrequent-connection (2.4 ± 1.7 species) and Rare-connection (1.2 ± 1.3 species). Regression analysis detected a significant influence of time since connection, but due to low numbers of observations in some categories, all pairwise comparisons were non-significant.

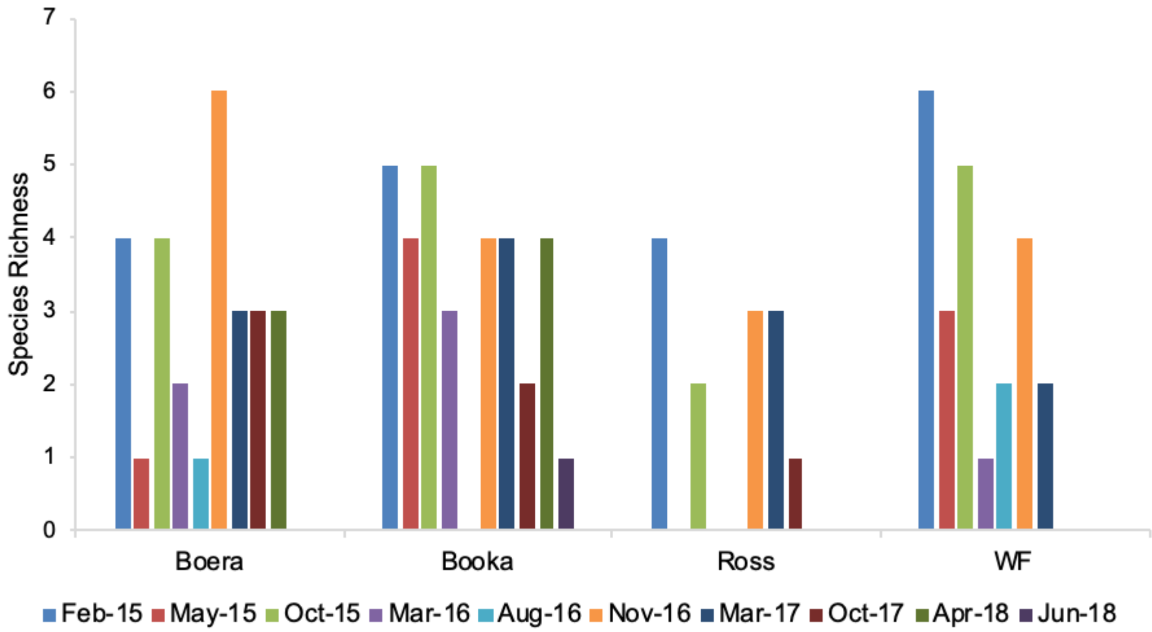


Figure L-3: Frog species richness across all survey periods.

Table L-3: Frog survey results for Boera Dam and Booka Dam 2014-19.

Scientific Name	Common Name	Boera Dam										Booka Dam									
		Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18	Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18
Crinia deserticola	Desert Froglet	2					2					1	15		4			14			
Crinia parinsignifera	Eastern Sign-bearing Froglet			1^																	
Cyclorana novaehollandiae	New Holland Frog								1	1		2								1	
Cyclorana platycephala	Eastern Water-holding Frog																			1	
Limnodynastes fletcheri	Barking Marsh Frog	1		5^			13^	36	1	1		2^		3			11^	143			
Limnodynastes salmini	Salmon Striped Frog						1										1				
Limnodynastes tasmaniensis	Spotted Marsh Frog		1	1^	1	20^	26	7	1	1			3	11			1	31		1	1
Litoria caerulea	Green Tree Frog				2							1		3			12	78	22	14	
Litoria peronii	Peron's Tree Frog	1		2^			5^	1					1	1							

Scientific Name	Common Name	Boera Dam										Booka Dam									
		Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18	Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18
Litoria rubella	Desert Tree Frog	4^										7		5	1				1		
Neobatrachus sudelli	Sudell's Frog						1						1								
Uperoleia capitulata	Small-headed Toadlet														1						
Individuals observed		**4**	**1**	**2**	**3**	**0**	**33**	**44**	**3**	**3**	**0**	**11**	**20**	**23**	**6**	**0**	**15**	**266**	**23**	**17**	**1**
Individuals heard		**4**	**0**	**7**	**0**	**20**	**15**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**10**	**0**	**0**	**0**	**0**
Total abundance		**8**	**1**	**9**	**3**	**20**	**48**	**44**	**3**	**3**	**0**	**13**	**20**	**23**	**6**	**0**	**25**	**266**	**23**	**17**	**1**
Species richness (observed)		**3**	**1**	**1**	**2**	**0**	**5**	**3**	**3**	**3**	**0**	**4**	**4**	**5**	**3**	**0**	**4**	**4**	**2**	**4**	**1**
Species richness (heard)		**1**	**0**	**4**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Total species richness		**4**	**1**	**4**	**2**	**1**	**6**	**3**	**3**	**3**	**0**	**5**	**4**	**5**	**3**	**0**	**4**	**4**	**2**	**4**	**1**

^includes species recorded by call

Table L-4: Frog survey results for Ross Billabong and Western Floodplain 2014-19.

Scientific Name	Common Name	Ross Billabong										Western Floodplain									
		Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18	Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18
Crinia deserticola	Desert Froglet	6										25^									
Crinia parinsignifera	Eastern Sign-bearing Froglet													17^		8^					
Cyclorana novaehollandiae	New Holland Frog																				
Cyclorana verrucosa	Rough Frog	1																			
Limnodynastes fletcheri	Barking Marsh Frog						6^	1	1			13^	13	13^			20^	1			
Limnodynastes salmini	Salmon Striped Frog						2														
Limnodynastes tasmaniensis	Spotted Marsh Frog												3	41^	3	50^	194 ^	8			
Litoria caerulea	Green Tree Frog	4		3^			10	6				1^					2				
Litoria peronii	Peron's Tree Frog	2		4^				8				22^		3^			54^				

Scientific Name	Common Name	Ross Billabong										Western Floodplain									
		Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18	Feb 15	May 15	Oct 15	Mar 16	Aug 16	Nov 16	Mar 17	Oct 17	Apr 18	Jun 18
Litoria rubella	Desert Tree Frog											13^	1	4							
Neobatrachus sudellae	Sudell's Frog																				
Uperoleia rugosa	Wrinkled Toadlet											2^									
Individuals observed		**13**	**0**	**2**	**0**	**0**	**16**	**15**	**1**	**0**	**0**	**3**	**17**	**35**	**3**	**0**	**270**	**9**	**0**	**0**	**0**
Individuals heard		**0**	**0**	**5**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**73**	**0**	**43**	**0**	**58**	**3**	**2**	**0**	**0**	**0**
Total abundance		**13**	**0**	**7**	**0**	**0**	**18**	**15**	**1**	**0**	**0**	**76**	**17**	**78**	**3**	**28**	**3**	**0**	**0**	**0**	**0**
Species richness (observed)		**4**	**0**	**2**	**0**	**0**	**3**	**3**	**1**	**0**	**0**	**2**	**3**	**4**	**1**	**0**	**4**	**2**	**0**	**0**	**0**
Species richness (heard)		**0**	**0**	**2**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**6**	**0**	**4**	**0**	**2**	**3**	**9**	**0**	**0**	**0**
Total species richness		**4**	**0**	**2**	**0**	**0**	**3**	**3**	**1**	**0**	**0**	**6**	**3**	**5**	**1**	**2**	**4**	**2**	**0**	**0**	**0**

^includes species recorded by call

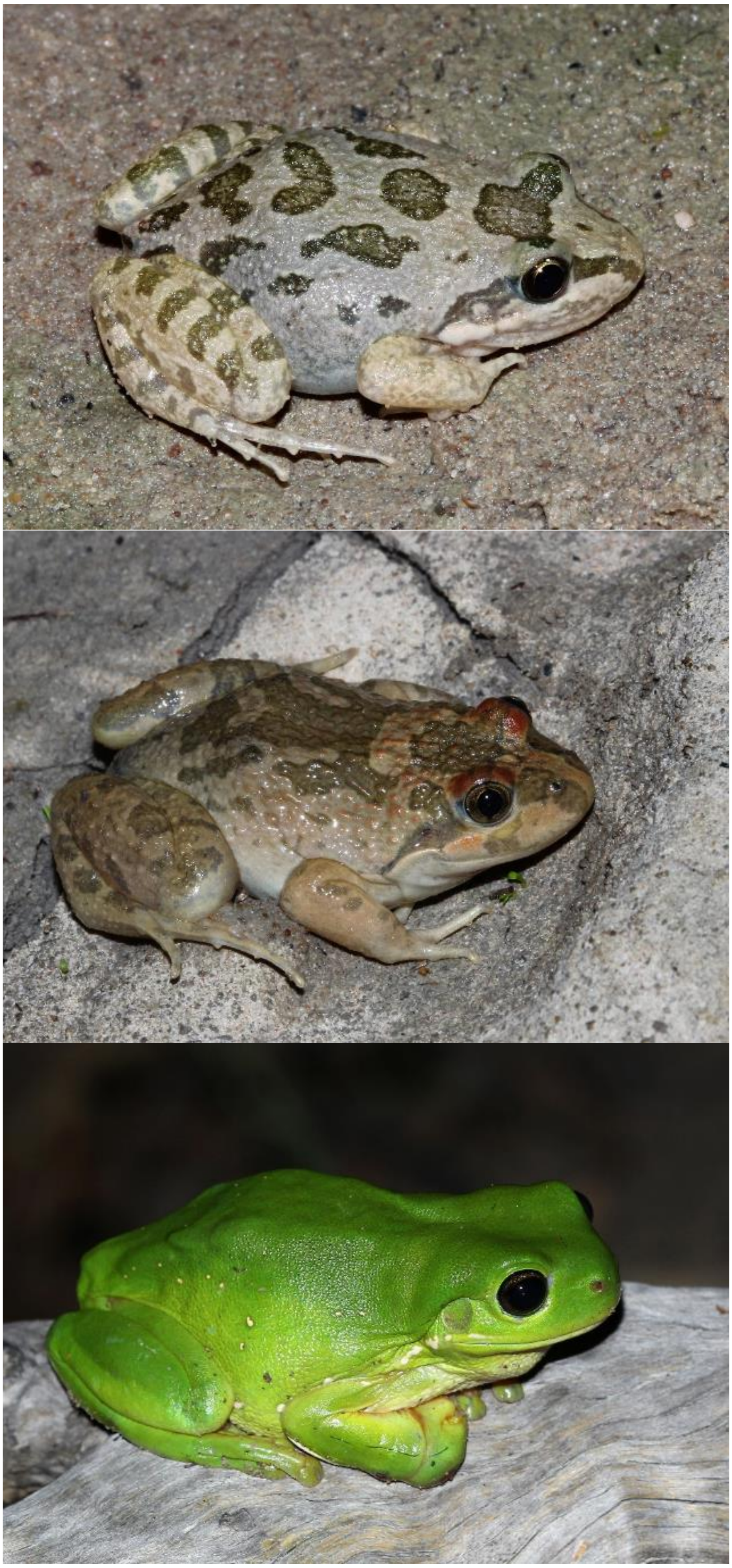


Figure L-4: Spotted marsh frog (*Limnodynastes tasmaniensis*; Top), barking marsh frog (*Limnodynastes fletcheri;* middle) and green tree frog (*Litoria caerulea;* bottom).

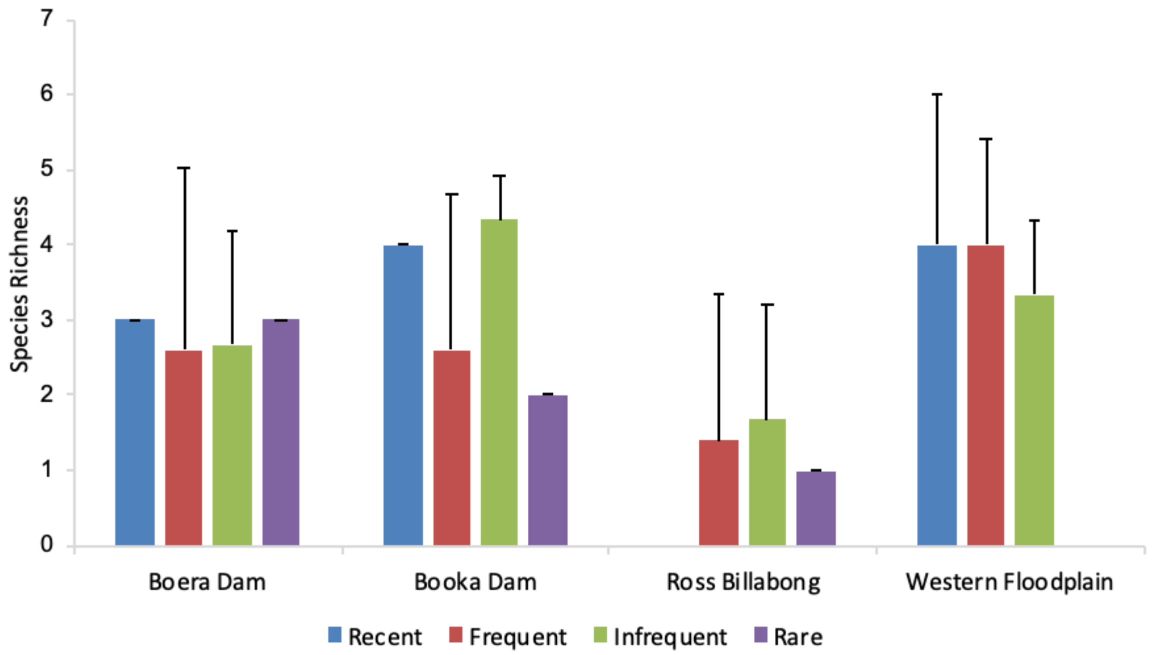


Figure L-5: Average frog species richness for each site per water connection category.

Booka Dam (30.70 ± 38.18 individuals/hr) had by far the highest average frog abundance (CPUE), followed by Western Floodplain (18.53 ± 31.31 individuals/hr), Boera Dam (8.97 ± 12.69 individuals/hr) and Ross Billabong (5.45 ± 8.95 individuals/hr; Figure L-6). Differences between Booka Dam and both Boera Dam ($p<0.005$) and Ross Billabong ($p<0.001$) were significant. Significant differences were also detected between sampling times ($p<0.001$) with November 2016 (44.96 ± 33.43 individuals/hr), and March 2017 (41.75 ± 61.31 individuals/hr) recording the highest average abundance scores of all survey periods during the project. High abundances during November 2016 were driven by observations of 88 barking marsh frogs/hr at the Western Floodplain site, and 31 spotted grass frogs/hr at Boera Dam. Similarly, during March 2017, high abundances of barking marsh frogs (71.5 individuals/hr and 18 individuals/hr observed at Booka and Boera Dams respectively) along with 39 green tree frogs/hr observed at Booka Dam contributed to the high overall frog abundances observed during this survey. No frogs were observed at any site during the August 2016 survey period, presumably due to the cold ambient temperatures limiting frog activity. Overall, Recent-connection conditions (21.38 ± 36.71 individuals/hr) recorded the highest average abundance scores, followed by Infrequent-connection conditions (20.21 ± 37.51 individuals/hr), Frequent-connection conditions (13.25 ± 15.86 individuals/hr) and Rare-connection conditions (8.10 ± 14.87 individuals/hr). Regression analysis detected a significant influence of time since connection, but due to low numbers of observations in some categories, all pairwise comparisons were non-significant.

Frog call data was not included in the abundance (CPUE) results above as the data of ‘heard’ frogs represents estimates only and as such cannot be relied upon for robust analysis. Despite this, frog call data collected during the LTIM project provides useful insights regarding frog activity in the Warrego-Darling Selected Area and the relationship with water connection. High abundances occurred on the Western Floodplain during Recent-connection conditions in February 2015, August 2016 and November 2016, as well as during Frequent-connection (52 days since connection) conditions in October 2015 (Figure L-6). This data shows that Western Floodplain inundation resulted in increased frog activity by providing high quality habitat for breeding.

Relatively high estimated abundance was indicated by frog calls at Boera Dam in August 2016 and Boera Dam and Booka Dam in November 2016. Both survey times fell into the Frequent-connection category (36 days and 27 days since connection for August 2016 and November 2016 respectively). These findings, along with the calling activity on the Western Floodplain, confirm the relationship between hydrological connection and frog activity within the Warrego-Darling Selected Area.

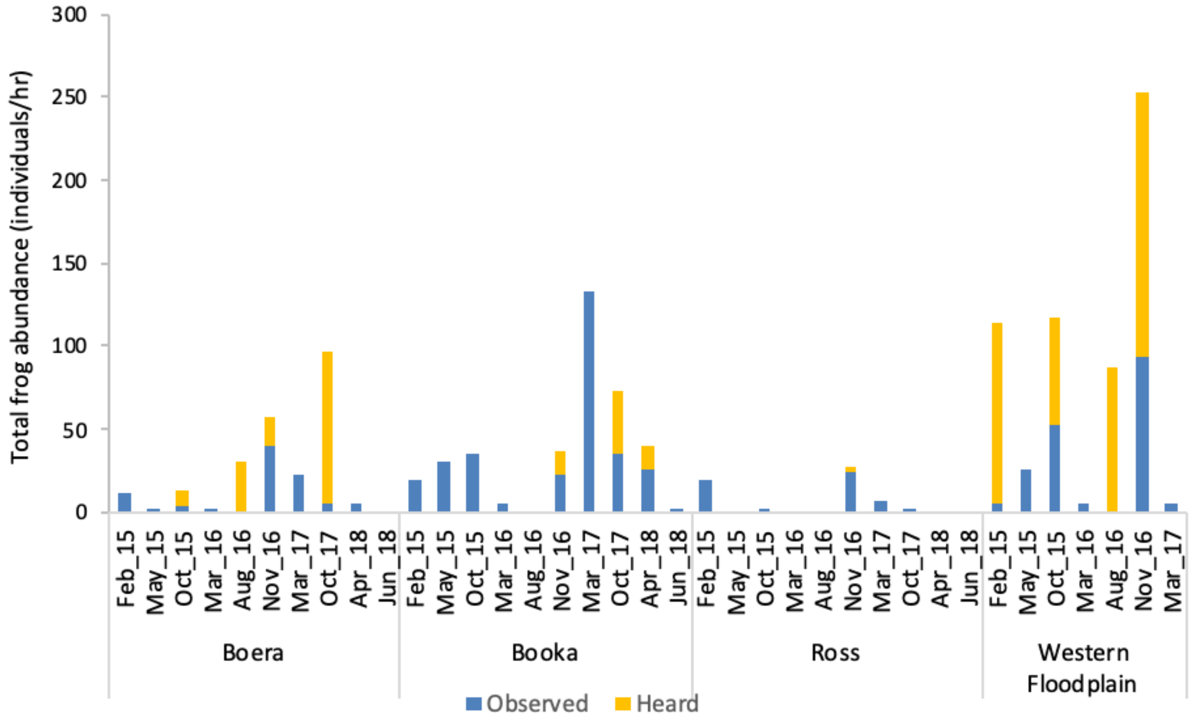


Figure L-6: Total abundance of frogs observed and heard in the surveys.

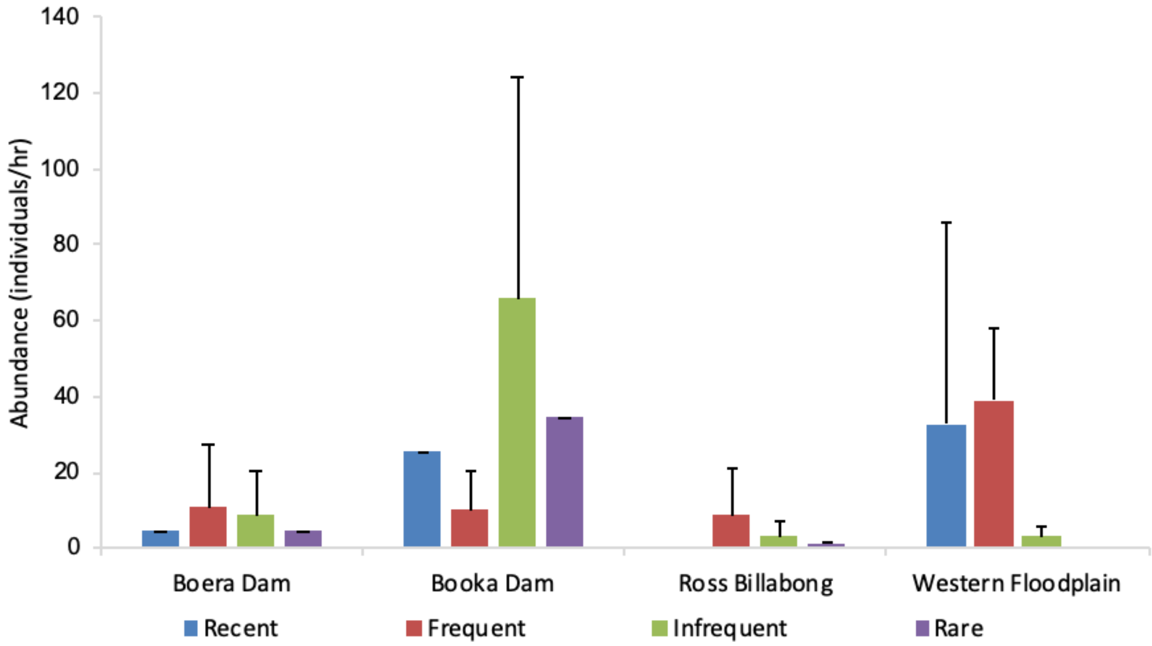


Figure L-7: Average abundance of frogs observed at each site per water connection category.

Booka Dam (0.78 ± 0.46) showed highest average diversity (H'), followed by Boera Dam (0.60 ± 0.5), Ross Billabong (0.41 ± 0.5) and the Western Floodplain (0.34 ± 0.39; Figure L-8), though these differences were not significant (p=0.3). Significant differences were detected between sampling times (p<0.05) with February 2015 (1.09 ± 0.31), and October 2015 (0.78 ± 0.59) having the highest average diversity of all survey periods during the project. February 2015 showed relatively high diversities at the Warrego River sites, while higher diversities were observed at Booka Dam and the Western Floodplain in October 2015 (Figure L-8). Overall, the highest average diversity was recorded under Frequent-connection conditions (0.67 ± 0.49), followed by Infrequent-connection conditions (0.48 ± 0.49) and Recent-connection conditions (0.48 ± 0.47), then Rare-connection conditions (0.21 ± 0.44; Figure L-9). Regression analysis suggested a significant influence of time since connection, but due to low numbers of observations in some categories, all pairwise comparisons were non-significant.

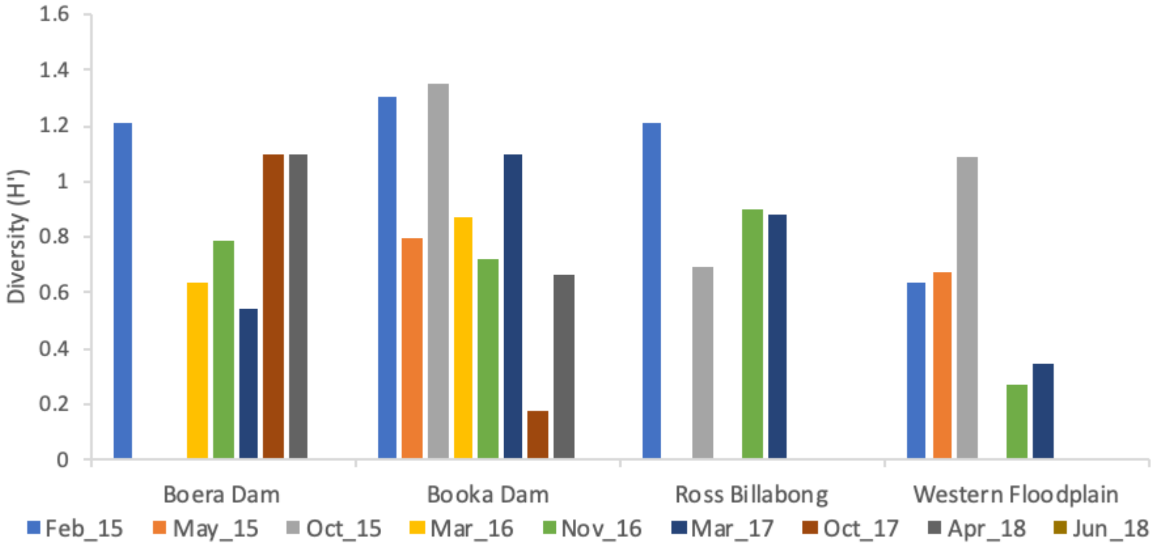


Figure L-8: Frog diversity (H') measured at each site over each sampling period.

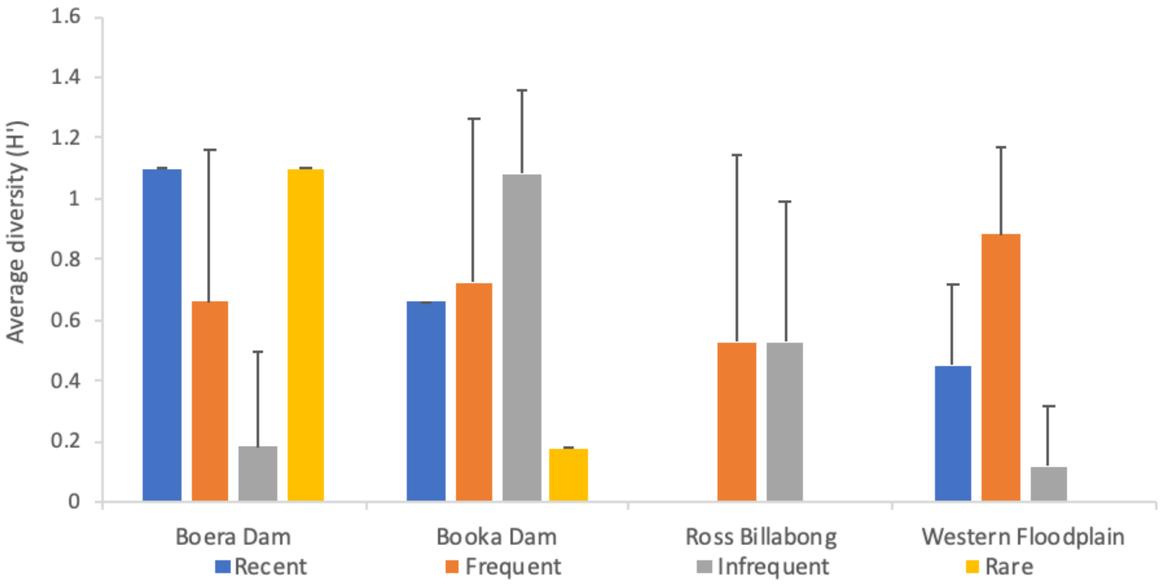


Figure L-9: Average diversity (H') pf frogs observed at each site per water connection category.

Community Composition

Multivariate analysis was undertaken on species abundance data (observed only) for all sampling periods. PERMANOVA tests identified a significant difference between sites (p=0.029) and between sampling periods (p=0.01), but no significant differences between inundation categories (p=0.275). The nMDS plot shows a greater spread of sites within October 2015, March 2016, October 2017 and April 2018 sampling periods (Figure L-10), suggesting sites at these times varied in their community composition. Pair-wise tests showed a significant difference between Boera Dam and Ross Billabong (p=0.048; Table L-5). SIMPER results suggest the spotted marsh frog and barking marsh frog contributed the most to the Boera Dam grouping, while the green tree frog, barking marsh frog and Peron’s tree frog contributed the most to the Booka Dam grouping (Table L-6). Significant differences were also noted between February 2015 and May 2015 (p=0.023), November 2016 (p=0.033) and March 2017 (p=0.019) (Table L-7). Here, desert froglet and the desert tree frog were most associated with the February 2015 grouping, while the spotted marsh frog was most associated with the May 2015 grouping (Table L-8). November 2016 and March 2017 had the highest abundances of any time period, with the barking marsh frog, green tree frog and salmon stripped frog contributing to the November 2016 grouping and the barking frog, spotted marsh frog and Peron’s tree frog contributing to the March 2017 grouping (Table L-8).

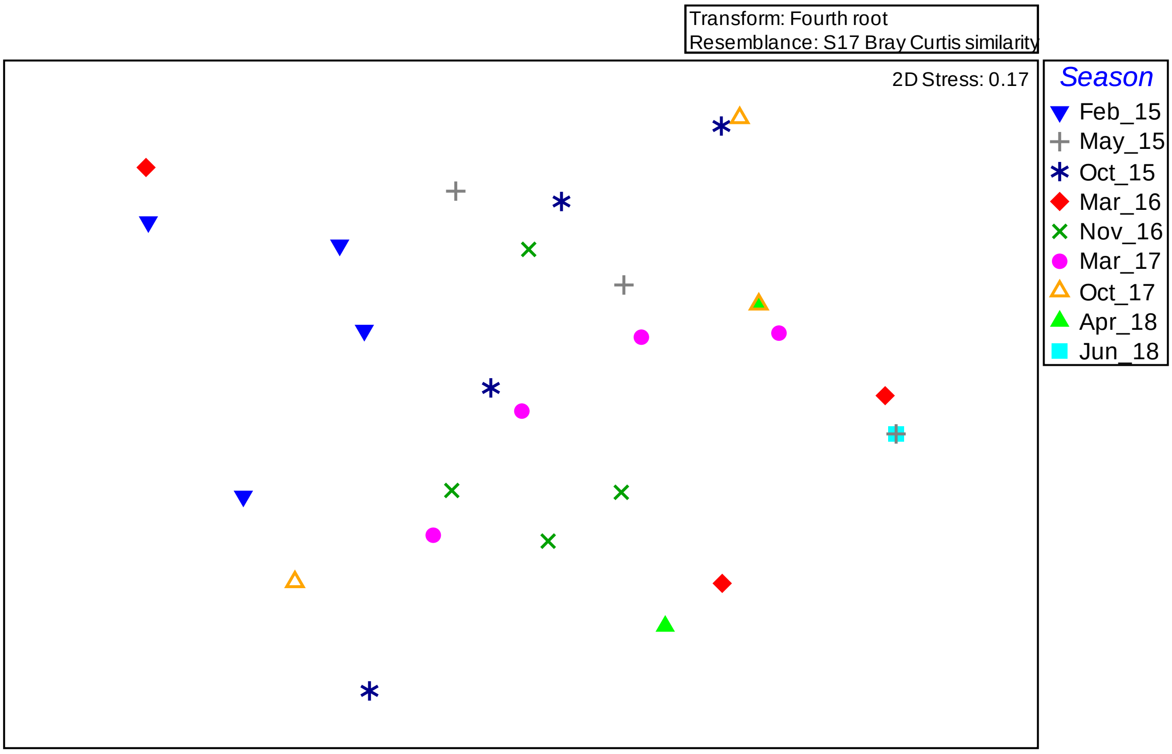
Table L-5: Pairwise tests that resulted in a significant difference in terms of monitoring sites.

Site	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain
Boera Dam		0.059	**0.048**	0.86
Booka Dam			0.206	0.401
Ross Billabong				0.112
Western Floodplain				

Bold text indicates a significant result.

Table L-6: SIMPER results of species contributions to groupings for each monitoring site. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Boera Dam	Spotted Marsh Frog	48.82
	Barking Marsh Frog	44.30
Booka Dam	Green Tree Frog	35.53
	Spotted Marsh Frog	29.48
	Desert Tree Frog	11.55
	Desert Froglet	11.33
Ross Billabong	Green Tree Frog	49.59
	Barking Marsh Frog	25.61
	Peron’s Tree Frog	24.80
Western Floodplain	Spotted Marsh Frog	52.49
	Barking Marsh Frog	31.47
	Desert Tree Frog	16.04



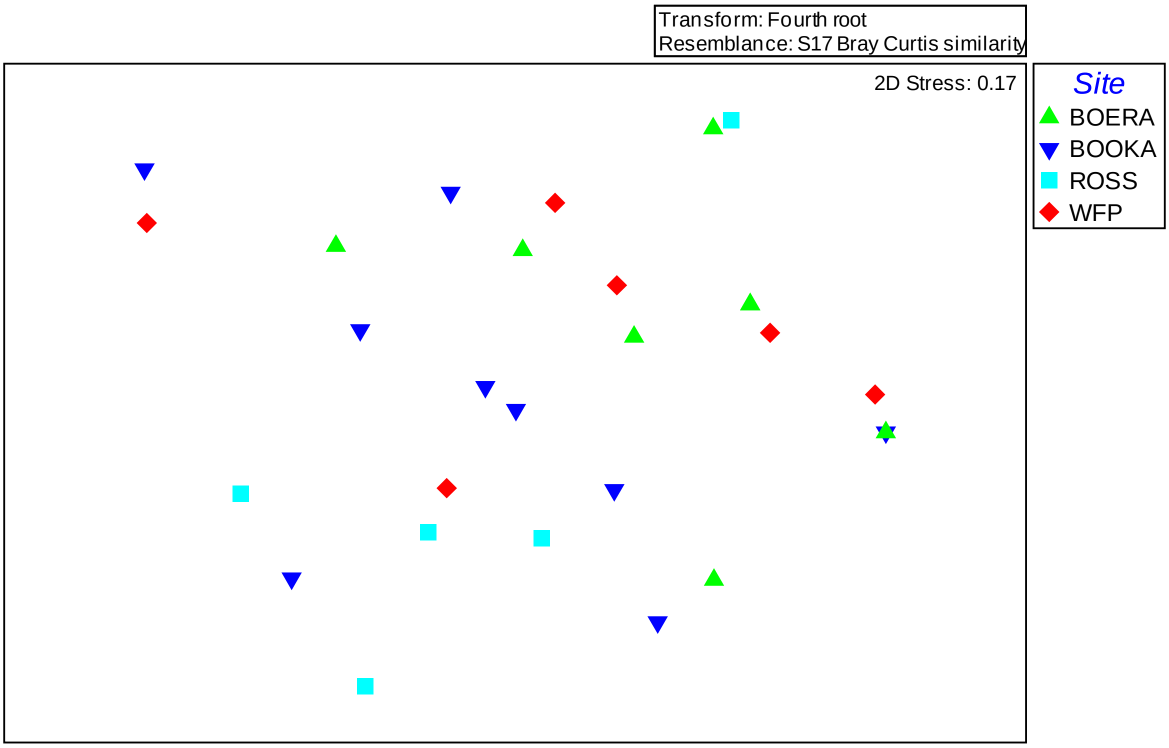


Figure L-10: nMDS plot of frog species abundance data from 2014-2019 grouped by season (top) and site (bottom).

Table L-7: Pairwise tests that resulted in a significant difference in terms of sampling times. Bold text indicates a significant result. Note: no frogs were observed in August 2016.

	Feb_15	May_15	Oct_15	Mar_16	Nov_16	Mar_17	Oct_17	Apr_18	Jun_18
Feb_15		**0.033**	0.183	0.111	**0.019**	**0.023**	0.14	0.073	0.2
May_15			0.203	0.912	0.08	0.336	0.4	0.193	1
Oct_15				0.327	0.507	0.732	0.837	0.333	0.431
Mar_16					0.097	0.213	0.484	0.608	1
Nov_16						0.517	0.66	0.071	0.198
Mar_17							0.653	0.19	0.392
Oct_17								0.685	0.733
Apr_18									0.35

Table L-8: SIMPER results of species contributions to groupings for each survey period. Species contributions of less than 10% were not included. Note: no frogs were observed in August 2016.

Grouping	Species	Contribution to grouping (%)
February 2015	Desert froglet	49.00
	Desert tree frog	31.27
May 2015	Spotted marsh frog	100.00
October 2015	Barking marsh frog	47.14
	Spotted marsh frog	16.01
	Desert tree frog	12.44
	Green tree frog	12.20
	Peron’s tree frog	12.20
March 2016	Spotted marsh frog	100.00
November 2016	Barking marsh frog	46.27
	Green tree frog	28.30
	Salmon striped frog	19.31
March 2017	Barking marsh frog	51.02
	Spotted marsh frog	33.02
	Peron’s tree frog	8.08
October 2017	Barking marsh frog	100.00
April 2018	New holland frog	50.00
	Spotted marsh frog	50.00

L.4 Discussion

Frog species richness, abundance and diversity all varied significantly over time, between sites, and with varying levels of hydrological connection within the Warrego-Darling Selected Area. In all cases, rarely connected sites displayed the lowest average results for each measure, highlighting the importance of hydrological connection to the frog communities in the Warrego-Darling Selected Area. Species richness and abundance were significantly high during times of recent connection and inundation on the floodplain, when access to habitats including emergent aquatic and littoral zone terrestrial vegetation were at their highest. Similarly, Booka Dam consistently had the highest frog richness, abundance and diversity of all survey sites, which is likely a response of the increased fringing habitat such as Lignum, and its longer persistence in the landscape.

Frog species richness peaked during November 2015 and November 2016, following periods where Warrego River sites were connected in late spring, and the Western Floodplain was inundated. On both occasions, Commonwealth environmental water or its management contributed to this connection and inundation (Appendix BC). Frog calling, indicative of frog activity was also highest on the Western Floodplain during these periods, with frogs taking advantage of the increased availability of optimal habitat and breeding conditions, such as shallow, slow moving waters, a high abundance of food and refuge from predators in the aquatic vegetation (Wassens and Maher 2011, Wassens *et al.* 2008, MacNally *et al.* 2009, Healey *et al.* 1997). Total frog abundance also peaked in the two sampling periods following the most substantial connection event through the Warrego-Darling Selected Area (November 2016 and March 2017). These events included 61% and 74% Commonwealth environmental water on the Western Floodplain and Warrego River respectively (Appendix C). These peaks were driven by increases in the abundance of barking frogs, spotted grass frogs and green and Peron's tree frogs at both floodplain and river sites (Figure L-11).

Figure L-11: A knot of Peron's tree frogs observed on the Western Floodplain during the November 2016 survey.

Along with inundation, temperature variations between sampling times likely influenced the results, with higher abundances and calling occurring in the warmer summer months. No frogs were recorded during the August 2016 survey and only one spotted grass frog was observed at Booka Dam during the June 2018 survey.

The influence of system wetting and drying on frog communities differed between sites on the Warrego River and the Western Floodplain. The Warrego River sites, being more permanent water bodies, host a more consistent frog community, as evidenced by the lower standard deviation for both average abundance and species richness. In contrast, frog populations on the Western Floodplain respond more immediately and dramatically to inundation and subsequent drying. This pattern sees higher frog abundance and species diversity during wet conditions, contrasted with few frogs during dry conditions (explaining the relatively high standard deviation, Figure L-12). This highlights the dynamic nature of systems such as those found in the Warrego-Darling Selected Area, which produce large booms of productivity when their floodplains become inundated. It also shows the importance of maintaining water in the channel sites to preserve frog populations in the long term. Managing Commonwealth environmental water to inundate the Western Floodplain and maintain more stable habitats in the Warrego River channel will assist in maintaining a diverse and healthy frog population in the Warrego-Darling Selected Area. A healthy frog population will in turn support higher level predators such as fish, birds and reptiles.

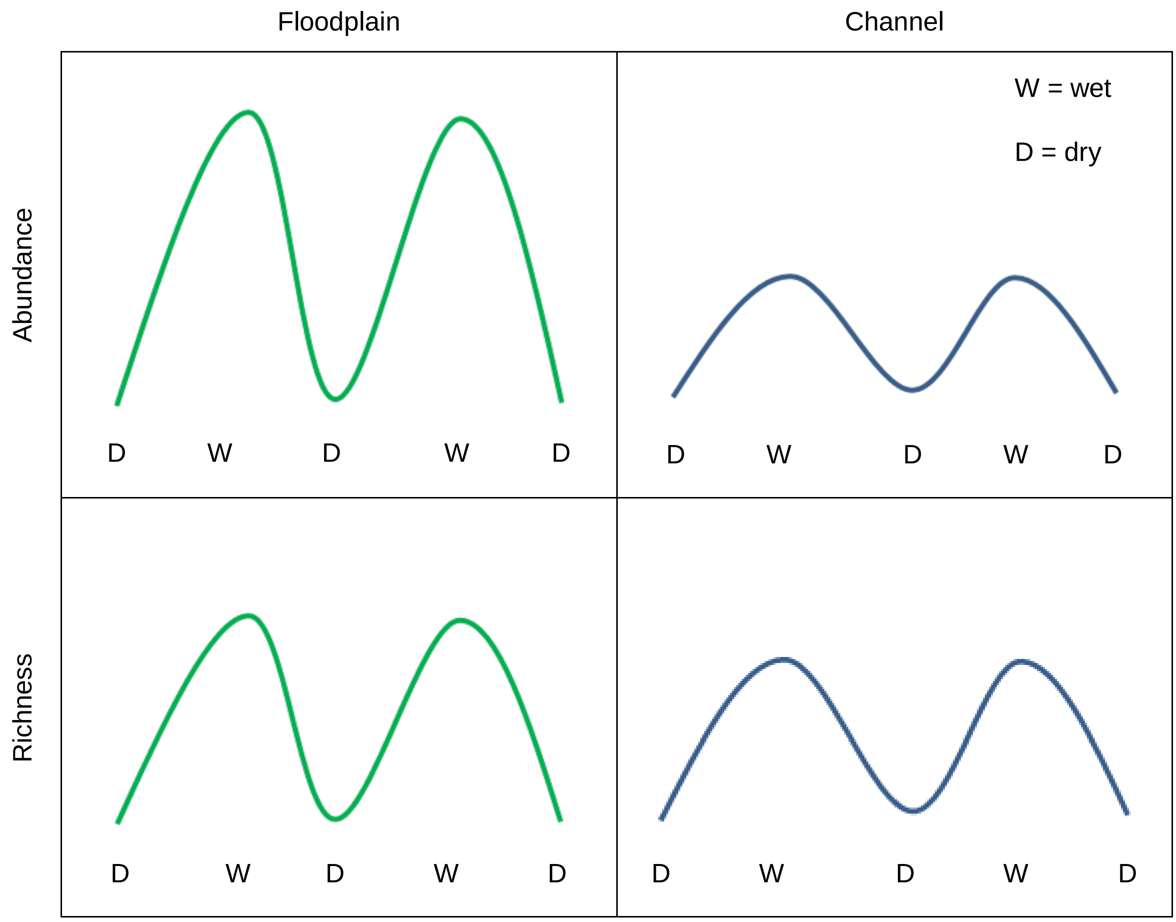


Figure L-12: Conceptual model of the relationship between frog abundance/richness and wet/dry periods.

L.5 Conclusion

Patterns of abundance and richness in the frog communities of the Warrego-Darling Selected Area reflect the availability and type of habitat and seasonal conditions. Both frog abundance and species richness in the Warrego-Darling Selected Area are positively associated with hydrological connection, with the greatest responses over the project driven by connection events influenced by Commonwealth environmental water or its management. During and shortly after the Western Floodplain was inundated, frog abundance and richness increased due to the newly available, highly productive temporary habitat capable of supporting breeding and larger frog populations. The more permanent sites in the Warrego River appear to offer more stable habitat for local frog populations, which also show an overall increased response to water connection. These responses highlight the importance of maintaining a mosaic of habitat types through environmental watering of the Warrego-Darling Selected Area to support regional scale frog diversity.

L.6 References

Commonwealth of Australia. 2014. *Commonwealth Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area*.

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Wassens, S. Watts, R. J., Jansen, A. and Roshier, D. 2008. Movement patterns of southern bell frogs (*Litoria raniformis*) in response to flooding. *Wildlife Research* **35,** 50-58

Appendix M Waterbird Diversity

M.1 Introduction

The Warrego River and its associated wetlands, including the Western Floodplain, support high conservation value biodiversity and are likely to provide refugia for waterbirds at a regional scale during dry periods (Capon, 2009). Little is known of the waterbird communities within the Junction of the Warrego and Darling Rivers Selected Area (Warrego-Darling Selected Area), however, ongoing waterbird monitoring conducted as part of the LTIM Project is helping to build an understanding of how waterbirds respond to environmental watering in this system. Waterbird monitoring conducted during 2018-19 represents the final seasonal monitoring for the LTIM Project. As such, this report summarises the results of the 5-year LTIM Project.

The monitoring of waterbird diversity in the Warrego-Darling Selected Area sought to address the following questions:

- What did Commonwealth environmental water contribute to waterbird populations?
- What did Commonwealth environmental water contribute to waterbird species diversity?
- What did Commonwealth environmental water contribute to waterbird survival?

M.1.1 Environmental watering during the LTIM Project (waterbird survey periods)

Unlike other Selected Areas, most environmental water is not specifically delivered to the Warrego-Darling Selected Area, rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. Flows down the Warrego River in the Warrego-Darling Selected Area have been sporadic over the LTIM Project (Figure M-1). In response to inflows, the regulating gates at Boera Dam were opened several times in 2015-16 and flows refilled waterholes and connected to the Darling River. The small flow event in January to March 2016 contained 4% environmental water from upstream, but no environmental water was accounted for in the Warrego River or Western Floodplain during 2015-16. In contrast, during 2016-17, larger Warrego River inflows resulted in 9,770 ML of environmental water flowing onto the Western Floodplain, and 7,770 ML of environmental water flowing down the Warrego River through the Warrego-Darling Selected Area between June 2016 and February 2017.

Flows in the Warrego River during the 2017-18 water year were very low, with water entering the Warrego-Darling Selected Area during four small flow events in October 2017, December 2017, March and April 2018, and in June 2018. Commonwealth environmental water made up 17.3% of the flow event during March and April 2018. Water levels in Boera Dam remained below the Western Floodplain connection level for most of the year with only one brief period of connection to the floodplain observed in December 2017 (Figure M-1). During the flow event in March and April 2018, the Boera Dam regulating gates were partially opened for a total of 16 days, though flows were restricted to 300 ML/d or less in response to Boera Dam inflows. This event reconnected the waterholes in the lower Warrego system and provided connection through to the Darling River.

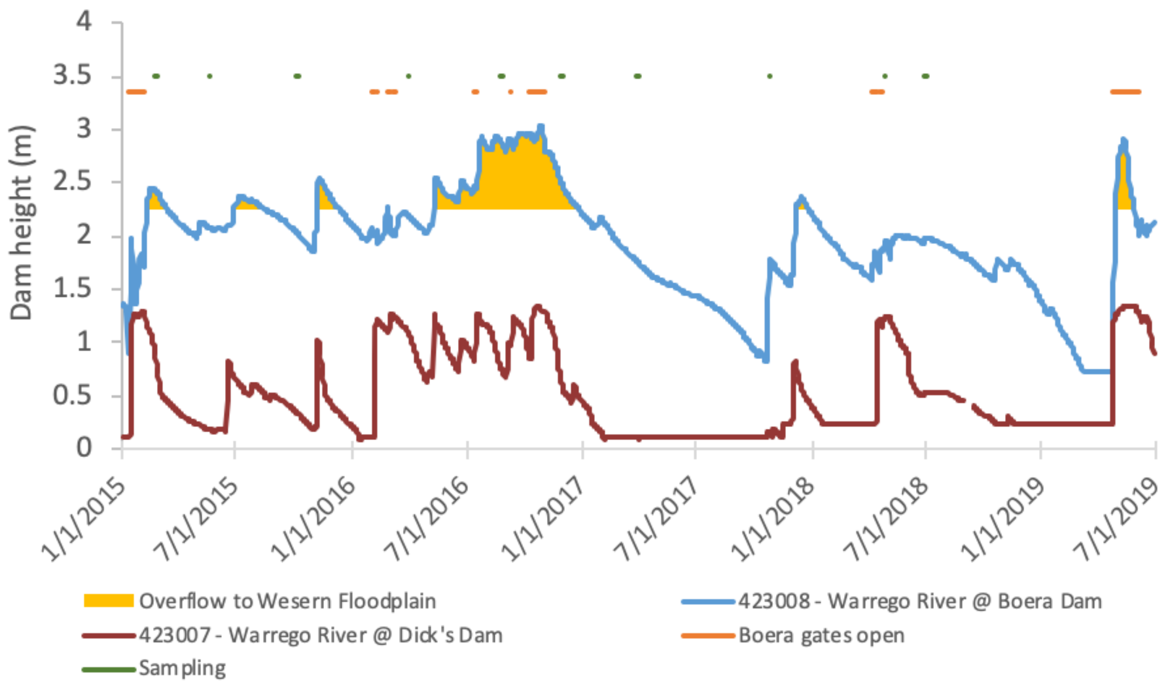

Figure M-1: Gauge heights in Boera and Dick's Dams and periods of connection down the lower Warrego Channel in 2015-2018. Sampling dates, overflow to Western floodplain and dates of Boera gates being opened are shown.

M.2 Methods

Three sites on the Warrego River (Boera Dam, Booka Dam and Ross Billabong) were surveyed 10 times for waterbirds between February 2015 and June 2018 (Table M-1). One site on the Western Floodplain was monitored eight times, having been excluded from monitoring in March 2016 and April 2018 due to the prevailing dry conditions. The four monitoring sites within the Warrego-Darling Selected Area have remained consistent across the entire monitoring period (Table M-2; Figure M-2). Ground-based observational surveys were undertaken for a minimum of 20 minutes and maximum of one hour at each survey point, conducted no more than 4 hours after sunrise and/or four hours before sunset, which resulted in a representative bird count for each site (Commonwealth of Australia 2015).

Surveys were conducted from one or more points per site to cover the largest possible area. Where multiple points were surveyed for a single site, these were, as far as possible, out of sight from each other and focussed on different sections of the site. All bird species seen and heard and identified at each survey point were recorded.

Species richness, density and diversity data were analysed using Poisson regression analysis to investigate the influence of site (Booka, Boera, Ross, Floodplain), sampling period (10 periods; Table M-1), and time since water connection. Time since water connection was calculated differently for the river and floodplain sites. For river sites, time since connection was calculated as the number of days between when the Boera Dam gates were shut, and the first day of sampling. Time since connection for the floodplain was calculated as the number of days between when levels in Boera Dam fell below the connection level to the Western Floodplain and the first day of sampling. Sites that were connected at the time of sampling were given a value of 0 days. The time since connection factor was applied in the modelling in two ways: as a continuous variable, and as a categorical variable with 4 levels.

These categories are outlined below:

- Recent-connection – 0 to 4 days since site was last connected (5 observations);
- Frequent-connection – 4 to 69 days since site was last connected (16 observations);
- Infrequent-connection – 69 to 303 days since site was last connected (12 observations); and
- Rare-connection – 303 to 550 days since site was last connected (6 observations).

Non-metric multidimensional scaling (nMDS) analyses was used to describe patterns of community composition for site, sampling period and connection category. Fourth-root transformation was applied to density data prior to the calculation of resemblance matrices using Bray-Curtis similarities in PRIMER Version 6.1.13 (http://www.primer-e.com/). Sites with no observations were removed from the analysis. PEMANOVA tests were then performed to compare between survey period and site type. SIMPER tests were performed to assess the dominant species associated with each data grouping.

Waterbird diversity was calculated in PRIMER using the Shannon Diversity Index (H') with natural logarithm (to the base *e*). In this index, a higher value indicates a higher diversity.

Table M-1: Timing of the 10 sampling occasions for waterbird diversity over the project.

Sampling occasion	Dates
February 2015	23 – 27 February 2015
May 2015	4 – 8 May 2015
October 2015	7 – 10 October 2015
March 2016	29 March – 2 April 2016
August 2016	23 – 26 August 2016
November 2016	29 November – 2 December 2016
March 2017	27 – 30 March 2017
October 2017	24 – 27 October 2017
April 2018	25 – 28 April 2018
June 2018	29 June – 2 July 2018

Table M-2: Location of waterbird monitoring sites. All coordinates reported in GDA94 zone 55.

Monitoring Zone	Site Name	Site Type	Easting	Northing
Warrego River	Ross Billabong	Channel	347242	6636926
	Booka Dam	Channel	349835	6658024
	Boera Dam	Channel	348720	6669094
Western Floodplain	Western Floodplain	Floodplain	347802	6665756

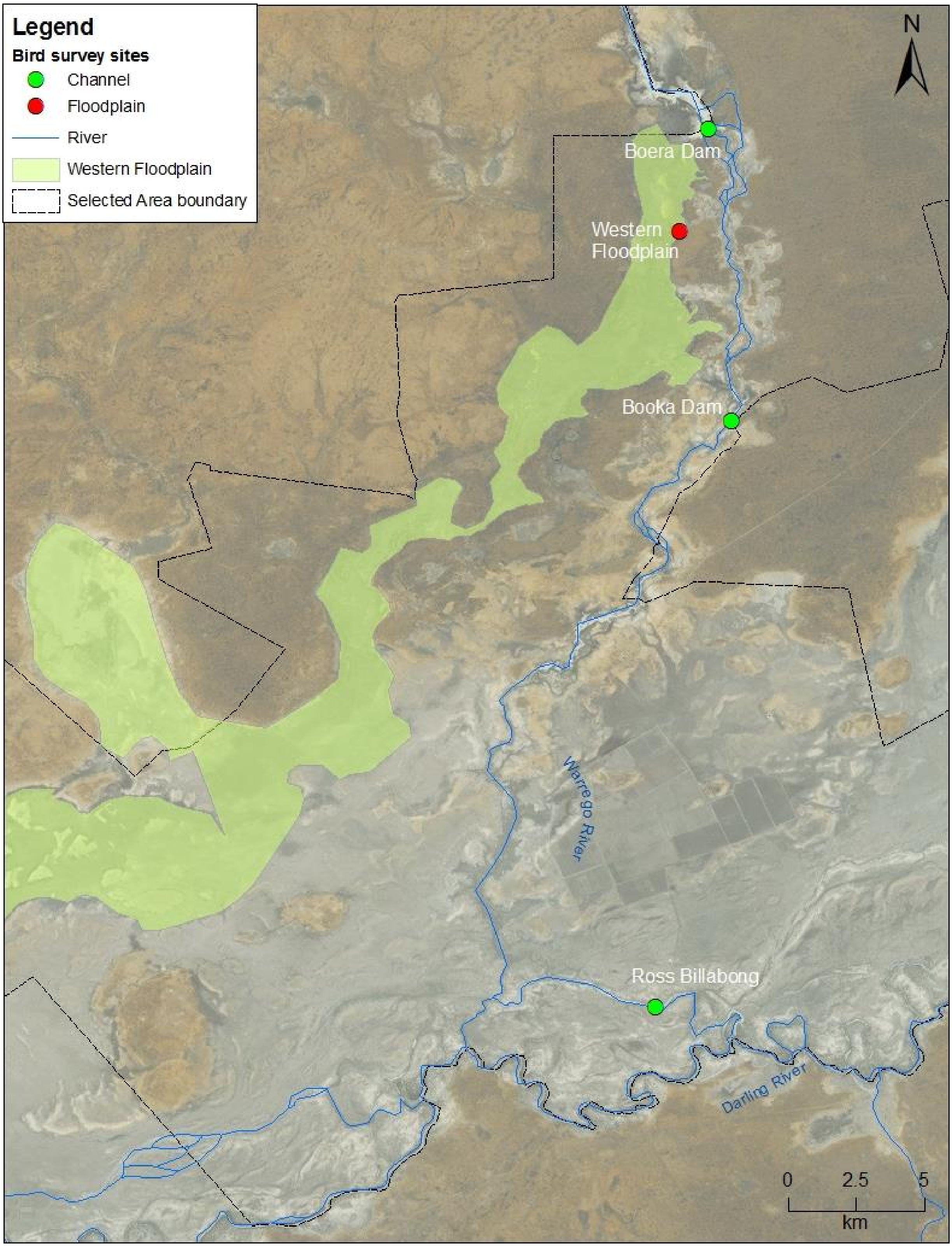

Figure M-2: Location of waterbird diversity monitoring sites within the Warrego-Darling Selected Area.

M.3 Results

M.3.1 **Waterbird species richness, density and diversity**

A total of 2,878 individual waterbirds from 57 species were recorded during the project at sites in the Warrego River and Western Floodplain (Table M-3). Across all years the grey teal (*Anas gracilis*) was by far the most abundant waterbird species with 1,013 individuals across all four sites. Australian wood duck (*Chenonetta jubata*) and Pacific black duck (*Anas superciliosa*) were the next-most abundant species with 242 and 195 individuals respectively, across all four sites. Throughout the 5-year survey period, a total of thirteen (13) species were recorded at all four monitoring sites (Table M-3).

Three species listed under international migratory bird agreements were recorded during the survey period, namely eastern great egret (*Ardea modesta* – CAMBA, JAMBA), common sandpiper (*Actitis hypoleucos* – CAMBA, JAMBA, ROKAMBA) and wood sandpiper (*Tringa glareola* – CAMBA, JAMBA, ROKAMBA). The common sandpiper and wood sandpiper are also listed as migratory species under the *Environment Protection Biodiversity Conservation Act* 1999 (EPBC Act), along with glossy ibis (*Plegadis falcinellus*) which was also recorded during the survey period. Additionally, freckled duck (*Stictonetta naevosa*), brolga (*Grus rubicunda*) and white-bellied sea-eagle (*Haliaeetus leucogaster*), which are listed as vulnerable under the NSW *Biodiversity Conservation Act 2016* (BC Act) were also recorded (Table M-3; Figure M-3). All seven listed species occurred at Boera Dam, whilst brolga and eastern great egret occurred at Western Floodplain, eastern great egret occurred at Booka Dam and white-bellied sea-eagle occurred at Ross Billabong.

Table M-3: Total counts and percent occurrence (across sites) of the 57 waterbird species recorded in the Warrego-Darling Selected Area during the project.

Functional Group	Common Name	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain	Occurrence (%)
Australian-breeding Charadriiform shorebirds	Black-fronted dotterel	34	36	44	18	100
	Black-winged stilt	17				25
	Masked lapwing	31	2	12	10	100
	Red-capped plover	12				25
	Red-kneed dotterel	20	2	3		75
	Red-necked avocet	9				25
Dabbling and filter-feeding ducks	Australasian shoveler	2		6	1	25
	Chestnut teal				1	25
	Freckled duck ^{v}	3				25
	Grey teal	687	24	216	86	100
	Pacific black duck	149	18	11	17	100
	Pink-eared duck	116	2	21	42	100
Diving ducks, aquatic gallinules and swans	Black swan	13	3	9		75
	Dusky moorhen	1			8	50
	Eurasian coot	16	2	6	30	100
	Hardhead	49	1		39	75

Functional Group	Common Name	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain	Occurrence (%)
	Hoary-headed grebe	13			2	50
Grazing ducks and geese	Australian shelduck			4		25
	Australian wood duck	125	56	46	15	100
	Plumed whistling-duck		21	78		50
Large wading birds	Australian white ibis	10		2	9	75
	Brolga [V]	2			4	50
	Glossy ibis [M]	32				25
	Royal spoonbill	6				25
	Straw-necked Ibis	1	29	42	20	100
	Yellow-billed spoonbill	13	4	4		75
Migratory Charadriiform shorebirds	Common sandpiper [MCJR]	1				25
	Wood sandpiper [MCJR]	1				25
Piscivores	Australasian darter	36	1	4		75
	Australasian grebe			11	18	50
	Australian pelican	43	14	105		75
	Eastern great egret [Cj]	4	2		1	75
	Great cormorant	3	1	4		75
	Great crested grebe			5		25
	Intermediate egret				1	25
	Little black cormorant	2	3	8	1	100
	Little pied cormorant	1	1		1	75
	Nankeen night-heron	2				25
	Pied cormorant	8	4	14	1	100
	Whiskered tern	13		1		50
	White-faced heron	8	6	8	7	100
	White-necked heron	1	14	6	4	100
Rails and shoreline gallinules	Black-tailed native-hen	55	5			50
	Purple swamphen				1	25
	Spotless crake				1	25
Raptors	Australian hobby			1		25
	Black kite	1		2		50
	Brown falcon	1				25
	Brown goshawk	1				25

Functional Group	Common Name	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain	Occurrence (%)
	Collared sparrowhawk		2		2	50
	Nankeen kestrel			6	2	50
	Wedge-tailed eagle	2		2	5	75
	Whistling kite	15	8	6	9	100
	White-bellied sea-eagle[V]	3		2		50
Reed-inhabiting passerines	Australian reed warbler				6	25
	Golden-headed cisticola				1	25
	Little grassbird				3	25

[C]= listed under CAMBA; [J]= listed under JAMBA; [R]= listed under ROKAMBA; [V]=Vulnerable (BC Act); [M]= Migratory (EPBC Act)

Figure M-3: Brolga (top) and white-bellied sea-eagle (bottom) observed in the Warrego-Darling Selected Area.

Boera Dam had the highest average species richness (11.9 ± 6.2 species), followed by Ross Billabong (8.9 ± 5.2 species), Western Floodplain (6.6 ± 6.5 species) and Booka Dam (6.0 ± 3.3 species; Figure M-4). These differences were significant ($p<0.005$), with Boera Dam having significantly higher richness than both the Western Floodplain ($P<0.01$) and Booka Dam ($p<0.01$), but not Ross Billabong ($p=0.098$). The influence of sampling time was also significant with February 2015 (14.3 ± 4.5 species) showing the greatest richness, followed by November 2016 (14.0 ± 3.8; Figure M-4). Both February 2015 and November 2016 survey periods fell in the same water connection categories with Frequent-connection conditions occurring at the Warrego River sites and Recent-connection conditions occurring at the Western Floodplain. Overall, sites that were frequently connected (9.2 ± 5.0 species) showed significantly higher richness than rarely connected sites (3.5 ± 3.1 species), with infrequently connected (9.0 ± 6.8 species) and recently connected (8.7 ± 6.3 species) sites showing intermediate richness (Figure A-4).

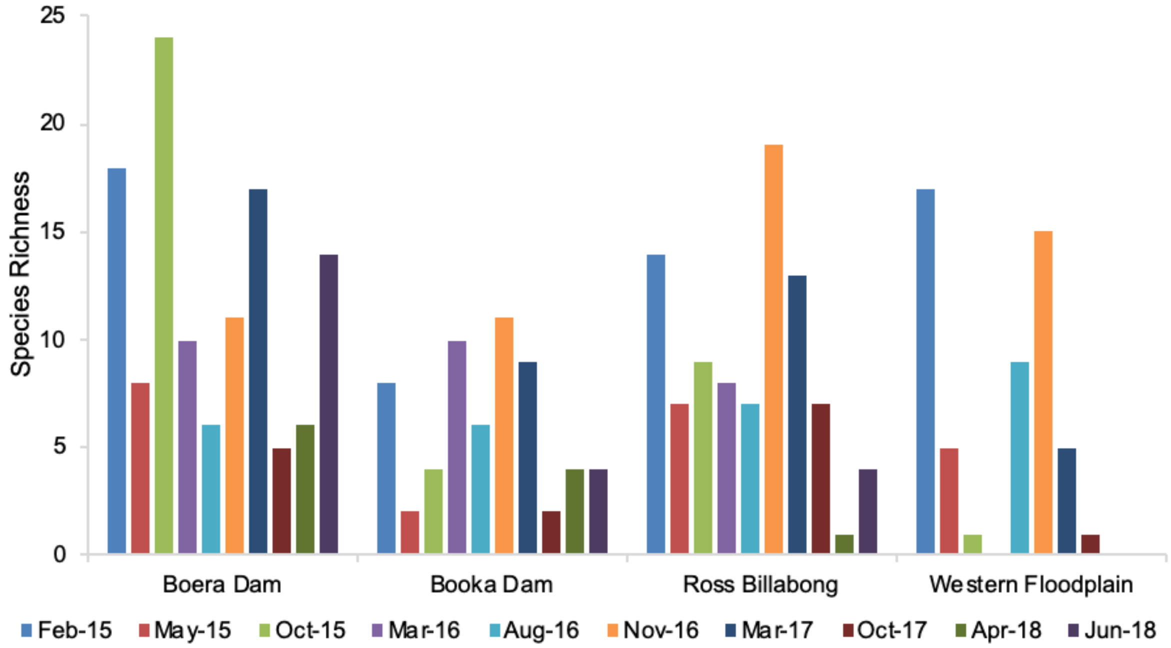

Figure M-4: Species richness for each site and sampling period for the 2014-19 monitoring period.

Similarly, Boera Dam had the highest average waterbird density (4.9 ± 5.3 birds/ha), followed by Booka Dam (2.0 ± 1.7 birds/ha), Ross Billabong (1.4 ± 1.4 birds/ha) and Western Floodplain (0.4 ± 0.5 birds/ha) (Figure A-5). These differences were significant ($p<0.001$), with Boera Dam having higher density than both the Western Floodplain ($p<0.001$) and Ross Billabong ($p<0.001$). Waterbird density also varied significantly over time ($p<0.005$) with February 2015 (5.0 ± 4.9 birds/ha) and October 2015 (4.6 ± 7.6 birds/ha) recording the highest average density across all survey periods (Figure A-5). During both surveys, these higher densities were driven by large flocks of grey teal observed at Boera Dam of 171 and 275 individuals in February 2015 and October 2015 respectively. The temporal availability of water and the size of monitoring sites are likely to influence these results, with the Western Floodplain being only periodically inundated and covering a much larger area (193 ha) than the Warrego River sites (13 ha to 40 ha). Overall, frequently connected (3.2 ± 2.9 birds/ha) sites showed significantly higher average species richness than both recently connected (0.5 ± 0.4 birds/ha; $p<0.005$) and rarely connected (0.4 ± 0.5 birds/ha; $p<0.01$) sites. Infrequently connected sites (2.5 ± 4.6 birds/ha) showed an intermediate average waterbird density (Figure A-6).

Boera Dam (1.6 ± 0.2) and Booka Dam (1.4 ± 0.5) had significantly higher Shannon diversity than both Ross Billabong (1.3 ± 0.6; $P<0.05$) and the Western Floodplain (1.1 ± 1.0; $p<0.001$). Shannon diversity measures also varied significantly over time ($p<0.05$) with November 2016 (2.1 ± 0.2), February 2015 (1.7 ± 0.2) and March 2017 (1.7 ± 0.4) recorded the highest average scores across all survey periods (Figure A-7). As noted above, February 2015 and November 2016 surveys occurred under similar water connection conditions, whilst March 2017 surveys were undertaken during Infrequent-connection conditions at all four monitoring sites. Overall, Rarely connected sites (0.7 ± 0.6) had significantly lower diversity than Recently connected (1.5 ± 0.8; $p<0.001$), Frequently connected (1.4 ± 0.5; $p<0.001$) and Infrequently connected (1.4 ± 0.6; $p<0.001$) sites (Figure A-8). These results suggest a positive correlation between waterbird diversity and water connection.

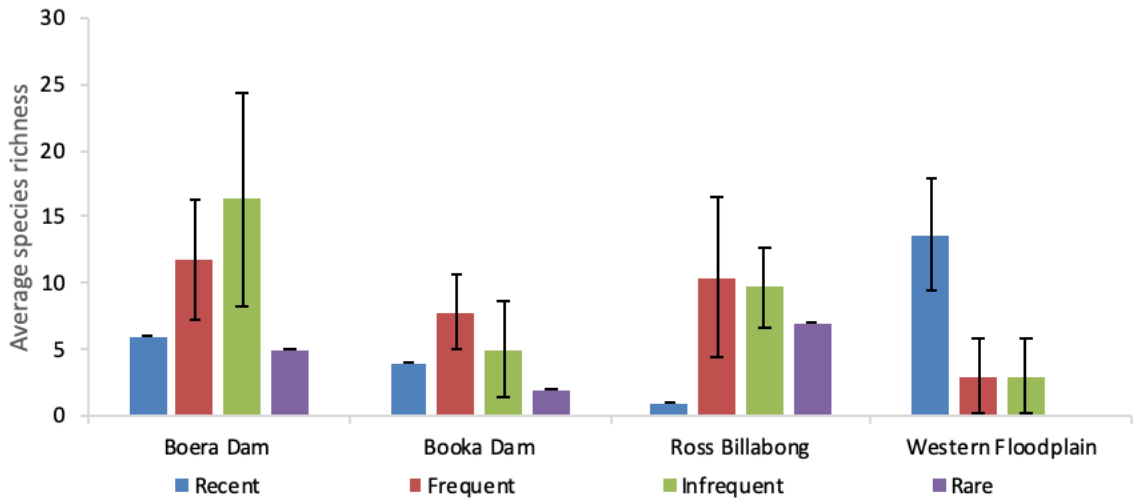

Figure M-5: Average species richness for each site under each water connection category.

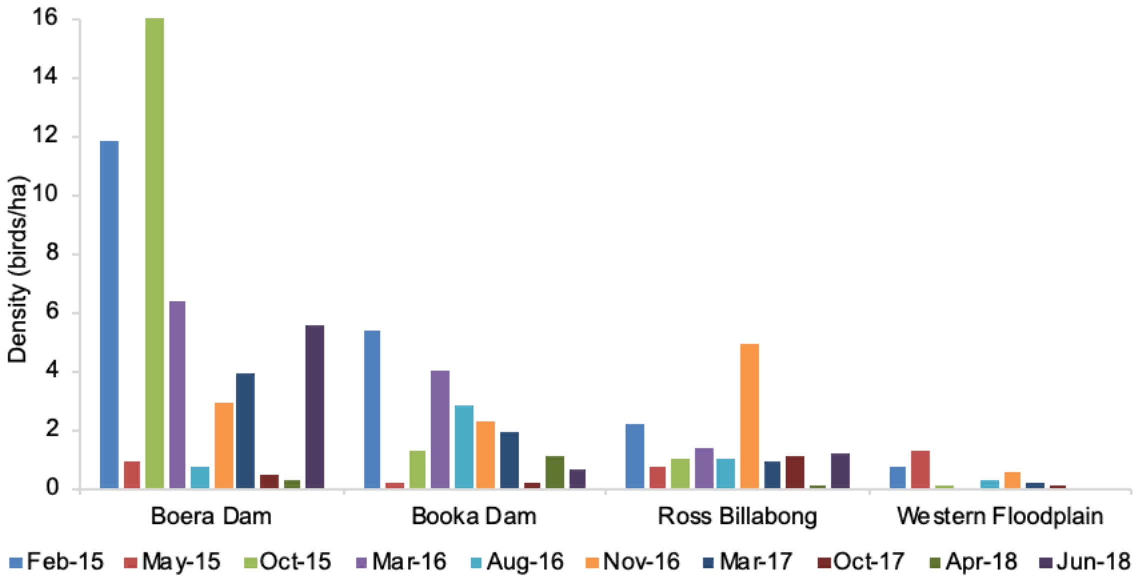

Figure M-6: Waterbird density (individuals per hectare) for each site and sampling period.

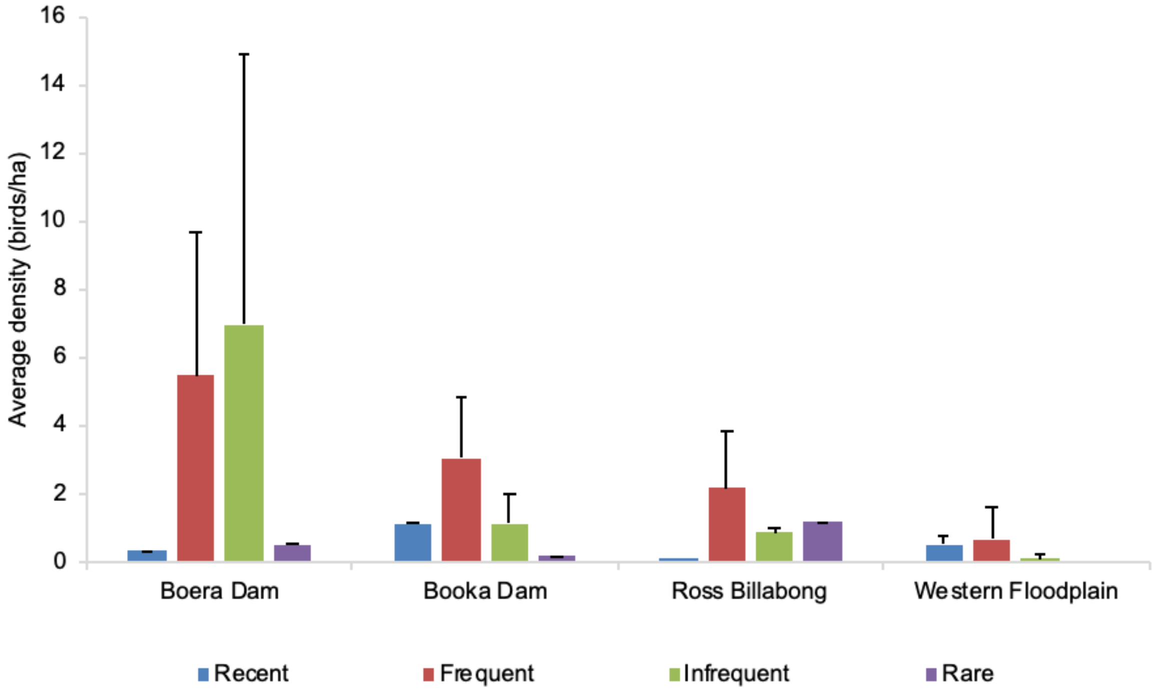

Figure M-7: Average waterbird density for each site under each water connection category.

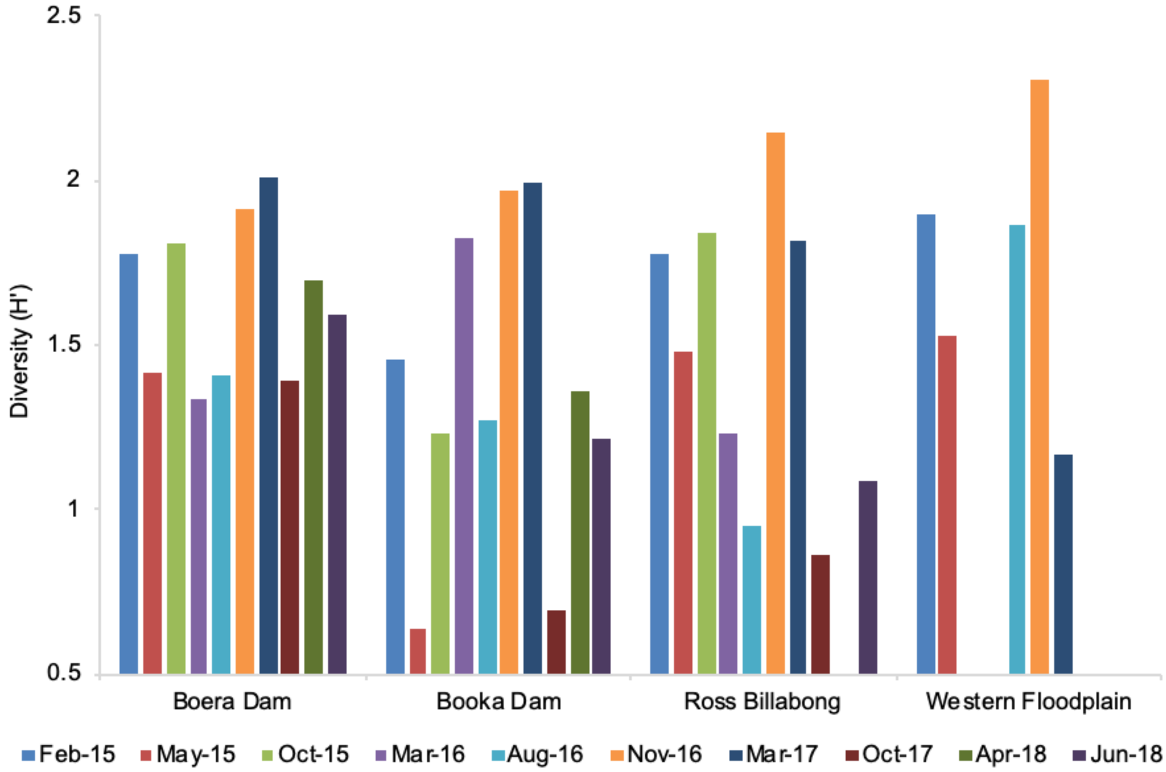

Figure M-8: Waterbird diversity (H') at each site during each sampling period, using the Shannon diversity index.

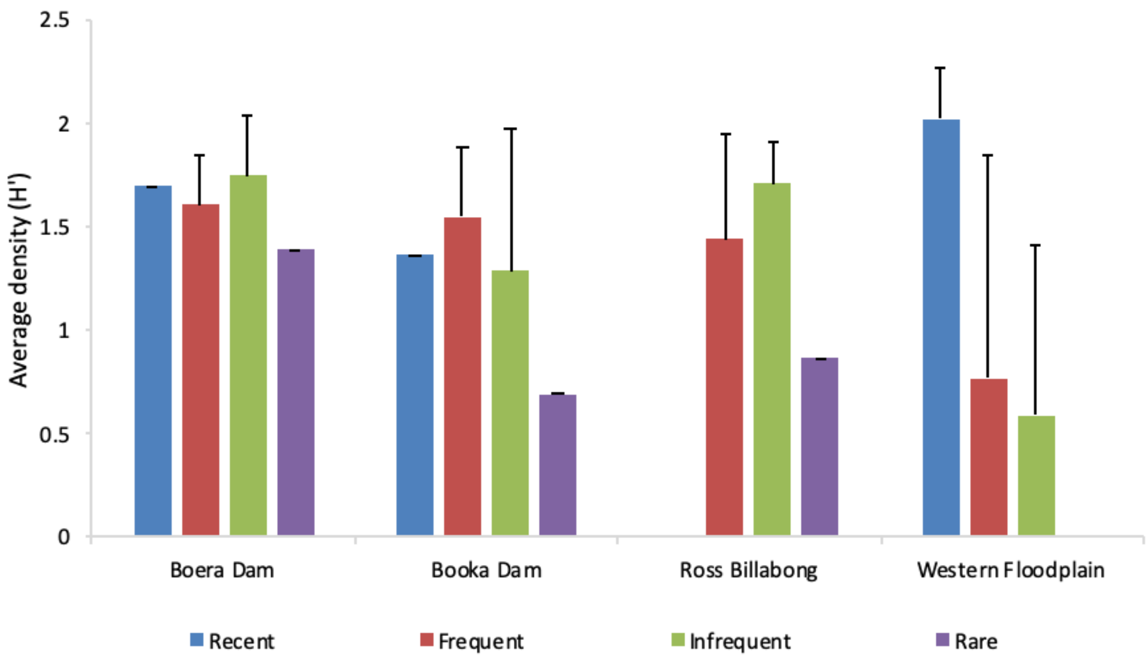

Figure M-9: Average waterbird diversity (H') for each site under each water connection category.

M.3.2 Waterbird community composition

To further explain patterns in waterbird community composition, multivariate analysis was undertaken on species abundance data. PERMANOVA tests identified a significant separation between sampling periods ($p<0.05$) when analysed with monitoring zone. The nMDS plot shows a greater spread of sites during sampling times after August 2016 (Figure M-10). While the interaction between sampling time and monitoring zone was significant ($p<0.05$), monitoring zone alone was non-significant ($p=0.14$). Pairwise tests suggest that February 2015 was significantly different to March 2016 ($p<0.05$) and April 2018 was significantly different to February 2015 ($p<0.05$), October 2015 ($p<0.05$), August 2016 ($p<0.05$) and November 2016 ($p<0.05$; Table M-4). The data from April 2018 had the lowest total waterbird abundance, species richness and density across the LTIM Project. Further to this, SIMPER analysis (Table A-5) highlights that species contribution to groupings during April 2018 was dominated by only two species: wedge-tailed eagle (58.49%) and yellow-billed spoonbill (41.51%).

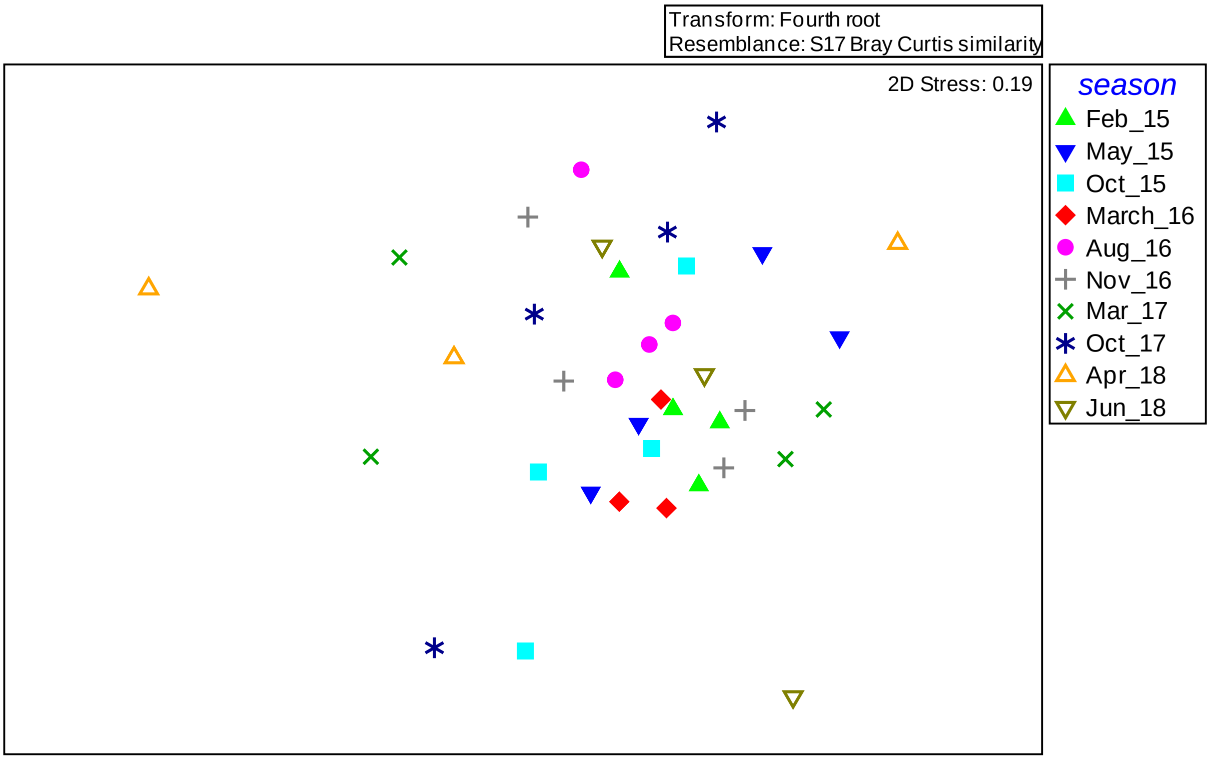

Figure M-10: nMDS plot of waterbird community composition data grouped by sampling period.

Table M-4: Pair-wise tests results for each sampling period.

	Feb_15	May_15	Oct_15	Mar_16	Aug_16	Nov_16	Mar_17	Oct_17	Apr_18	Jun_18
Feb_15		0.86	0.51	**0.037**	0.07	0.08	0.13	0.14	**0.044**	0.33
May_15			0.89	0.11	0.34	0.11	0.39	0.15	0.18	0.83
Oct_15				0.61	0.32	0.38	0.25	0.47	**0.048**	0.28
Mar_16					0.18	0.54	0.08	0.12	0.10	0.79
Aug_16						0.14	0.19	0.10	**0.045**	0.64
Nov_16							0.28	0.14	**0.031**	0.52
Mar_17								0.57	0.13	0.32
Oct_17									0.20	0.79
Apr_18										0.19

Significant results are in **bold**.

Table M-5: SIMPER results of species contributions to groupings in community composition data for each sampling period. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
February 2015	Grey teal	28.98
	Whistling kite	11.93
May 2015	Pacific black duck	41.00
	Grey teal	17.77
	Masked lapwing	14.95
October 2015	Whistling kite	28.26
	Black-fronted dotterel	24.27
March 2016	Australian wood duck	22.95
	White-faced heron	17.52
	Whistling kite	16.35
August 2016	Grey teal	36.33
	Black-fronted dotterel	33.45
	Pacific black duck	13.58
November 2016	Grey teal	30.15
	Black-fronted dotterel	22.80
	Pink-eared duck	10.54
March 2017	Whistling kite	25.68
	Hardhead	12.96
	Pacific black duck	10.58
	Grey teal	10.23
October 2017	Grey teal	52.95
	Whistling kite	25.19
	Masked lapwing	21.87
April 2018	Wedge-tailed eagle	58.49
	Yellow-billed spoonbill	41.51
June 2018	Grey teal	30.97
	Black-fronted dotterel	21.00
	White-faced heron	18.02
	White-necked heron	15.16
	Masked lapwing	14.85

PERMANOVA analysis showed no significant difference between sites (p=0.31). However, there was a significant difference between connection categories (p=0.01), with an interaction between sites and connection categories (p=0.05). The nMDS plot grouped by connection category, showed that the Frequent-connection and Recent-connection categories grouped more tightly, suggesting more similar waterbird communities at sites within these categories than in the Rare-connection and Infrequent-connection categories (Figure M-11). Pair-wise tests show a significant difference between Frequent-connection and Infrequent-connection periods, as well as between Frequent-connection and Recent-connection periods (Table A-6).

SIMPER analysis showed that grey teal and whistling kite abundances were most responsible for the species groupings between sampling periods (Table A-7). June 2018 had the largest spread of contributions to species grouping, with five individual species responsible for greater than 10% contribution. Contributions to species groupings by individual species were by far the highest during Rare-connection seasons, followed by Recent-connection seasons. In contrast, Infrequent-connection and Frequent-connection seasons were characterised by multiple species with smaller contributions to species groupings.

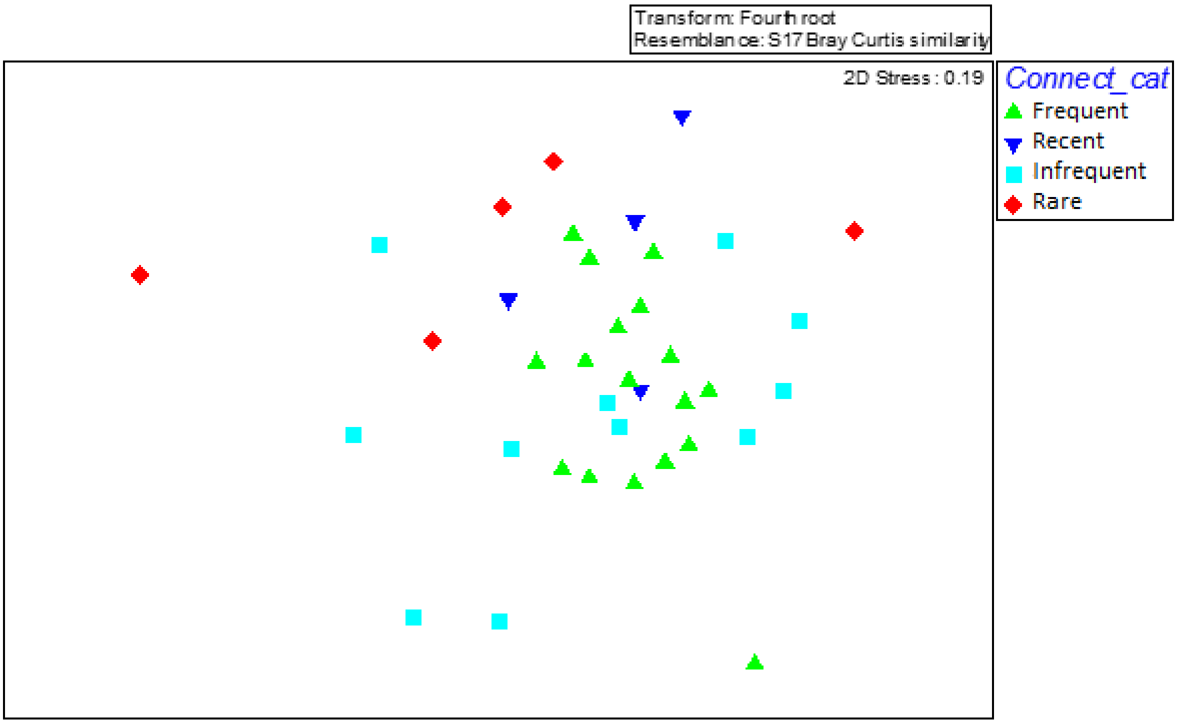

Figure M-11: nMDS plot of waterbird community composition data, grouped by connection category.

Table M-6: Pair-wise tests results for time since water connection categories.

	Rare	Infrequent	Frequent	Recent
Rare		0.34	0.11	0.13
Infrequent			**0.041**	0.07
Frequent				**0.001**
Recent				

Significant results are in **bold**.

Table M-7: SIMPER results of species contributions to groupings in community composition data for each time since water connection category. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Rare	Grey teal	50.23
	Masked lapwing	25.21
	Pacific black duck	10.18
Infrequent	Whistling kite	31.78
	Pacific black duck	13.44
	Grey teal	13.21
Frequent	Grey teal	25.55
	Black-fronted dotterel	18.33
	Australian wood duck	10.87
Recent	Wedge-tailed eagle	35.21
	Black-fronted dotterel	27.44

M.3.3 Waterbird breeding and functional guilds

Breeding has been observed across seven waterbird species throughout the project (Table A-8). Evidence of breeding was recorded at all sites except Booka Dam, and it was only observed at sites with recent or frequent hydrological connectivity.

Ten waterbird functional guilds were present in the Warrego-Darling Selected Area during the project. Piscivores were the most diverse guild across all survey periods, with 13 species recorded. This was followed by Raptors, with nine species. Dabbling and filter-feeding ducks were the most abundant guild present during the survey, with 1,402 individuals recorded. The next-most abundant were the Piscivores, and Grazing ducks and geese, with 367 and 345 individuals recorded respectively. Four of the guilds (Australian-breeding Charadriiform shorebirds, Dabbling and filter-feeding ducks, Piscivores and Raptors) were represented in all monitoring periods, whilst Reed-inhabiting passerines and Migratory Charadriiform shorebirds were present across only one and two survey periods respectively (Figure A-13).

Over the duration of the project, the four monitoring sites had similar numbers of functional guilds, with Boera Dam, Booka Dam and Western Floodplain each having eight functional guilds, and Ross Billabong having seven. Despite similar totals, assessing the sites for each survey period reveals that the Warrego River sites of Boera Dam (5.5 ± 1.9 guilds), Booka Dam (4.2 ± 1.7 guilds) and Ross Billabong (4.7 ± 1.9 guilds) recorded on average, higher diversity of functional guilds compared with the Western Floodplain (3.5 ± 3.1 guilds; Figure A-12). The lower average and higher standard deviation at the Western Floodplain reflect the pattern of waterbird fluctuations in response to the periodic inundation and drying of the floodplain.

Functional guild richness was highest during periods of Frequent-connection (5.1 ± 1.9 guilds) and Recent-connection (5.0 ± 2.8 guilds), with periods of Infrequent-connection (4.3 ± 2.2 guilds) and Rare-connection (2.3 ± 1.7 guilds) having lower mean functional guild richness. This suggests a non-linear relationship linking decreased water availability to declining functional guild richness.

Table M-8: Summary of breeding activity over the 2014–2019 survey period.

Site Name	Common Name	Breeding Evidence
Boera Dam	Australasian darter	Nest
Western Floodplain	Australasian grebe	Male in breeding plumage
Ross Billabong	Black-fronted dotterel	Courting
Boera Dam	Freckled duck	Roosting
Ross Billabong	Grey teal	24 ducklings present
Boera Dam	Royal spoonbill	Courting
Ross Billabong	Whistling kite	Nest in stag

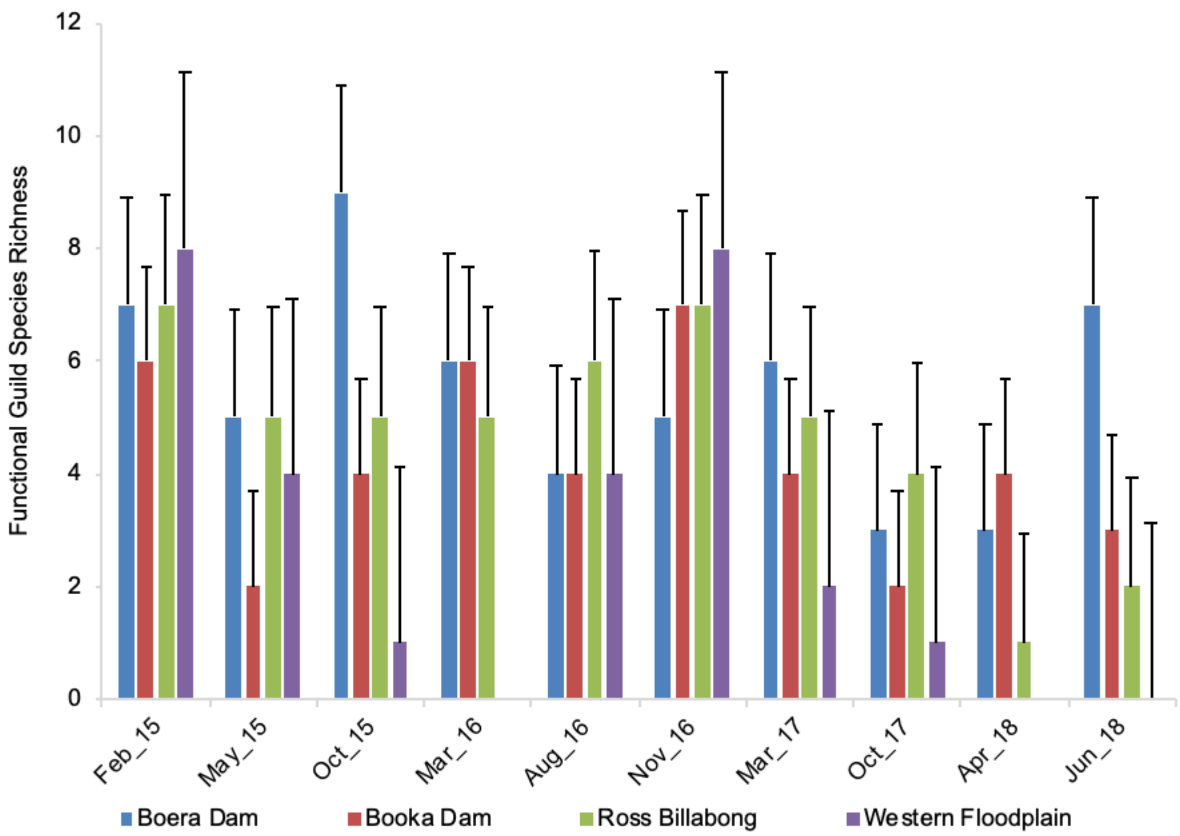

Figure M-12: Waterbird functional guild species richness for each site and survey period.

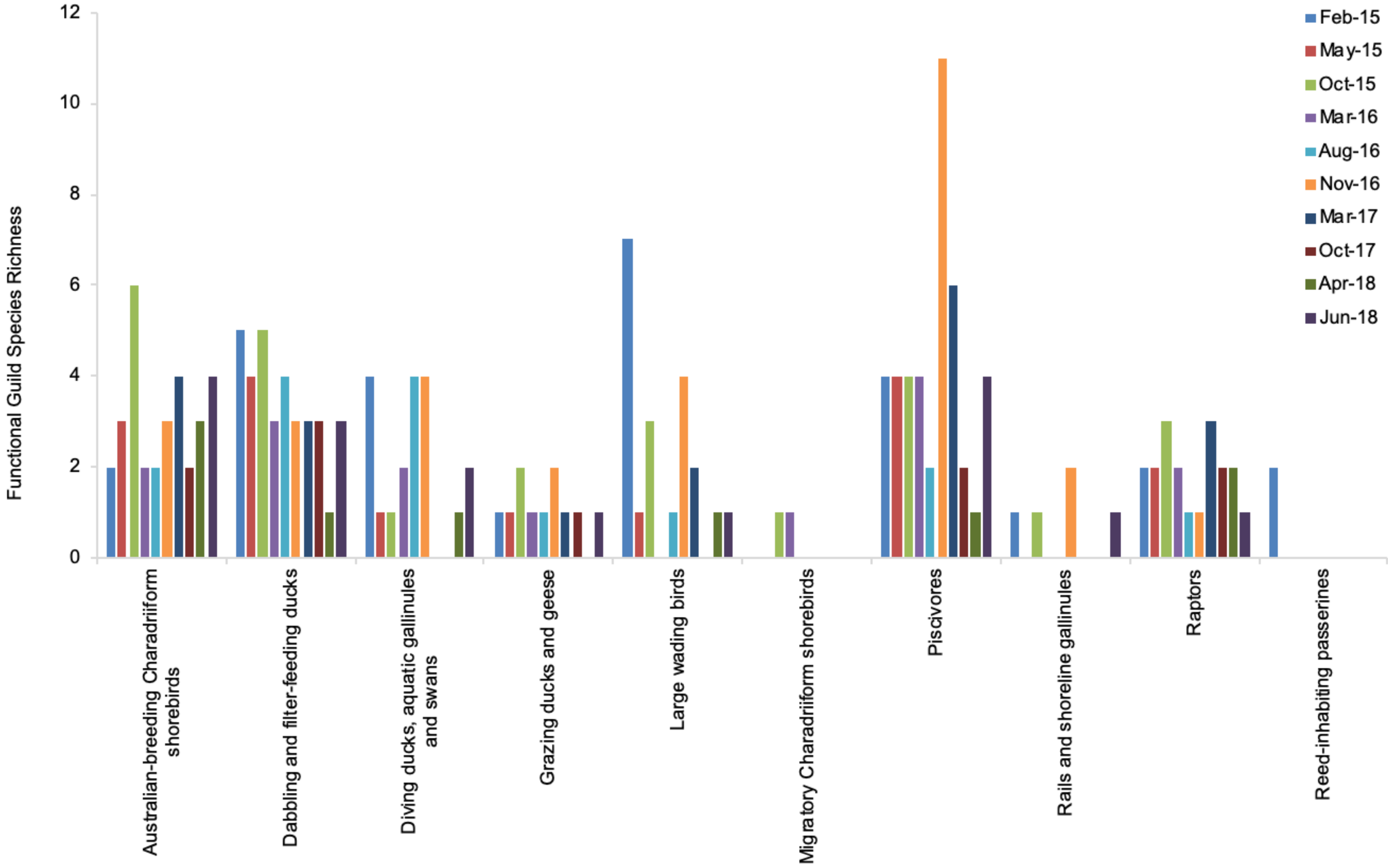

Figure M-13: Waterbird species richness for each functional group observed throughout the project across all sites.

M.4 Discussion

Waterbird species richness, density and diversity all varied significantly over time, between sites, and with varying levels of hydrological connection within the Warrego-Darling Selected Area over the LTIM Project. In all cases, rarely connected sites displayed the lowest average results for each measure, highlighting the importance of hydrological connection to the waterbird communities. For richness and density, intermediate levels of connection (from 17 to 68 days since connection) produced the highest results for these measures. These findings conform to the intermediate disturbance hypothesis that suggests that intermediate levels of hydrological connection lead to higher diversity in communities (Horn 1975, Townsend *et al.* 1997). The apparent preference for intermediate levels of connection by waterbirds, may be due to the time taken for lower levels of the food web (invertebrates, plants) to build up in abundance to levels that will feed the waterbird community. Once food is abundant enough, waterbirds then move in and feed.

High waterbird diversity, richness and density was observed during the February 2015 and November 2016 surveys. These followed periods where Warrego River sites were connected, and the Western Floodplain was inundated. On both occasions, Commonwealth environmental water or its management contributed to this connection (Appendix B). These patterns were influenced by higher richness of large wading birds and piscivores during the February 2015 and November 2016 survey times respectively. During the February 2015 survey, large flocks of grey teal were observed at Boera Dam (171 individuals) and on the floodplain (64 individuals). At Boera Dam, 77 Pacific black ducks also contributed to the higher waterbird density during the February 2015 survey time.

The influence of time since connection on waterbird populations differed between the Warrego River and Western Floodplain. The Warrego River sites, being more permanent water sources, appear to have more stable waterbird communities. This is especially so with Boera Dam, which consistently showed the greatest richness and diversity. On the Western Floodplain, waterbird populations respond more immediately and dramatically to inundation and subsequent drying. Higher standard deviations associated with average species richness and functional guild scores on the Western Floodplain suggest that waterbird use of the floodplain fluctuates over time. This likely reflects changing habitats and levels of productivity between inundation events. The high species richness for surveys on the recently inundated Western Floodplain suggest that waterbirds are taking advantage of the highly productive and diverse habitats on the floodplain soon after it becomes inundated. This contrasts with lower standard deviations recorded at the Warrego River sites, suggesting more stable waterbird populations. The assessment of density at Warrego River sites also demonstrates the differing response to inundation, with waterbird density falling during Recently-connected surveys at these sites. It is likely that increased water availability led to increased dispersal of waterbird populations and as such, an associated fall in waterbird density at permanent water sources such as the Warrego River sites.

While the Warrego River waterholes and Western Floodplain support a range of waterbird species, sometimes in large abundance, limited waterbird breeding was recorded during the project. Never the less, all seven records of waterbird breeding occurred at sites that were recently or frequently connected. This indicates that hydrological connection within the Warrego-Darling Selected Area elicits a breeding response from waterbirds. Given the relatively small area of Western Floodplain that was surveyed, it is likely that waterbird breeding is more widespread than was captured during the surveys. More targeted breeding surveys could be carried out to confirm this.

M.5 Conclusion

Waterbird monitoring at the Warrego-Darling Selected Area during the LTIM Project has shown a positive response of waterbirds to hydrological connection provided by Commonwealth environmental water and its management. This response appears to be more rapid on the Western Floodplain, while maximum richness and density at Warrego River sites followed lag times in productivity in lower food-web levels that were stimulated by connection. The data also suggests that the Warrego River waterholes appear to provide longer-term refugia that support more stable populations. This contrasts with the Western Floodplain, which, when inundated provides more diverse and productive habitats that waterbirds take advantage of. Due to its increased permanence and variety of available habitats, Boera Dam supported a more diverse and abundant waterbird community than any other location surveyed.

M.6 References

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Appendix N Fish Movement around Booka Dam

N.1 Introduction

The report outlines findings from targeted fish sampling undertaken in May 2019 around Booka Dam on the Warrego River channel. Previous sampling for the Fish (River) indicator identified the presence of juvenile fish within the lower Warrego system including golden perch (*Macquaria ambigua*) which actively moved down through the system in response to Warrego River flows (Appendix K). While Booka Dam controls the majority of flow down the channel, a secondary channel (Western Bywash) to the west of the dam also conveys flow during release from Boera Dam upstream. Information on the use of this secondary channel by fish during connection will inform flow management and the planning for the upgraded Dam structures at Booka Dam. The aim of this survey was to quantify the movement of fish through Booka Dam (via the regulation pipes) or around the dam via the Western Bywash.

N.1.1 Environmental watering in 2018-19

No flows were experienced through the lower Warrego River system during the majority of 2018-19 with levels receding in both Boera and Dicks Dams (Figure N-1). Widespread rainfall from a tropical depression in the upper Warrego catchment produced a flow event down the Warrego that entered the Warrego-Darling Selected Area in April 2019. The gates at Boera Dam were opened on the 22 April 2019 and remained open for 40 days until the flow pulse had moved through the system. During this time 8,106 ML of environmental water was accounted against the Toorale Warrego River licence, which comprised 40% of the total flow.

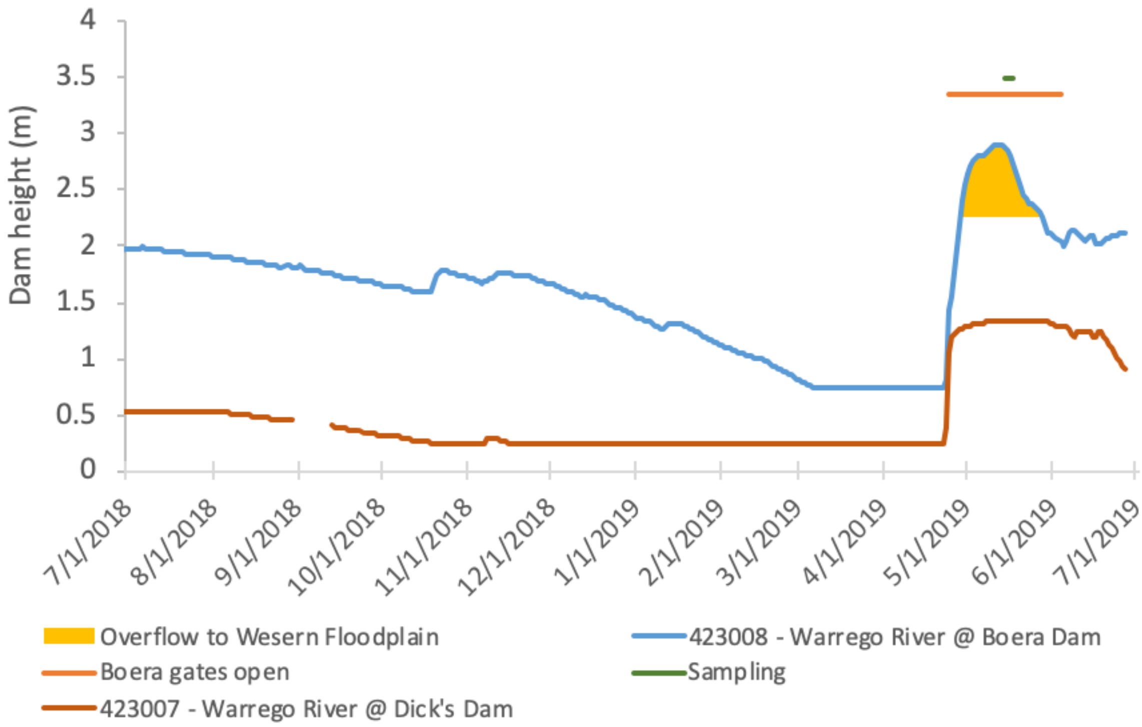

Figure N-1: Boera and Dicks dam water levels during 2018-19 water year and flows to the Western floodplain and/or into the lower Warrego river (Boera gates open).

N.2 Methods

N.2.1 Sampling sites

Data was collected from four sites near Booka Dam on the Warrego River (Figure N-2): one site on the Western Bywash, one downstream of the Booka Dam pipes, one site in the Warrego River upstream of the Western Bywash confluence and one downstream. All four sites were surveyed during fieldwork undertaken from 14 to 17 May 2019. Five sites were originally proposed for sampling, however, the proposed site upstream of Booka Dam in the impoundment was too deep for effective netting.

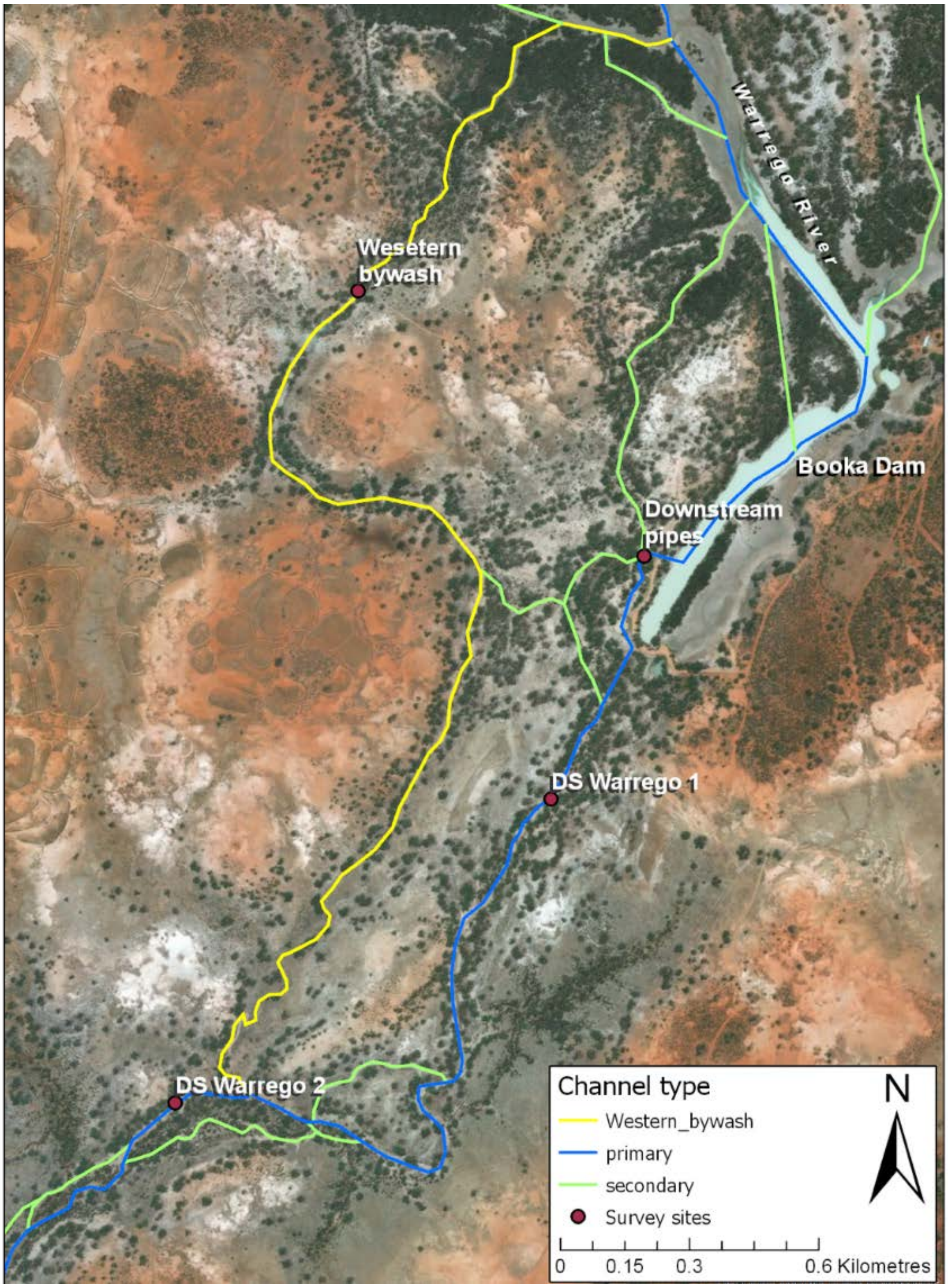

Figure N-2: Location of sampling sites in the lower Warrego River used for Fish River Warrego-Darling Selected Area assessment.

During the survey, Booka Dam was near capacity and water was flowing through several of the secondary channels to the west of the Dam (Figure N-3). The gates at Boera Dam were open to capacity (600 ML/d) and flows were returning from the Western Floodplain through a breach in the eastern embankment. This produced flows downstream at Dicks Dam in the range of 682 to 687 ML/d during the survey period.

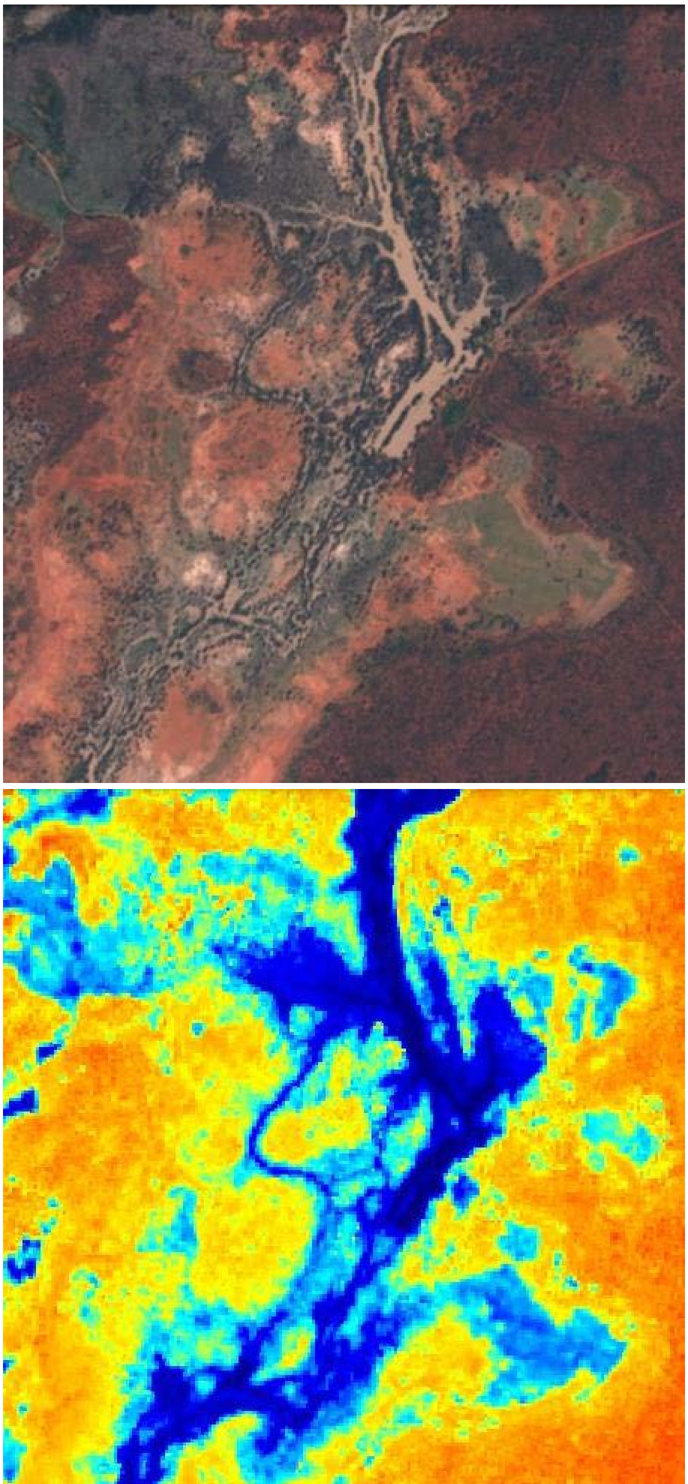

Figure N-3: Sentinel satellite imagery and moisture index at Booka Dam taken 15/05/2019.

N.2.2 Sampling protocols

A combination of small and large fyke nets were used to sample fish (Table N-1; Figure N-4). A single large double wing fyke net (3 mm mesh) was set at every site facing upstream to capture fish moving down through the system. A single small fyke net was set perpendicular to flow at each of three sites to assess upstream movement. This combination resulted in the survey of the majority of the width of the channel at each site (Figure N-4; Figure N-5). Fyke nets were set overnight for a minimum of 12 hrs and retrieved the next morning.

All fish captured were identified, counted, and measured to the nearest mm. A selection of small golden perch individuals (<100 mm) were retained and frozen for later otolith aging. Physio-chemical water quality variables (turbidity, temperature, conductivity, dissolved oxygen and pH) were also recorded at each sampling site using a turbidity meter and YSI water quality probe.

Table N-1: Netting configuration.

Site	Large fyke (facing upstream)	Small fyke (facing downstream)
DS pipes	1	
DS Warrego 1	1	1
DS Warrego 2	1	1
Western Bywash	1	1

Figure N-4: Nets at Western Bywash sampling site.

N.3 Results

N.3.1 Site Conditions

The water at all sites was flowing swiftly with a maximum depth of ~2 m. In-stream habitat for fish was generally good, with submerged trees and shrubs, small and large pieces of woody debris, as well as fringing undercut banks, providing most of the cover. The substratum at all sites was dominated by mud, sand and silt. Most sites were fringed by only a sparse riparian zone, dominated by large native trees such as river red gums (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) as well as small quantities of a range of native shrubs <1.7 m in height.

Turbidity was high at all sites (538 to 720 NTU) but typical of the Warrego River (Commonwealth of Australia 2017; Table N-2). Temperature was slightly higher at the Warrego DS2 site measuring 16.75 °C compared to 15 °C to 15.37 °C for the other sites. This is likely the result of measurement later in the afternoon at the Warrego DS2 site. Conductivity ranged from 105 to 120 µS/cm, and dissolved oxygen was moderate ranging between 62% and 79.2% (6.26 to 7.8 mg/l). pH was natural to slightly alkaline at 7.08 to 7.66 (Table N-2).

Table N-2: Physio-chemical water quality results recorded at sampling sites on the 16th May 2019.

Site	Downstream Pipes	Western Bywash	Warrego DS1	Warrego DS2
Time sampled	10:30	15:00	8:30	16:37
Turbidity (NTU)	720	538	692	563
Temperature (°C)	15.37	15.17	15	16.75
Conductivity (µS/cm)	0.105	0.114	0.12	0.113
Dissolved Oxygen (%)	79.2	62	69.9	69.2
Dissolved Oxygen (mg/L)	7.8	6.26	7.05	6.72
pH	7.08	7.22	7.66	7.16

Figure N-5: Warrego River downstream from Booka Dam Pipes during sampling, May 2019.

Figure N-6: Warrego River downstream from confluence with Western Bywash.

N.3.2 Fish captures

In total, 28 fish were caught at three sites comprising two native fish species (Table N-3). No exotic fish were caught. One Hyrtl's tandan (*Neosilurus hyrtlii*) was caught at the Downstream Warrego 2 survey site measuring 230 mm (Figure N-7). Twenty-seven juvenile golden perch, ranging in length from 25 to 35 mm, were captured in the two Warrego River downstream sites and the Western Bywash site. All fish were caught in the larger upstream facing fyke nets, suggesting a preference for downstream movement. No fish were caught in the net placed directly below the Booka Dam outlet pipes. From these results it appears that fish were moving through the secondary channels including the Western Bywash around Booka Dam, in preference to through the pipes on the Dam.

Table N-3: Fish captures during May 2019 Booka Dam surveys.

Site	Large fyke (facing upstream)	Small Fyke (facing downstream)
Downstream Pipes	No fish	Not sampled
DS Warrego 1	12 Golden perch (20 to 35 mm)	No fish
DS Warrego 2	4 Golden perch (20 to 30 mm) 1 Hyrtls Tandan (230 mm)	No fish
Western Bywash	11 Golden perch (20 to 35 mm)	No fish

Figure N-7: Hyrtl's Tandan at DS Warrego 2.

Figure N-8: Juvenile Golden Perch captured at DS Warrego 2.

N.3.3 Macroinvertebrate and tadpole captures

Approximately 400 large light-coloured tadpoles (Figure N-9), possibly of the Sudell's burrowing frog (*Neobatrachus sudellae*), and approximately 220 smaller dark coloured tadpoles (potentially *Limnodynastes* spp.) were collected (Table N-4). Fairy shrimp (*Anostraca*) and shield shrimp (*Notostraca*) were highly abundant at all sites (Figure N-10). In total, approximately 23,500 fairy shrimp and 850 shield shrimp were caught across all sites. Approximately one quarter of the fairy shrimp had light-orange egg sacs under their tails. In addition, approximately 300 freshwater snails (*Gastropoda*), and 17 freshwater shrimp (*Atyidae*) were also recorded in total and were present fairly evenly across all sites.

Table N-4: Macroinvertebrate and tadpole captures during May 2019 Booka Dam surveys.

Site	Large fyke (facing upstream)		Small Fyke (facing downstream)	
	Species	Count	Species	Count
Downstream Pipes	Fairy shrimp	2,000*	None	N/A
	Shield shrimp	75*		
	Freshwater shrimp	5		
	Tadpoles (light)	50*		
	Tadpoles (dark)	25*		
	Freshwater snail	10		
DS Warrego 1	Red fairy shrimp	10,000*	Fairy shrimp	500*
	Shield shrimp	500*	Shield shrimp	25
	Freshwater shrimp	4	Tadpoles (light)	10
	Tadpoles (light)	200*		
	Tadpoles (dark)	100*		
	Freshwater snail	200*		
DS Warrego 2	Fairy shrimp	5,000*	None	N/A
	Shield shrimp	200*		
	Freshwater shrimp	2		
Western Bywash	Red fairy shrimp	6,000*	Fairy shrimp	10
	Shield shrimp	200*	Shield shrimp	3
	Freshwater shrimp	3	Freshwater shrimp	3
	Tadpoles (light)	150*	Tadpoles (light)	1
	Tadpoles (dark)	100*	Freshwater snail	1
	Freshwater snail	100*		

* Approximate count

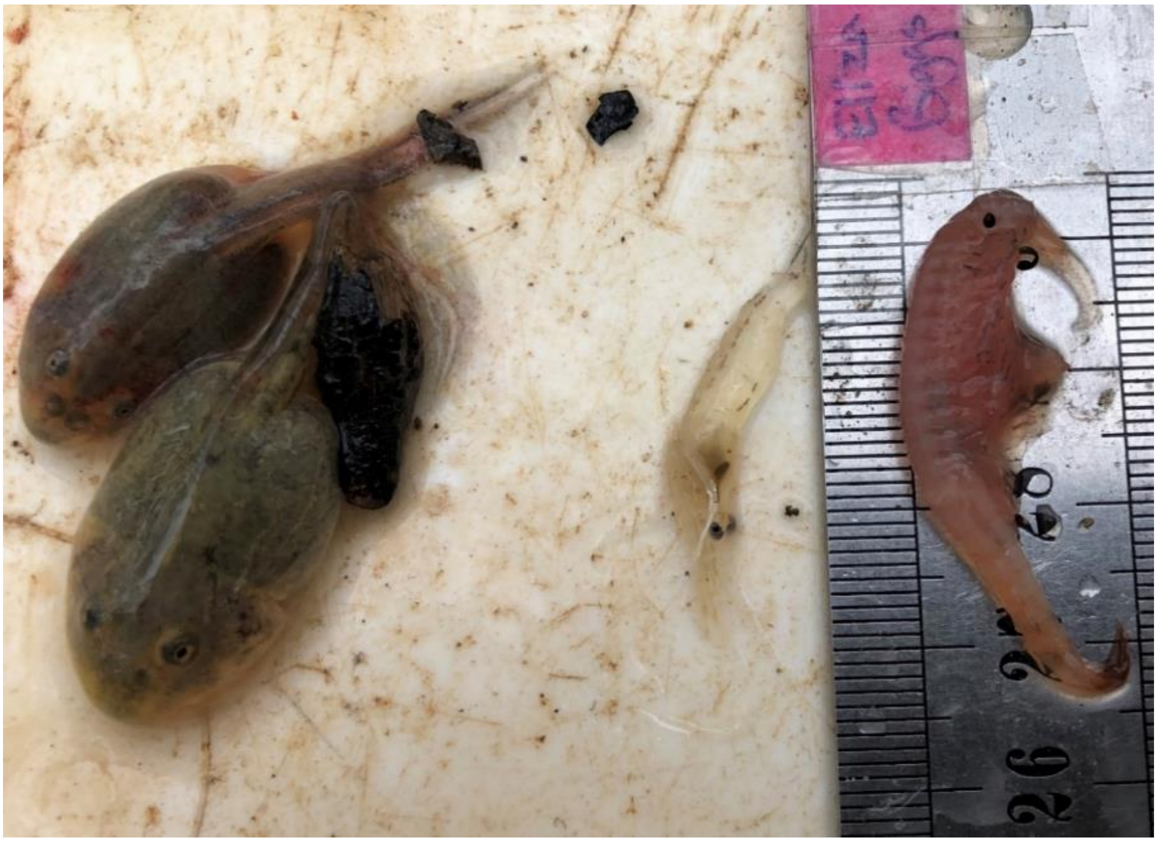

Figure N-9: Large light-coloured tadpoles (L), freshwater prawn (C) and fairy shrimp (R).

Figure N-10: Fairy shrimp and shield shrimp from DS Warrego 1.

N.4 Discussion

The results of fish sampling around Booka Dam are consistent with previous fish (river) indicator findings and the prevailing conditions experienced at the site before the May – June 2019 flow event. During the LTIM Project, between 5-8 fish species have been recorded at Booka Dam. However, only two species were recorded in May 2019, most likely a result of this section of the system being completely dry in the months leading up to the 2019 flow (Appendix B), and not supporting a resident fish population. Given this, it is highly likely that the fish recorded during the Booka fish movement sampling moved into the system from upstream as the flow proceeded. Both golden perch and Hyrtl's tandan are known for their ability to disperse during flow periods and possess the ability to handle often rapid and wide-ranging changes in the surrounding abiotic conditions (Katz and Freeman 2015; Kerezsy *et al.* 2013). Comparing the size of the captured golden perch with previously collected golden perch length-at-age data (Appendix K), it is estimated that they were between 30 and 60 days old. This suggests that these individuals were likely recruits having been spawned upstream and drifted into the lower Warrego system. In contrast, the Hyrtl's tandan individual was an adult fish that was likely foraging and taking advantage of the abundant food resources in the area.

Fish were captured in the Western Bywash, and downstream in the Warrego River sites during the current study. This suggests that fish were using the secondary channels located to the west of Booka Dam, to move through the system and back into the Warrego River downstream. The increased catches of fish in the upstream facing nets suggests that these fish were preferentially moving downstream. No fish were caught in the nets set directly below Booka Dam regulating pipes which were open and passing water at the time. Booka Dam itself was not sampled due to access limitations and unsuitable water depths. Without this information we cannot confidently conclude that the pipes were restricting the movement of fish downstream. Previous fish sampling in the system during times when the only flows into the lower Warrego system were through Boera Dam suggest that golden perch recruits were successfully negotiating the Boera Dam regulating gates, which are similar in dimension to those at Booka Dam. During the current study, a breach in the floodplain embankment was observed to be allowing water to return from the floodplain back into the Warrego River upstream of the sampling locations. Therefore, it is possible that some of the recruits captured may have come via the floodplain. In any case, it appears that under the current arrangements at Booka Dam, fish are successfully negotiating their way around the dam, either through the regulating gates or via the Western Bywash and network of secondary channels to the west of the dam.

Substantial macroinvertebrate and tadpole biomass was collected during the sampling around Booka Dam, primarily in the form of fairy and shield shrimps and tadpoles. This highlights the productive nature of the system during flooding, with many species responding quickly to inundation. Both the fairy and shield shrimps are known to rely on an eggbank that is desiccation resistant. Some species of both animals are thought to require a period of egg desiccation before they will develop (Williams 1980). Thus, they are well-suited to the variable nature of the Warrego system. This increased productivity is thought to be particularly important for the overall functioning of arid and semi-arid rivers like the Warrego, sustaining aquatic animals through the less productive drier times (Arthington and Balcombe 2011).

N.5 Conclusion

Golden perch and Hyrtl's tandan were recorded during the sampling around Booka Dam, along with a large biomass of macroinvertebrates. Most individuals were captured from upstream facing nets, suggesting downstream movement. Golden perch recruits were recorded from sites within the Western Bywash, and in the Warrego River channel downstream of Booka Dam, which suggests that they are using the secondary channels to the west of the Dam. A breach in the embankment that separates the Warrego and Western Floodplain was allowing floodwater to return from the floodplain to the river upstream of Booka Dam. For this reason, it is uncertain if golden perch recruits had moved down the channel network through Boera Dam or from the floodplain. However, previous monitoring through the fish (river) indicator suggests that they can travel through the Boera Dam regulating gates. In any case, it appears that under the current arrangements at Booka Dam, fish are successfully negotiating their way around the Dam, either through the regulating gates or via the Western Bywash and network of secondary channels to the west of the Dam.

N.6 References

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