Appendix A Hydrology (River)

A.1 Introduction

The Hydrology (River) indicator provides in-channel hydrological information on the character of Commonwealth environmental water and other environmental water deliveries. This information is directly relevant to a number of other indicators measured in the Junction of the Warrego and Darling rivers Selected Area (Selected Area) including the Vegetation Diversity, Waterbird Diversity, Fish, Microinvertebrate and Macroinvertebrate indicators. The particular influence of hydrology of these indicators will be addressed under their respective chapters. The Hydrology (River) indicator will also provide information on the degree of hydrological connectivity maintained through the Selected Area during the 2015-16 water year. One specific question was addressed in relation to this indicator:

- What did Commonwealth environmental water contribute to hydrological connectivity?

A.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January-March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year. (Appendix B).

A moderate pulse in the Darling River began in June 2016 reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by 30 June 2016, and peaking at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

A.1.2 2014-15 monitoring outcomes

In 2014-15 the Darling River was connected (that is, water was flowing through the reach, and not backed up behind Weir 20A) for 60% of the time, with the longest period of flow being 96 days at the beginning of the water year. This was followed by an extended period of disconnection lasting 117 days. Flows generated mainly in the Condamine-Balonne catchment helped to restore connectivity in this section of the Darling in February-March and rainfall in the Border Rivers catchment in May-June 2015 provided fresh flows through the Selected Area which, along with several 'top-up' events kept the channel connected at the end of the water year.

The Warrego River channel upstream of the Selected Area experienced one significant rainfall-driven event from December 2014 – January 2015 that resulted in flow at Fords Bridge for 63 days. Several smaller flow events that resulted from storm runoff occurred towards the end of the water year which produced minor inflows to the Selected Area.

Water levels in Boera Dam were relatively high early in the 2014-15 water year but declined steadily until January 2015 when the flow, described above, reached the dam. To meet downstream licence conditions the gates were opened on 13 January 2015 which initiated full connection through to the Darling River for a period of 24 days before gates were closed on 5 February 2015. Continued inflows to Boera Dam after closure of the gates resulted in water spilling onto the Western Floodplain.

A.2 Methods

An assessment of the hydrological connectivity experienced along the Darling River within the Selected Area was undertaken by comparing flow regimes at the Weir 19A gauge (NSW425037) (upstream) with the gauging station at Louth (NSW425004) which is the first reliable gauge downstream of the Selected Area (Commonwealth of Australia 2015; Figure A-1). This reach was considered to be fully connected when water was flowing past both gauges. For the Warrego, flows entering the Selected Area were measured by plotting flows past Fords Bridge (Figure A-1). Flows at the Warrego River @ Fords Bridge gauge (NSW423001) (Main channel) were combined with flows at the Warrego River @ Fords Bridge Bywash gauge (NSW423002) to give a total flow past Fords Bridge.

To quantify flows down the Warrego River channel within the Selected Area the duration one or both the control gates on Boera Dam were open was compared with flows registered at the gauging station at Dicks Dam (NSW423007). Operation of the gates at Boera Dam was assessed using the Remote Access Camera mounted in Boera Dam along with operational reports from Toorale National Parks staff. Here full connection was considered to have occurred when the Boera control gates were open and when Dicks dam was rising in level. Spells analysis (Gordon *et al.* 1992) was undertaken to assess the total duration and frequency of flows passing down each channel.

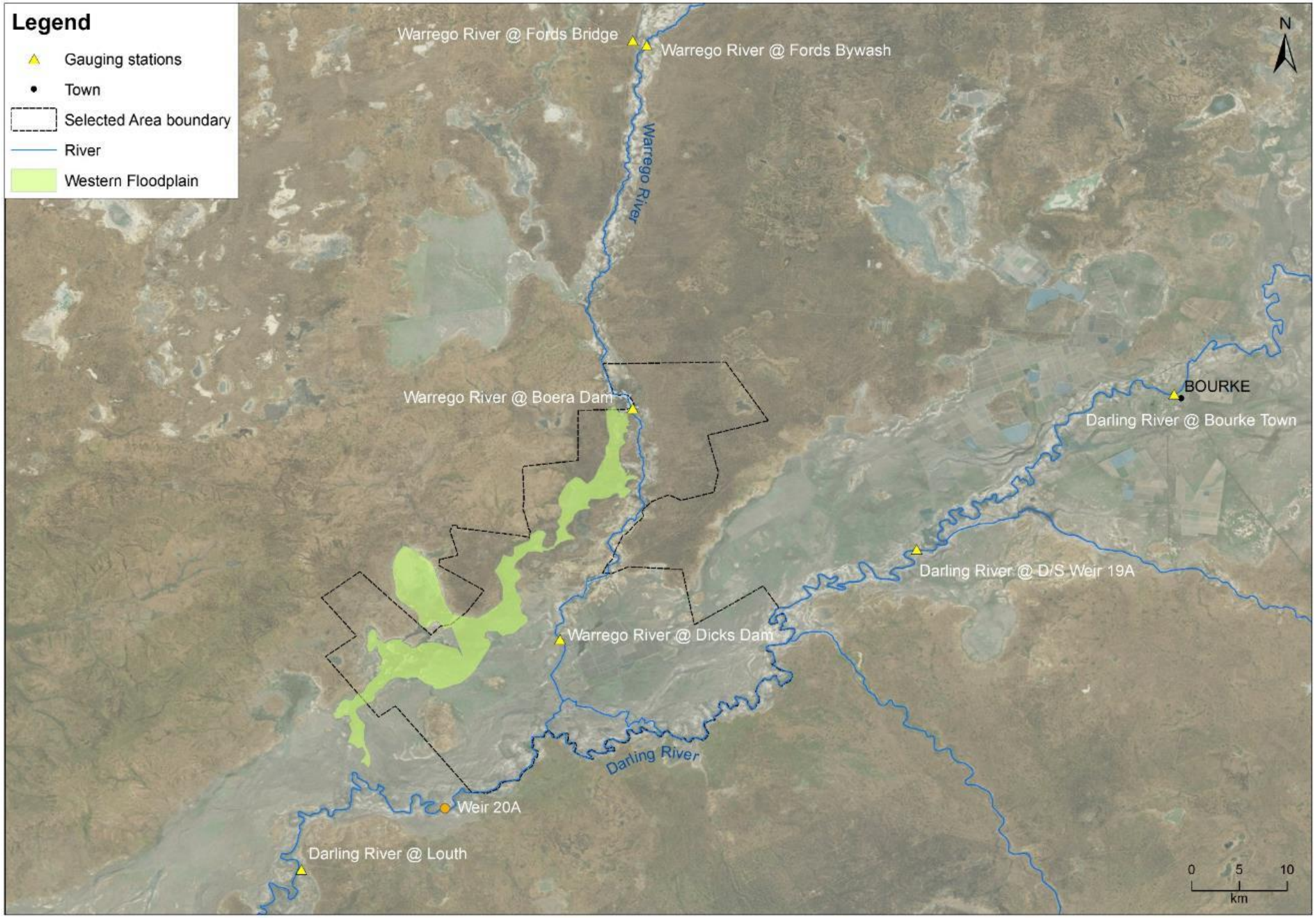

Figure A-1: Location of flow gauging stations used in the hydrological connectivity analysis and extent of the Western Floodplain.

A.3 Results

The Darling River within the Selected Area was connected for 61% of days during 2015-16 (Figure A-2). Connectivity was dominated by a single long connection event of 163 days early in the water year. There was a subsequent period of moderate length connectivity in February – March 2016 of 37 days and three short connection events of between two and 13 days in May and June 2016.

The longest period of connectivity was driven by two consecutive flow events containing Commonwealth environmental water down the Darling River channel (Appendix B). In July – October 2015 these flows included 3,547 ML of Commonwealth environmental water from the Queensland Border Rivers, Moonie and upper Barwon Rivers as well as localised entitlements at Toorale. In the November 2015 connection event, 1,208 ML of Commonwealth environmental water from Queensland Border Rivers and the Gwydir River entered the Selected Area. A third flow comprising 13,955ML of Commonwealth environmental water from the Queensland Border Rivers, Upper Barwon, Condamine-Balonne and Warrego Rivers occurred in January – March 2016. This took until 18 February 2016 to influence connectivity in the monitored reach of the Darling River and resulted in a connection event lasting 37 days.

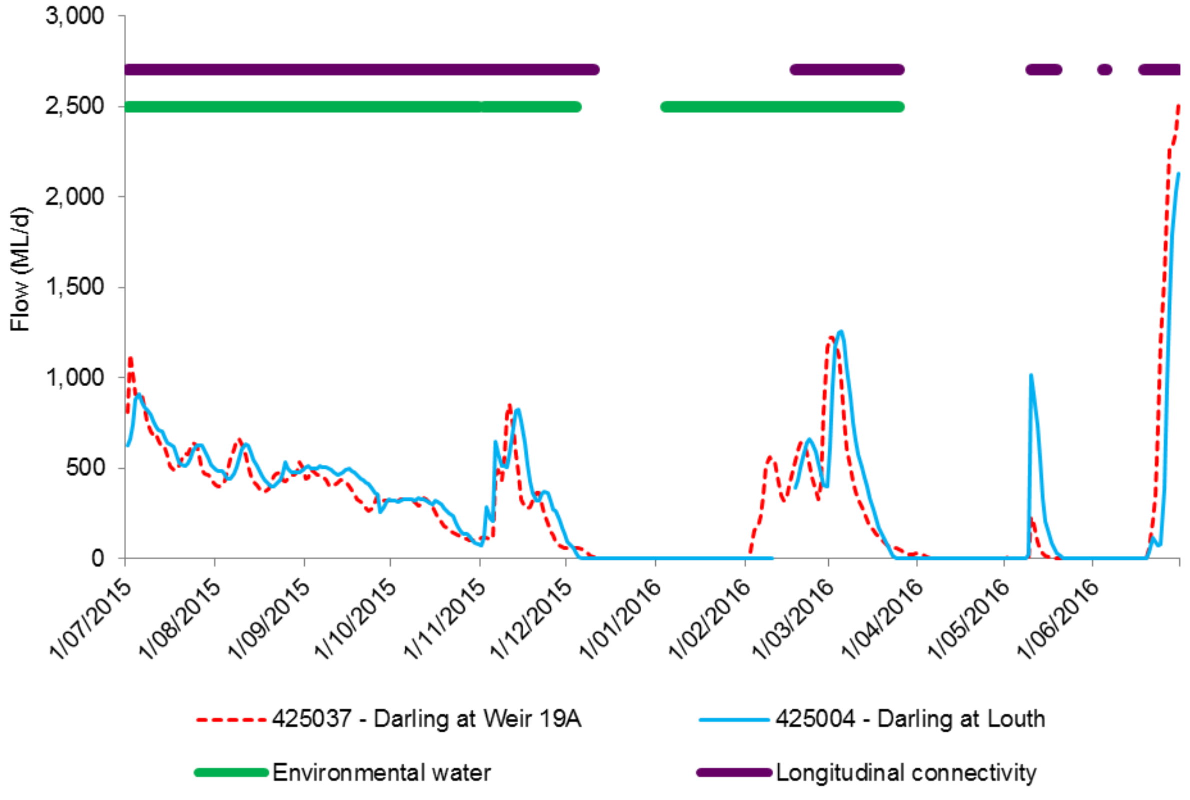

Figure A-2: River flows down the Darling River channel and the timing of longitudinal connectivity in this reach.

Two significant flow events in early 2016 entered the Selected Area from the Warrego catchment (Figure A-3). 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.

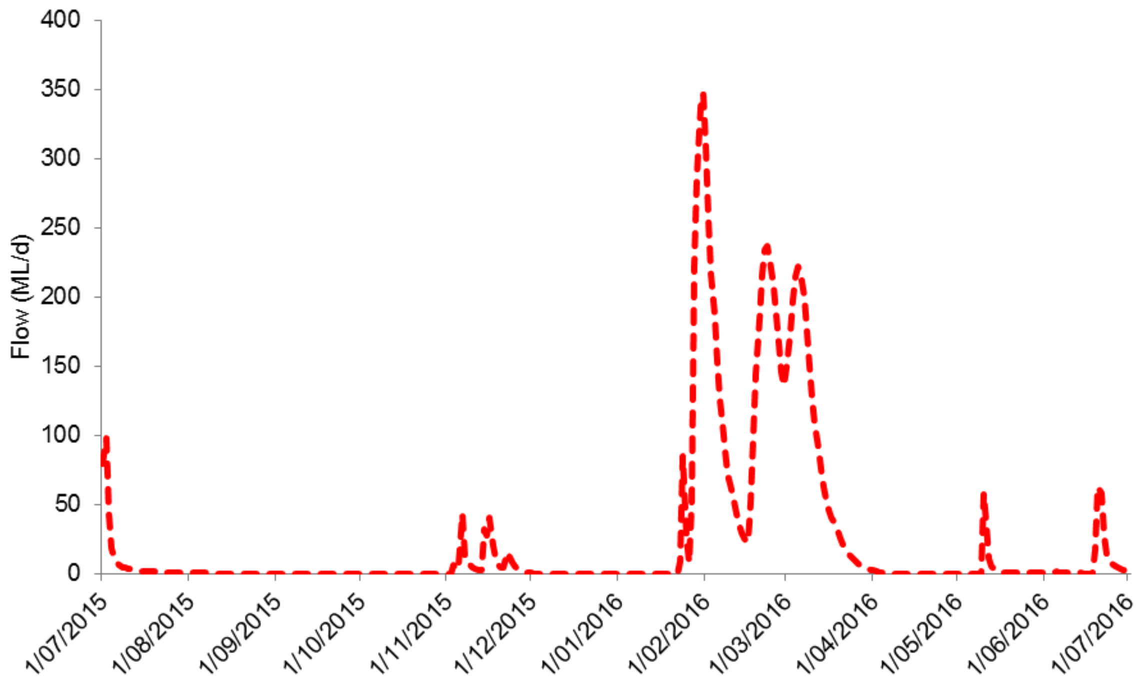

Figure A-3: Flow hydrograph for Warrego River at Fords Bridge upstream of the Selected Area. Note gauges 423001 and 423002 have been combined to produce a total flow past Fords Bridge.

Boera Dam was above the estimated overflow level of 2.26 m at the commencement of the 2015-16 water year and remained so until mid-August 2015. During July – 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 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 A-4). Importantly, in the context of Commonwealth environmental water, no Toorale licences on the Warrego River were triggered during the 2015-16 water year.

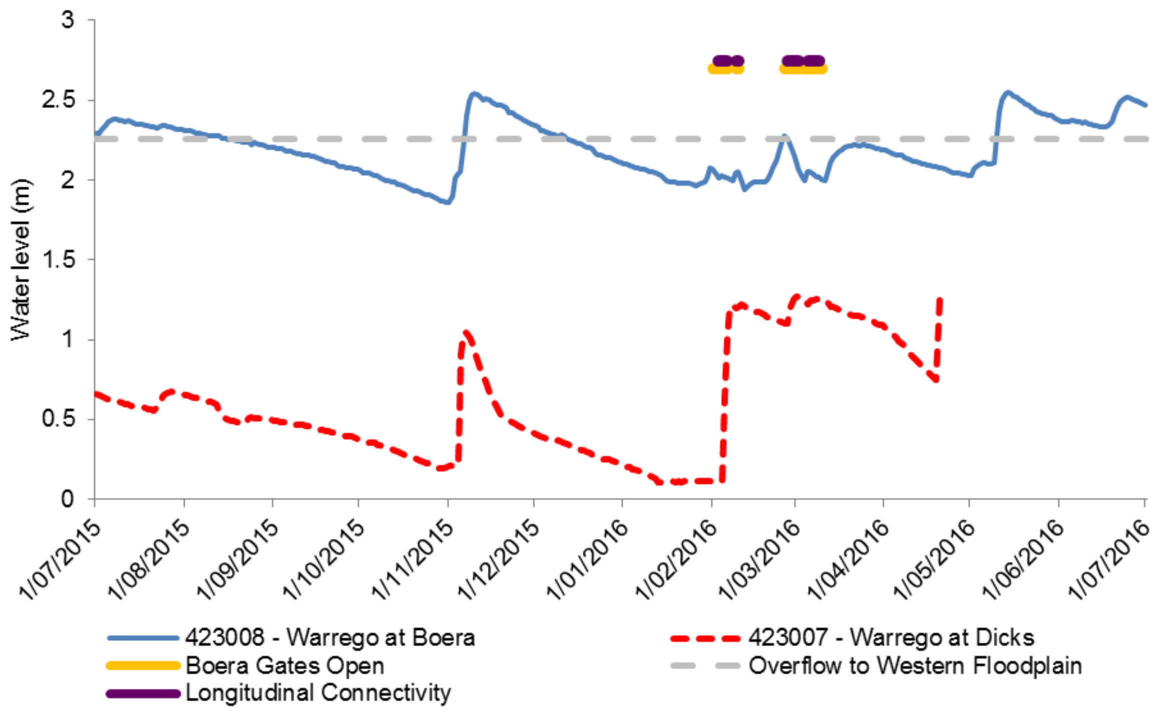

Figure A-4: Water levels (m) at Boera and Dicks Dams and periods of longitudinal connection and overflow to Western Floodplain.

A.4 Discussion

Flows down the Darling River were moderate to low in the early part of the 2015-16 water year. Flow events were derived from local rainfall events late in the 2014-15 water year supplemented by inflows from northern tributaries containing a proportion of environmental water. There were several small flow peaks throughout the year, one supported by inflows to the Selected Area containing environmental water. All flows remained well below bankfull. Channel capacity in this reach is around 30,000 – 40,000 ML/d (M. Southwell unpublished data) and peak flows in 2015-16 were only around 2,500 ML/d. Hydrology in this section of the Darling River is heavily influenced by weirs, including Weir 19A upstream of the Selected Area and Weir 20A downstream. These weirs help to maintain connectivity through the Selected Area in times of low flow. Given the tendency for salt build up (N. Foster pers comm) and algal blooms (Mitrovic *et al*. 2011) in these weirs, flushing flows are important for maintaining water quality in this reach and dispersing floating vegetation (Figure A-5; Appendix F).

Two closely-spaced flow events in February and March 2016 dominated the hydrology of the Warrego River channel during 2015-16. In-line with the operating rules associated with the Toorale water licences, flows were let through Boera Dam and increased flows in the Darling River. Levels in Boera Dam remained relatively high throughout the water year and overflow to the Western Floodplain occurred on three separate occasions in July-August 2015, November – December 2015 and May 2016.

Figure A-5: Pacific azolla in the Darling River at Akuna Homestead

A.5 Conclusion

Full longitudinal connection was achieved through the Darling River for 61% of the time in the 2015-16 water year and for 16 days in total through the Warrego River within the Selected Area. These flows helped to maintain water quality (Appendix F) and, at the end of the 2015-16 water year, reached sufficient volume to provide access to in-channel habitat (Appendix D). In the Darling River, connection was driven largely by three environmental water deliveries, two of which were delivered consecutively in late 2015. In the Warrego River, inflows from northern tributaries, including an environmental water delivery in early 2016 resulted in connection for 16 days total and also allowed delivery of flushing flows to the Darling River in February and March 2016. The releases from Boera Dam also resulted in the filling of downstream dams which provided aquatic habitat along the system.

A.6 References

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

Gordon, N. D., McMahon T.A. and Finlayson, B.L. 1992. *Stream Hydrology - An introduction for Ecologists.* Brisbane, Wiley.

Mitrovic, S.M., Hardwick, L. and Dorani, F. 2011. Use of flow management to mitigate cyanobacterial blooms in the Lower Darling River, Australia. *Journal of Plankton Research*, *33(2)*, 229-241

Appendix B Hydrology (Northern Tributaries)

B.1 Introduction

This chapter examines Commonwealth environmental water in the northern tributaries of the Murray Darling Basin (MDB). In particular, it considers the hydrological influences of Commonwealth environmental water at the junction of the Warrego and Darling rivers Selected Area (Selected Area), during the 2015-16 water year. This indicator links closely with the Hydrology indicators as well as the Water Quality and Stream Metabolism indicators. The specific question addressed in this chapter is:

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

B.1.1 Northern Tributaries of the Murray Darling Basin

The northern tributaries of the MDB catchment upstream of the Selected Area drains the Great Dividing Range in southern Queensland and northern NSW, flowing more than 500 km in a westerly direction across extensive floodplains. The Warrego River catchment defines the western extent of the catchment upstream of the Selected Area, meeting the Darling River at Toorale Station (Figure B-1).

Major tributaries upstream of the 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 MDB upstream of the 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. The northern tributaries are home to a population of approximately 560,000 people with annual production values of $5.2b and $1.45b for agriculture and irrigated agriculture, respectively (www.mdba.gov.au). Agricultural water uses include cotton, horticulture, and livestock production.

B.1.2 Commonwealth environmental water holdings

Total Commonwealth environmental water holdings for the northern tributaries are currently 445,565 ML (Table B-1). The Long Term Average Annual Yield (LTAAY) provides an indication of the long-term reliability of these entitlements or the amount that would be available on average each year. At the time of writing, the LTAAY of Commonwealth environmental water for the northern tributaries upstream of

Louth was 222,807 ML, and it is this amount that is used by the Commonwealth Environmental Water Holder for annual decision-making regarding water use priorities.

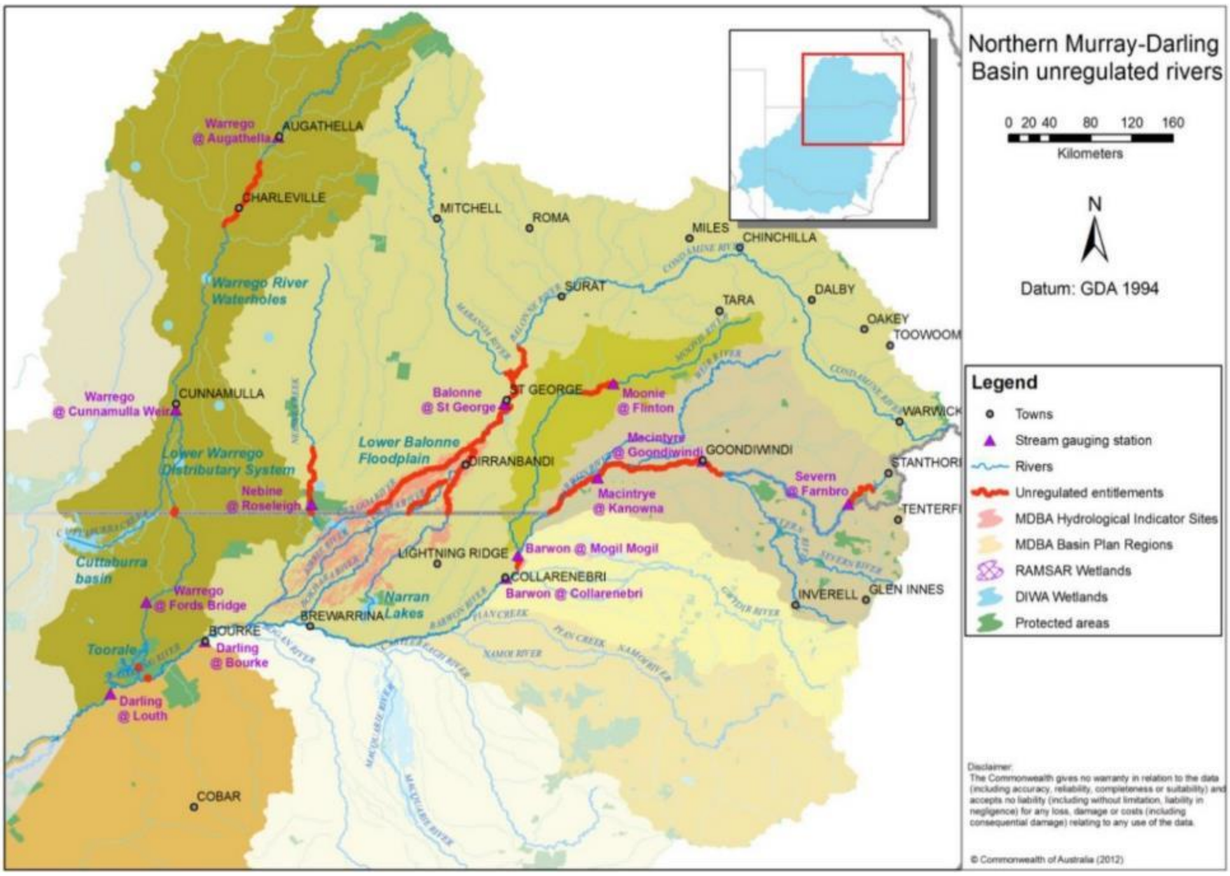

Figure B-1: Northern Tributaries of the Murray Darling Basin (Commonwealth Environmental Water Office, 2015).

Table B-1: Commonwealth Water Holdings for Northern Tributaries to mid-May 2016 (source Commonwealth Environmental Water Holder).

Catchment	Regulated (ML)		Unregulated (ML)		Total (ML)	
	Entitlement	LTAAY	Entitlement	LTAAY	Entitlement	LTAAY
Condamine-Balonne[1]	45	43	94,598	57,309	94,643	57,352
Moonie	0	0	1,415	1,100	1,415	1,100
Warrego (Qld)	0	0	16,050	8,000	16,050	8,000
Warrego (NSW) - Toorale	0	0	17,826	17,826	17,826	17,826
Barwon-Darling	0	0	24,279	24,279	24,279	24,279
Border Rivers	15,960	5,409	16,518	6,502	32,478	11,911
Gwydir[2]	94,033	36,737	20,451	3,886	114,484	40,623
Namoi	8,617	6,635	0	0	8,617	6,635
Peel	1,257	326	0	0	1,257	326
Macquarie[2]	126,224	53,014	8,292	1,741	134,516	54,755
TOTAL	*246,136*	*102,164*	*199,429*	*120,643*	*445,565*	*222,807*

Notes:

[1] Includes (all LTAAY): Nebine Creek (1,000 ML); lower Balonne unsupplemented and overland flow: 56,082 ML; Condamine unsupplemented: 227 ML

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

B.1.3 Hydrology within the Selected Area

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

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

During drier times, such as this year, the relationship becomes more complex. From a water management point of view, the Barwon-Darling River system is considered to be 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 into which end-of-system flows may disappear.

The Warrego River is essentially unregulated, but due to its semi-arid setting, provides water to the Selected Area only during periods of flow. Within the Selected Area, river flows are further influenced by a number of in-stream structures, such as Boera, Booka, Dicks and Peebles dams.

Commonwealth environmental water 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, Commonwealth environmental water may or may not be accounted for once the flow trigger is reached.

B.2 Methods

The downstream passage of Commonwealth environmental water events was observed and assessed using NSW DPI Water real-time flow data for gauging stations located along the Barwon-Darling River system, using mean daily discharge data for the following hydrometric stations:

- 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 Town
- 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 B-2.

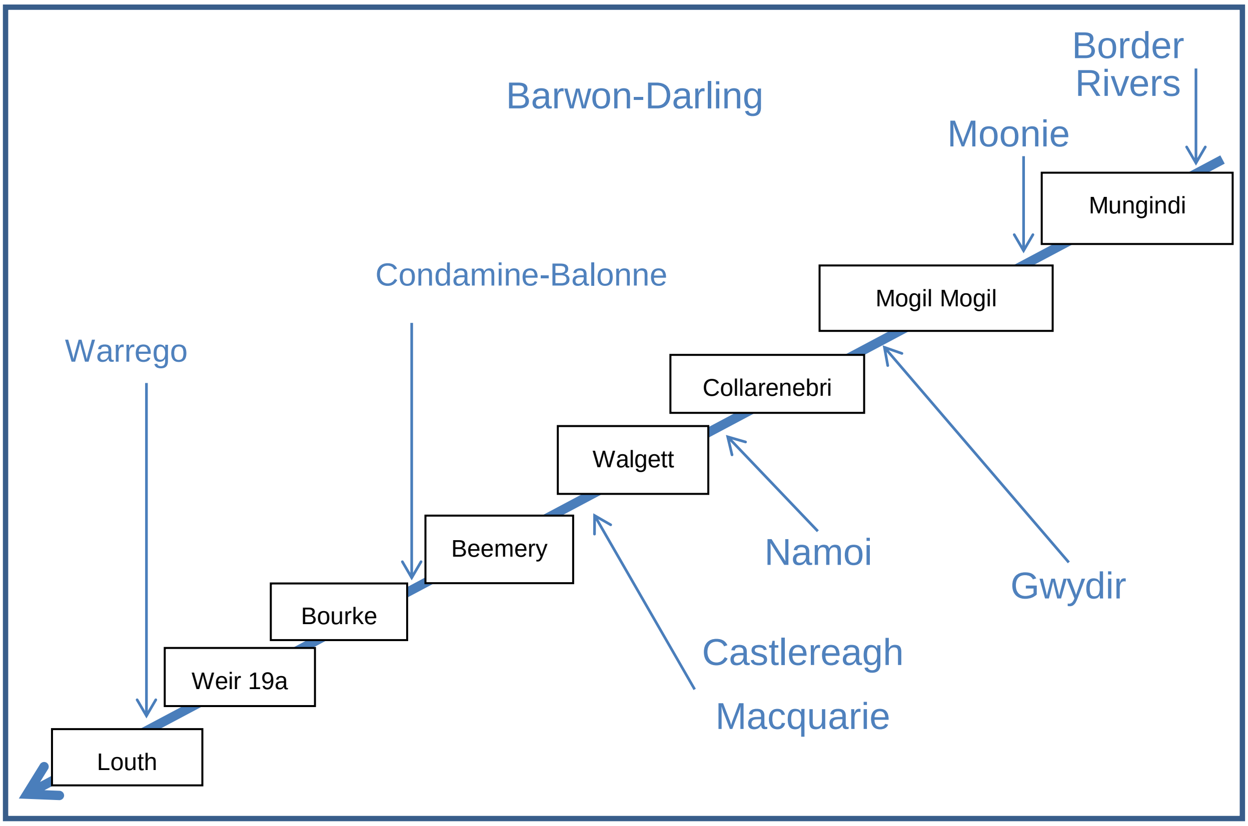

Figure B-2: Gauging stations and key tributaries on the Barwon-Darling River system.

End-of-system (EOS) Commonwealth environmental water was estimated based on advice from Department of the Environment and Energy, NSW Office of Water and the CSIRO MDB Sustainable Yields project (Table B-2).

Table B-2: End of System flow estimates used to assess downstream passage of Commonwealth environmental water.

Catchment	Applied EOS flow percentage
Border Rivers	80
Moonie	72.9
Gwydir	24.16
Namoi	63
Macquarie/Castlereagh	76
Condamine-Balonne	37
Barwon-Darling (Mungindi to Bourke)	80
Warrego	33.93

B.3 Results

B.3.1 2015-16 water year

Daily flow records (DPI Water) were cross-referenced with internal operational reports (CEWO) to assess key flow events where Commonwealth environmental water was accounted for in the northern tributaries during the 2015-16 water year.

Four flow ‘events’ were identified that included a component of Commonwealth environmental water take (Figure B-3):

Event 1. July – October, 2015: comprising 3,547 ML Commonwealth environmental water from the Queensland Border Rivers, Moonie and upper Barwon Rivers as well as localised entitlements at Toorale.

Event 2. November, 2015: comprising 1,208 ML Commonwealth environmental water from Queensland Border Rivers and Gwydir River.

Event 3. January – March, 2016: comprising 13,955 ML Commonwealth environmental water from Queensland Border Rivers, Upper Barwon, Condamine-Balonne and Warrego Rivers.

Event 4. June 2016: comprising 2,454 ML Commonwealth environmental water from the Nebine catchment and Toorale local entitlements.

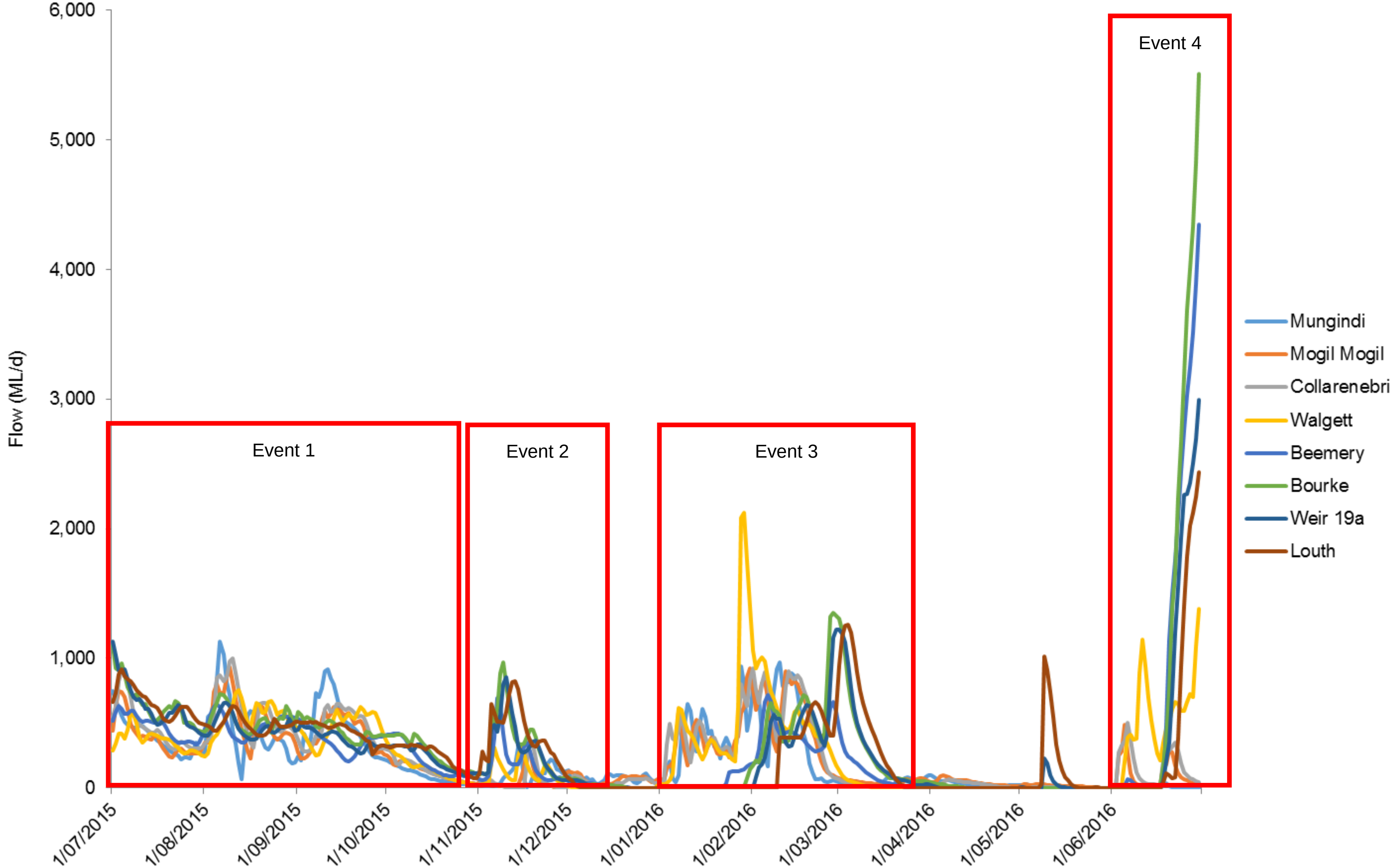

Figure B-3: Mean daily flow at gauging stations on Barwon-Darling River system (1 July 2015 - 30 June 2016). Events used in the analysis of northern tributary contributions are boxed in red.

Although event 4 represents the most significant flow event recorded during 2015-16 (Figure B-3), both the event and Commonwealth environmental water take continued into the 2016-17 water year. Accordingly, full analysis of event 4 will be undertaken during 2016-17 reporting.

A localised event occurred in the vicinity of the Selected Area on 9 May 2016, but was insufficient to trigger Commonwealth environmental water take.

Commonwealth environmental water events can be divided into regulated and unregulated events. Unregulated events are linked to prevailing climatic conditions, requiring specific streamflow conditions to be met in order to trigger individual Commonwealth environmental water entitlements. Unregulated Commonwealth environmental water take for each event is presented for each catchment in Table B-3.

Table B-3: Unregulated Commonwealth environmental water events for 2015/16 water year.

Basin Plan Region	Tributary	Unregulated CEW take (ML)	Comments
QLD Border Rivers	Dumaresq-Macintyre River	CEW 1 – 644.2	Series of small short fresh flows triggered CEW in late July/early August and late August.
		CEW 2 – 243.5	10,000 Ml/d flow recorded at Goondiwindi in November, 2015.
		CEW 3 – 137.1	Early February 2016.
	Severn River	CEW 3 – 22.22	Very brief period of CEW take on 31 January-1 February.
QLD Moonie	Lower Moonie River	CEW 1 – 200.98	Brief period of CEW access 25-28 July, 2015.
QLD Condamine – Balonne	Nebine Creek	CEW 4 - 997.78	CEW triggered during June 2016.
QLD Warrego	Upper Warrego River	0	No CEW triggering events during 2015/16.
	Lower Warrego River	CEW 3 – 859.29	Early January flows peaking at 10,000 ML/d at Cunnamulla allowed CEW access 17-19 January 2016.
NSW Condamine-Balonne	Lower Balonne	CEW 3 – 9,454.90	Flows peaked at 25,000 ML/d at St George on 11 February, 2016. CEW access 9-16 February.
NSW Gwydir	Mallowa Creek	CEW 2 - 336	Supplementary water event triggered by natural flow events during November 2015.
	Mehi River	CEW 2 - 964	Supplementary water event in 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 CEW access licences at Toorale.

Basin Plan Region	Tributary	Unregulated CEW take (ML)	Comments
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-flow for the Western Floodplain, however, as these were local events and not observed at Ford's Bridge, no CEW was taken.
NSW Barwon - Darling	Barwon-Darling River	CEW 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.
		CEW 3 – 3,481.13	Late January – February event 3,481.13 ML of B Class entitlements at Collarenebri.
		CEW 4 – 1,456.67	June 2016 – 1100 ML B Class and 356.67 ML C Class at Toorale.

Regulated Commonwealth 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 Commonwealth environmental water take for each river system is presented in Table B-4.

Assessing the regulated Commonwealth environmental water accounted during 2015-16, the following Commonwealth environmental water events were considered likely to influence flows within the 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 Commonwealth Environmental water was not delivered to these. Flows remained below the 50 ML/day 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 B-4: Regulated Commonwealth environmental water take, 2015/16.

Basin Plan Region	Tributary	Regulated CEW take (ML)	Comments
NSW Gwydir	Gwydir River	1,750	750 ML CEW released to offset extracted flows during January 2016 flow event. 600 ML CEW in February, 2016. 400 ML low-flow augmentation release commenced 10 April for 30-40 days duration.
	Mallowa Creek	3,486	2136 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 Commonwealth environmental water used in the Namoi during 2015/16.
NSW Macquarie-Castlereagh	Macquarie Marshes	12,114	A total of 52,554 ML (40,440ML 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 water.

End-of-system flow event analysis

End-of-system Commonwealth environmental water figures are considered indicative only, but provide an estimation of the volumetric contribution of upstream Commonwealth environmental water as it passes through the Barwon-Darling system to the Selected Area and further downstream.

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 B-3). Commonwealth 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 Selected Area (Table B-5).

Event 2 was a short duration natural fresh that occurred between 2 November and 4 December 2015 (Figure B-3). Commonwealth environmental water take during this period comprised 1207.5 ML.

Allowing for system losses, this was estimated to contribute around 4% of flow volume at the Selected Area (Table B-6).

Commonwealth environmental water event 3 occurred between 4 January and 25 March 2016 (Figure B-3). Commonwealth 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 Commonwealth environmental water contributed approximately 30.3% of flow volume at the Selected Area during this event (Table B-7). During this event approximately 7,880 ML entered the Selected Area via the Warrego River, of which approximately 4% was considered to be Commonwealth environmental water, allowing for system losses.

As indicated above, Commonwealth environmental water event 4 continued well into the 2016-17 water year and the total contribution of Commonwealth environmental water at the Selected Area will be analysed as part of 2016-17 reporting.

Table B-5 Commonwealth environmental water flow event 1 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream CEW Take	Estimated EOS CEW	
	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

Table B-6 2015-16 Commonwealth environmental water flow event 2 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream CEW Take	Estimated EOS CEW	
	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

Table B-7 2015-16 Commonwealth environmental water flow event 3 end of system flow assessment.

Gauging Station	Event Duration			Total Event Discharge	Upstream CEW Take	Estimated EOS CEW	
	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

In addition to upstream flow events, there are a number of local Commonwealth environmental water entitlements directly associated with agreed watering actions at the Selected Area (Table B-8). The total 2015-16 take against these local Commonwealth environmental water entitlements was 1,529.67 ML. This includes 73 ML accounted against the A Class Darling River at Toorale Station licences during July 2015 as well as 1,100 ML B Class and 356.67 ML C Class during June 2016.

Table B-8 Commonwealth environmental water entitlements associated with the Selected Area.

Water source	Water Access Licence	Registered entitlement (ML)	LTAAY (ML)	Trigger flow conditions (ML/d – location)
Warrego River at Toorale Station	Boera Dam WAL27558	1134	8106	Fresh in Warrego reaching Darling (approx. 300 ML/d at Ford's Bridge) plus >330 ML/d at Louth (425004).
	Upstream Boera WAL27555	972		
	Peebles Dam WAL27552	6000		
Warrego Western Floodplain	Special High Flow – Boera Dam WAL31152	9720	9720	Visible flow in Warrego at or near Darling plus >979 ML/d at Louth (425004).
Darling River at Toorale Station	A Class WAL33701 WAL33704	51 22	8362	>350 Ml/day at Bourke (425003) and > 260 ML/d at Louth (425004).
	B Class WAL33784 WAL35944	1560 1188		>1,250 Ml/day at Bourke (425003) and > 1,130 ML/d at Louth (425004).
	C Class WAL35943	5535		>1,339 ML/d at Louth (425004).

B.3.2 Multi-year comparison

The 2015-16 water year is the second year of the five year LTIM project. Comparing 2015-16 flows and 2014-15 flows, it is apparent that both years were characterised by predominantly low flow conditions with occasional small in-channel flow pulses of insufficient volume to exceed channel capacity.

Both years were characterised by small-scale events from July through to October after the typical summer flood season, however, these were more pronounced during 2015-16, and several flow events during the remainder of each water year.

During 2014-15 a regulated block release of 16,972 ML (originating in the Gwydir system) in response to very low river flows passed along the Barwon-Darling River during late October and early November. This flow gradually attenuated as it passed downstream and no influence was measured at the Louth gauge.

The two unregulated 2014-15 events (Event 1 and Event 2) were generally longer lasting and exhibited higher average daily flow volumes than those during 2015-16, potentially due to the pumping embargo in place at the time. However, total event volumes at Louth during both years tended to be similar (Figure B-4). Event 1 during 2015-16 was the largest, reflecting the extended duration of the event rather than high daily discharge volumes.

Total proportions of Commonwealth environmental water varied between 4% and 30%, with greater proportions of environmental water occurring during larger flow events, reflecting wider spread rainfall and greater triggering of Commonwealth environmental water entitlements.

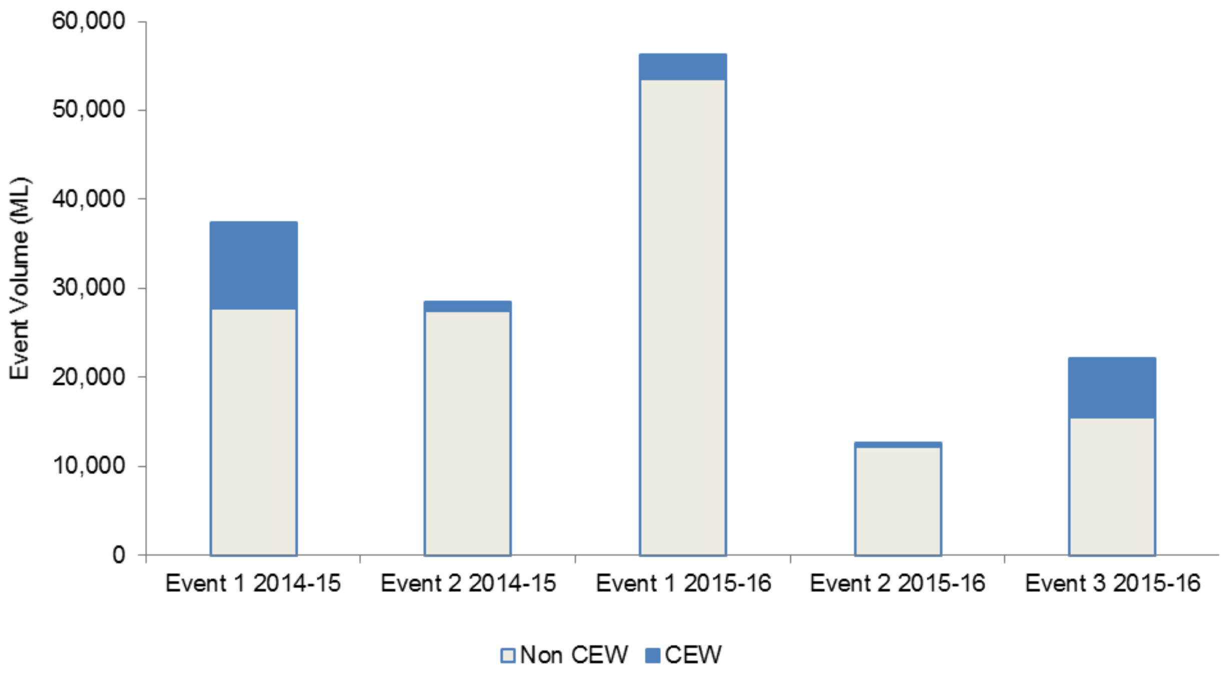

Figure B-4: Comparison of 2014-2015 and 2015-16 flow event at Louth gauge. Note 2016 Event 4 will be evaluated in 2016-17 reporting.

B.4 Discussion

The 2015-16 water year provided four in-channel, flow events during which Commonwealth environmental water was considered likely to influence flows down the Darling River and at the Selected Area.

The first event was characterised by ongoing patchy rainfall events between July and October, 2015, which were sufficient to trigger Commonwealth environmental water take from the Border Rivers and Moonie River catchments. In addition, flows in the Barwon-Darling were sufficient to enable upstream take above Collarenebri as well as Class A water at Toorale station. It is estimated that Commonwealth environmental water contributed approximately 5% of total flows at the Selected Area during this flow event.

The second event was a small, but pronounced, fresh during November 2015, triggering Commonwealth environmental water take from the Border Rivers catchments as well as supplementary flows within the Mehi River (part of the Gwydir catchment). This small event resulted in a maximum flow peak of approximately 820 ML/d at the Louth gauge.

The third Commonwealth environmental water event occurred as a series of pulses between January and March 2016, during which take occurred further west, to include the Warrego, Condamine-Balonne, Barwon-Darling and Border Rivers catchments. The wider rainfall patterns increased the relative percent contribution of Commonwealth environmental water at the Selected Area to approximately 30% of total flows, however, the peak flow at Louth of 1,260 ML/d was insufficient to trigger take against local licences.

A fourth, larger, event commenced during mid-June enabling Commonwealth environmental water take from the Nebine catchment within the Condamine Balonne system, as well as triggering local licence entitlements at the Selected Area. At the time of writing this event remained ongoing, and will be analysed as part of the 2016-17 water year.

Overall flow behaviour was similar to that experienced during the 2014-15 water year. Both years were characterised by generally low flow conditions, three distinct, flow pulses and similar end-of-system total discharge volumes. In both years the total proportion of end-of-system Commonwealth environmental water was variable, reflecting the differing nature of individual triggering events, at an event scale.

B.5 Conclusion

The 2015/16 water year was characterised by dry conditions within the Northern Tributaries. Four in-channel flow events sufficient to trigger Commonwealth environmental water take occurred during July-October 2015, November 2015, January- March 2016 and June 2016. Events 1, 2 and 3 provided approximately 56,000 ML, 12,600 ML and 22,100 ML of water, respectively, at Louth, downstream of the Selected Area. It is estimated that during each event Commonwealth environmental water made up around 5%, 4% and 30% of these flows respectively, enhancing in-channel longitudinal connection through the Selected Area.

These results are similar to those experienced during 2014-15, where two Commonwealth environmental water events contributed 4% and 25% of flows at the Selected Area.

Analysis of these flow events indicates that during 2015-16, Commonwealth environmental water take in upstream catchments played a small role in promoting the transmission of natural flow events downstream towards the Selected Area. The relative contribution of Commonwealth environmental water tended to increase as take was triggered in catchments further west.

B.6 References

Commonwealth of Australia. 2015. *Commonwealth Environmental Water Office Long Term intervention Monitoring Project Junction of the Warrego and Darling Rivers Selected Area – 2014-15 Evaluation Report*. Commonwealth of Australia, Canberra.

Appendix C Hydrology (Channel)

C.1 Introduction

The lower Warrego River within the junction of the Warrego and Darling rivers Selected Area (Selected Area), is a complex channel, with multiple secondary channels bordering a main channel for most of its length (Holz *et al.* 2008). Along this reach of the river a number of in-channel dams and flow diversion structures have been established over the last 160 years (Aurecon 2012). At present these dams are in various states of repair, with some still heavily influencing the hydrology, while others have breached and have little influence on river flows (Capon 2009). The Hydrology (Channel) indicator describes the channel network and inter-channel connectivity of the lower Warrego River. Previous reporting on this indicator quantified the length of the channel network and assessed flow travel times through the Warrego catchment (Commonwealth of Australia 2015). This chapter further characterises the size and shape of the channels of the lower Warrego River within the selected Area. This indicator links to other indicators being measured including Hydrology (Floodplain and River), Water Quality, Stream Metabolism, Microinvertebrates, Frogs and Waterbird Diversity. This indicator addresses the following question:

- What did Commonwealth environmental water contribute to hydrological connectivity?

C.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area in 2015-16. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January – March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River (Figure C-1; Appendix A).

C.1.2 2014-15 monitoring outcomes

Several hydrological aspects were investigated with respect to the lower Warrego River in the 2014-15 evaluation (Commonwealth of Australia 2015). This included mapping of primary and secondary flow paths and an assessment of flow travel times down the Warrego catchment into the Selected Area. A total of 185.2 km of channels were mapped along the Warrego River within the Selected Area. Of these, 65.4 km (35%) were mapped as primary channels, and 119.8 km (65%) mapped as secondary channels. Secondary channels in the northern section of the Selected Area tend to be longer and are reflective of channels that once connected the Western Floodplain to the main channel before the western embankment was established. There are also several larger flow paths to the east of the Warrego main channel, one of which is called the eastern bywash, through which water can travel around and effectively bypass the Boera Dam wall. The eastern bywash is thought to commence-to-flow when Boera Dam reaches a stage height of 2.91 m (P.Terrill unpublished data). Through the mid sections of the Warrego River zone (from Booka Dam to Peebles Dam) the secondary channels tend to be shorter and in closer proximity to the primary river channel. At the downstream end of the Warrego, the influence of the larger Darling River is seen. Channels and wetlands like Ross Billabong are more related to Darling River geomorphic processes than those of the Warrego.

Analysis of a flow event that occurred in the Warrego catchment in December 2014-March 2015 suggested that flows generated in the top of the Warrego catchment around Augathella take around 29 days to reach the selected area. Travel of flows through the Warrego channel within the Selected Area from Boera Dam to the confluence with the Darling river are relatively fast with flows only taking a single day to move through this reach (Figure C-1).

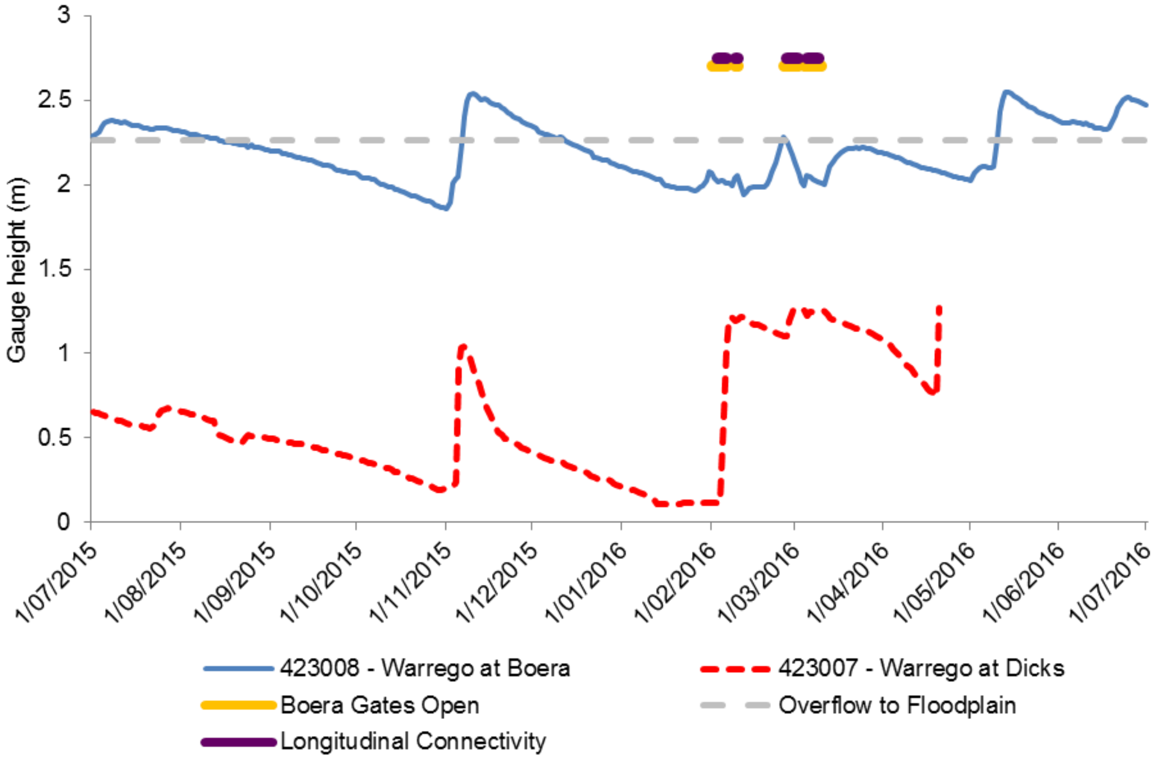

Figure C-1: Gauge heights in Boera and Dicks dam and periods of connection down the lower Warrego channel in 2015-16 water year. All available data plotted for Warrego at Dicks Dam gauging station.

C.2 Methods

In order to further describe the character of the channel network in the lower Warrego River, a series of 17 cross-sectional transects were measured spanning the lower Warrego channel network and its floodplain. These transects were produced from the 5 m Digital Elevation Model (DEM), and were evenly spaced down the Warrego River from Boera Dam to the Darling River confluence (Figure C-2).

Each transect was interrogated to define the width and depth of each primary and secondary channel that intercepted the transect. Primary and secondary channels were identified by overlaying the channel network GIS layer developed in the 2014-15 year evaluation (Commonwealth of Australia 2015). In some instances, due to the sinuosity of the channels, the channels did not intersect the transects at a perpendicular angle. In these instances, channel width was estimated by manually measuring an appropriate perpendicular line across the channel based on aerial imagery in ArcGIS. Once the width and depth of each primary and secondary channel was determined, the width/depth ratio of each was calculated. Width/depth ratio is a common measure of channel shape used to characterise river channels (Rosgen 1994).

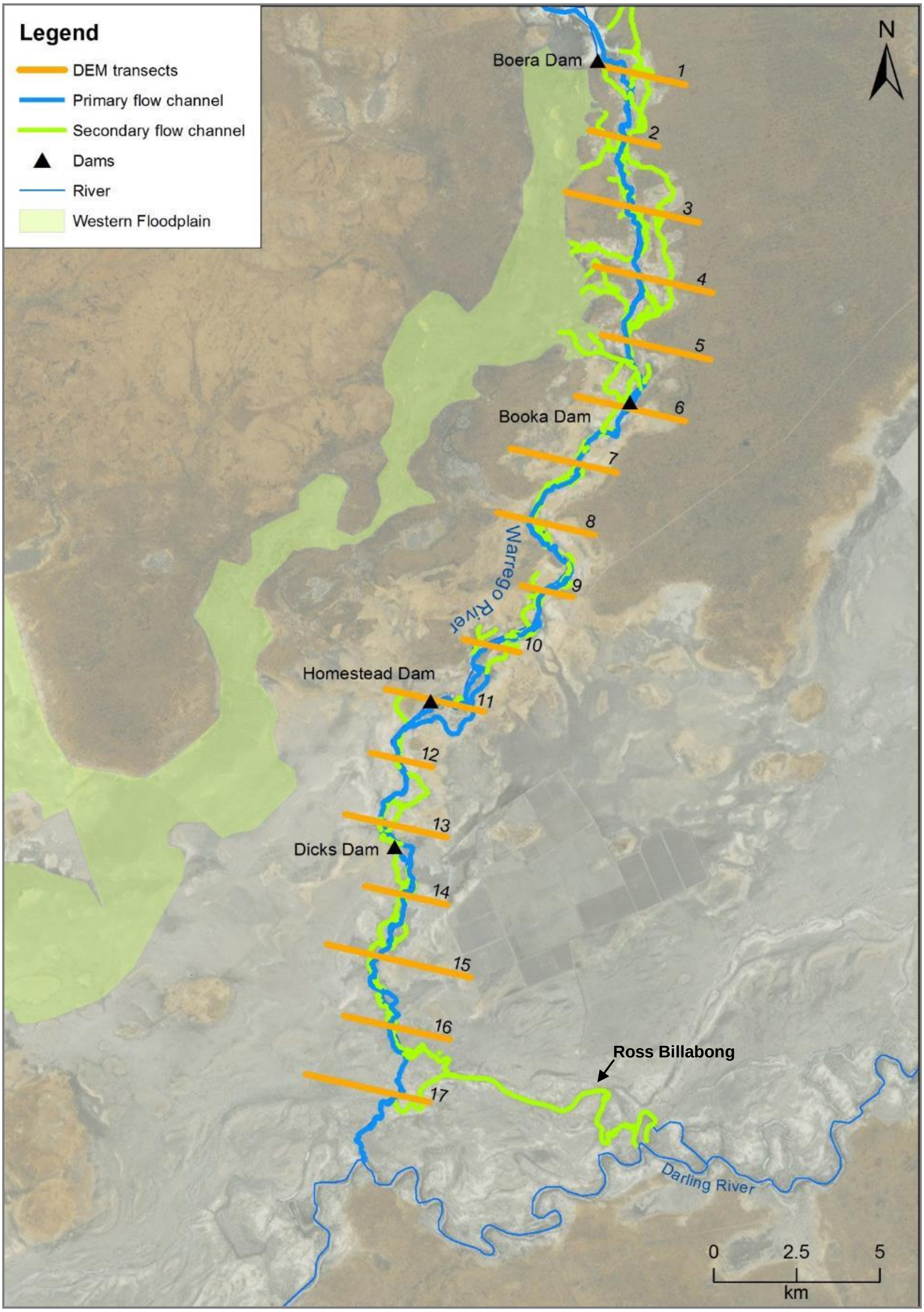

Figure C-2: The lower Warrego channel network showing the location of DEM derived transects.

C.3 Results and Discussion

From the 17 transects, 55 individual channel cross sections were assessed. These ranged in width from 10-265 m, depth from 0.2-3.66 m and width/depth ratios from 7.7-759. Of the 55 cross sections, 19 were on channels previously mapped as primary channels, and 32 were on secondary channels. As expected, primary channels were wider (89±67 m) and deeper (1.0±0.9 m) on average (±SD) than secondary channels (width 85±61 m; depth 0.7±0.6 m).

There was little consistent downstream trend in either width, depth or the width/depth ratios of primary channels (Figure C-3). However, there did appear to be a relationship between the location of the dams within Toorale and channel character, with cross-sections located within the ponded sections of dams (cross-sections 10-12 in Homestead Dam, cross-section 15 on Dicks Dam and 17-18 in Peebles Dam; Figure C-3a; Figure C-3b) tending to be wider and generally shallower than cross sections in other areas. This pattern was also observed in the width/depth ratios (Figure C-3c). Whether this trend is a result of the influence of damming on channel character through sedimentation and widening, or due to the preferencial placement of dams in wider areas of the channel remains unclear.

There appears to be a diversity of channel characteristics within the secondary channels of the lower Warrego River. Multivariate analysis identified four clusters in the data at the 60% similarity level (Figure C-4). Group 1 channels were characterised by relatively deep (~1 m), narrow (<25 m) cross-sections and lower W/D ratios (<40; Table C-1). Groups 2 and 3 had shallower (<1 m) and wider (>35 m) channels with high W/D ratios (<60), and group 4 contained one channel which was the deepest channel recorded with a depth of 2.95 m (Table C-1). Similarly to primary channels, there appeared to be little downstream trend in channel character of secondary channels (Figure C-5).

Description of the channel network of the lower Warrego river in the 2015-16 evaluation suggested that a significant proportion (65%) of the total length of channels were smaller secondary channels that carry water during higher flow levels. This analysis supports these observations by providing information on the character of these channels. The consistently high W/D ratio values of these channels is consistent with the distributary nature of the system (Schumm 1985; Rosgen 1994; Holz *et al*. 2008), and suggests that these channels are not incised into the surrounding landscape. The presence of distinct groupings of secondary channels in terms of their cross-sectional character is a reflection of the diverse geomorphology of the surrounding landscape and the historically variable flow regime of the system. While some channels are relatively deep and tend to act as more consistent flow paths in the system, others reflect shallower broad flood channels that only connect at higher river levels (Figure C-6).

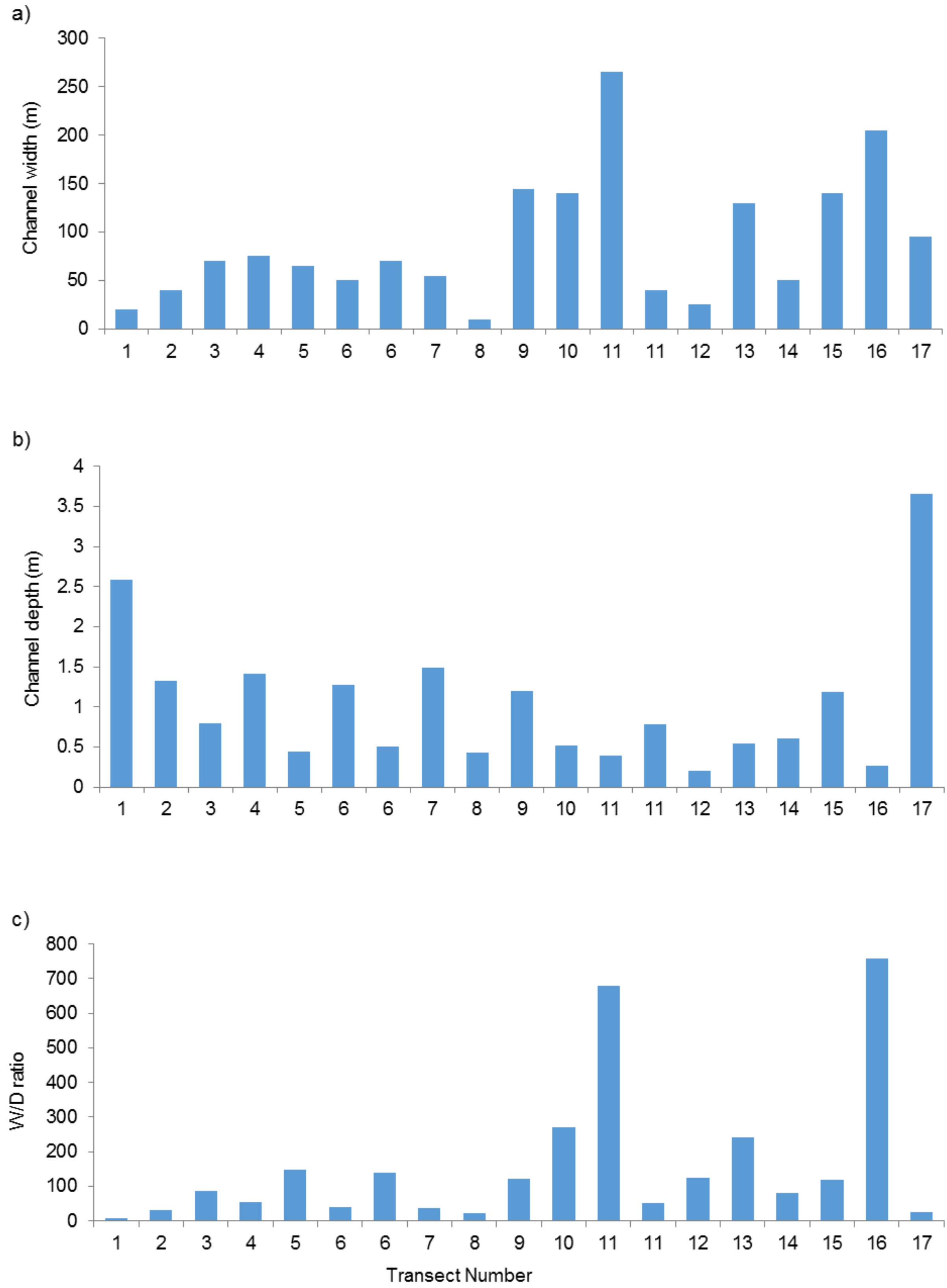

Figure C-3: Channel cross-sectional a) width, b) depth and c) width/depth ratio for primary channels measured along the Warrego River between Boera Dam and the Darling confluence. Numbered in downstream order.

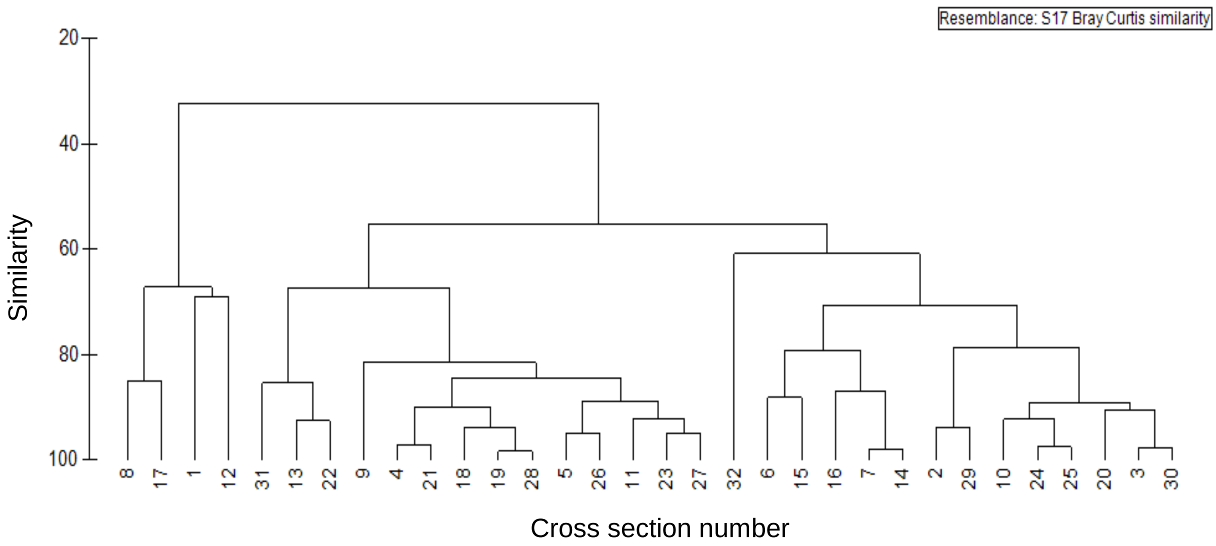

Figure C-4: Cluster diagram of Warrego River secondary channel character.

Table C-1: Descriptive statistics for secondary channel character groupings.

	Group 1			Group 2			Group 3			Group 4		
	Depth (m)	Width (m)	W/D ratio	Depth (m)	Width (m)	W/D ratio	Depth (m)	Width (m)	W/D ratio	Depth (m)	Width (m)	W/D ratio
Mean	0.90	18.75	26.32	0.78	78.46	100.76	0.36	112.14	300.79	2.95	70.00	23.73
Min	0.37	10.00	13.09	0.28	35.00	59.14	0.13	35.00	205.88			
Max	1.91	25.00	40.54	1.09	140.00	168.67	0.62	260.00	531.91			

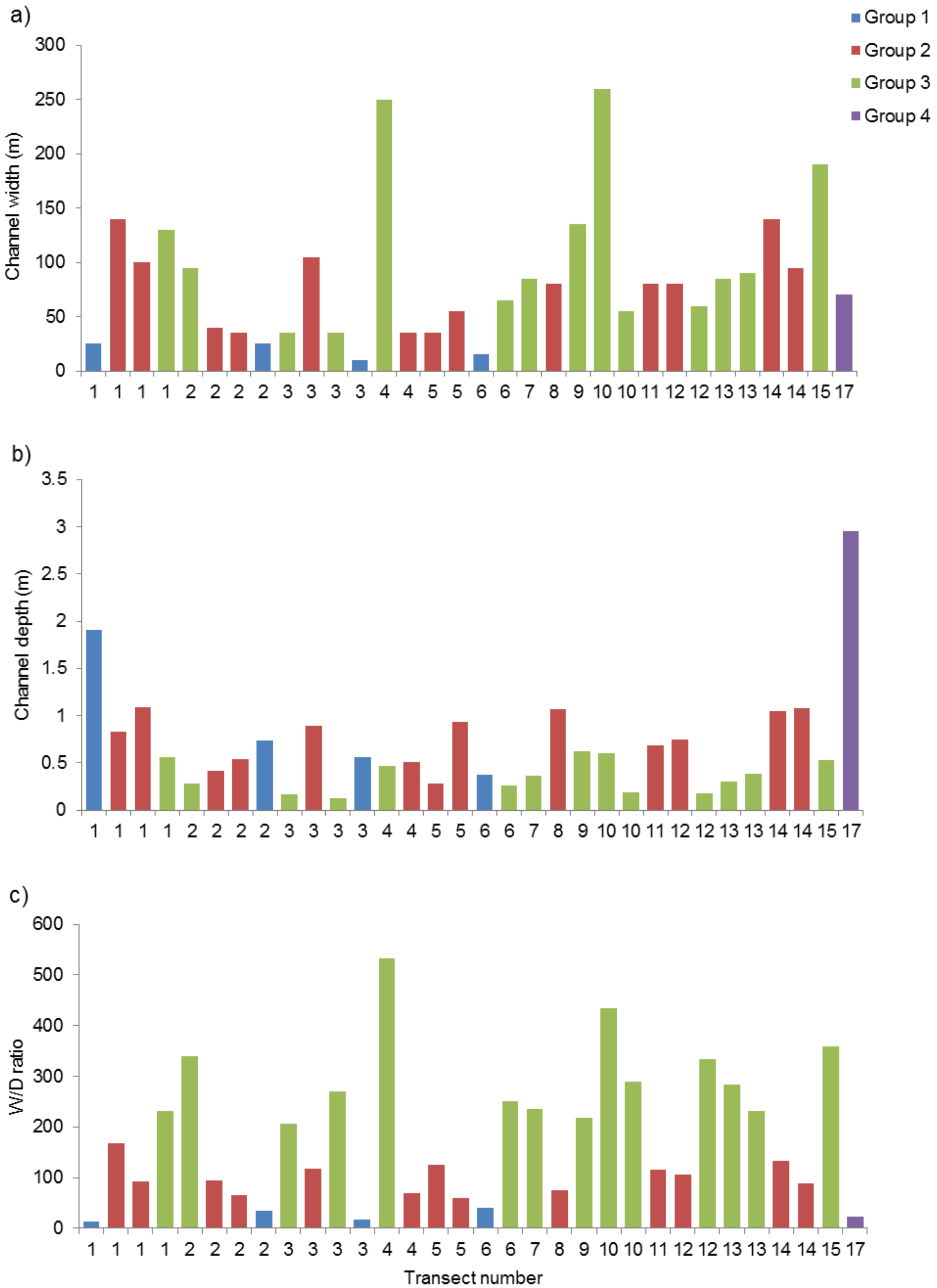

Figure C-5: Channel cross-sectional a) width, b) depth and c) width/depth ratio for secondary channels measured along the Warrego River between Boera Dam and the Darling confluence. N.B. Some transects had multiple channels.

Figure C-6: Examples of secondary channels of the lower Warrego River.

C.4 Conclusion

The lower Warrego River is composed of a number of channels that are diverse in both their length, connectivity and cross-sectional area. Larger primary channels exist along the system whose downstream dimensions appear to be associated with dams along the system, with the channels being relatively wide and shallow in the upstream proximity of the dams. The greater proportion of channels are smaller in nature, but diverse in character. These channels tend to be relatively wide for their depth - a characteristic of distributary channel networks. Geomorphic diversity has been linked broadly to increased ecological diversity in river systems, but this can be dependent on the degree of connection between different parts of the river channel network (Thorp *et al.* 2008). Work in coming years will further elucidate the implications of this complexity in channel character for hydrological connectivity, the ecology and ecosystem processes along the lower Warrego River within the Selected Area.

C.5 References

Commonwealth of Australia. 2015. *Commonwealth Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area – 2014-15 Evaluation Report.* Commonwealth of Australia, Canberra.

Holz, L., Barma, D. and Wettin, P. 2008. *Warrego River Scoping Study*. WMA Water, Sydney.

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Schumm, S.A. 1985. Patterns of Alluvial Rivers. *Annual Review of Earth Planetary Science, 13,* 5-17.

Thorp , J.H., Thoms, M.C. and Delong, M.D. 2008. *The Riverine Ecosystem Synthesis.* Elsevier, Sydney.

Appendix D Hydrology (Habitat)

D.1 Introduction

The Hydrology (Habitat) indicator documents the degree of hydrological connection of in-channel habitats including snags (large woody debris), bench surfaces and anabranch channels along the Darling channel and assesses the relative influence of Commonwealth environmental water on this connection. These habitat features have been shown to be important for the storage and supply of nutrients and organic matter (Southwell 2008; Thoms *et al*. 2005; Thoms and Sheldon 1997), and as habitat for native fish and other aquatic species (Crook and Robertson 1999; NSW DPI 2015). They have also been targeted in environmental flow planning to increase habitat and facilitate nutrient and carbon cycling (Commonwealth of Australia 2015). This indicator is directly relevant to other indicators measured in the Junction of the Warrego Darling Rivers Selected Area (Selected Area) including Hydrology (River and Northern Tributaries), Water Quality, and Stream Metabolism. This indicator addresses the following question:

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

D.1.1 Environmental watering in 2015–16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth water is held as unregulated entitlements and its influence is thus reliant on flows out of upstream catchments. During the 2015-16 water year, four flow events containing environmental water flowed down the Darling River within the selected area (Appendix B). These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. All four flows were in-channel pulses. Due to low river flows recorded at the water licence trigger locations during 2015-16, no additional take occurred against the other water licences associated with the Selected Area. However, a small flow event containing 4% Commonwealth environmental water from the upper Warrego catchment flowed through the Selected Area (Appendix B). This flow was constrained to the lower Warrego channel and did not influence inundation of the Western Floodplain. Total proportions of Commonwealth environment water in the Darling River varied between 4% and 30% (Appendix B).

A moderate pulse in the Darling River began in June reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by the 30 June 2016, and peaked at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

D.2 Methods

Benches and anabranches were identified through desktop mapping of in-channel habitat and aerial photograph interpretation along the Darling River within the Selected Area (Commonwealth of Australia 2015). Identified habitat features were verified in the field, and additional benches and anabranches mapped. In addition to the number and size of individual habitats 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-flow for anabranch channels (Commonwealth of Australia 2015). Commence-to-flow heights were recorded to the nearest vertical metre.

Snag data were obtained from the 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 D-1).

Grade 1: Woody habitat stand – single trunk or branch.

Grade 2: Woody habitat stand – trunk or branch with one or two branches.

Grade 3: Woody habitat stand – one or more trunks with multiple branches.

Grade 4: Woody habitat stand–highly complex complete tree with multiple branches, or accumulation of separate branches.

Figure D-1: Classification system used to grade complexity of snags (NSW DPI 2015).

The vertical commence-to-flow heights of individual habitats 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 (NSW 425037) gauge upstream of the Selected Area, while benches and anabranches downstream of the confluence were linked to the gauging station at Louth (NSW425004) (Figure D-3). Snags for the entire reach of the Darling River within the 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-flow discharges were reported at the Bourke Town (NSW 425003) gauging station as it has a more comprehensive flow record. In order 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 and 20 000 ML/d at the gauges from 2002 to present (total length of Weir 19A gauge record). Travel time between gauges was taken into account, with trend lines and associated regression equations of the relationship between gauges calculated (Figure D-2). Some variation was observed around the Weir 19A/Bourke town gauge relationship, which is likely a result of the influence of localised rainfall between these stations. These equations were used to express the commence-to-flow discharges measured at the Louth and Weir 19A gauges to the Bourke Town gauge. The commence-to-flow for each anabranch channel was determined using the entry or exit with the highest gauge height to better represent water flow into each anabranch.

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 benches in the Selected Area were inundated during 2015-16 to provide an estimate of total nutrient loads contributed to the river from these benches during the water year.

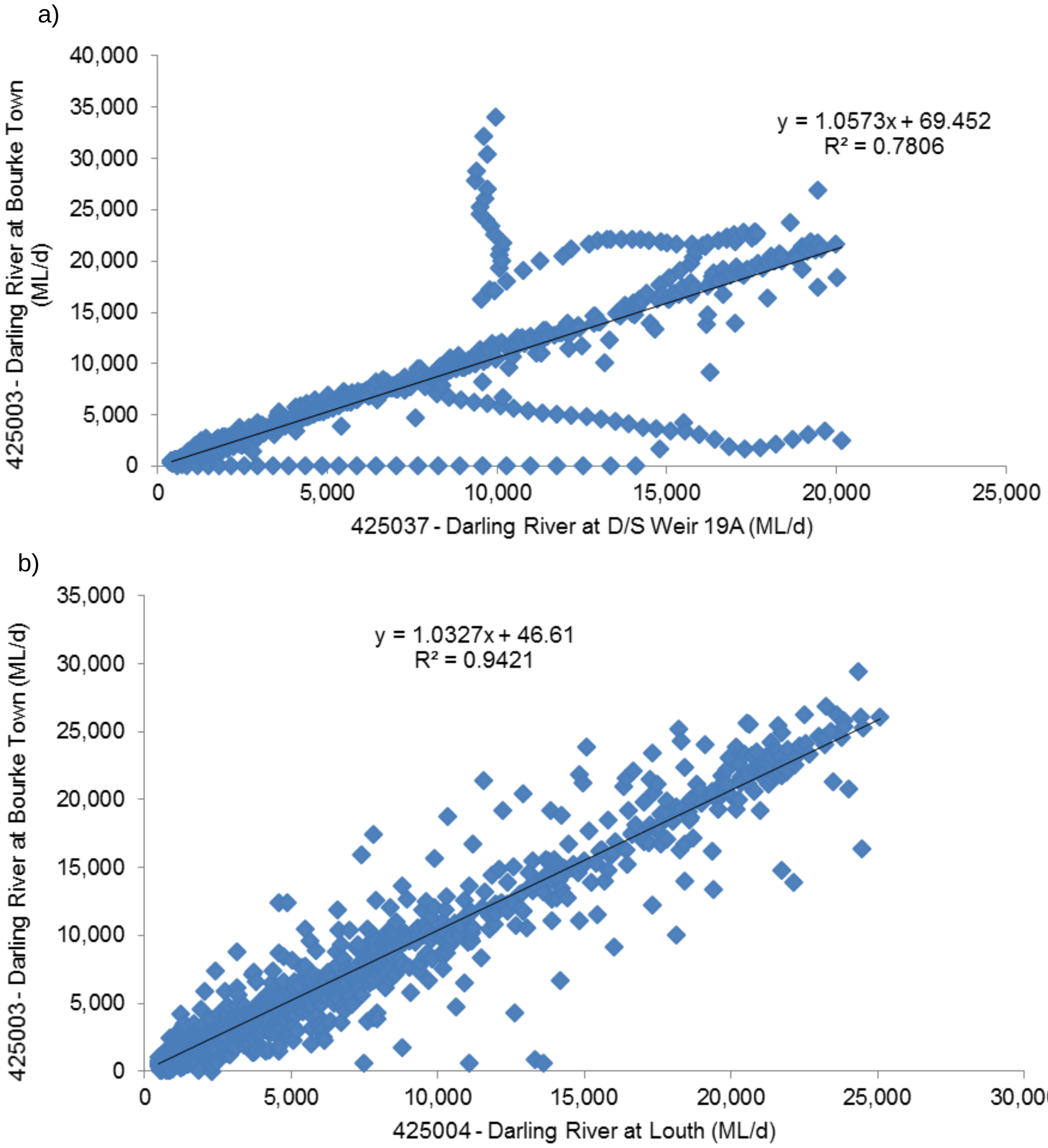

Figure D-2: Relationships between the Darling River @ Bourke Town gauge and a) Darling River @ Weir 19A and b) Darling River @ Louth gauging stations.

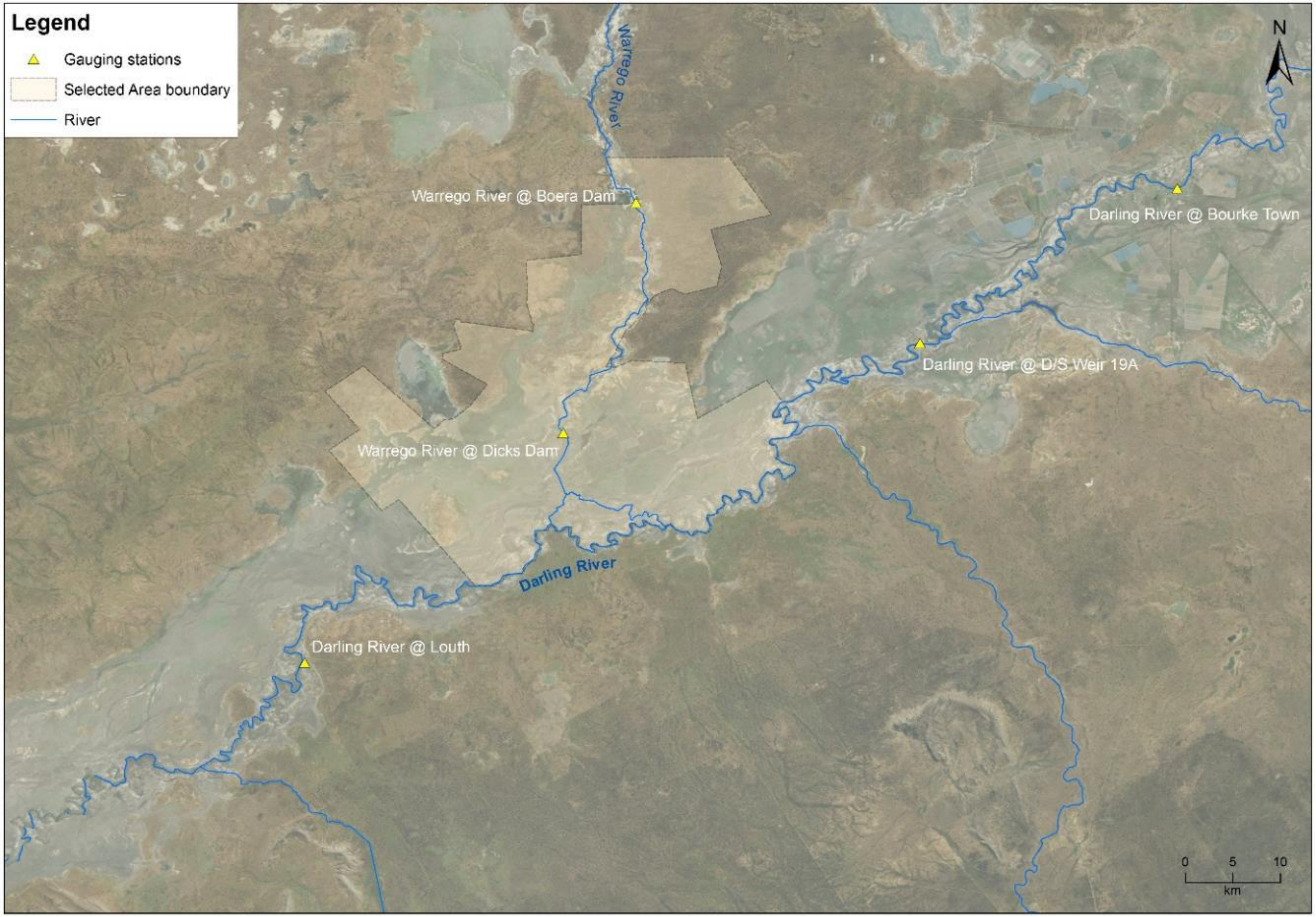

Figure D-3: Location of the gauging stations used in the hydrology (Habitat) indicator analysis.

D.3 Results

D.3.1 Bench surfaces and anabranch channels

One hundred and seventy-three benches with a total area of 8.38 ha were identified along the 76 km reach of the Darling River within the Selected Area. Commence-to-inundate levels of benches ranged from 1,846 ML/d to 18,889 ML/d. Benches tended to be located low in the river channel, with 124 (71%) benches becoming inundated at flows less than 10,000 ML/d (Table D-1). Of these, 45 (26%) surfaces would become inundated at flows less than 2,000 ML/d.

Table D-1 Number of bench surfaces in each discharge class and their total area

Discharge class (ML/d)	Number of benches	Proportion of benches (%)	Bench area (ha)
<2000	45	26	1.98
2,000–6,500	29	17	1.66
6,500–10,000	50	29	2.44
10,000–14,000	33	19	1.44
14,000–20,000	16	9	0.87
total	173		8.38

Twenty anabranch channels were identified within the study reach. The combined length of these anabranches was 60 km, which is 44% of the total length of channel in the study reach including the Darling River. Commence-to-flow discharges of anabranch channels ranged from 1,846 ML/d to 16,673 ML/d, with the majority of channels (90%) commencing-to-flow at discharges less than 10,000 ML/d (Table D-2). Further details of the analysis of the extent and distribution of habitat provided in the form of benches and anabranches is provided in the 2014-15 monitoring report (Commonwealth of Australia 2014).

Table D-2 Links between Anabranch channel discharge class, proportion of channels and channel length

Discharge class (ML/d)	Number of anabranches	Proportion of anabranch channels (%)	Channel length (km)	Proportion of channel length (%)
<2000	5	25	14.9	25
2,000–4,000	7	35	15.5	26
4,000–10,000	6	30	25.5	42
10,000–18,000	2	10	4.3	7
total	20		60.3	

D.3.2 Snags

A total of 3,735 snags were identified within the Darling River zone. Complexity was generally low across all inundation heights, with the majority of snags classified as Grade 1 and Grade 2. The greatest proportion (26%) of snags are found on the channel bed and are inundated when flow is greater than 69 ML/d (Figure D-4).

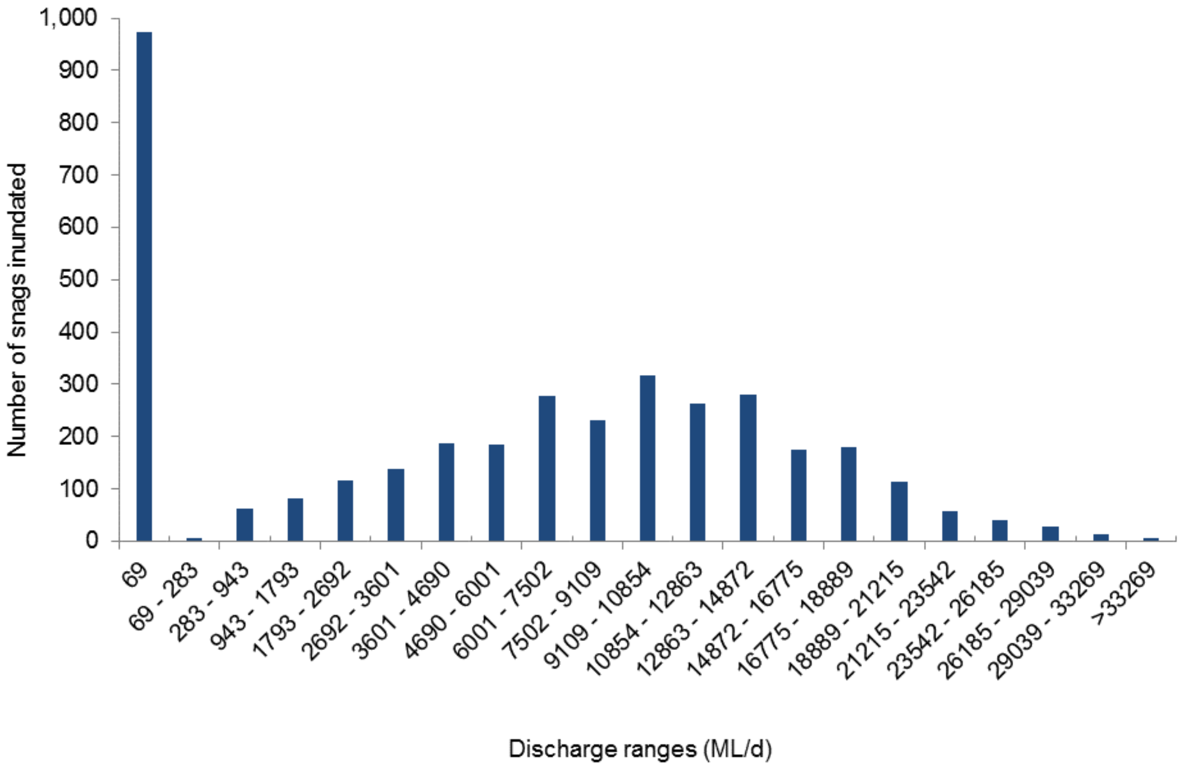

Figure D-4: Distribution of snags across discharge classes. Discharge measured at the Bourke Town gauge (NSW425003).

D.3.3 Connectivity in 2015–16

Three small flow events occurred in the 2015–16 water year. Flows in November and February peaked at 970 ML/d and 1,349 ML/d. These events were not sufficient to inundate benches in the lowest discharge class (<2,000 ML/d) as benches in this class become inundated above 1,800 ML/d. At the end of the 2015-16 water year a larger flow event occurred. By the end of the water year this flow had not yet peaked, and had reached 4,468 ML/d by the 30 June 2016. During this end of year event, benches that inundate at less than 2,000 ML/d were inundated for at least seven days (Figure D-5; Figure D-6). These benches account for 26% of the total number of benches identified within the Darling River zone, providing 19,762 m^2 of habitat. Combining this with the average 72 hourly nutrient release rates reported in Southwell (2008), it is estimated that these benches would have contributed 3.6 kg of total dissolved organic carbon, 1.1 kg of total dissolved nitrogen and 1.2 kg of total dissolved phosphorus to the river system during the time they were inundated.

Anabranches in the <2,000 ML/d and 2,000-4,000 ML/d discharge classes would have flowed during June 2016 (Figure D-7). The combined distance of the anabranches that connected during this partial event was 15.4 km. Together, these anabranches account for approximately 60% of the total number of identified anabranches, and 51% of the combined length of all anabranches identified in the zone.

Snags in the lower discharge ranges were inundated in the 2015-16 water year. The lowest discharge class (<69 ML/d) was inundated for at least 222 days throughout the 2015-16 water year, accounting for 973 (26%) of all snags. These snags may have been inundated for longer periods if located in pools, even though no flow was recorded at the Bourke Town gauge. A further seven snags in the 69 – 283 ML/d class were inundated for 171 days but only accounted for 0.2% of all snags. 61 snags in the 283 – 943 ML/d class were inundated for 19 days. There was not sufficient flow for other classes to be inundated until the moderate pulse event in June 2016. During this event 1,568 snags that are located to a flow height equivalent to 4,690 ML/d were inundated for at least four days. This represents 42% of the total number of snags mapped in the Selected Area.

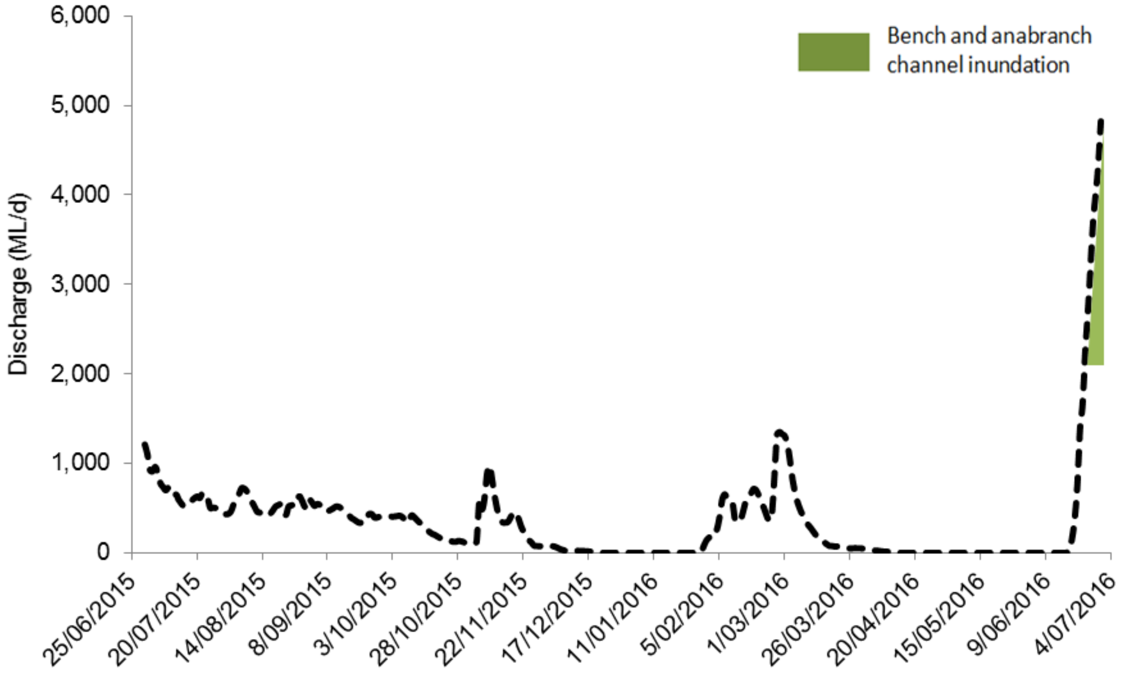

Figure D-5: Period of bench and anabranch channel inundation during the 2014–15 water year along the Darling River within the Selected Area. Discharge measured at the Bourke Town gauge (NSW425003).

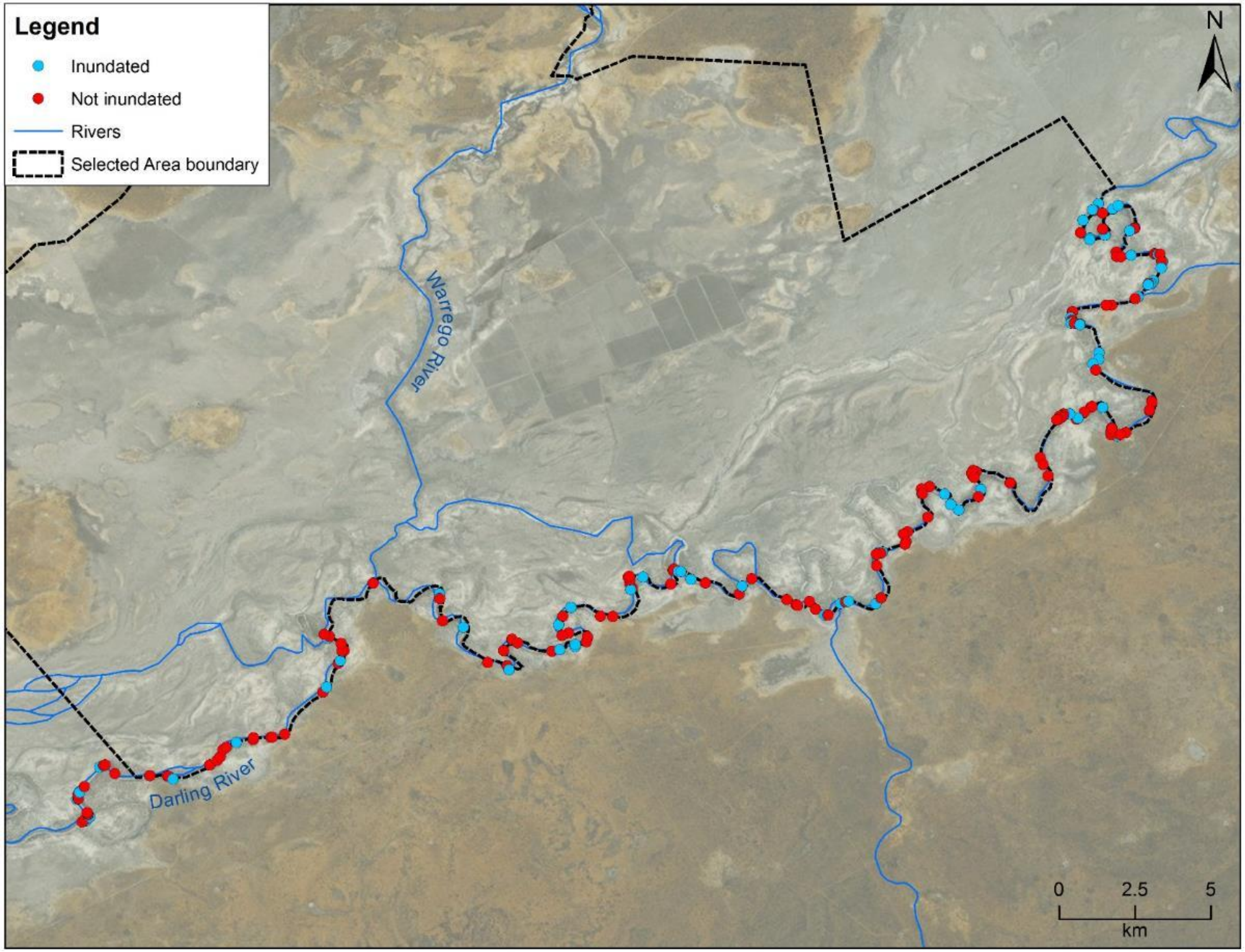

Figure D-6: Distribution of inundated bench surfaces in 2015-16 along the Darling River zone within the Selected Area.

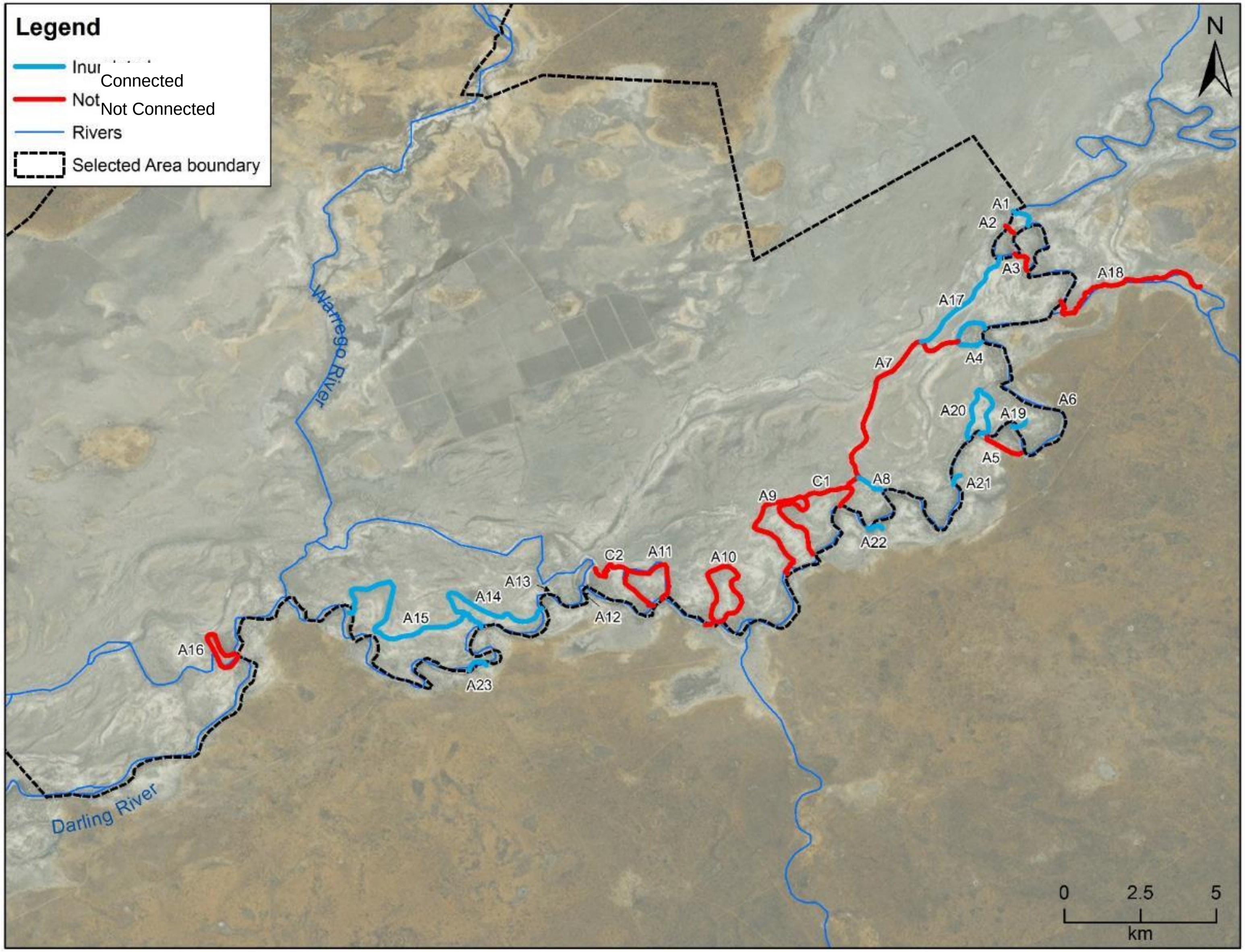

Figure D-7: Distribution of inundated anabranch channels in 2015-16 along the Darling River within the Selected Area.

D.4 Discussion

This study has quantified the number and character of key in-channel habitats along the Darling River within the Selected Area. A total of 173 individual bench surfaces and 20 anabranch channels were identified, that connect to the river channel at flows below bank full. Large proportions of these benches (71%) and anabranch channels (90%) become connected to the river at flows less than 10,000 ML/d measured at the Bourke Town gauge. These flows are within the range that may be influenced by Commonwealth environmental water in this reach of the Darling River (Commonwealth of Australia 2015).

Flows containing Commonwealth environmental water, from upstream tributaries while being relatively small in magnitude, inundated 25% and 31% of benches and anabranches respectively in the Selected Area during 2015–16. These events led to the release of small but potentially important quantities of dissolved carbon and nutrients from bench surfaces into the river channel ecosystem. This dissolved organic matter is a source of carbon that forms the foundation of aquatic food webs, and provides a source of energy for aquatic organisms (McGinness and Arthur 2011; Sheldon and Thoms 2006). Benches and anabranch channels also provide habitat during connection and are sites where organic matter and sediment accumulate during inundation (Thoms, *et al*. 2005; Southwell 2008). This two-way exchange of material, at relatively low river discharges, is thought to be important for maintaining the river ecosystem between larger flooding events (Sheldon and Thoms 2006). In addition, bench and anabranch channels form spawning and refuge habitat for fish and other animals (NSW DPI 2015).

Flow events containing a proportion of Commonwealth environmental water inundated 42% of the total number of snags mapped in the Selected Area along the Darling River reach. While 26% of these snags are located on the channel bed and are hence inundated for the majority of the time, the inundation of an additional 595 (16%) individual snags would have provided benefits to the system for a range of reasons. Snags play a major role in geomorphological processes and provide important habitat for aquatic and terrestrial organisms, including shade, refuge from high velocity flow and predators, spawning and nursery sites, and attachment sites for invertebrates (Treadwell 1999; Koehn and Nicol 2014). Snags also have a role in carbon and nutrient processing, by providing a substrate for biofilm development in which the bacterial and fungal components contribute to woody substrate decomposition, in-turn providing food for benthic algae, invertebrates and microorganisms that form part of food web for fish species (Treadwell 1999; NSW DPI 2015).

D.5 Conclusion

In-channel snags, bench surfaces and anabranch channels along the Darling River within the Selected Area are inundated at relatively low discharge volumes, with discharges <10,000 ML/d inundating the majority of these features. During 2015–16, around 30% of benches and anabranch channels were inundated by flow events containing Commonwealth environmental water, which were estimated to contribute small but potentially important quantities of dissolved carbon and nutrients to the river system. Forty two percent of snags were also inundated throughout the year providing additional habitat for fish and other aquatic biota.

D.6 References

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Appendix E Hydrology (Floodplain)

E.1 Introduction

The Hydrology (Floodplain) indicator provides information on the extent of inundation on the Western Floodplain produced by Commonwealth environmental water. This information is directly relevant to a number of other indicators measured in the Junction of the Warrego and Darling rivers Selected Area (Selected Area) including Vegetation Diversity, Waterbird Diversity, Hydrology (river and channel), Stream Metabolism and Microinvertebrates. The particular influence of hydrology on these indicators will be addressed under their respective sections.

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 water licence (Commonwealth of Australia 2015). Water managers have the ability to 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 information to evaluate the success of these watering decisions. The Hydrology (Floodplain) indicator aims to achieve this by combining information from a range of sources to build relationships between inflows, inundation extent and volumes of water in the Western Floodplain. Specifically this chapter addresses the following question:

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

E.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year (Figure E-1).

A moderate pulse in the Darling River began in June reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by the 30 June 2016, and peaking at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

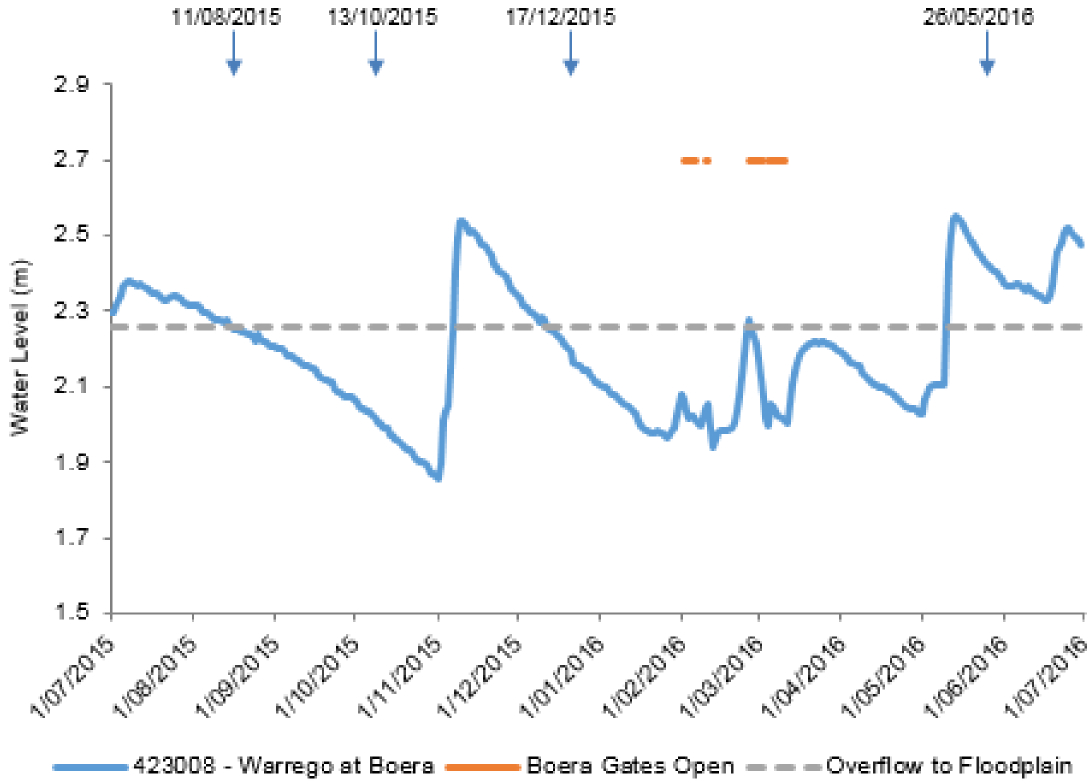

Figure E-1 Boera Dam levels during 2015-16 water year and flow to Western Floodplain and/or into lower Warrego channels (gates open).

E.1.2 2014-15 Monitoring outcomes

Inundation extent in the 2014-15 water year ranged from 0.5-36.9 ha when Boera Dam was above 2.26 m, the estimated overflow level to the Western Floodplain. Inundation of the floodplain increased at a greater rate when levels in Boera Dam exceeded 2.36 m. At lower gauge levels, inundation was restricted to a single flood channel at the northern section of the floodplain. At higher levels water spread through multiple flood channels, filling a waterhole on the eastern side of the floodplain and flowing south through numerous smaller channels.

Boera Dam water levels peaked at 2.44 m during February 2015 corresponding to inundation on the floodplain of 36.90 ha. Three vegetation communities were inundated at this time; lignum shrubland wetland, coolibah open woodland wetland and coolibah - river coobah - lignum woodland.

E.2 Methods

A number of 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:

- Lidar data
- Landsat imagery
- Existing vegetation mapping
- Water level records associated with water sensors and gauging stations

These data sources were scrutinised and combined to produce relationships with 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.

E.2.1 Landsat image analysis

All available Landsat 8 images captured during the 2015-16 season were assessed via the USGS Glovis website (http://glovis.usgs.gov/). Those with no cloud cover or other issues were chosen for further analysis. Four images spanning the season were selected for analysis, being captured on the following dates; 11 August 2015, 13 October 2015, 17 December 2015 and 26 May 2016.

The extent of inundation within each image was classified using density slicing of band 6 as described in Frazier and Page (2000). All inundated polygons within the extent of the Western Floodplain were retained, hence, inundation as a result of recent rainfall was also included. This may potentially overestimate the degree of inundation as a result of overland flow from Boera Dam, but does provide a broader picture of the Western Floodplain influenced by inundation during the 2015-16 water year. 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.

E.2.2 Digital elevation modelling

Flood delineation and volume calculations were undertaken by manipulating a 5m DEM derived from recently captured Lidar data (Commonwealth of Australia 2015) and a DEM developed by the MDBA in 2009. The resulting single DEM was then flattened by applying a correction plane (Figure E-2) to remove the regional north-south gradient. This was done to represent the floodplain as a 'closed' system to allow for the estimation of inundation volumes. To 'flatten' the DEM, average height at 20 points at 1 km intervals down the floodplain were calculated; the height difference from the maximum average height value and the maximum overall height of the transect was calculated; and a point layer extrapolated to the grid using the height difference to create the adjustment surface.

The flattened DEM was hypothetically flooded and the water levels visually checked against a 'wet' image (Bing maps June 2012). A good correlation was achieved. Inundation extent and volume for two gauge heights at Boera Dam corresponding to peaks in water level were modelled by hypothetically flooding the flattened DEM. The 'flood' was constrained to where the predicted inundated areas were connected to the dam overflow point. A constraint layer was developed for each modelled water level. Development of the constraint layers required consideration of obstructions (e.g. culverts, vegetation impacting the DEM) and a gap between lengths of channel up to 20 m was considered connected.

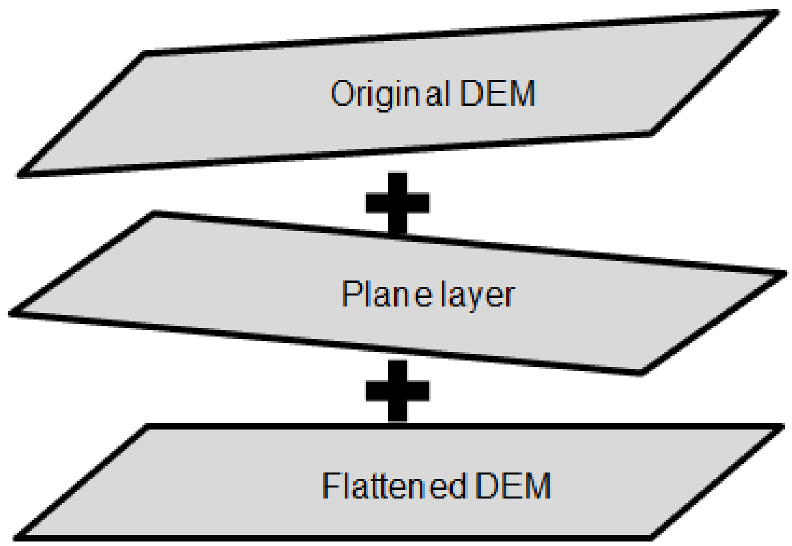

Figure E-2: Adjustment of the DEM to remove regional gradient.

E.3 Results

E.3.1 Landsat image analysis

Landsat imagery showed that the total extent of inundation varied throughout the water year on the Western Floodplain (Table E-1; Figure E-3). Inundation was estimated at 206.31 ha in August 2015. This followed a period of low level 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 was consistent 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 presumed 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 E-1; Figure E-4), 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.

Table E-1 Inundation extent of vegetation communities on Western Floodplain based on Landsat 8 image analysis.

Vegetation Community	Inundated area (ha)			
	Aug 15	Oct 15	Dec 15	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 Coobah - 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**

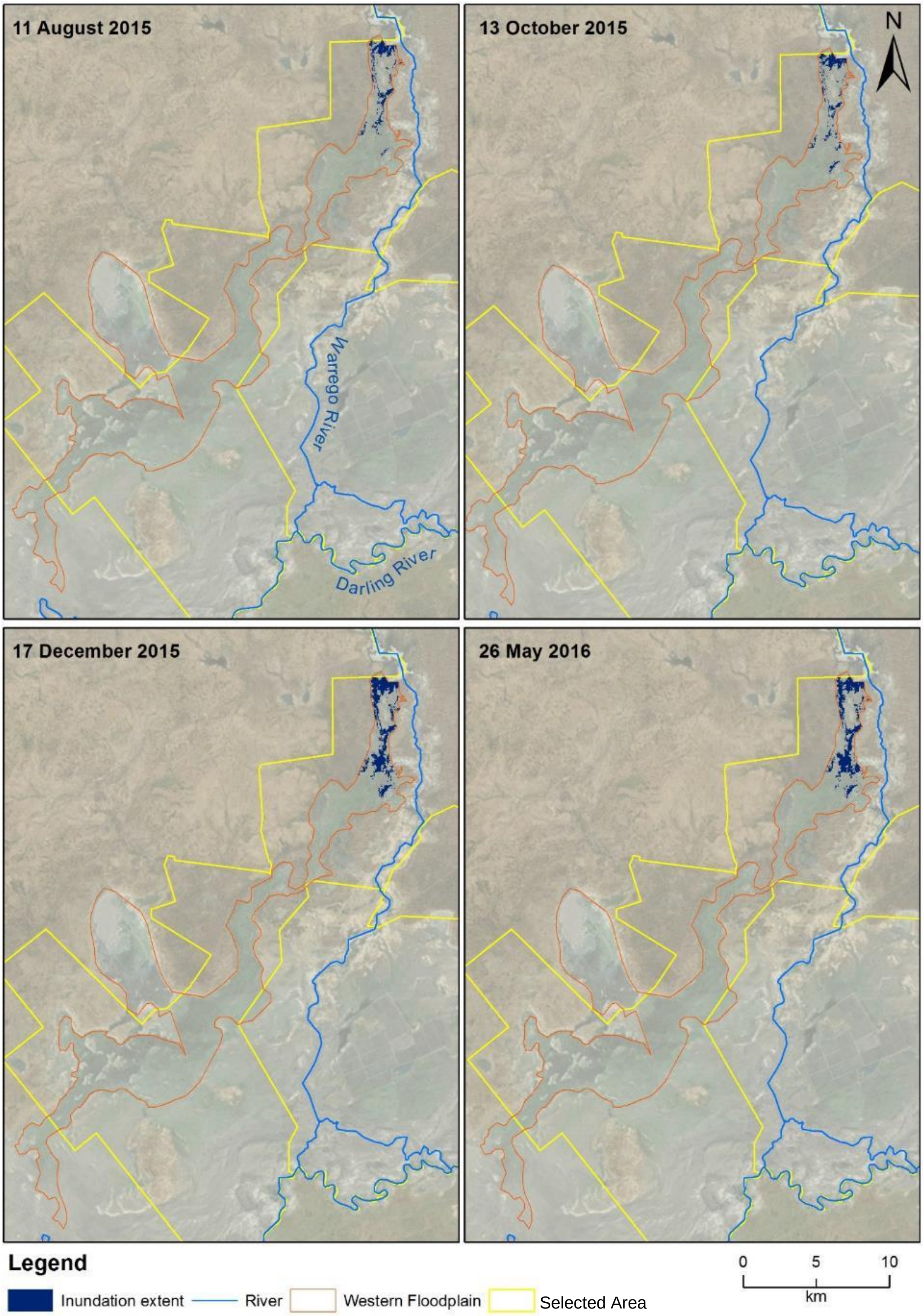

Figure E-3 Inundation extent on the Western Floodplain based on Landsat 8 image analysis for images captured on various dates throughout 2015-16.

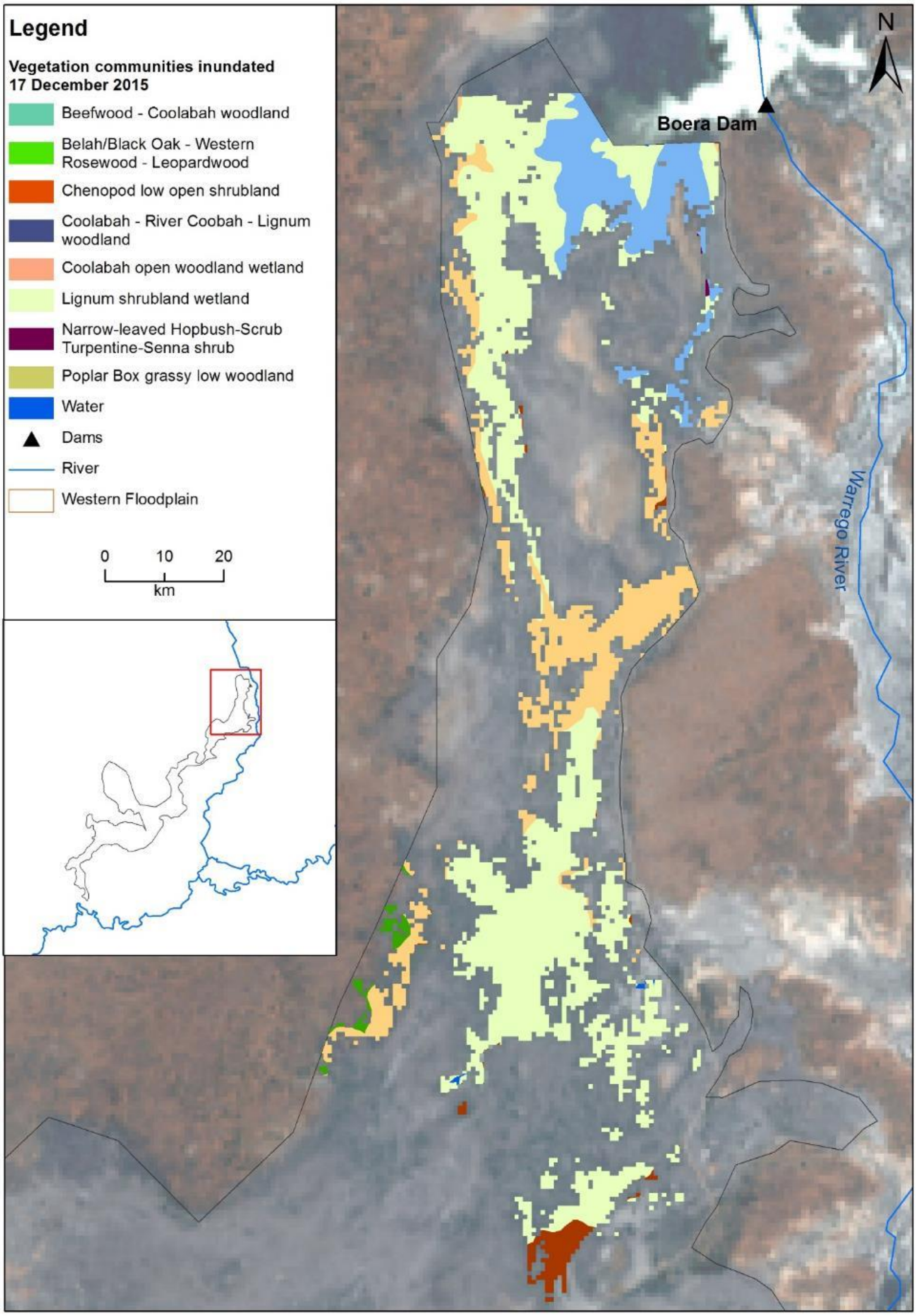

Figure E-4 Inundation of vegetation communities on the Western Floodplain based on Landsat 8 image analysis of image captured 17 December 2015 (maximum inundation captured).

E.3.2 Digital elevation modelling

Inundation modelling using the DEM was undertaken on several key water levels recorded at Boera dam during the 2015-16 water year. The lower of these levels was 2.41 m which occurred in July 2015. At this height it was estimated that 36.1 ha of floodplain was inundated with water flowing from Boera Dam with a corresponding volume of 60 ML stored on the floodplain (Table E-2; Figure E-5). The second modelled flow height was 2.54 m which was the maximum water height observed in Boera Dam during 2015-16. At this height, 141.17 ha of floodplain was estimated to be inundated as a result of flows from Boera Dam (Table E-2; Figure E-5), with a corresponding volume of 221.95 ML of water estimated to be stored in the floodplain at this water level (Table E-2).

Table E-2 Floodplain volume calculations at nominated gauge heights at Boera Dam.

Gauge height at Boera Dam (m)	AHD height (+102.6 m)	Description	Volume estimate (ML)	Area (ha)
2.41	105.01	Water level recorded July 2015	60.97	36.15
2.54	105.14	Maximum water level recorded in 2016	221.95	141.17

Four vegetation communities were inundated at the maximum extent of modelled inundation (Table E-3). Lignum shrubland was the most extensively inundated at 95.86 ha followed by coolibah open woodland at 28.68 ha, with much smaller areas of coolibah - river cooba - lignum and chenopod low open shrubland inundated at 5.82 ha and 7.22 ha respectively.

Table E-3 Modelled inundation extent of vegetation communities on Western Floodplain based on DEM.

Vegetation Community	Inundated area (ha) at maximum modelled inundation
Chenopod low open shrubland	7.2
Coolibah - River Coobah - Lignum woodland	5.8
Coolibah open woodland wetland	28.7
Lignum shrubland wetland	95.9
Stream/River/Dam	3.5
Total area inundated (ha)	141.1

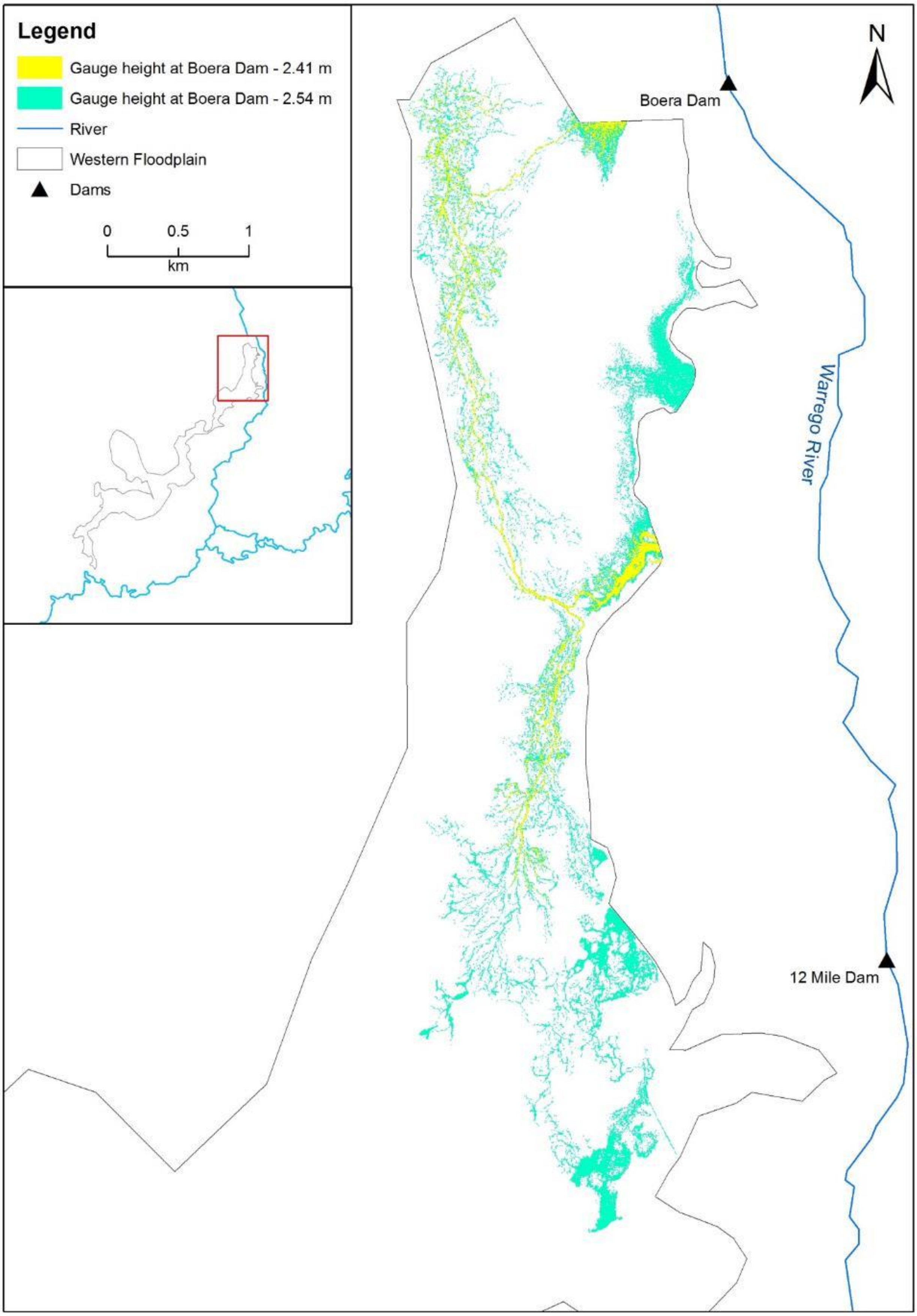

Figure E-5 Inundation extent derived from DEM modelling for water levels recorded in the 2015-16 water year on the Western Floodplain.

E.4 Discussion

Previous monitoring in 2014-15 showed a high level of agreement between DEM inundation modelling and Landsat image analysis for gauge heights up to 2.44 m, however in 2015-16 the results varied widely. DEM modelling was used to investigate expected inundation at two of the main flow peaks for the
2015-16 year and Landsat analysis was used to estimate actual inundation at other time periods. A comparison of both analyses at or near the November 2015 flow peak shows that modelled inundation using the DEM represents approximately 30% of the estimated inundation observed in the December 2015 Landsat image.

There are a number of explanations for this difference in results between the DEM and Landsat approaches. Firstly, the DEM modelling approach confined inundation extent to areas that were connected to the main flow connection path from Boera Dam onto the Western Floodplain. In contrast, the Landsat method identified all areas of inundation on the floodplain, which could include rainfall generated inundation along with river flow derived inundation. Given the above average rainfall recorded in the area in the months preceding Landsat capture in both December 2015 and late May 2016 (Figure E-6), a reasonable proportion of the inundation recorded in this Landsat image is likely to be rainfall generated. Secondly, the coarser 30 m resolution of the Landsat data compared to the 5 m resolution of the DEM would produce a consistently higher estimation from the Landsat data. Thirdly, close interrogation of the DEM flow paths within areas vegetated by thick lignum stands, suggest that there may be some masking of true channel occurrence in the Lidar data used to build the DEM due to thick lignum vegetation obscuring ground surface detection, therefore providing an underestimation of modelled inundation in these areas.

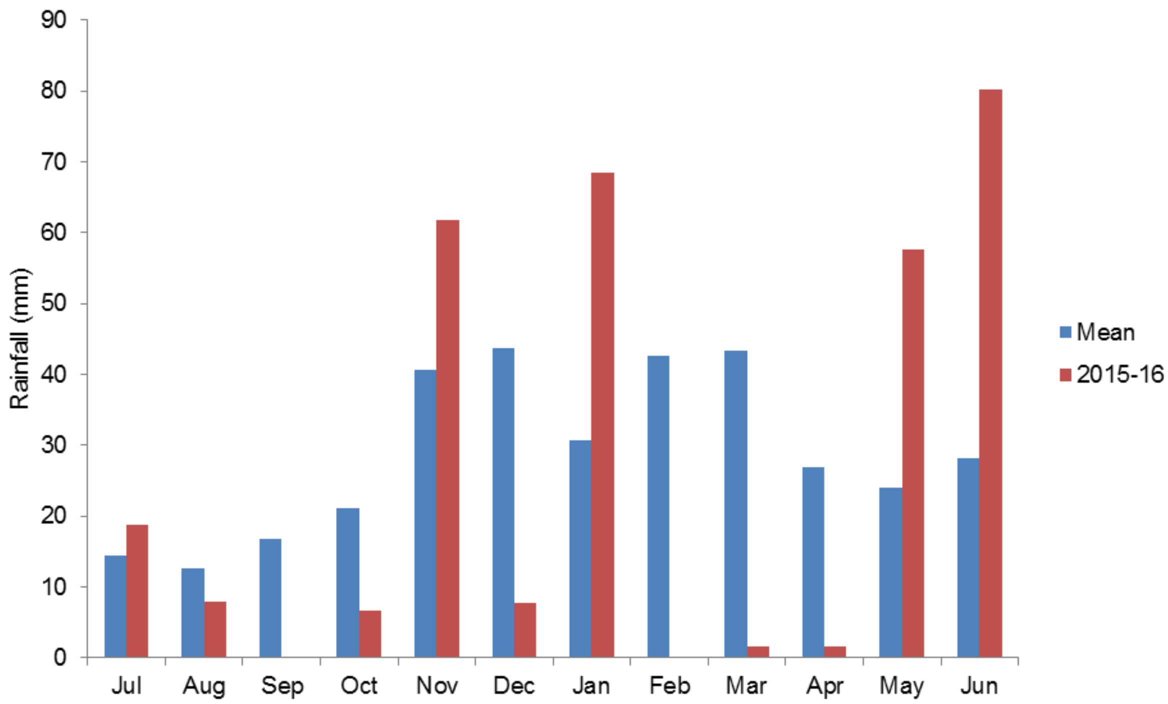

Figure E-6 Mean monthly rainfall for the 2015-16 water year at Bourke compared to long-term mean monthly rainfall

Given the factors outlined above, it is likely that the true inundation as a result of flows from the Warrego River lies in the range estimated from each method used in this analysis. Development of a hydrodynamic model for the Western Floodplain to improve inundation estimations will be investigated in year 3 of the project. In any case, significant areas of key floodplain vegetation communities were inundated in the northern sections of the Western Floodplain during 2015-16. At the time of maximum inundation extent, the largest inundation extent occurred in lignum shrubland, followed by coolibah open woodland and coolibah - river coobah - lignum woodland. This result is consistent with the distribution of large expanses of lignum shrubland that dominate northern sections of the floodplain (Gowans *et al*. 2012). Inundation of areas of beefwood-coolibah woodland and ironwood woodland on the far eastern side of the floodplain identified in the Landsat analysis are likely related to localised rainfall throughout the year.

E.5 Conclusion

In total, between 141.17 ha and 464.14 ha of the Western Floodplain was inundated from a combination of overflow from Boera Dam and rainfall during 2015-16. Maximum inundation occurred in November-December 2015 following a flow peak resulting in a gauge height of 2.54 m at Boera Dam. Lignum shrublands in the northern part of the floodplain were the most commonly inundated, along with coolibah and river cooba communities bordering flood channels and waterholes. The maintenance of water levels in Boera Dam above the Western Floodplain overflow level late in the water year, bodes well for prolonged inundation of some areas of the floodplain such as waterholes and connecting channels.

E.6 References

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Appendix F Water Quality

F.1 Introduction

The Category I Water Quality indicator aims 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 (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 the 2015-16 water year:

- 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?

F.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year (Appendix B). These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River.

F.1.2 Previous monitoring

In the 2014-15 water year, there were insufficient data to make comment on the effect of Commonwealth environmental water due to delays in project commencement and equipment being sourced (Commonwealth of Australia 2015). The two Hydrolab water quality meters were installed late in the 2014-15 water year.

F.2 Methods

Water quality parameters were monitored at two stations in the Darling River zone of the Selected Area that have permanent surface water in a defined channel. The Darling upstream station 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; Appendix B). The

Darling downstream station is located downstream of the confluence of the Warrego and Darling Rivers near Akuna homestead (Figure F-1). As such, the Darling downstream station can be used to assess the influence of Warrego River flow to the water chemistry of the Darling River.

Continuous monitoring of the dependant variables temperature (°C), pH, conductivity (mS/cm), turbidity (NTU), dissolved oxygen (mg/L) and chlorophyll *a* (µg/L) occurs at the two stations using a Hydrolab DS5-X logger. Each probe was mounted to a floating pontoon to ensure it was kept under the water but away from obstructions. In the Darling upstream station, the probe was connected via a 3-G telemetered system to an RMTek website for data monitoring and download. In the Darling downstream station, the probe was connected to a local logger and downloaded during each visit or periodically by NPWS staff. Each water quality variable is logged at 10 minute intervals. Due to issues with power supply and instrument failure at both sites, datasets were partly discontinuous in the 2015-16 water year. In addition, there was no pH data available from the downstream station due to instrument and data retrieval issues.

Four periods with various magnitudes, duration and variability in discharge were used to examine differences in water quality parameters (Figure F-2). Different amounts of Commonwealth environmental water occurred in each event:

- Period 1 – variable flow peaks – approximately 400 to 600 ML/d at Bourke Town (28 August to 28 September 2015; period length = 32 days). Both stations experienced flows commencing in July 2015, receiving flows from the Border Rivers, Moonie River and upper Barwon River, approximately 3.4-5% of which was Commonwealth environmental water. The downstream station was also influenced by localised entitlements at Toorale.

- Period 2 – small peak – flow peak up to approximately 1,000ML/d at Bourke Town (29 October to 29 November 2015; period length = 32 days). Both stations received Commonwealth environmental water (approximately 3.4%) from the Border Rivers and Gwydir River down the Darling channel.

- Period 3 – low flow – below 25ML/d at Bourke Town (10 December to 17 December 2015; period length = 8 days). Both stations experienced natural base flow without Commonwealth environmental water influence.

- Period 4 – higher flow – flow peak up to 1,350ML/d at Bourke Town, containing approximately 30% Commonwealth environmental water, with the gates at Boera Dam opened in the Warrego River (25 February to 7 March 2016; period length = 12 days). Both stations experienced the highest flow of the year and water flowed through the lower Warrego channel providing connection to the Darling River at the downstream station.

Daily means (midnight to midnight) of each water quality parameter were calculated from 10 minute interval data, with analyses based on the assumption that daily means were temporally independent. Daily means of water quality parameters were compared between periods and stations. Regression analyses were used to explore relationships between discharge (ML/d) and each water quality parameter in an attempt to separate the time/season of delivery from the discharge volume.

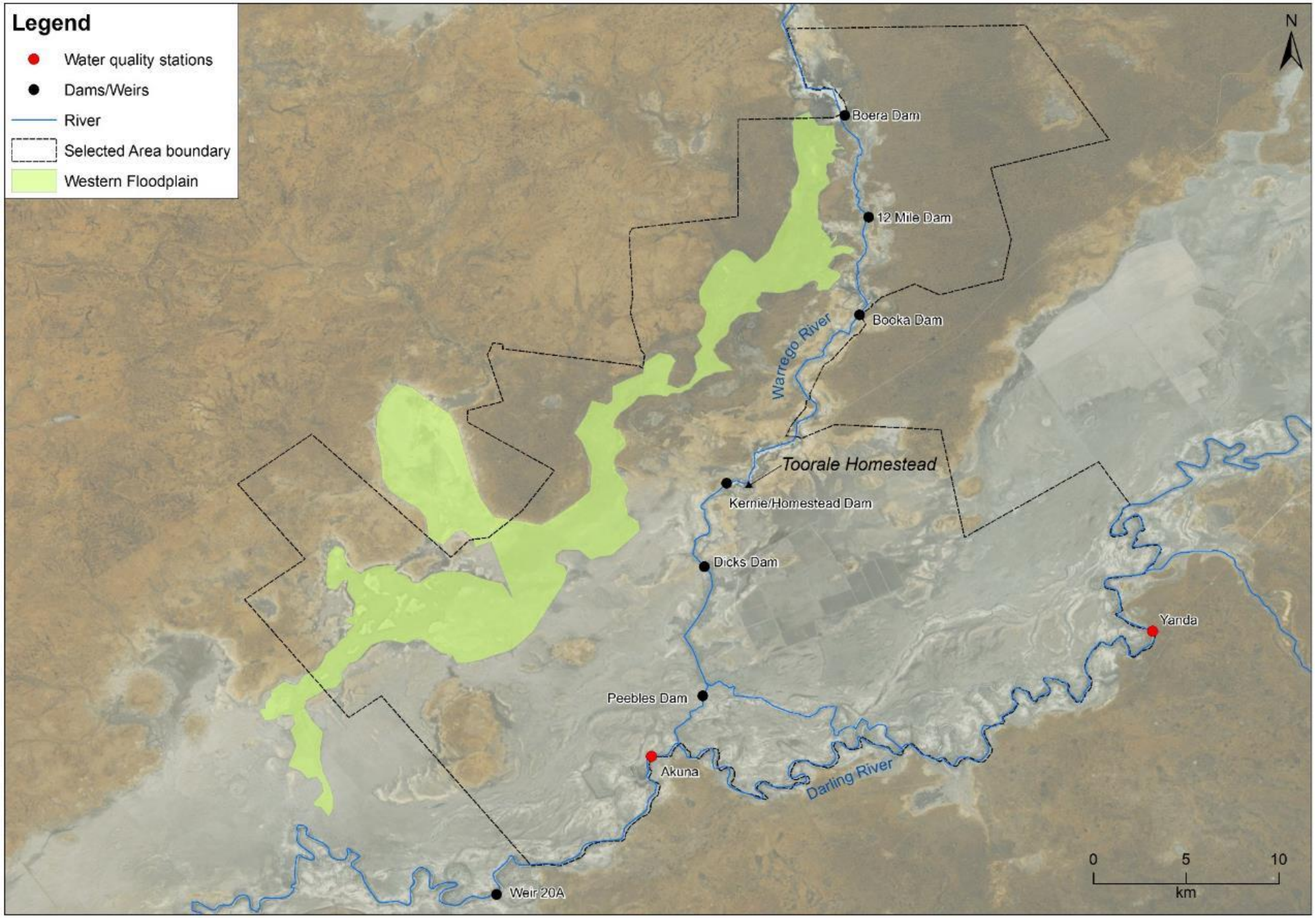

Figure F-1: Location of long-term water quality monitoring stations in the Darling River zone within the Selected Area.

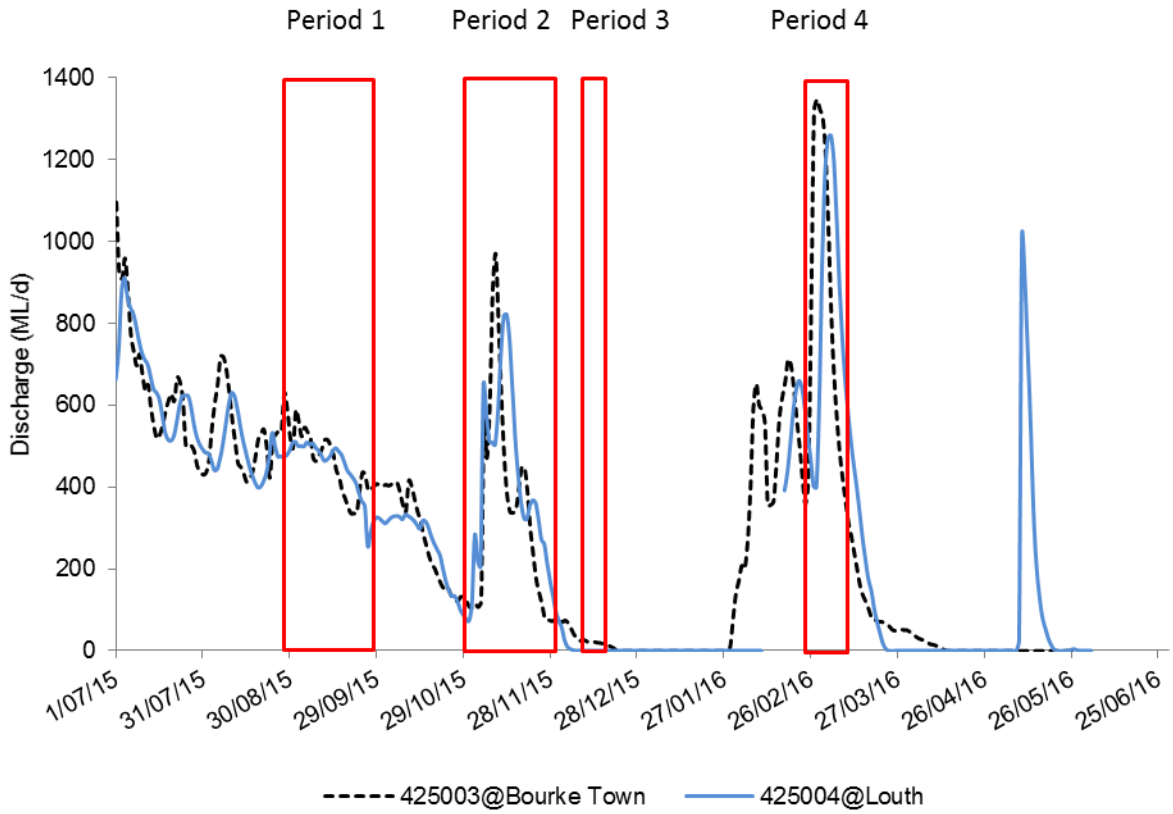

Figure F-2: Mean daily discharge at Darling@Bourke Town gauging station (NSW425003) and Darling@Louth gauging station (NSW425004) on the Darling River system. Discharge periods are boxed in red.

F.3 Results

The Darling River upstream and downstream stations exhibited similar magnitudes of discharge during the four periods, with a short time lag for downstream flow. Period 1, 2 and 4 discharge patterns were influenced by the flows down the Darling River zone with portions of Commonwealth environmental water accounted for in upstream tributaries. Period 3 discharge patterns represent natural base flow conditions without Commonwealth environmental water.

Mean daily temperature increased steadily from August, (Period 1; 15.0 °C to 19.5 °C) to March (Period 4; 28.7 °C to 30.4 °C) due to seasonal variation (Figure F-3a). Temperature was not significantly different between the upstream and downstream locations, and did not have strong predictable linear relationship with discharge (

Figure F-4a), with seasonal rather than flow patterns exerting the largest influence.

Mean daily pH at the upstream station ranged from 7.9 to 9.1, and was consistently alkaline and above the ANZECC water quality guideline (pH between 6.5 and 8; Figure F-3b). The lowest pH recorded was during the variable flow period 1, while highest pH record was found during the low flow period 3. A negative relationship was recorded between pH and discharge up to approximately 500 ML/d (

Figure F-4b).

Mean daily turbidity ranged from 21 NTU to 305 NTU and was generally above the ANZECC water quality guideline (6-50NTU; Figure F-3c). The highest turbidity was recorded during period 1 at the downstream station. Mean turbidity decreased below ANZECC water quality guideline in period 2 at the upstream station and during period 3 at the downstream station. Turbidity recorded at the downstream station displayed a unimodal relationship with discharge suggesting the wetting of bank features relatively low in the channel at critical flow levels may be influencing turbidity, and likely other water quality parameters as well. (

Figure F-4c).

Mean daily conductivity ranged from 0.47mS/cm to 1.68 mS/cm and were consistently within the ANZECC guideline trigger value (0.125 and 2.2 mS/cm; Figure F-3d). The lowest conductivity record was during period 1 and the highest conductivity recorded during period 4. Upstream conductivity was consistently higher than that at the downstream station in all flow periods suggesting localised inputs in this reach. Conductivity increased with discharge at both stations (

Figure F-4d).

Mean daily dissolved oxygen concentrations ranged from 3.44 mg/L to 10.84 mg/L (42% to 116% saturation; Figure F-3e) and were outside the ANZECC water quality guideline (85-110% in dissolved oxygen percent) on some occasions. Dissolved oxygen concentrations were higher during period 1 and lower during period 4. Upstream dissolved oxygen concentrations were consistently higher than that recorded at the downstream station. Similar to turbidity, dissolved oxygen concentrations had a unimodal relationship with discharge (

Figure F-4e).

Mean daily chlorophyll *a* concentrations ranged from 6.9 µg/L to 31.4 µg/L and were consistently above the ANZECC water quality guideline value (5 µg/L; Figure F-3f). Chlorophyll *a* acted in a similar manner to dissolved oxygen in that concentrations were higher during period 1. Chlorophyll *a* concentrations had a unimodal relationship with discharge (

Figure F-4f).

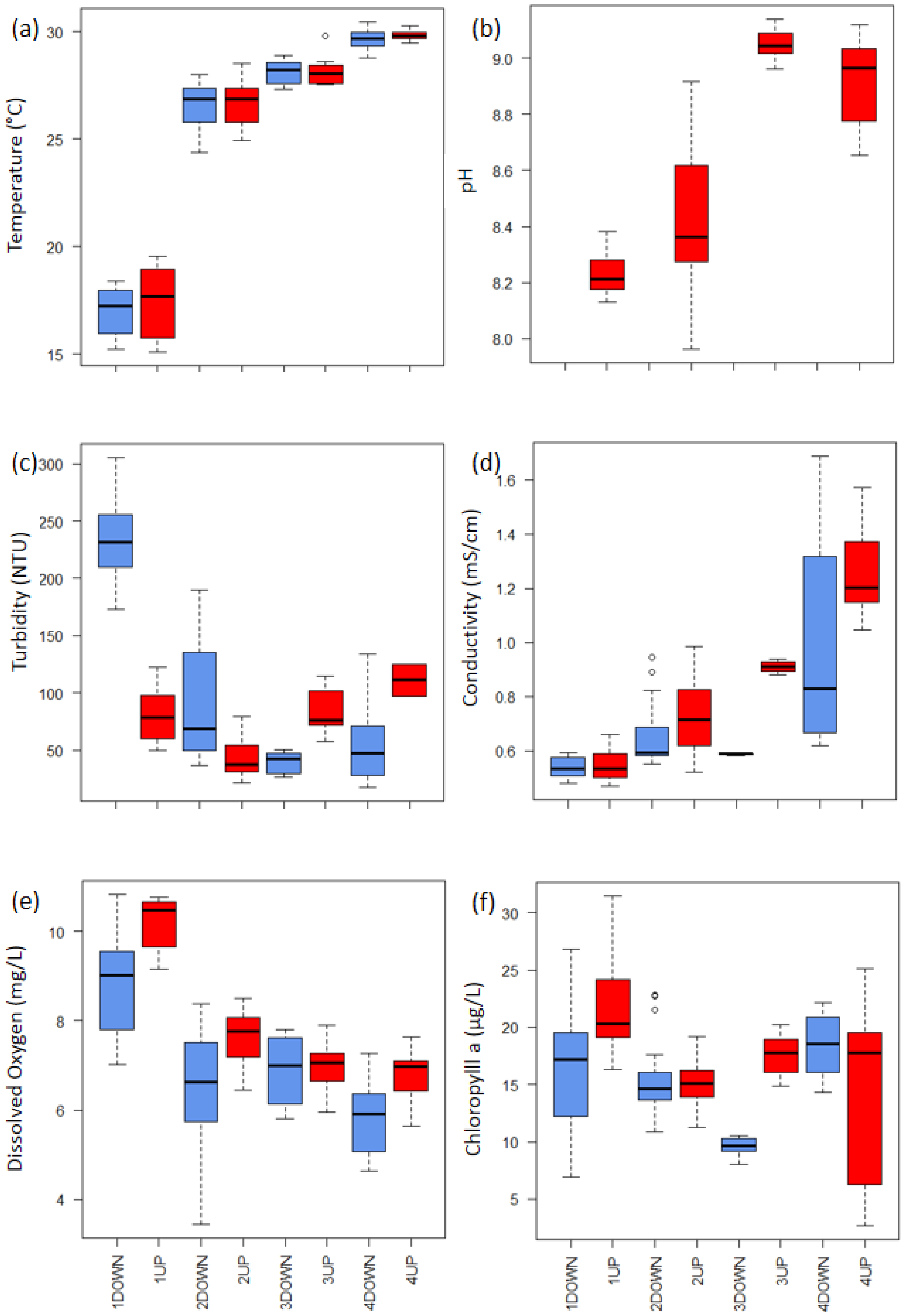

Figure F-3: Boxplots of median, lower quartile (25%), upper quartile (75%), the minimum and maximum values of daily (a) temperature, (b) pH, (c) turbidity, (d) conductivity, (e) dissolved oxygen concentration and (f) chlorophyll *a* concentrations at Darling downstream water quality station (Blue) and Darling upstream water quality station (Red).

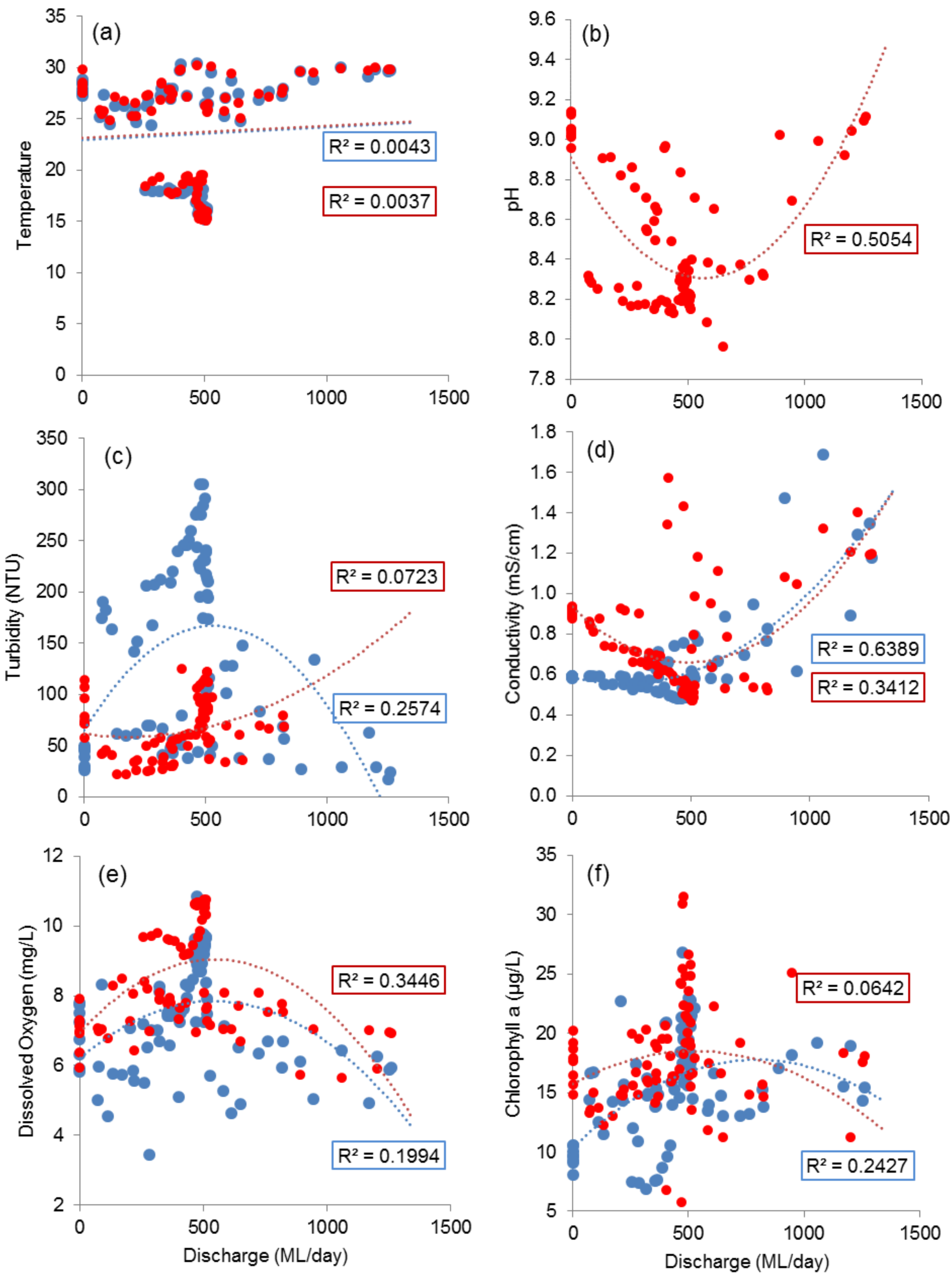

Figure F-4: Regressions between discharge at Darling@Bourke Town gauging station (NSW425003) and Darling@Louth gauging station (NSW425004) and mean daily (a) temperature, (b) pH, (c) turbidity, (d) conductivity, (e) dissolved oxygen and (f) chlorophyll a concentrations. Blue indicates Darling downstream water quality station. Red indicates Darling upstream water quality station.

F.4 Discussion

The lowest pH and conductivity levels, and highest dissolved oxygen and chlorophyll *a* concentrations were recorded during flow period 1 dominated by variable and fluctuating flows supported by Commonwealth environmental water. This suggests that flows in the Darling River channel augmented by Commonwealth environmental water can inundate low lying in-channel features such as bars and promote nutrient and carbon release to stimulate primary production (higher oxygen) and chlorophyll *a* concentrations.

During the low flow period that did not have a Commonwealth environmental water component, pH increased to the highest levels recorded among the four study periods, possibly from sustained elevated primary production (as seen in increased chlorophyll *a* concentrations) and increased residence time for water in the channel. The process of photosynthesis by algae in water uses hydrogen, thus affecting pH levels. Likewise, respiration and decomposition can lower pH levels. High algal biomass in slow-flowing pool type habitats can therefore affect local pH values.

Elevated conductivity is a persistent issue in the Darling River, however the highest concentrations of salts were recorded in Period 4 associated with the highest flow peak of 1,350 ML/d occurring in the 2015-16 water year. This flow event also increased the water column pH, and reduced the concentrations of dissolved oxygen, reflecting the transport of increased dissolved ions and salts along the Darling River with increased flows.

Temperature changes among the four defined flow periods were attributed to broader regional seasonal patterns in temperature rather than flow conditions. The similar oxygen and chlorophyll *a* concentrations recorded during the small peak and low flow periods suggests no deterioration of water quality that may lead to algal blooms. There was a large outbreak of Azolla (*Azolla filiculoides*) in the Darling River between 10 September and 15 November 2015 (Figure F-5; Figure F-6). Water quality remained similar throughout this period and when compared with periods where Azolla was absent, suggesting that the 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) that contain Commonwealth environmental water could prevent potential water quality problems and ecological consequence such as hypoxia linked to an Azolla outbreak.

The Darling River zone of the Selected Area has exceptionally high turbidity with levels recorded in 2015-16 similar to those observed in 2014-15. At the downstream station, the highest turbidity recorded was 6 times higher than the ANZECC water quality guideline, and was significantly higher than the upstream station reflecting the localised input from the highly turbid (peaks over 1100 NTU) Warrego River. 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) will be limited by the very shallow photic depth (light penetration).

All water quality parameters had poor relationships with discharge with chlorophyll *a* recording the highest r^2 relationship of all parameters of 0.6. Many of the water quality parameters had their highest recorded values when discharge was around 500 ML/d, suggesting that this may be a key threshold for the inundation of in-channel bars that subsequently affect water quality in the Darling River under relatively low flow conditions.

Figure F-5: *Azolla* spp. in the Darling River downstream station on 8 Oct 2016.

Figure F-6: *Azolla* spp. in the Darling River (between Darling upstream and downstream stations at Darling pump microinvertebrate site) on 8 Oct 2016.

F.5 Conclusion

Water quality parameters were highly variable during the four time periods analysed in 2015-16 which covered a range of low volume discharges and contributions of Commonwealth environmental water. Many water quality parameters had their highest recorded values at approximately 500 ML/d, suggesting that this may be a key threshold for the inundation of in-channel bars that subsequently affect water quality in the Darling River under relatively low flow conditions. Similarly, elevated conductivity was recorded under the highest reported flows in the 2015-16 water year rather than during the very low flow conditions (flow period 3) suggesting the transport of increased dissolved ions and salts along the Darling River with increased flows. In contrast, the increase in discharge reduced turbidity, dissolved oxygen and chlorophyll a concentrations, reflecting a dilution effect provided by higher discharge for these parameters. An outbreak of the floating aquatic weed Azolla completely covered the water surface of the Darling River channel in spring yet water quality parameters remained similar throughout this period and when compared with periods where Azolla was absent. This highlights the benefit of smaller magnitude flows (highest discharge of 971 ML/d) that contain Commonwealth environmental water in preventing potential water quality problems and ecological consequence such as hypoxia linked to an Azolla outbreak.

F.6 References

Commonwealth of Australia. 2015. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area. Annual Evaluation Report – Year 1.* Commonwealth of Australis, Canberra.

Close, A. 1990. River salinity. *The Murray*. pp. 127-144.

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Appendix G Stream Metabolism

G.1 Introduction

The Category I Stream Metabolism indicator aims to assess the contribution of Commonwealth environmental water to improving stream metabolism in the Darling River zone of the Junction of the Warrego and Darling rivers Selected Area (Selected Area). As such, this indicator is linked to Hydrology (River and Northern tributaries), Water Quality and Fish (Channel) indicators. Two specific questions were addressed through this indicator within the Darling River zone during the 2015-16 water year:

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

G.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year (Appendix B). These occurred in July – October 2015, November 2015, January-March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River.

G.1.2 Previous monitoring

In the 2014-15 water year, there were insufficient data to make comment on the effect of Commonwealth environmental water due to delays in project commencement and equipment being sourced (Commonwealth of Australia 2015). The two Hydrolab water quality meters were installed late in the 2014-15 water year.

G.2 Methods

Water quality parameters (Table G-1) were monitored at two stations in the Darling River zone of the Selected Area that have permanent surface water in a defined channel. The Darling upstream station is located near Yanda homestead, and all Commonwealth environmental water derived in the upstream northern tributaries of the Murray Darling Basin (except Warrego River) passes through this reach (Figure G-1; Appendix B). The Darling downstream station is located downstream of the confluence of the Warrego and Darling Rivers near Akuna homestead (Figure G-1). As such, the Darling downstream station can be used to assess the influence of Warrego River flow to the water chemistry of the Darling River.

Continuous monitoring of the dependant variables temperature (°C), pH, conductivity (mS/cm), turbidity (NTU), dissolved oxygen (mg/L) and chlorophyll *a* (µg/L) occurs at the two stations using a Hydrolab DS5-X logger. Each probe was mounted to a floating pontoon to ensure it was kept under the water but away from obstructions. In the Darling upstream station, the probe was connected via a 3-G telemetered system to an RMTek website for data monitoring and download. In the Darling downstream station, the probe was connected to a local logger and downloaded during each visit or periodically by NPWS staff. Each water quality variable is logged at 10 minute intervals. Photosynthetically active radiation (PAR) and barometric pressure were also logged at 10 minute intervals.

Issues with power supply and instrument failure (turbidity and biofouling) at both sites has meant that datasets were partly discontinuous in the 2015-16 water year. Water quality samples were collected at approximately 6 weekly intervals throughout the year and analysed at the NATA accredited Environmental Analytical laboratories at Southern Cross University. Monitoring was conducted following the Standard Operating Procedures in Hale *et al*. (2013).

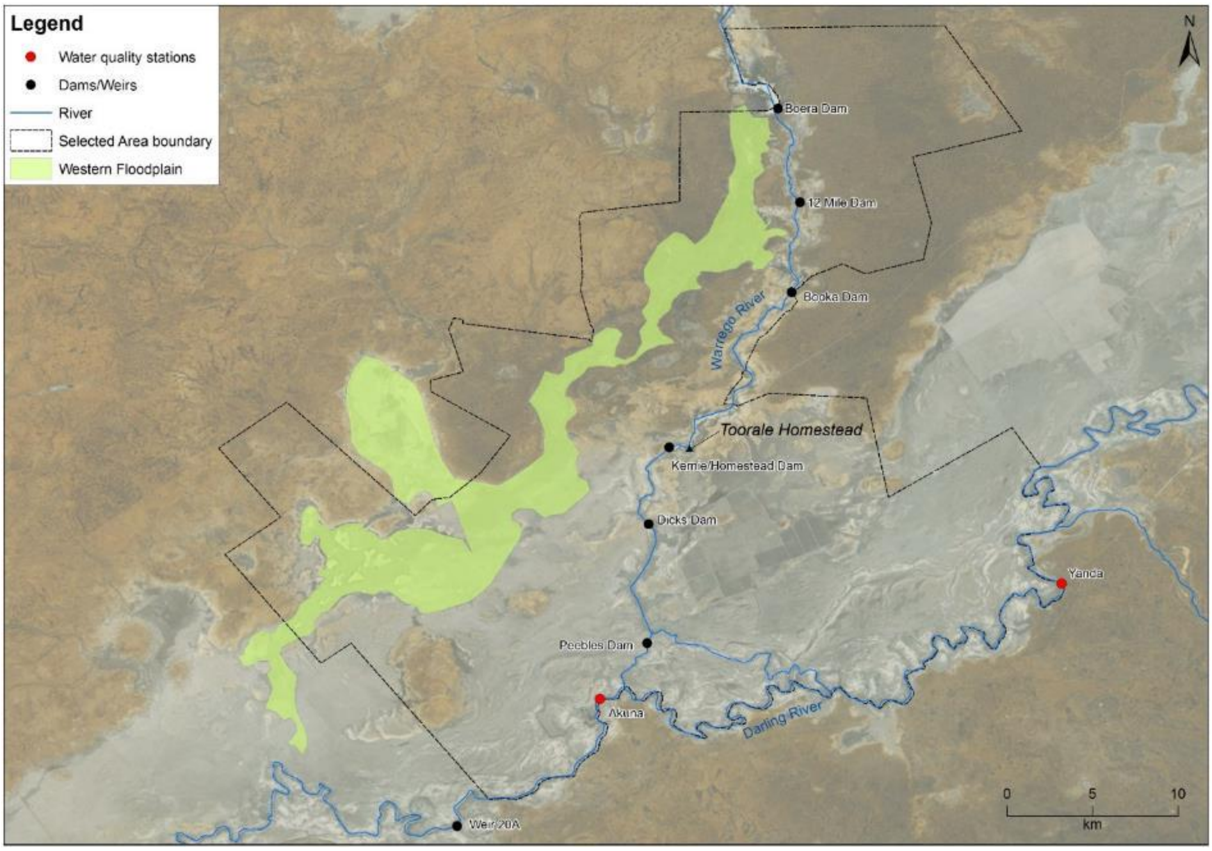


Figure G-1: Location of two water quality stations (Yanda and Akuna) in the Darling River zone of the Selected Area.

Table G-1 Environmental and water quality variables measured at each site and sampling occasion.

Environmental sets	Variables		Units	Code
Water quality	i.	Temperature	°C	temp
	ii.	pH	-	ph
	iii	Conductivity	mS/cm	cond
	iv.	Dissolved Oxygen	mg/L	do
	v.	Turbidity	NTU	turb
Water nutrient and particulate	i.	Total Nitrogen	µg/L	TN
	ii.	Total Phosphorus	µg/L	TP
	iii	Nitrate-nitrite	µg/L	NOx
	iv.	Filterable Reactive Phosphorus	µg/L	FRP
	v.	Dissolved Organic Carbon	µg/mL	DOC
	vi.	Total Suspended Solid	mg/L	TSS
Stream metabolism	i.	Chlorophyll a	µg/L	Chla
	ii.	Gross Primary Production	mg O2/L/day	GPP
	iii	Ecosystem Respiration	mg O2/L/day	ER
	iv.	Net Primary Production	mg O2/L/day	NPP

Three periods with various magnitude, duration and variability in discharge were used to examine shifts in metabolism and water quality parameters (Figure G-2). Different amounts of Commonwealth environmental water occurred in each event:

:

- Period 1 – variable flow (28 Aug to 28 Sep 2015) – Both upstream and downstream stations received flows containing approximately 3.4-5% Commonwealth environmental water from the Border River, Moonie River and upper Barwon River while the downstream station was also influenced by localised entitlements from Toorale. (n=32)

- Period 2 – flow peak – (29 Oct to 29 Nov in 2015) – Both upstream and downstream stations were influenced by flows containing approximately 30% Commonwealth environmental water from the Border and Gwydir Rivers, while the downstream station was also influenced by the Warrego River confluence following a small local run-off event (this local event was not Commonwealth environmental water). (n=32)

- Period 3 – low constant flow (10 Dec to 17 Dec in 2015) – Both stations experienced a base flow period without Commonwealth environmental water influence. (n=8)

Daily means (midnight to midnight) of dissolved oxygen were calculated from 10 minute interval data, with analyses based on the assumption that daily means were temporally independent. Daily means of water quality parameters were compared between periods and stations. Regression analyses were used to explore relationships between discharge (ML/d) and each water quality parameter in an attempt to separate the time/season of delivery from the discharge volume.

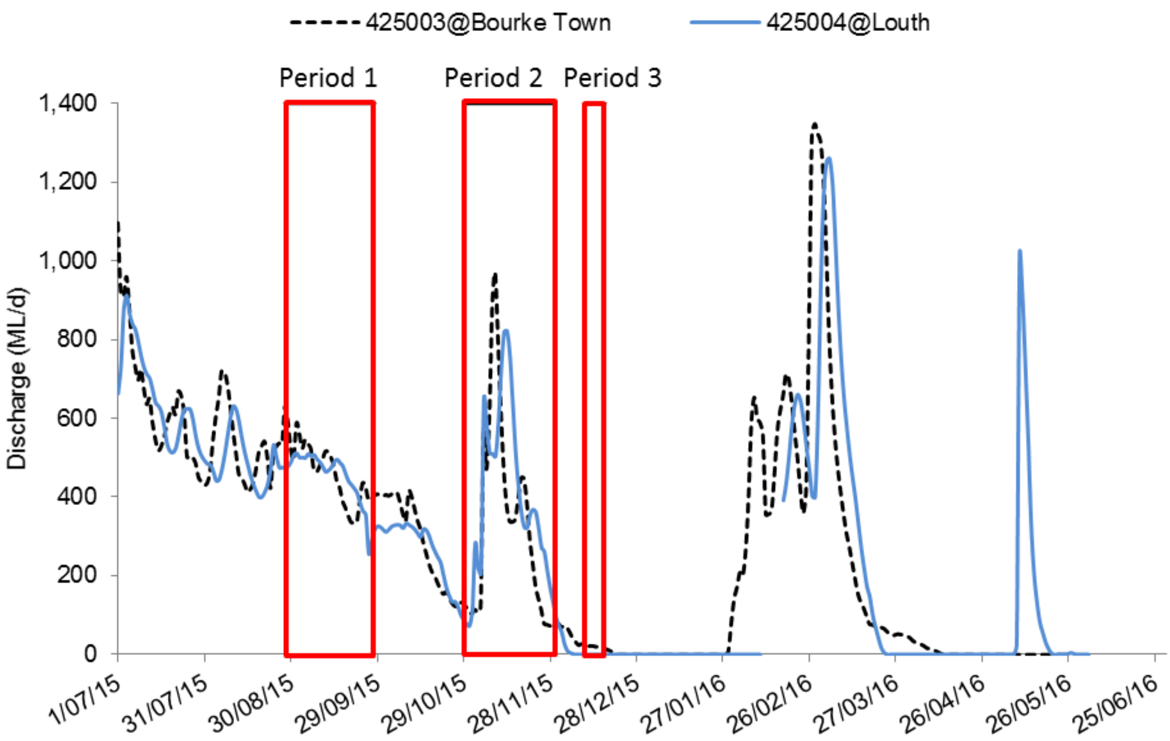


Figure G-2: Mean daily discharge at Darling@Bourke Town gauging station (NSW425003) and Darling@Louth gauging station (NSW425004) on the Darling River system. Study periods outlines in red.

G.3 Results

The Darling River upstream and downstream stations experienced a similar magnitude of discharge during three periods, with a short time lag for downstream flow. Period 1 and 2 discharge patterns were influenced by flows with portions of Commonwealth environmental water from upstream northern tributaries (except Warrego River), plus a small influence from the Warrego River from localised overflow events in Toorale NP. Period 3 discharge patterns represent base flow condition without Commonwealth environmental water or Warrego River influence.

Rates of mean gross primary production (GPP) ranged from 0.55 to 3.78 mg O_2/L/day (Figure G-3a) and rates of mean ecosystem respiration (ER) ranged from 0.52 to 5.37 mg O_2/L/day (Figure G-3b). Net primary production (NPP) was consistently negative. The highest NPP was 5.37 mg O_2/L/day (Figure G-3c) net oxygen consumption during Period 2 at the downstream station driven by an increase in respiration with increased discharge. All periods and stations were net heterotrophic throughout the study period except the upstream station at period 1 (Figure G-3c). Weak positive relationships were recorded at both stations between increased discharge and higher rates of GPP (Figure G-4a) and ER (Figure G-4b). NPP (Figure G-4c) at the upstream station had a very weak negative unimodal relationship with discharge.

Overall, nutrient concentrations were highly variable across time and between stations (Table G-2). Total nitrogen, nitrate-nitrite, ammonium and total phosphorus concentrations were generally within the ANZECC water quality guideline value, with a few sampling occasions being above the ANZECC value.

Filterable reactive phosphorus and chlorophyll *a* concentrations were frequently above the ANZECC water quality guideline value.

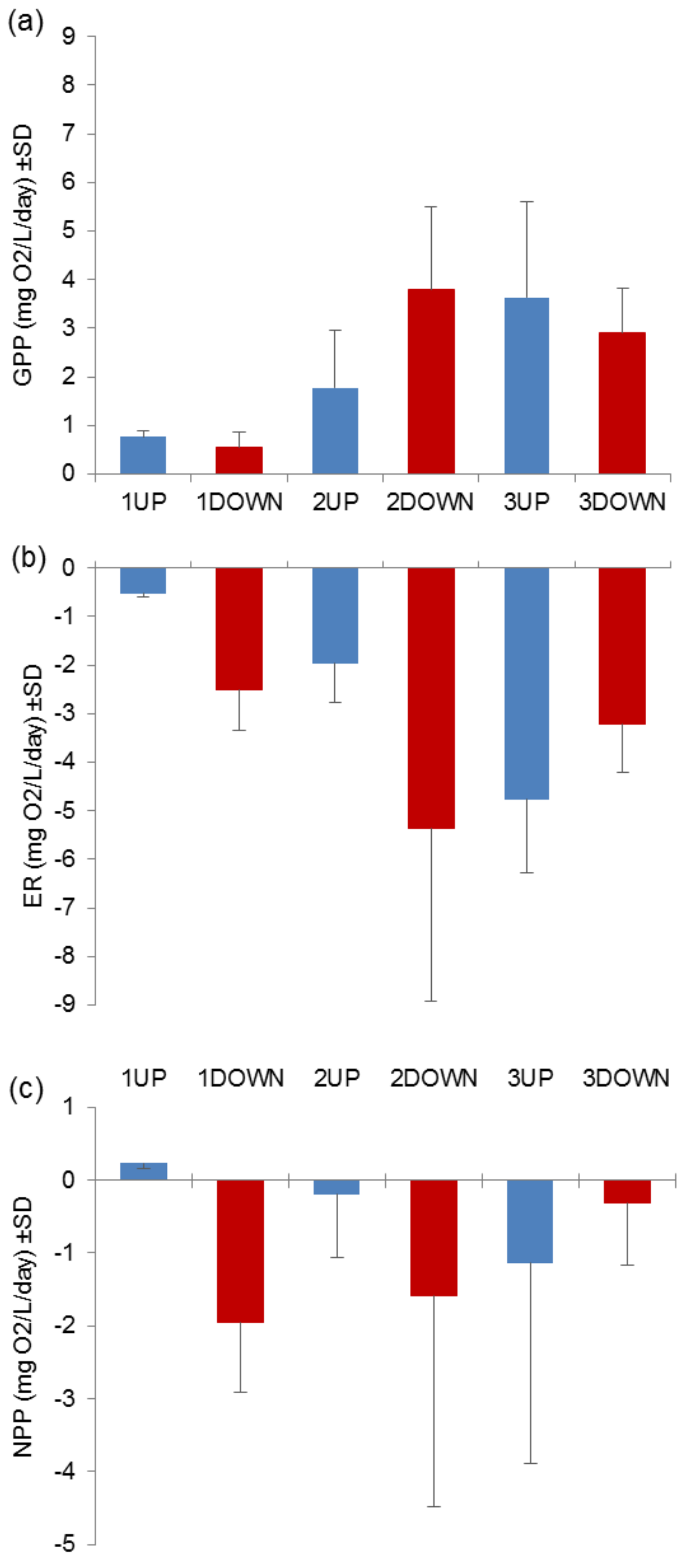


Figure G-3: Mean rates ± standard deviation (SD) of (a) Gross Primary Production, (b) Ecosystem Respiration and (c) Net Primary Production. P=period, DS=downstream site, US=upstream site.

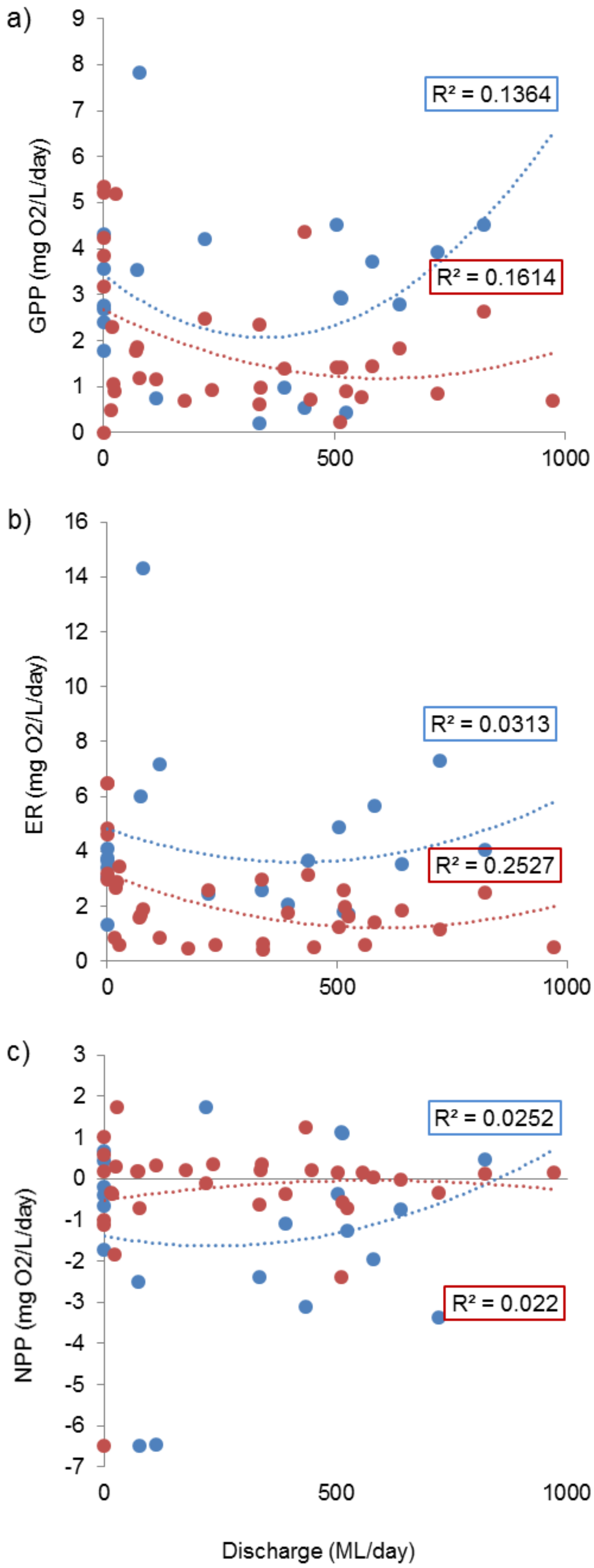


Figure G-4: Regressions between discharge at Darling@Bourke Town gauging station (NSW425003) and Darling@Louth gauging station (NSW425004) and mean daily (a) Gross Primary Production, (b) Ecosystem Respiration and (c) Net Primary Production. Blue indicates Darling downstream water quality station. Red indicates Darling upstream water quality station.

Table G-2: Concentrations of total nitrogen, nitrate-nitrite, ammonium, total phosphorus, filterable reactive phosphorus, dissolved organic carbon and chlorophyll a. Bold number represented concentrations that exceed ANZECC water quality guideline value.

Parameters (mg/L)	ANZECC (mg/L)	Darling Upstream - YANDA				Darling Downstream - AKUNA						
		Aug-15	Sep-15	Dec-15	Mar-16	Aug-15	Sep-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16
		day(15)	15	10	30	15	14	2	10	18	16	30
Total Nitrogen	0.500	0.41	0.47	0.43	**0.69**	0.44	0.41	0.43	0.48	0.47	0.50	0.46
Nitrate-nitrite	0.040	0.025	**0.074**	<0.005	**0.390**	<0.005	**0.094**	<0.005	<0.005	<0.005	<0.005	<0.005
Ammonium	0.020	0.020	**0.021**	0.020	**0.024**	0.020	0.017	**0.038**	**0.021**	0.018	0.019	0.019
Total Phosphorus	0.050	0.05	0.05	0.05	**0.08**	0.04	**0.07**	0.03	0.05	0.03	0.05	0.05
Filterable Reactive Phosphorus	0.020	**0.035**	**0.035**	**0.027**	**0.063**	0.019	**0.057**	**0.029**	**0.030**	0.015	**0.031**	**0.036**
Dissolved Organic Carbon	-	9.6	9.3	9.3	10.5	10.3	8.4	9.6	10.3	9.5	11.3	10.7
Chlorophyll *a*	0.005	**0.033**	**0.025**	**0.015**	**0.016**	**0.033**	**0.031**	**0.024**	**0.025**	**0.025**	**0.023**	**0.036**

G.4 Discussion

Both upstream and downstream stations recorded the lowest rates of GPP during Period 1 when temperatures were cooler and flows were low but fluctuating. Rates of GPP and ER generally increased between station 1 and 2, with the highest rates of GPP and ER recorded in the downstream station during Period 2. Similarly, the highest NPP was recorded in Period 2 at the downstream station. These results suggest that increased discharge is leading to increased rates of production and respiration, driven by a reduction in water column turbidity and increase in chlorophyll *a* (Appendix F). Flow peaks inclusive of the Commonwealth environmental water therefore contributed to improved water clarity and/or increased inorganic nutrients that promoted pelagic primary production. This was most evident at the downstream station, and suggests that discharge from the Warrego River is contributing directly to the increased rates in GPP and ER in the Darling River.

All periods and stations were net heterotrophic, except for the upstream station during Period 1 which was slightly autotrophic. Overall the Darling and Warrego Rivers were a carbon sink during the sampling periods. The major reason for heterotrophy in these systems was high rates of respiration and low rates of primary production. Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway rather than a pelagic grazer pathway, in which dead organic matter is colonized by microbes and fungi or consumed by detritivores that are then eaten by higher consumers (Kobayashi *et al.* 2009).

G.5 Conclusion

The monitoring of water quality and metabolism during 2015-16 revealed positive relationships between rates of GPP, ER, NPP and nutrient concentrations, and relatively minor changes in hydrology. Increased rates of GPP and ER were associated with higher discharge, suggesting environmental water in the Darling River contributes to improved water clarity and/or increase inorganic nutrients that promote pelagic primary production.

G.6 References

Commonwealth of Australia. 2015. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area. Annual Evaluation Report – Year 1.* Commonwealth of Australia, Canberra.

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S., Gawne, B., and Stewardson, M. 2014. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods*. Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 29.2/2014, January, 175 pp.

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

Appendix H Microinvertebrates

H.1 Introduction

The Microinvertebrate indicator aims to assess the contribution of Commonwealth environmental water to microinvertebrate abundance and diversity. Several specific questions were addressed through this indicator within the Junction of the Warrego and Darling rivers Selected Area (Selected Area) during the 2015-16 water year:

Category III – Water Quality indicators evaluation questions:

- 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?

Category III – Stream Metabolism indicators evaluation questions:

- 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?

Category III – Microinvertebrates indicators evaluation questions:

- What did Commonwealth environmental water contribute to microinvertebrate productivity?
- What did Commonwealth environmental water contribute to microinvertebrate community composition?
- What did Commonwealth environmental water contribute to connectivity of microinvertebrate and vegetation communities in floodplain watercourse?

H.1.1 Environmental watering in 2015-16

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year. (Appendix B).

H.1.2 Previous monitoring

In the 2014-15 water year, there was no consistent evidence for changes in patterns of nutrient concentrations among sites or over time (Commonwealth of Australia 2015). Rates of gross primary production (GPP) and ecosystem respiration (ER) were consistently higher in the Warrego zone compared with the Darling River zone. All sites (except the Western Floodplain in May 2015) were net heterotrophic and therefore a carbon sink throughout the 2014-15 year. The inundation of the Warrego River zone increased regional scale abundance and diversity of aquatic microinvertebrates as well as the development and succession of different aquatic microinvertebrate communities between river systems, and between channel and floodplain habitats.

H.2 Methods

H.2.1 Design

The Category III Water Quality indicators were measured in association with Category III Stream Metabolism and Category III Microinvertebrate indicators in October 2015 and March 2016 (Table H-1; Table H-2). Sampling sites were located in two Sampling Zones within the Selected Area: Darling River and Warrego River (Table H-2; Figure H-2).

Table H-1: Location of sites on the Junction of the Warrego and Darling Rivers Selected Area for microinvertebrate surveys. Map projection GDA94 Zone 55.

Sampling Zone	Site Name	Site Code	Easting	Northing	Inundation	
					Oct-15	Mar-16
Darling River	Akuna homestead	AKUNA	340008	6634629	Wet	Wet
	Darling Pump	DARPUMP	350768	6635351	Wet	Wet
Warrego Channel	Boera Dam	BOERA	348526	6669158	Wet	Wet
	Booka Dam	BOOKA	349357	6658461	Wet	Wet
	Ross Billabong	ROSS	347281	6636893	Wet	Wet
	Western Floodplain	WF	347643	6665399	Wet	Dry

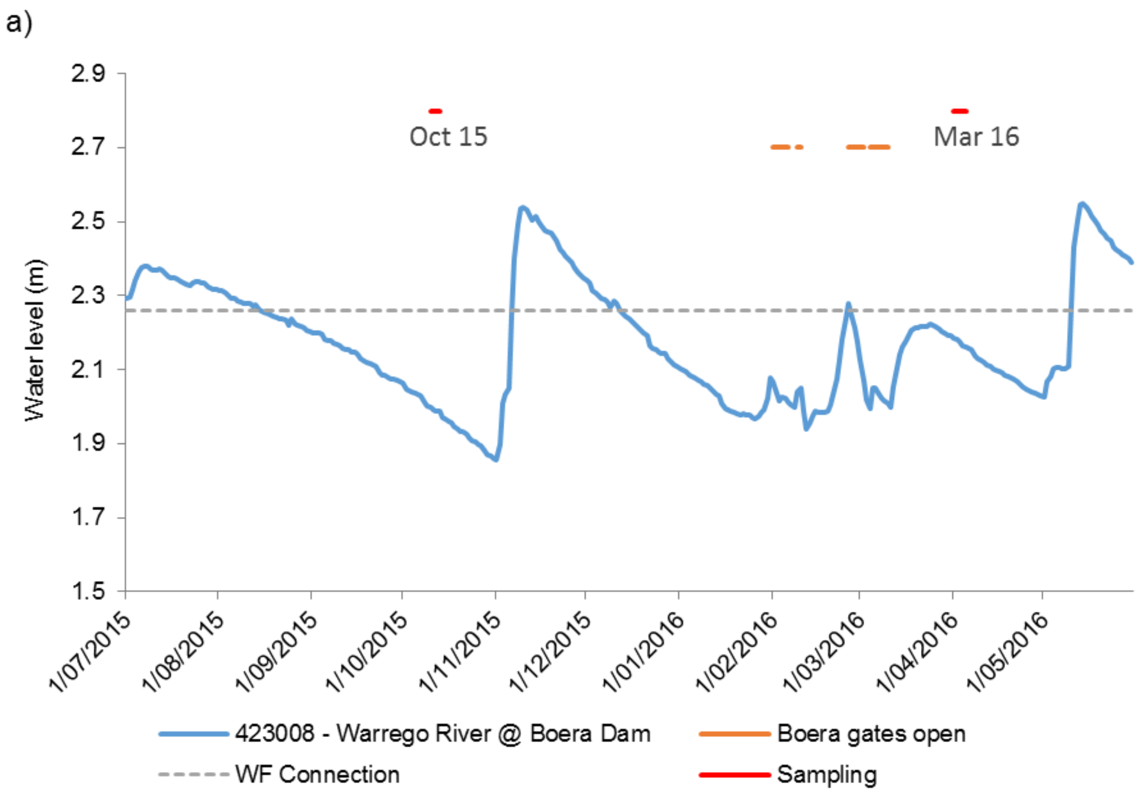
Table H-2: Environmental variables, ecosystem function and microinvertebrate responsive variables measured at each sites and sampling occasion.

Environmental sets	Variables		Units	Code
Water quality	i.	Temperature	°C	temp
	ii.	pH	-	ph
	iii	Conductivity	mS/cm	cond
	iv.	Dissolved Oxygen	mg/L	do
	v.	Turbidity	NTU	turb
Water nutrient and particulate	i.	Total Nitrogen	µg/L	TN
	ii.	Total Phosphorus	µg/L	TP
	iii	Nitrate-nitrite	µg/L	NOx
	iv.	Filterable Reactive Phosphorus	µg/L	FRP
	v.	Dissolved Organic Carbon	µg/mL	DOC
	vi.	Total Suspended Solid	mg/L	TSS
Stream metabolism	i.	Chlorophyll a	µg/L	Chla
	ii.	Gross Primary Production	mg O2/L/day	GPP
	iii	Ecosystem Respiration	mg O2/L/day	ER
	iv.	Net Primary Production	mg O2/L/day	NPP
Microinvertebrate	i.	Density	individual/L	-
	ii.	Diversity	-	-
	iii.	Richness	-	-
	iv.	Community presence/absence	-	-
	v.	Community abundance (sq root)	-	-

Hydrological conditions within the Selected Area during sampling are described below.

- Oct 15 – Dry period - (7-10 Oct 2015). During Oct-15 sampling, three Warrego channel sites (Boera Dam, Booka Dam and Ross Billabong) were disconnected from each other and the Darling River. A small area of the Western Floodplain was inundated via a local run-off event in July that raised water levels in Boera Dam above commence to flow for the Western Floodplain (Figure H-1a). However, this local event was not accounted for against environmental water licences for Toorale. The Darling River hydrology was in the falling limb of low magnitude variable flow period (Figure H-1b).

- Mar 16 – Wet period – (29 March to 2 April 2016). During Mar-16 sampling, the Warrego channel was connected with the Darling River as a result of the Boera gates being open for 16 days prior to the sampling period (Figure H-1a). However, during this time the Western Floodplain was dry, so no samples were taken. The Darling River experienced base flow conditions, after a higher flow event one month prior to sampling (Figure H-1b).



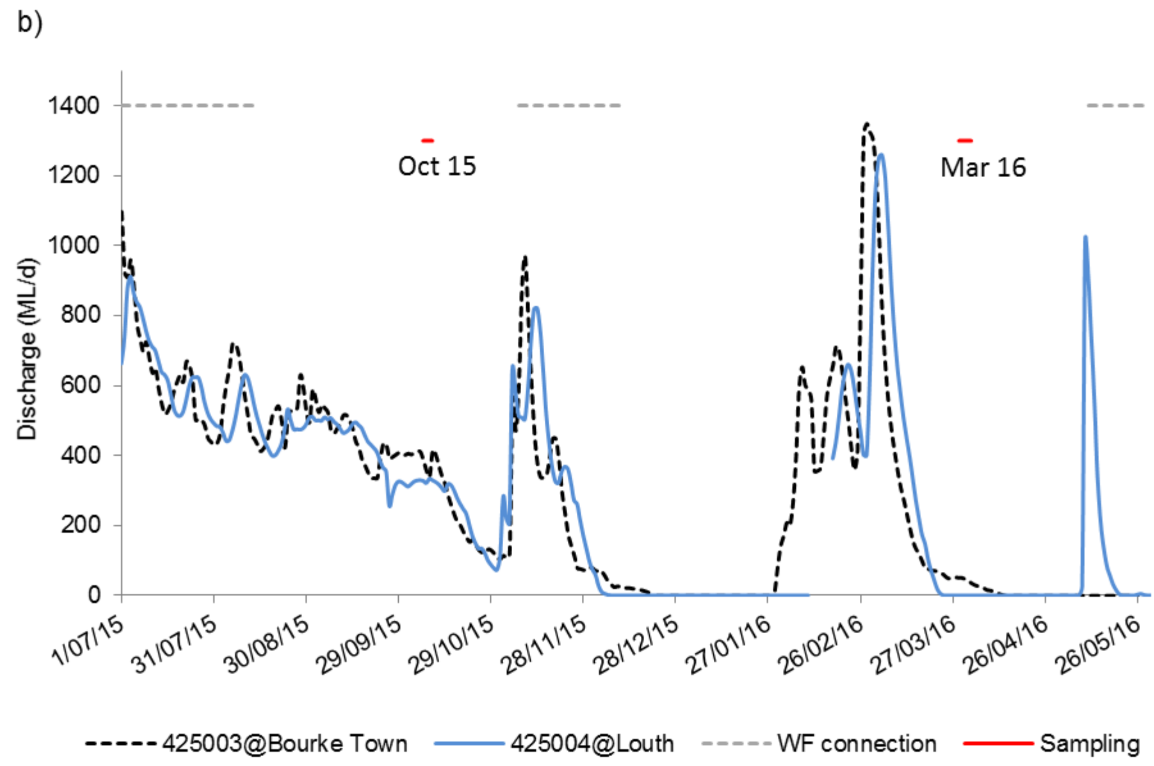


Figure H-1: Water level at (a) Boera Dam and (b) discharge at Darling River.

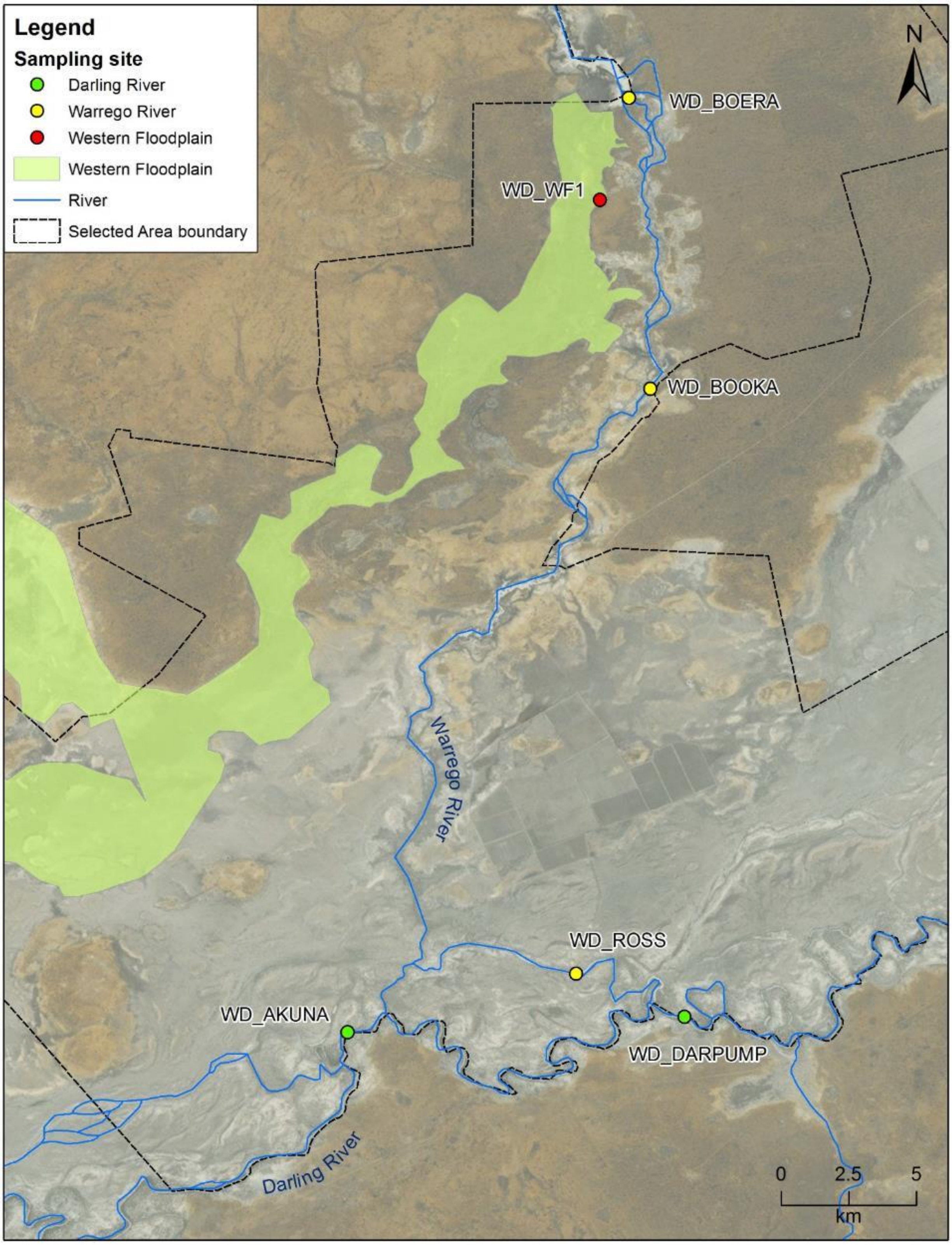


Figure H-2: Map of the Selected Area with microinvertebrate sites marked in 2014-15.

H.2.2 Field methods

Microinvertebrate field methods

Benthic microinvertebrates were haphazardly sampled by compositing five cores (50 mm diameter x 120 mm long with 250 mL volume) for each site. Replicates were separated by a minimum of 20 linear metres. The composite sample was allowed to settle for a minimum of 1 hr. 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 20 L of the water column at each of five locations throughout the site. Samples were poured through a plankton net (63 µm) into a single, 100-L composite sample. Retained samples were stored in ethanol (70 % w/v) with Rose Bengal stain until laboratory analysis.

Nutrient field methods

In-situ spot measurements of water column pH, turbidity (NTU) and specific conductivity (µS/cm) were taken using a Hydrolab Quanta water quality multi-probe. Water column samples were collected for laboratory analysis of chlorophyll *a*, total nitrogen (TN), total phosphorus (TP), nitrate-nitrite (NOx), ammonium (NH_4), filterable reactive phosphorus (FRP) and dissolved organic carbon (DOC). Samples were transferred to labelled PET containers that had been acid-washed and thrice rinsed with sample water. Duplicate samples of each variable were taken from each site and stored cold and in the dark until processing each night.

Chlorophyll *a* was sampled by filtering as much sample water as possible (100–1000 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 prelabelled 10 mL vial which was then sealed, wrapped in aluminum foil, placed inside a labelled ziplock bag and then refrigerated below 4 °C.

TN and TP were sampled by collecting duplicate 125 mL, unfiltered water samples that were frozen until laboratory analyses. NOx and FRP were sampled by collecting duplicated 125 mL water samples that were filtered through Whatman microfiber filter papers (effective pore size of 0.2 µm) and frozen until laboratory analyses. The 125 mL PET bottles for total and dissolved nutrients were acid-washed and thrice rinsed in sample water before use.

Duplicate NH_4 samples were filtered through Whatman microfiber filter papers (effective pore size of 0.2 µm) and placed in acid-washed, 30-mL vials thrice rinsed in sample. Samples were frozen until laboratory analyses. Duplicates remain frozen for audit purposes.

Duplicate Dissolved Organic Carbon samples were filtered through Whatman Microfiber filter papers (effective pore size of 0.2 µm) into 30 mL vials thrice rinsed in sample and frozen until analysis.

A 10% subsample of randomly selected samples was sent to the Environmental Analytical Laboratories at Southern Cross University NATA accredited laboratory as part of the project Quality Assurance Plan. All samples returned did not significantly differ from those analysed at the UNE laboratories.

Metabolism field methods

At each sampling site and period, a single D-Opto dissolved oxygen (DO) logger was deployed in the water column ensuring they were positioned in the water column not touching the sediment or where the logger would be exposed. Loggers were allowed to equilibrate and measured temperature, DO percent saturation and DO concentration (mg/L) at 10-minute intervals over a minimum 48-hour period from midnight to midnight. A Hobo PAR logger was simultaneously deployed in the air. Barometric pressure data were retrieved from the nearest BoM locality at Bourke.

H.2.3 Laboratory methods

Microinvertebrate laboratory methods

Samples were thoroughly mixed and a 30-mL subsample was sorted on a Bogorov tray under a stereo microscope at up to 400x magnification. Microinvertebrates were identified to family level (cladocerans), class (copepods) and ostracods. The volumes of the total samples were recorded and subsample totals were scaled up to each total sample volume and reported as density/L. Samples were stored in 70% ethanol with Rose Bengal for auditing purposes.

Nutrient laboratory methods

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 and 750 nm.

TN was analysed by digesting an unfiltered water sample in a digestion tube with 10 mL of digestion mixture. This contained 40 g of di-potassium-peroxodisulfate ($K_2S_2O_8$) and 9 g of sodium hydroxide (NaOH) in 1000 mL of Milli Q water. This sample was then digested in the autoclave for 20 minutes. Five mL of the sample was then placed into a 50 mL, acid-washed measuring cylinder and diluted to 50 mL (Hosomi and Sudo 1986). Five mL of buffer solution was added: 100 g of NH_4Cl, 20 g sodium tetra borate and 1 g EDTA to 1000 mL with Milli Q water. Nitrite-nitrate (NOx) was analysed by re-filtering the water sample through a Whatman microfiber filter paper (effective pore size of 0.2 μm), diluting 5 mL of sample with 50 mL of Milli Q water, and adding 5 mL of buffer solution.

Fifty mL of each nitrogen sample was measured into a numbered jar. The samples were then filtered. Firstly, the cadmium reduction column was rinsed with 10% buffer solution, making sure the cadmium granules remained covered at all times by either the 10% buffer solution or the sample. The column was drained to 5 mm above the cadmium granules, and 25 mL of the first sample added. This was collected in a separate beaker as it drained through to rinse the column and was discarded. The column was then filled with the sample and 20 mL was collected in the same sample jar. One mL of sulfanilamide solution was added and mixed thoroughly. After 2 minutes, 1 mL of dihydrochloride solution was added and mixed. This was repeated for all water samples. After 10 minutes, the absorbance of each sample was measured using a UV-1700 Pharmaspec UV-visible spectrometer at 543 nm. This colormetric determination of nitrogen can be used when nitrogen is in the range 0.0125 to 2.25 μg/mL. Standards were also prepared before analyzing the samples to calculate linear regression at 0, 0.2, 0.5, 1, 2 and 5 μg/mL of known nitrogen concentration.

TP was measured by digesting an unfiltered water sample in a digestion tube with 10 mL of digestion mixture. This contained 40 g of di-potassium-peroxodisulfate ($K_2S_2O_8$) and 9 g of sodium hydroxide (NaOH) in 1000 mL of Milli Q water. This sample was then digested in the autoclave for 20 minutes. Before FRP was analysed, the sample was re-filtered through a Whatman Microfiber filter paper (effective pore size of 0.2 μm).

Twenty mL of each phosphorus sample was then added to a plastic FRP tube with 2 mL of colour reagent: 20 mL of ascorbic acid solution with 50 mL of molybdate antimony solution. This was repeated for all water samples. After 8 minutes, the absorbance of each sample was measured using a UV-1700 Pharmaspec UV-visible spectrometer at 705 nm. Standards were prepared before analyzing the samples to calculate linear regression at 0, 0.02, 0.05, 0.2 and 0.5 μg/mL of known phosphorus concentration.

NH_4 was analysed using an Orion 95-12 Ammonia Electrode. Samples, standards and the ammonia electrode were equilibrated to a constant temperature. Standards were prepared before analyzing samples to calculate linear regression at 0.01, 0.02, 0.04, 0.06, 0.10, 0.29 and 0.47 ppm.

The concentration of DOC (µg/L) was determined using a Sievers InnovOx Laboratory TOC Analyser.

H.2.4 Water quality, water nutrients and metabolism statistical methods

A mixed-effects general linear model was used to test hypotheses for differences in water quality, water nutrients and metabolism between time (with 2 random levels, Oct-15 and Mar-16), ZONE (with 2 fixed levels, Darling and Warrego) and site (with 6 fixed levels, AKUNA, DARPUMP, BOERA, BOOKA, ROSS and WF) where site was nested with zone. Data were checked for normality using the Shapiro-Wilk test and heterogeneity of variances using the Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. The natural log (ln) transformation was applied to conductivity, water nutrient and metabolism data to satisfy the assumptions of approximate normality and homogeneous variances.

H.2.5 Microinvertebrate statistical methods

To describe and summarize the diversity of microinvertebrate community composition, taxa richness (S), Shannon Weiner diversity (d) and density (number of individual/L) was calculated in PRIMER v6.1.13 using the DIVERSE function.

A mixed-effects general linear model was used to test hypotheses for differences in microinvertebrate taxa richness, diversity and density between time (with 2 random levels, Oct-15 and Mar-16), habitat (with 2 fixed levels, benthic and pelagic), zone (with 2 fixed levels, Darling and Warrego) and site (with 6 fixed levels, AKUNA, DARPUMP, BOERA, BOOKA, ROSS and WF) where site was nested with zone. Data were checked for normality using the Shapiro-Wilk test and heterogeneity of variances using the Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. The significance level was set at 0.05. Where statistically significant differences were detected, post-hoc Tukey's Honestly Significant Difference comparisons were used to determine the source of the significant differences. The natural log (ln) transformation was applied to density data to satisfy the assumptions of approximate normality and homogeneous variances.

Since different sampling methods were used in benthic and pelagic habitat, a permutational multivariate analysis of variance (PERMANOVA) analysis was used to test the difference in the microinvertebrate community composition based on the presence-absence dataset between habitats. Up to 999 random permutations estimated the probability of p-values, with levels of significance reported as $p<0.05$. Where PERMANOVA results were significant, two datasets by habitat were developed to further explore the effects of time, zone and site (zone).

PERMANOVA analyses were used to test the hypotheses for differences in microinvertebrate community composition between time (with 2 random levels, Oct-15 and Mar-16), zone (with 2 fixed levels, Darling and Warrego) and site (with 6 fixed levels, AKUNA, DARPUMP, BOERA, BOOKA, ROSS and WF) where site was nested with zone. Up to 999 random permutations estimated the probability of p-values, with levels of significance reported as $p<0.05$.

The abundance data were transformed into two datasets that weigh the contributions of common and rare species differently. (1) Presence-absence data represents actual taxa occurrence in a community. (2) Abundance data (square root transformation to stabilize variance and to improve normality; Clarke and Warwick, 2001) represents relative proportions of taxa occurrence in a community.

A Bray-Curtis dissimilarity matrix was generated by rank correlating the community structure between samples. Then, nonmetric 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. nMDS output with stress values of less than 0.2 were considered appropriate for interpretation (Clarke and Warwick, 2001).

All univariate analyses were performed in SYSTAT v13 (SYSTAT Software Inc, 2009) and multivariate 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 Water quality indicators

All sites exhibited highly variable water quality conditions during the two sampling periods. Temperature ranged from 18.4 to 25.5 °C during the two sampling occasions with no significant spatial or temporal patterns. pH was consistently alkaline and generally above the ANZECC guideline (pH between 6.5-8). pH in Oct-15 was significantly higher ($F(1,10)$, 52.684, $p<0.005$) than in Mar-16, ranging from 8.34 to 9.04 in Oct-15 and 7.74 to 8.36 in Mar-16 (Figure H-3a).

Turbidity ranged from 84 to 1,117 NTU, and was consistently higher than the ANZECC water quality guideline (turbidity between 6-50 NTU) across all sites (Figure H-3b). Turbidity in the Warrego River sites was significantly higher than the Darling sites ($F(1,10)$, 6.831, $p<0.05$). The highest turbidity recorded of above 1,000 NTU was observed in Booka Dam, and was significantly higher than all other sites (pairwise, $p<0.05$).

Conductivity ranged from 0.18 to 1.08 mS/cm, and was within the ANZECC water quality guideline (conductivity between 0.125 and 2.2 mS/cm). Conductivity in the Darling River sites was significantly higher than the Warrego sites ($F(1,10)$, 72.380, $p<0.001$; Figure H-3c). In the Warrego, Ross Billabong had significantly higher conductivity than Boera Dam and Booka Dam (pairwise, $p<0.05$).

Dissolved Oxygen (DO) concentrations ranged from 14.1% to100.2% (1.39 to 8.31mg/L), and were consistently lower than the ANZECC water quality guideline (DO percent between 85% and 110%). There were no significant spatial and temporal patterns observed in DO concentrations (Figure H-3d).

H.3.2 Water nutrients

Total nitrogen (TN) concentrations were high, with the highest recorded concentration over 2800 µg/L on the Western Floodplain in Oct-15, over five times the ANZECC guideline trigger value (TN at 500 µg/L) in a lowland river ecosystem. TN concentrations in Oct 15 were consistently higher than at Mar 16 ($F(1,10)$ =33.643, $p<0.005$; Figure H-4a). This temporal pattern was consistent among sites with TN concentrations at all Darling and Warrego sites above the ANZECC guideline trigger value in Oct-15, and below the trigger value in Mar-16. There were no significant spatial patterns among sites or zones.

Nitrate-nitrite concentrations were higher than the ANZECC guideline trigger value (Nitrate-nitrite at 40 µg/L) in most of the sites and sampling occasions. The highest mean Nitrate-nitrite concentration of 660 µg/L at Ross Billabong was 16 times higher than the ANZECC value. Nitrate-nitrite concentrations were consistently higher at Oct-15 ($F(1,10) = 19.288$, $p < 0.005$; Figure H-4b), with the mean ranging from 234 µg/L to 660 µg/L in Oct-15 and from 13 µg/L to 184 µg/L in Mar-16. There were no significant spatial pattern among sites or zones.

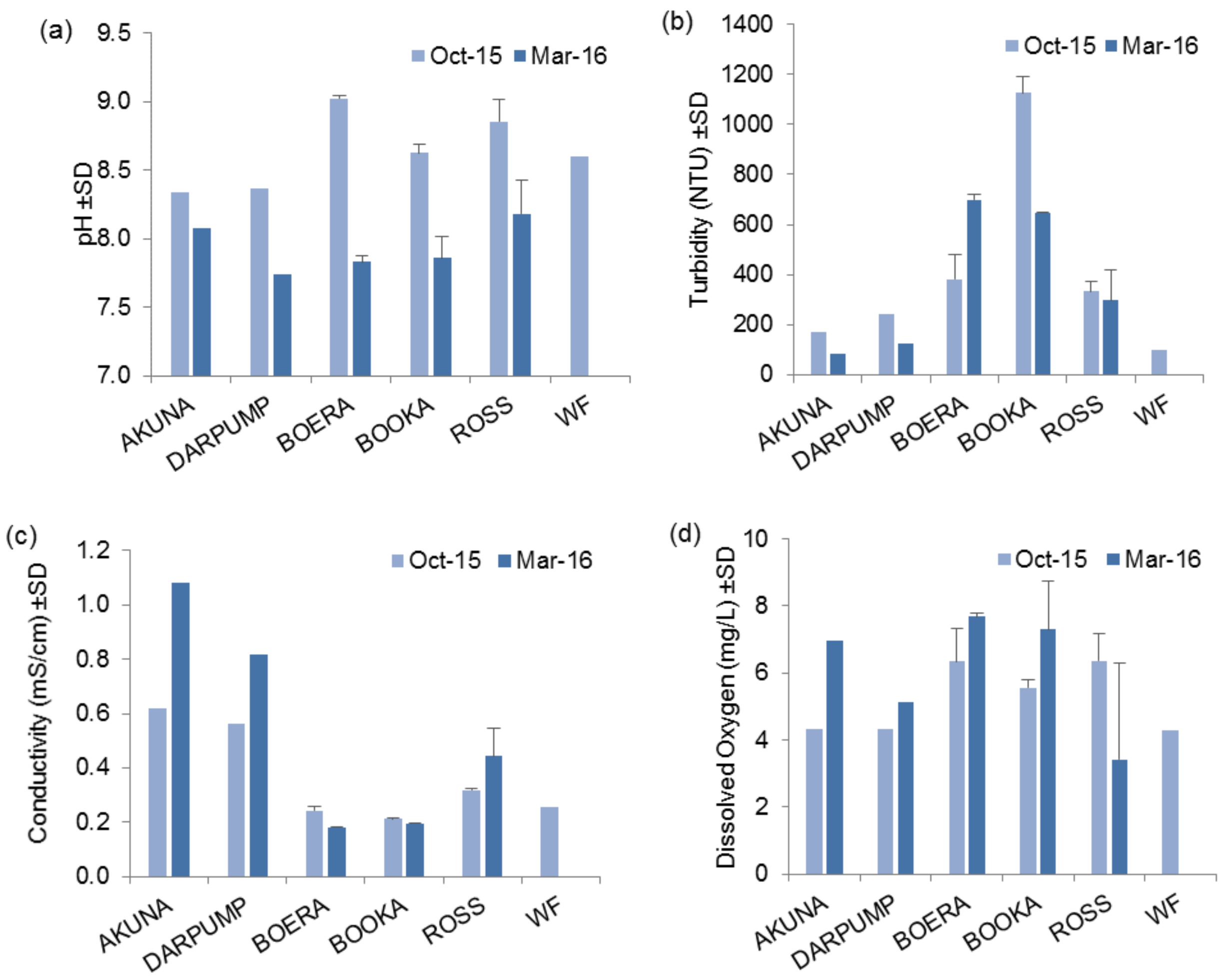


Figure H-3: M Mean concentrations ± standard deviation (SD) of (a) pH, (b) Turbidity, (c) Conductivity and (d) Dissolved Oxygen.

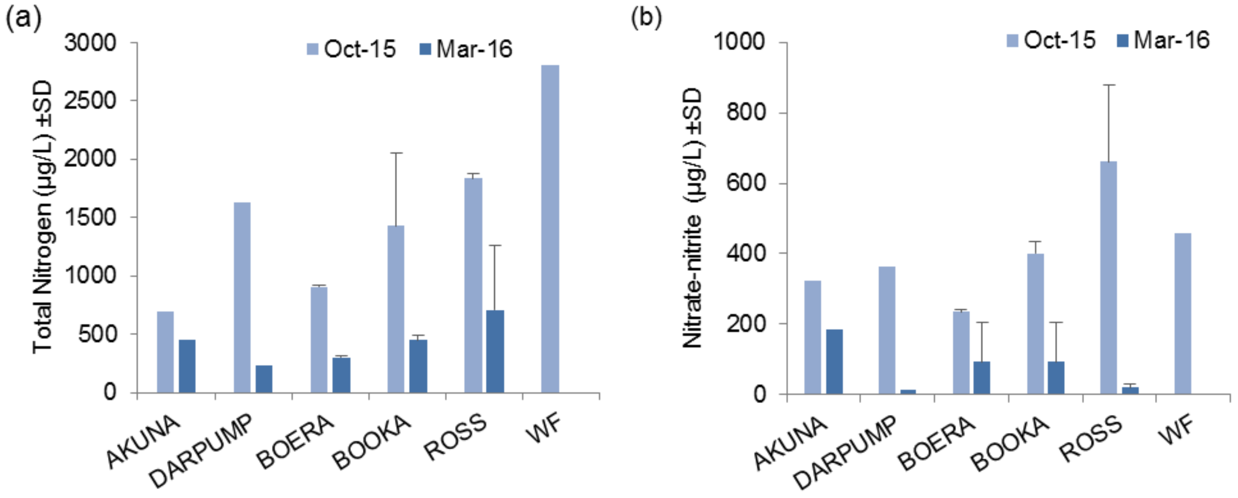


Figure H-4: Mean concentrations ± standard deviation (SD) of (a) pH, (b) Turbidity, (c) Conductivity and (d) Dissolved Oxygen.

Total phosphorus (TP) concentrations were higher than the ANZECC guideline trigger value (TP at 50 µg/L) for lowland river ecosystems. The highest mean of over 1,600 µg/L was 32 times higher than the ANZECC guideline trigger value at Ross Billabong in Mar 16. TP concentrations were generally higher in Mar-16 than Oct-15 among all sites ($F(1,10) = 27.839$, $p<0.005$; **Figure H-5**a). There were no significant spatial pattern among sites or zones.

Filterable reactive phosphorus (FRP) concentrations were higher than the ANZECC guideline trigger value (FRP at 20 µg/L) in most sites and sampling occasions. FRP concentrations ranged from 20 µg/L to 80 µg/L in the Darling River, and from 53 µg/L to 820 µg/L in the Warrego River, with differences between systems being significant ($F(1,10) = 14.200$, $p<0.005$; **Figure H-5**b). In particular, Ross billabong had significantly higher FRP than other sites (Tukey post hoc: $p<0.05$; **Figure H-5**b). There were no significant temporal patterns observed.

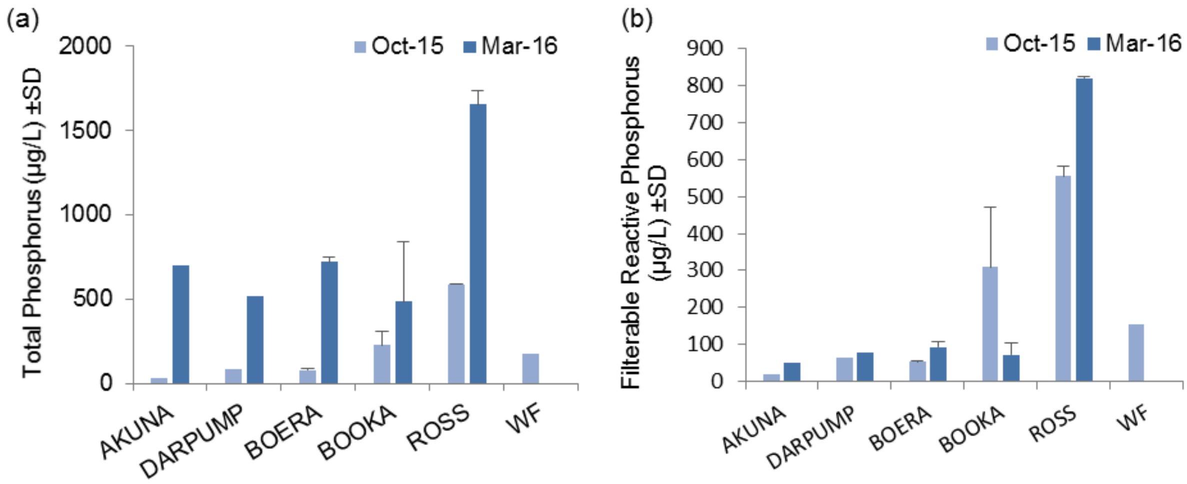


Figure H-5: Mean concentrations ± standard deviation (SD) of (a) Total Phosphorus and (b) Filterable Reactive Phosphorus.

Dissolved Organic Carbon (DOC) concentrations were significantly higher in the Warrego River ($F(1,10) = 20.913$, $p<0.005$; Figure H-6a). DOC concentrations ranged from 8 µg/mL to 13 µg/mL in the Darling River, and from 9 µg/mL to 26 µg/mL in the Warrego. DOC concentrations were higher at Ross billabong, except in October 2015 where they were higher on the Western Floodplain (Tukey post hoc: $p<0.05$; Figure H-6a). There were no significant temporal patterns observed.

Total Suspended Solid (TSS) concentrations were significantly different between the two rivers ($F(1,10) = 17.706$, $p<0.005$; Figure H-6b). TSS concentrations ranged from 33 mg/L to 123 mg/L in the Darling River, and from 43 mg/L to 420 mg/Lin the Warrego River. In particular, Booka Dam had significantly higher TSS compared with other sites (Tukey post hoc: $p<0.05$; Figure H-6b). There were no significant temporal patterns observed.

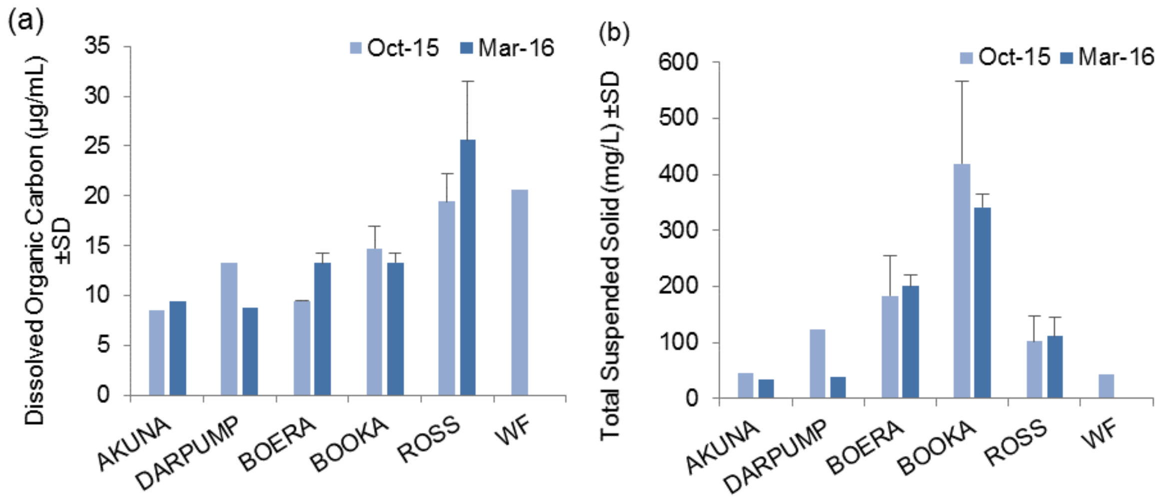


Figure H-6: Mean concentrations ± standard deviation (SD) of (a) Dissolved Organic Carbon and (b) Total Suspended Solid.

H.3.3 Stream Metabolism

Chlorophyll *a* concentrations were generally above the ANZECC guideline trigger value (chl *a* 5 µg/L) for lowland river ecosystems, with a spike of 63 µg/L at Ross billabong in Mar 16 (Figure H-7) associated with peak phosphorus concentrations. However, there were no significant differences in chlorophyll *a* between time, Warrego and Darling Rivers, or site due to high spatial and temporal variability.

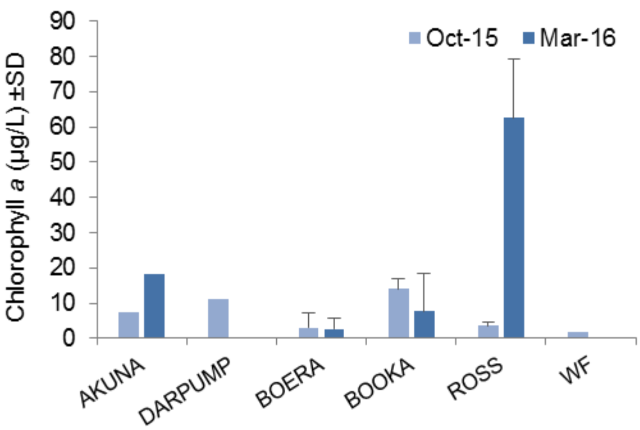


Figure H-7: Mean concentrations ± standard deviation (SD) of Chlorophyll a.

Rates of mean GPP ranged from 0.17 to 14.61 mg O_2/L/day (Figure H-8a) and mean ER ranged from 1.18 to 17.32 mg O_2/L/day (Figure H-8b). Rates of ER were consistently higher than GPP leading to negative rates of NPP. The highest rate of NPP was 7.23 mg O_2/L/day (Figure H-8c) net oxygen consumption in the Darling River at Akuna at Mar-16. Therefore, all sites were net heterotrophic throughout the study period (Figure H-8c).

Rates of GPP, ER and NPP were significantly spatially and temporally different throughout the study period. A consistent temporal pattern was observed across all sites with significantly higher rates of GPP in Mar-16 ($F_{(1,9)}$, 7.656, $p<0.05$) , ER ($F_{(1,9)}$, 77.914, $p<0.005$) and NPP ($F_{(1,9)}$, 38.68, $p<0.005$). Spatially, the rates of GPP ($F_{(1,9)}$, 6.968, $p<0.05$) and ER ($F_{(1,9)}$, 20.903, $p<0.005$) were significantly higher in the Warrego channel compared with the Darling River. Within the Warrego zone, the Western Floodplain had significantly higher rates of ER compared with all other sites (pairwise $p<0.05$).

Scaling up the NPP to the whole wetland the Western Floodplain was net heterotrophic storing over 426 g of oxygen (as the rates of respiration exceeded primary production during Oct-15 sampling occasion) (Table H-3).

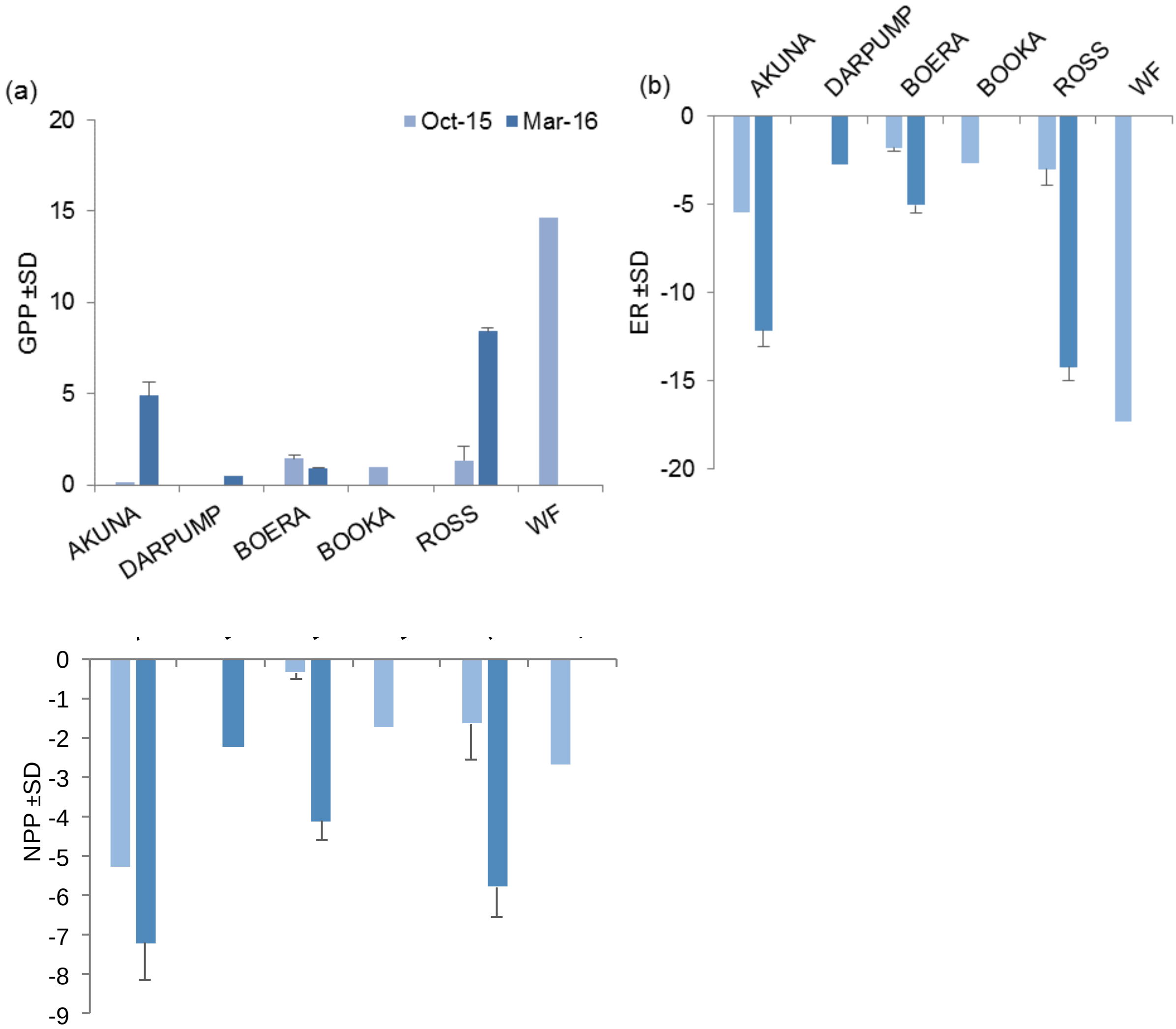


Figure H-8: Mean rates ± standard deviation (SD) of (a) Gross Primary Production, (b) Ecosystem Respiration and (c) Net Primary Production.

Table H-3: Wetland scale Gross Primary Production, Ecosystem Respiration and Net Primary Production (mg DO) in the Western Floodplain.

	GPP (mg DO)	ER (mg DO)	NPP (mg DO)
Western Floodplain	2298.4	-2724.0	-425.6

H.3.4 Microinvertebrates

A total of 36 taxa were identified (from 34 samples). The 15 most abundant taxa (>1% in total abundance) comprised 93% of the total abundance. The most abundant taxa Cladoceran nauplii (22% of the total abundance) occurred at all sites and sampling occasions. The other most abundant species in descending order were rotifer Family Brachionidae (14%), Class Ostracoda (13%) and Phylum Nematoda (9%).

Density

Benthic microinvertebrate communities had higher densities than pelagic communities ($F(1,26)$, 87.650, $p<0.005$; Figure H-9a). Benthic densities ranged from 1218/L to 29920/L while pelagic densities ranged from 57/L to 5215/L. In particular, microinvertebrate densities in the Warrego channel were significantly higher than those in the Darling River ($F(1,26)$, 16.741, $p<0.005$; Figure H-9b). There was no significant temporal pattern in microinvertebrate density.

At the wetland system scale in the Western Floodplain, microinvertebrate abundance was 1,539,516 in the benthic habitat and 61,159 in the pelagic habitat during the Oct-15 sampling occasion.

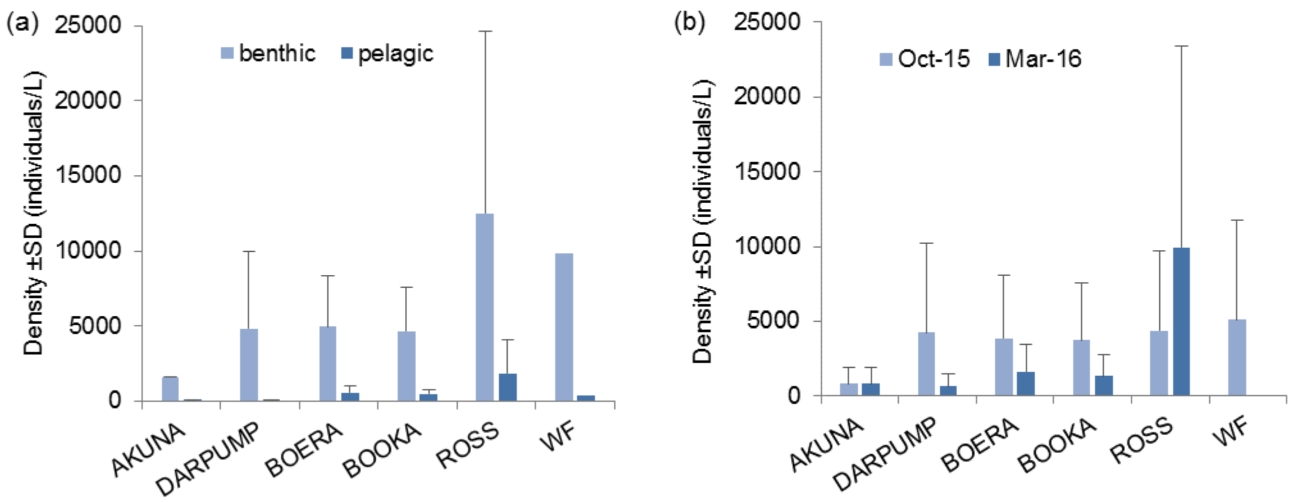


Figure H-9: Mean ± standard deviation (SD) of microinvertebrate density (a) by sampling occasions and (b) by habitat.

Diversity indices

Across all sites and sampling occasions, microinvertebrate richness ranged from 7 to 21 taxa (Figure H-10a). Taxa richness did not show any significant spatial or temporal difference.

Shannon diversity ranged from 0.83 to 2.45 across all samples, with Ross Billabong significantly lower than all other sites (F(4,26), 4.451, p<0.05; Figure H-10b). There was no significant temporal pattern in Shannon diversity during the sampling period.

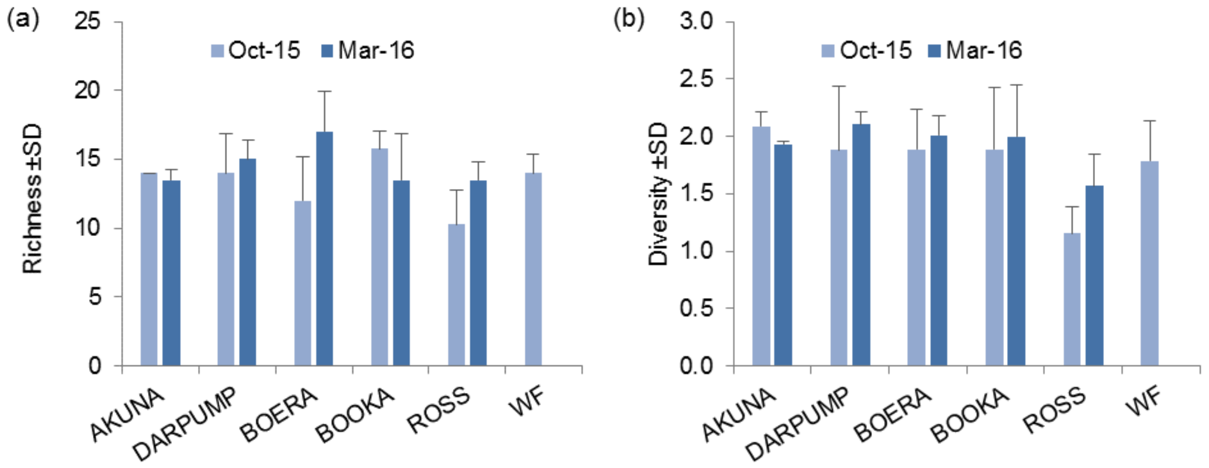


Figure H-10: Mean ± standard deviation (SD) of microinvertebrate (a) taxonomic richness and (b) diversity.

Taxonomic composition

Initially, a one-way PERMANOVA analysis was used to test if habitat could explain differences in the microinvertebrate community composition based on the presence/absence dataset. The PERMANOVA result suggested that the taxonomic composition was significantly different between benthic and pelagic habitats (Pseudo-F=13.596, p=0.001; Figure H-11). Since the taxonomic composition was predominantly driven by habitat, two datasets by habitat were developed to further explore the effects of time, zone and site (zone).

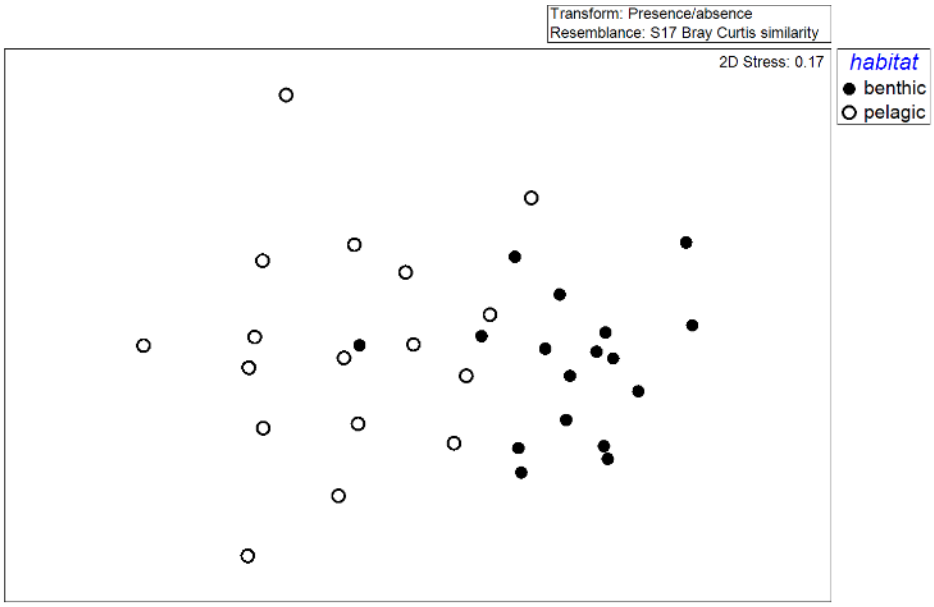


Figure H-11: Mean rates ± standard deviation (SD) of (a) Gross Primary Production, (b) Ecosystem Respiration and (c) Net Primary Production

The community difference between habitats was driven by the higher average abundance of Phylum Nematoda, Class Ostracoda, Phylum Annelida and Cladoceran Family Macrothricidae in the benthic habitat and a higher average abundance of rotifer Families Filiniidae and Hexarthridae in the pelagic habitat (Table H-3). The average abundance of these six taxa contributed to 31% cumulative dissimilarity between two habitats (Table H-4).

Table H-4: Microinvertebrate taxa contributing most of the dissimilarities between benthic and pelagic communities based on presence-absence data. Bold numbers are the higher average abundance group.

Taxa	Average Abundance		Contribution %	Cumulative %
	Benthic	Pelagic		
P. Nematoda	**0.94**	0.12	7	7
C. Ostracoda	**0.82**	0.18	6	12
P. Annelida	**0.76**	0.24	5	17
F. Filiniidae	0.24	**0.76**	5	22
F. Hexarthridae	0.29	**0.71**	5	27
F. Macrothricidae	**0.65**	0.24	5	32
F. Sididae	0.41	**0.88**	5	36
F. Lecanidae	**0.76**	0.41	4	40
F. Chydoridae	**0.82**	0.47	4	45
F. Synchaetidae	0.12	**0.59**	4	49
O. Bdelloida	**0.88**	0.53	4	53

In terms of benthic community composition, a three-way PERMANOVA analysis showed a significant interaction between time and zone (Pseudo-F= 3.3796, d.f.=1, p=0.037) in the benthic community composition. In the Warrego channel, a significant temporal shift in community composition was found between Oct-15 and Mar-16 in a pairwise test (p=0.036). There was no significant spatial pattern observed (Figure H-12a). In the Warrego channel, the community difference between Oct-15 and Mar-16 was driven by the higher abundance of Phylum Annelida and Cladoceran Family Chydoridae in Oct-15 and a higher abundance of Cladoceran Families Daphniidae and Sididae, and rotifer Family Trichocercidae in Mar-16 (Table H-5). The average abundance of these five taxa contributed 30% to cumulative dissimilarity between the two sampling occasions. In the benthic habitat abundance dataset, no statistically significant difference was found between time, zone and among site (zone).

In terms of pelagic community composition, a three-way PERMANOVA analysis revealed a significant interaction between time and zone (Pseudo-F= 2.709, d.f.=3, p=0.003) based on the abundance dataset. In Oct 15, the Darling River and Warrego channel community composition were significantly different (p=0.038). In Mar 16, compositional differences between the Darling and Warrego became less clear and no significantly different was found. In the Warrego channel, a significant temporal shift in community composition was found between Oct-15 and Mar-16 (p=0.014) (Figure H-12b). Similar patterns were also observed when analysing the presence/ absence dataset. The community difference between the Darling Oct-15 and Warrego Oct-15 was driven by the higher abundance of Cladocera nauplii, Copepod family Calanoidae and rotifer family Filiniidae at Warrego Oct-15 and higher abundance of Cladoceran family Chydoridae in the Darling Oct-15 (Table H-6).

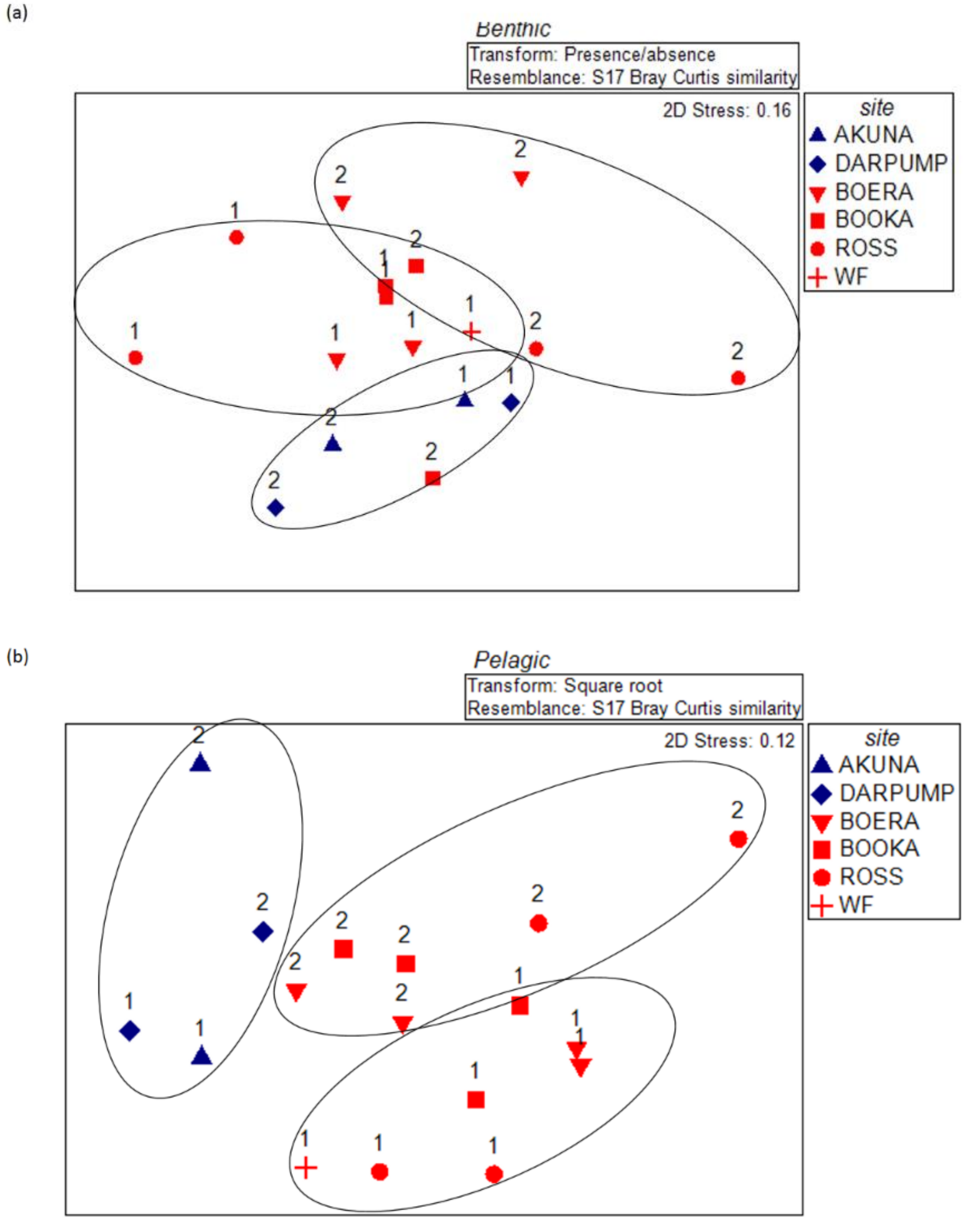


Figure H-12 NMDS ordination of microinvertebrate community composition in (a) benthic habitat using presence-absence dataset and (b) pelagic habitat using abundance dataset. Sampling occasions 1=Oct-15 and 2=Mar-16. Ellipsoids represent significant dissimilarity between community groups in PERMANOVA analysis

Table H-5: Microinvertebrate taxa contributing most of the dissimilarities between Warrego Oct 15 and Mar 16 communities based on benthic habitat presence-absence dataset. Bold numbers are the higher average abundance group.

Taxa	Average Abundance		Contribution %	Cumulative %
	Oct 15	Mar 16		
P. Annelida	**1.00**	0.33	7	7
F. Daphniidae	0.14	**0.67**	7	14
F. Sididae	0.29	**0.67**	6	20
F. Trichocercidae	0.43	**0.50**	5	25
F. Chydoridae	**1.00**	0.50	5	31
F. Moinidae	0.29	**0.50**	5	36
F. Colurellidae	0.14	**0.50**	5	42
F. Filiniidae	0.00	**0.50**	5	47
F. Euchlanidae	**0.43**	0.33	5	52

Table H-6: Microinvertebrate taxa contributing most of the dissimilarities between benthic Darling and Warrego communities at Oct 15 based on pelagic habitat abundance dataset. Bold numbers are the higher average abundance group.

Taxa	Average Abundance		Contribution %	Cumulative %
	Darling	Warrego		
nauplii	3.97	**15.19**	18	18
O. Calanoida	2.58	**9.97**	13	30
F. Filiniidae	0.50	**4.94**	7	37
F. Chydoridae	**3.11**	2.10	6	43
F. Hexarthridae	0.00	**3.85**	6	49
F. Sididae	0.50	**2.84**	4	53

H.4 Discussion

Sampling of water quality variables in 2015-16 suggested that turbidity and nutrient concentrations were consistently exceeded the ANZECC water quality guideline values, reflecting the nature of extreme water quality conditions in the intermittent and low gradient inland freshwater ecosystems within the Selected Area. The measured water quality indicators varied across the Warrego and Darling Rivers and with time, with some broader patterns influenced by seasonal as well as individual flow events. Similar water temperature among sites during spring (Oct-15) and autumn (Mar-16) samplings are attributed to broader regional climate patterns rather than flow or other environmental conditions. The Darling River sites had higher conductivity and lower turbidity compared with the Warrego River sites regardless of flow conditions, suggesting that broader spatial patterns or local saline inputs were driving conductivity in the Darling.

All sites in the Selected Area had exceptionally high nitrogen and phosphorus concentrations irrespective of flow conditions or connectivity. This mirrors the trends observed in the 2014-15 watering year. Nitrogen concentrations were significantly higher in the 'Dry period' as flows receded suggesting internal recycling of nitrogen from the water column and sediments linked to reduced oxygen conditions. Phosphorus concentrations were significantly higher in the 'Wet period' and had a profound effect on rates of GPP (particularly in Ross Billabong) suggesting longitudinal and lateral inputs associated with higher flow events. This is further supported by the poor relationship between high FRP and low TP concentrations that suggest the uptake of FRP by algae and aquatic plants during the inundation period.

Broader spatial patterns also influenced nutrient availability within the Selected Area, for example the Warrego River had higher dissolved organic carbon and soluble inorganic phosphorus concentrations than the Darling River. In particular, Ross billabong had the highest carbon and phosphorus concentrations and subsequently highest chlorophyll *a* concentration. The response of algal biomass measured as chlorophyll *a* to shifts in nutrient concentrations were less clear, and appear to better reflect short term changes in hydrology that either dilute or evapoconcentrate nutrients, overlying the long term patterns of nutrient storage in wetland and watercourse systems.

The increase in rates of GPP and ER corresponded to higher phosphorus availability during the 'Wet period'. As this temporal pattern was consistent among sites, phosphorus availability appears to be the limiting factor governing metabolism rates in the Selected Area. Therefore, the hydrological connectivity of the Warrego channel and Darling River has increased phosphorus loadings across the systems and boosted algal (phytoplankton) productivity, resulting in higher dissolved oxygen concentrations.

Despite high nutrient concentrations driving GPP, all sites were net heterotrophic and therefore a carbon sink during the water year, recording rates up to 7.23 mg O_2/L/day net oxygen consumption. Heterotrophy was due to high respiration rates rather than low algal production. This reflects the energy flow dominated by the heterotrophic (detritus-decomposer-consumer) pathway, where dissolved or particulate organic matter colonized by microbes and fungi is consumed by detritivores that are then eaten by higher consumers (Kobayashi *et al*. 2009). At the same time, an autotrophic (producer-consumer) pathway was evident (but not dominant) from high chlorophyll *a* concentrations. GPP in the Selected Area is driven by high turbidity that limits light penetration and rates of ecosystem production. Turbidity ranged from 84 to 1117 NTU, and was consistently higher than the ANZECC water quality guideline. The lowest rates of GPP and ER corresponded to turbidity, regardless of high nutrient loading, suggesting light and not nutrients are regulating rates of production.

Microinvertebrate density did not show any temporal or spatial pattern during the monitoring period, suggesting secondary production followed primary production and was regulated by light availability and phosphorus concentrations. Microinvertebrate richness and diversity did not display clear patterns or significant relationships with time and site factors, but did influence community composition. In the benthic habitat, microinvertebrate community composition was similar in the two Darling River sites irrespective of flow. In contrast, microinvertebrate community composition in the Warrego channel sites differed between sampling periods linked with an increase in phosphorus concentrations and GPP during the 'Wet period'. Therefore, connectivity of Warrego channels contributed to the development and succession of different microinvertebrate communities between channel sites, even without the inundation of the Western Floodplain.

H.5 Conclusion

Monitoring during 2015-16 revealed significant differences in water quality, the availability of resources and subsequent ecological processes between the two sampling periods, and the Warrego and Darling Rivers. Flow connectivity improved pH, DO and salinity to values within the ANZECC guideline. Turbidity concentrations were exceptionally high and affected rates of metabolism.

Flow events elevated carbon and phosphorus concentrations and diluted nitrogen concentrations, boosting algal productivity and microbial heterotrophy, and stimulating microinvertebrate food webs. Rates of ecosystem respiration were consistently higher than rates of algal productivity resulting in all systems being net heterotrophic in all flow periods, acting as carbon sinks. Low rates of algal productivity and respiration corresponded to high turbidity, regardless of higher nutrient loadings suggesting that turbidity reducing water column light is the principal driver of rates of metabolism in the Selected Area.

There were no consistent patterns in microinvertebrate densities among sites or over time. However, microinvertebrate community composition differed between the Warrego and Darling Rivers, indicating the potential benefits of the delivery of Commonwealth environmental water to the Warrego system for increasing regional level diversity through inundation of wetland and channel habitats. Hydrological connectivity through the channels of the Selected Area contributed to the development and succession of different microinvertebrate communities between systems. Microinvertebrate community composition in the Warrego Channel 'Dry period' were significantly different from 'Wet period' when phosphorus concentrations and productivity increased. Therefore, connectivity of Warrego channels contributed to the development and succession of different microinvertebrate communities between channel sites, even without the inundation of the Western Floodplain, providing a range of potential prey options for consumer animals such as fish, frogs, macroinvertebrates and birds.

H.6 References

Boulton, A., Brock, M., Robson, B., Ryder, D., Chambers, J., and Davis, J. 2014. *Australian freshwater ecology: processes and management*. John Wiley & Sons.

Clarke, D. R. and Warwick, R. M. 2001. *Changes in marine communities: an approach to statistical analysis and interpretation*. Natural Environmental Research Council, Plymouth, England.

Commonwealth of Australia. 2015. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Junction of the Warrego and Darling rivers Selected Area. Annual Evaluation Report – Year 1.* Commonwealth of Australia, Canberra.

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

Appendix I Macroinvertebrates

I.1 Introduction

The macroinvertebrate indicator aims to assess the contribution of Commonwealth environmental water to macroinvertebrate abundance and diversity. A specific question was addressed through this indicator within the Junction of the Warrego and Darling rivers Selected Area (Selected Area) during the 2015-16 water year:

- What did Commonwealth environmental water contribute to macroinvertebrate diversity?

I.1.1 Environmental watering in 2015-16

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year. (Appendix B).

I.1.2 Previous monitoring

Macroinvertebrates were not monitored in Year 1 of the LTIM project in the Junction of the Warrego and Darling Rivers Selected Area.

I.2 Methods

I.2.1 Design

Category III macroinvertebrate indicators were monitored in October 2015 and March 2016. Sampling sites were located in two Sampling Zones within the Selected Area: Darling River and Warrego River (Table I-1).

Table I-1: Location of the sites on the Junction of the Warrego and Darling Rivers Selected Area for macroinvertebrate surveys. Map projection GDA94 Zone 55.

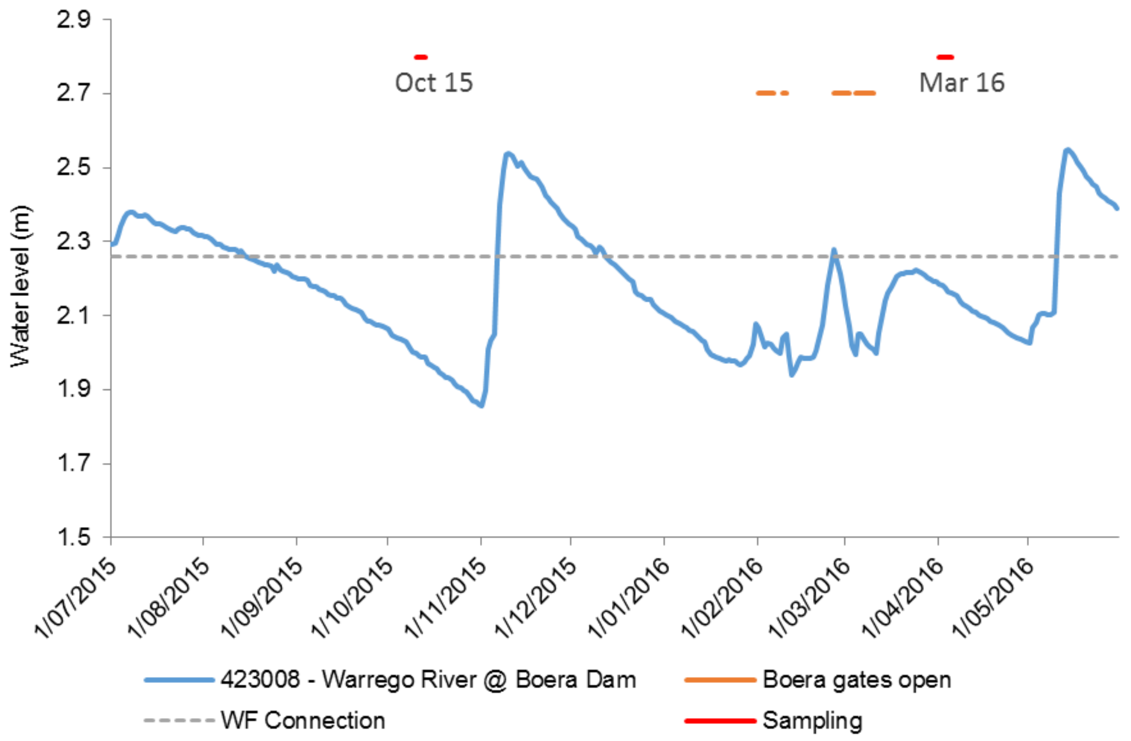
Sampling Zone	Site Name	Site Code	Easting	Northing	Inundation	
					Oct-15	Mar-16
Darling River	Akuna homestead	AKUNA	340008	6634629	Wet	Wet
	Darling Pump	DARPUMP	350768	6635351	Wet	Wet
Warrego Channel	Boera Dam	BOERA	348526	6669158	Wet	Wet
	Booka Dam	BOOKA	349357	6658461	Wet	Wet
	Ross Billabong	ROSS	347281	6636893	Wet	Wet
	Western Floodplain	WF	347643	6665399	Wet	Dry

Hydrological conditions within the Selected Area during sampling are described below.

- Oct 15 – Dry period - (7-10 Oct 2015). During Oct-15 sampling, three Warrego channel sites (Boera Dam, Booka Dam and Ross Billabong) were disconnected from each other and the Darling River. A small area of the Western Floodplain was inundated via a local run-off event in July that raised water levels in Boera Dam above commence to flow for the Western Floodplain (Figure I-1a). However, this local event was not accounted for against environmental water licences for Toorale. The Darling River hydrology was in the falling limb of low magnitude variable flow period (Figure I-1b).

- Mar 16 – Wet period – (29 March to 2 April 2016). During Mar-16 sampling, the Warrego channel was connected with the Darling River as a result of the Boera gates being open for 16 days prior to the sampling period (Figure I-1a). However, during this time the Western Floodplain was dry, so no samples were taken. The Darling River experienced base flow conditions, after a higher flow event one month prior to sampling (Figure I-1b).

a)



b)

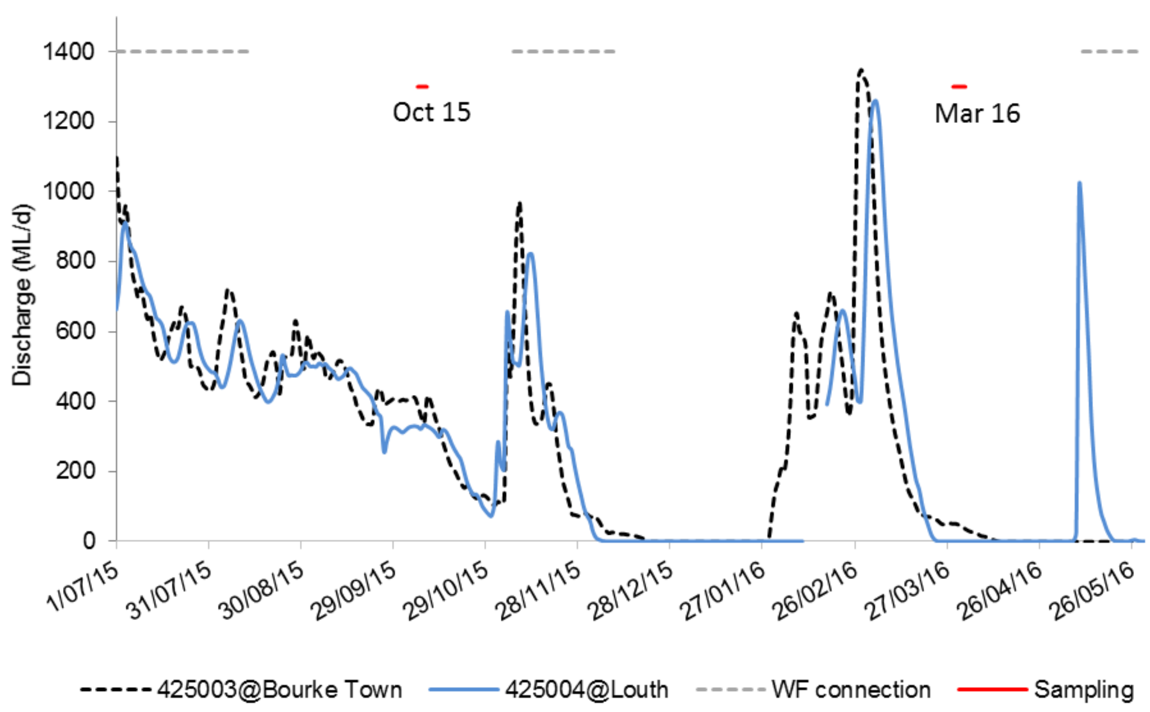


Figure I-1: Water level at (a) Boera Dam and (b) discharge in the Darling River.

I.2.2 Field and laboratory methods

Category III macroinvertebrate indicator monitoring were conducted following the Standard Operating Procedures in Hale *et al*. (2013).

I.2.3 Statistical methods

To describe and summarize the diversity of macroinvertebrate community composition, taxa richness (S), Shannon Weiner diversity (d) and density (number of individual/m^2) were calculated in PRIMER v6.1.13 using the DIVERSE function.

A mixed-effects general linear model was used to test hypotheses for differences in macroinvertebrate taxa richness, diversity and density between time (with 2 random levels, October 2015 and March 2016, river (with 2 fixed levels, Darling and Warrego) and site (with 6 fixed levels, AKUNA, DARPUMP, BOERA, BOOKA, ROSS and WF) where site was nested with river. Data were checked for normality using the Shapiro-Wilk test and heterogeneity of variances using the Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. The natural log (ln) transformation was applied to all data to satisfy the assumptions of approximate normality and homogeneous variances.

Permutational multivariate analysis of variance (PERMANOVA) analysis was used to test the hypotheses for differences in macroinvertebrate community composition between time (with 2 random levels, October 2015 and March 2016), river (with 2 fixed levels, Darling and Warrego) and site (with 6 fixed levels, AKUNA, DARPUMP, BOERA, BOOKA, ROSS and WF) where site was nested with river. Up to 999 random permutations estimated the probability of p=values, with levels of significance reported as $p<0.05$.

The abundance data were transformed into two datasets which weigh the contributions of common and rare species differently. (1) Presence-absence data represents actual taxa occurrence in a community. (2) Abundance data (square root transformation to stabilize variance and to improve normality; Clarke and Warwick, 2001) represents relative proportions of taxa occurrence in a community.

A Bray-Curtis dissimilarity matrix was generated by rank correlating the community structure between samples. Then, nonmetric 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. nMDS output with stress values of less than 0.2 were considered appropriate for interpretation (Clarke and Warwick, 2001).

All univariate analyses were performed in SYSTAT v13 (SYSTAT Software Inc., 2009) and multivariate analyses were performed in PRIMER v6.1.13 with the PERMANOVA+ v1.0.3 add-on package (PRIMER-E, 2009).

I.3 Results

A total of 36 taxa were identified (from 17 samples). The 10 most abundant taxa (>1% in total abundance) comprised 95% of the total abundance with the most abundant taxa Notonectidae (39% of the total abundance). The other most abundant species in descending order are Corixidae (22%), Crambidae (7%), Tanypodinae (7%) and Chironominae (5%). Corixidae and Chironominae were common in all sites.

I.3.1 Density

Macroinvertebrate communities in the Warrego had higher densities than those in the Darling (F(1,4), 8.058, p<0.05; Figure I-2), ranging from 12 individuals per m^2 to 1075 individuals per m^2 and 21 individuals per m^2 to 102 individuals per m^2 in the Darling. Although there was no significant temporal pattern, most of the sites (except Ross Billabong) had a lower macroinvertebrate density in March 2016 compared with October 2015.

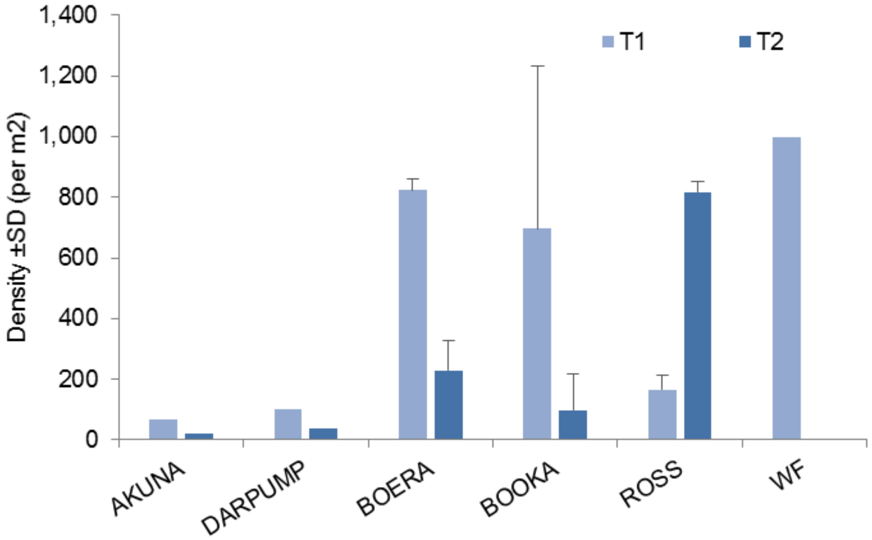


Figure I-2: Mean ± standard deviation (SD) of macroinvertebrate density (individuals/m^2).

I.3.2 Diversity indices

Across all sites and sampling occasions, macroinvertebrate richness ranged from 5 to 16 taxa (Figure I-3a). Taxa richness in the Warrego was significantly higher than those in the Darling (F(1,4), 13.303, p<0.005). There was no significant temporal pattern in richness. Shannon diversity ranged from 0.89 to 3.21 across all samples (Figure I-3b). Taxonomic diversity did not show any significant response to time, river or site factors. Interestingly, although there were no significant statistical differences, most of the Warrego River sites had increased richness and diversity during March 2016, while all of the Darling River sites had lower richness and diversity during this period.

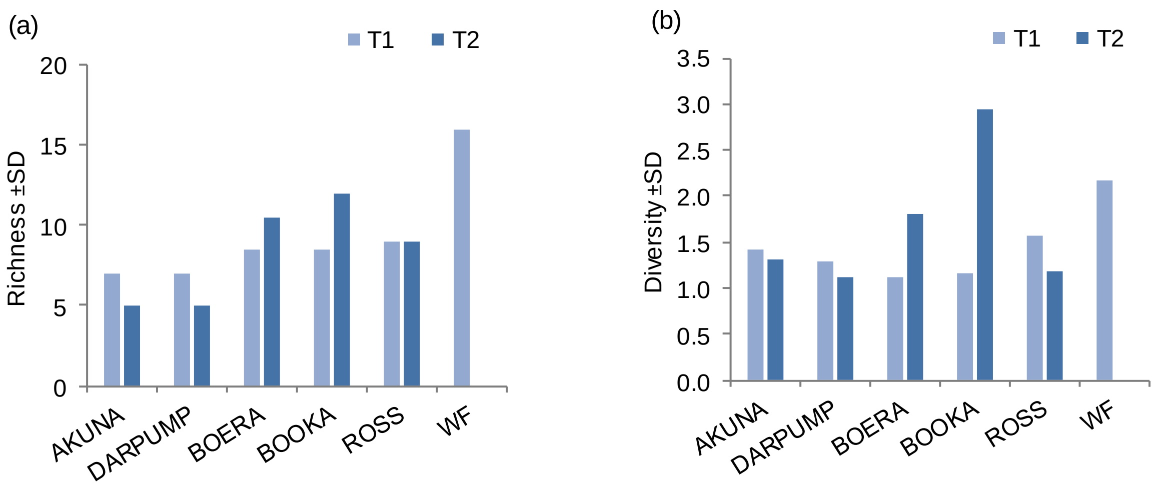


Figure I-3: Mean ± standard deviation (SD) of macroinvertebrate (a) family richness and (b) diversity.

I.3.3 Taxonomic composition

The three-way PERMANOVA analyses showed no significant interaction between time, river and site. However, the nMDS ordination based on presence-absence data (stress value of 0.12; Figure I-4a) and abundance data (stress value of 0.13; Figure I-4b) showed that community composition was strongly influenced by zone.

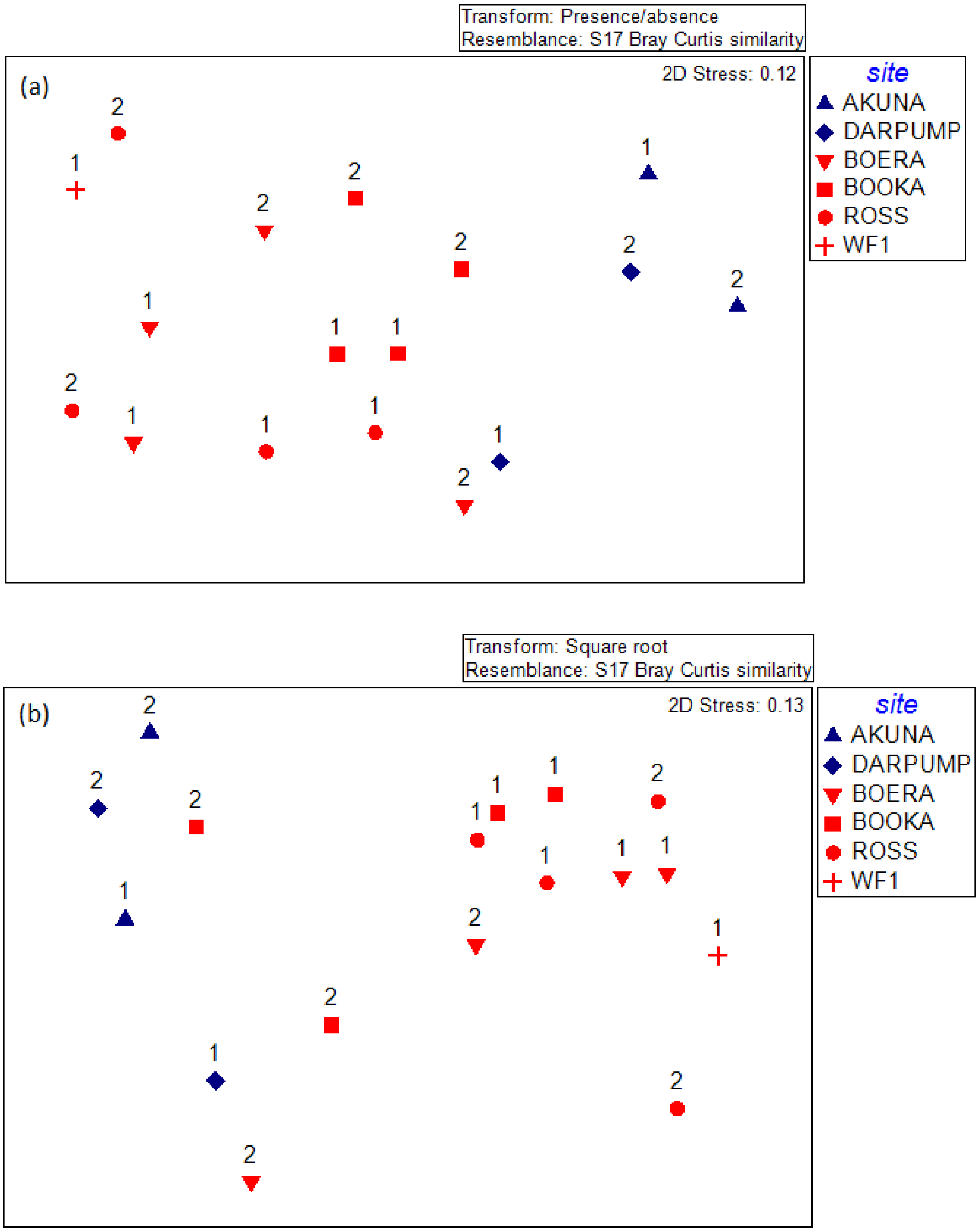


Figure I-4: NMDS ordination of macroinvertebrate community composition using (a) presence-absence dataset and (b) abundance dataset.

I.4 Discussion

During 2015-16, macroinvertebrate densities in the Warrego River that experienced connection and disconnection phases were substantially higher than those in the Darling River that remained permanently inundated. This pattern was observed for both sampling occasions, reflecting spatial, hydrologic and hydraulic differences between the two rivers exerting a strong influence on macroinvertebrate density. A similar decrease in macroinvertebrate density was observed across most sites in the 'Wet' phase suggesting that temporal changes in hydrology and/or environmental conditions were a consistent and strong influence.

Macroinvertebrate family richness in the Warrego River was significantly higher than in the Darling River. In particular, the temporarily inundated Western Floodplain had the highest richness of 16 families during the 'Dry' phase. This diversity of macroinvertebrates represents an important food resource for insectivorous waterbirds such as Herons, Egrets, Ibis and Spoonbills. This highlights that inundating the Western Floodplain is critical to maintaining local-scale macroinvertebrate diversity and supporting the food web for higher consumers. Macroinvertebrate community composition varied between sites and time, but there were clear differences between the Warrego and Darling River zones that mirrored the changes in density.

I.5 Conclusion

The Warrego River sites had increased macroinvertebrate density and richness compared with Darling River sites regardless of time of year, and current or antecedent flow conditions. This suggests that the connection and disconnection phases in the Warrego channel, in addition to the habitat and resource diversity provided by the inundated Western Floodplain are key drivers of macroinvertebrate communities in the Selected Area.

I.6 References

Clarke, D. R. and Warwick, R. M. 2001. *Changes in marine communities: an approach to statistical analysis and interpretation*. Natural Environmental Research Council, Plymouth, England.

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S., Gawne, B., and Stewardson, M. 2014. *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods*. Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 29.2/2014, January, 175 pp.

Appendix J Ecosystem Type

J.1 Introduction

The Ecosystem type indicator contributes to the broader scale evaluation of Commonwealth environmental waters influence on ecosystem diversity. While primarily designed to inform at the basin scale, information on the types of ecosystems influenced by Commonwealth environmental water is also useful at the Junction of the Warrego and Darling rivers Selected Area (Selected Area) scale. Several specific questions were addressed by measuring Ecosystem type within the Selected Area during the 2015-16 water year:

- 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?

J.1.1 Environmental watering in 2015-16

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January-March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year. (Appendix B).

A moderate pulse in the Darling River began in June 2016 reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by 30 June 2016, and peaking at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

J.2 Methods

The ANAE classification for each site in the Selected Area was mapped using a process of desktop identification and field verification (Commonwealth of Australia 2015). Existing ANAE GIS layers (Brooks *et al*. 2013) were used to assign an Ecosystem type to each monitoring site, and this was then verified in the field. Sites where existing ANAE mapping did not provide coverage were assigned an ANAE classification using available desktop information and then verified in the field. Field based verification was undertaken following a dichotomous key (Brooks *et al*. 2013).

Monitoring of the Fish (Channel) indicator commenced in the 2015-16 water year. Fish sampling was undertaken at five sites within the Warrego River. ANAE classification was mapped for two sites (Homestead Dam and Dicks Dam) that had not been previously sampled as part of the Junction of the Warrego and Darling rivers Selected Area LTIM project.

J.3 Results

Monitoring is being undertaken at 62 sites as part of the Junction of the Warrego and Darling rivers Selected Area LTIM project. These are classified into nine ANAE Ecosystem types, including five Floodplain types, two Lacustrine types, one Riverine type and one Palustrine type (Table J-1).

Forty-one sites are located within the Selected Area (Figure J-1), with the other sites being river flow gauging stations located on upstream tributaries. Homestead Dam and Dicks Dam are new sites included in the 2015-16 water year and are mapped as Lt2.1: Temporary lake type.

Within the Selected Area, a total of 16 sites, accounting for 39% of all sites, were inundated during the 2015-16 water year (Figure J-2; Figure J-3). Five ecosystem types were inundated, including F1.11: River cooba woodland floodplain, F1.8: Black box woodland floodplain, F2.2: Lignum shrubland floodplain, Lt2.1: Temporary lake and Rp1.4: Permanent lowland stream (Figure J-3). All survey sites within the Lt2.1: Temporary lake and Rp1.4: Permanent lowland stream ecosystem types that were inundated were influenced by Commonwealth environmental water.

Table J-1: ANAE Ecosystem Type's covered by monitoring sites in the Junction of the Warrego Darling rivers Selected Area LTIM Project.

ANAE Typology	Number of sites (All Zones)	% of all sites
F1.10 Coolibah woodland and forest floodplain	4	10
F1.11 River cooba woodland floodplain	6	15
F1.8 Black box woodland floodplain	3	7
F2.2 Lignum shrubland floodplain	6	15
F2.4 Shrubland floodplain	6	15
Lt2.1 Temporary lake	7	17
Lt2.2 Temporary floodplain lake with aquatic beds	2	5
Pt2.2.1 Temporary sedge/grass/forb floodplain marsh	3	7
Rp1.4 Permanent lowland stream	4	10
Total	41	

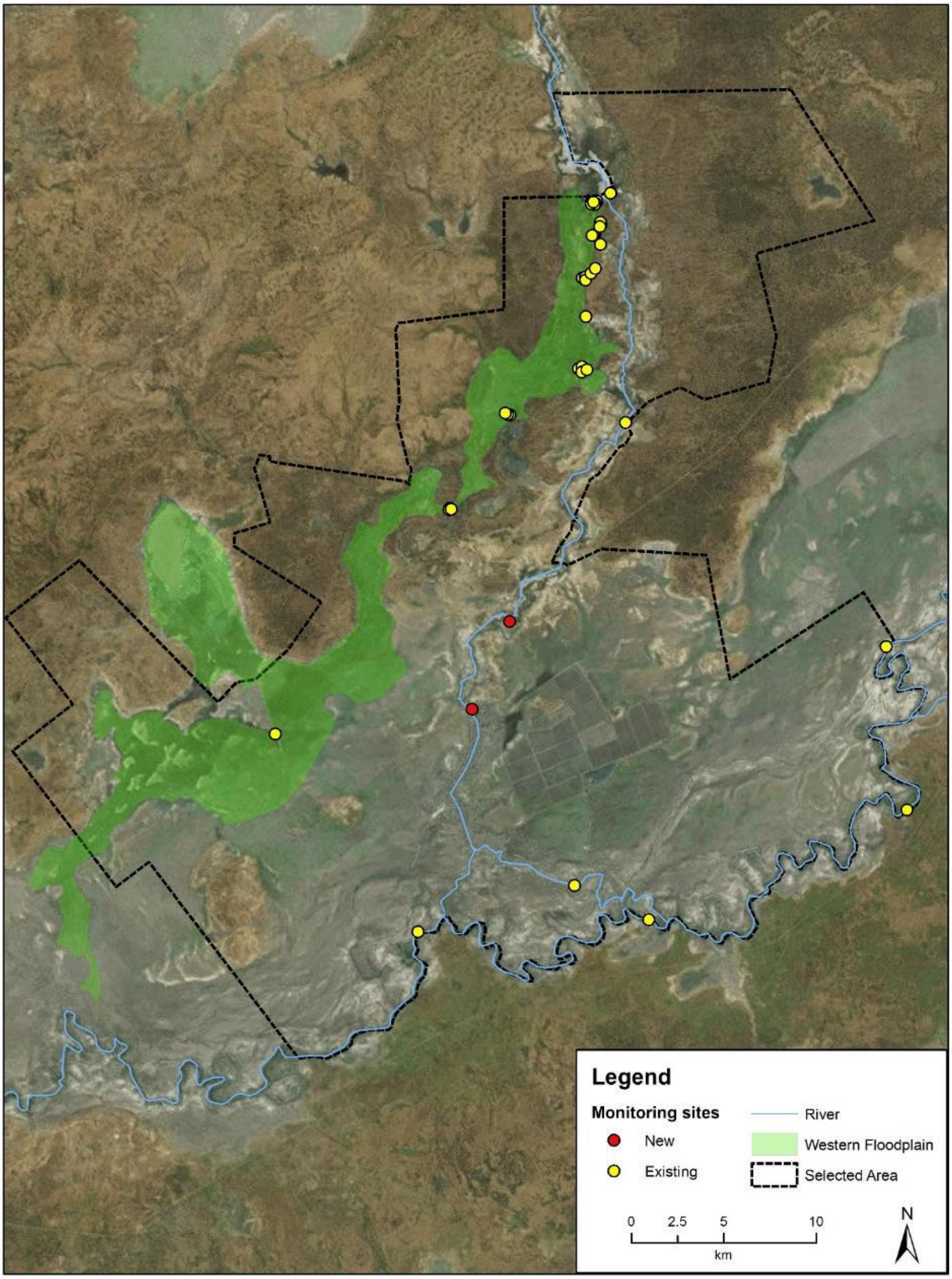


Figure J-1: New and old sites monitored within the Selected Area for the 2015-16 water year.

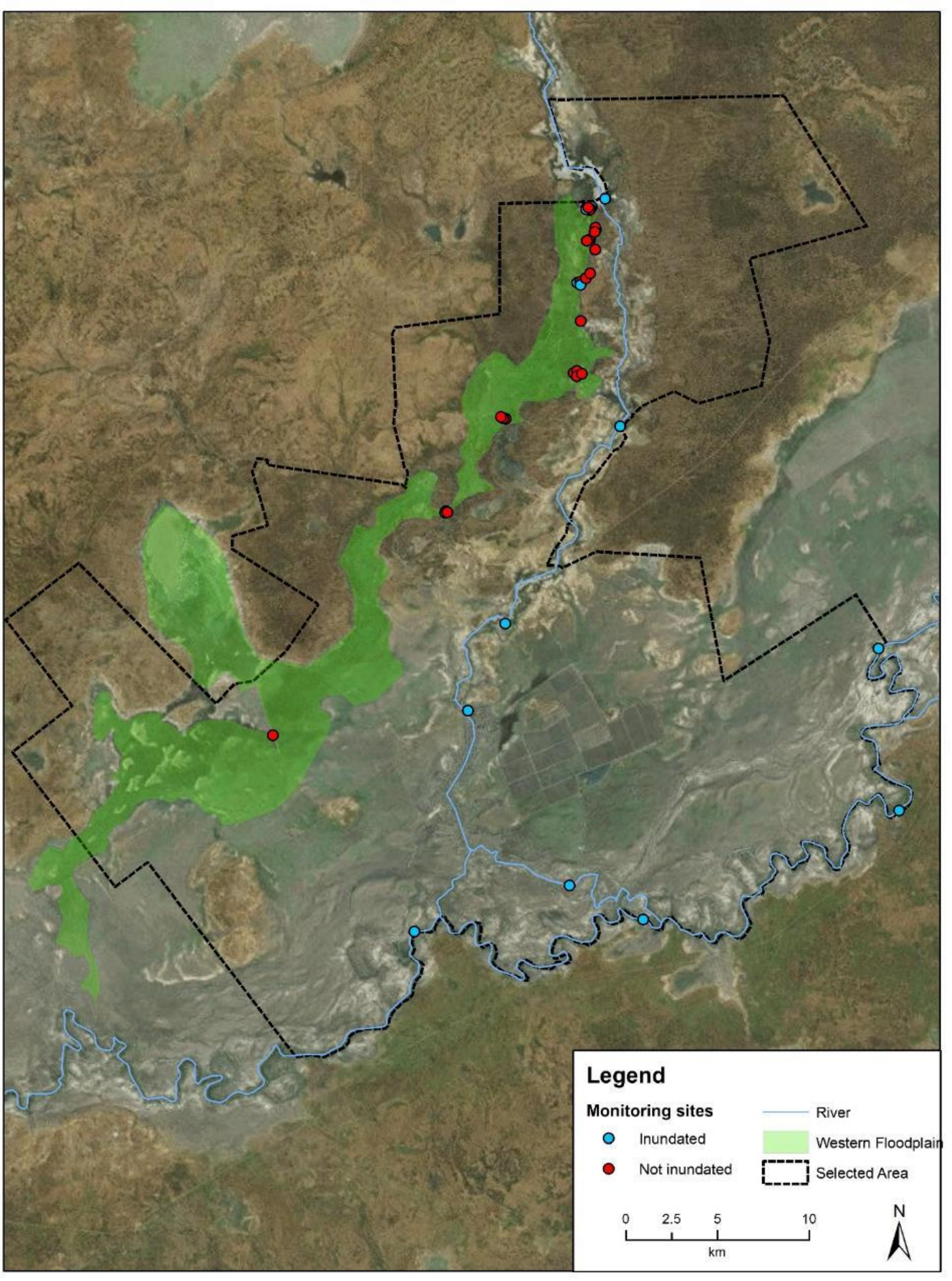


Figure J-2: Inundation status of sites sampled in the Selected Area during the 2015-16 water year.

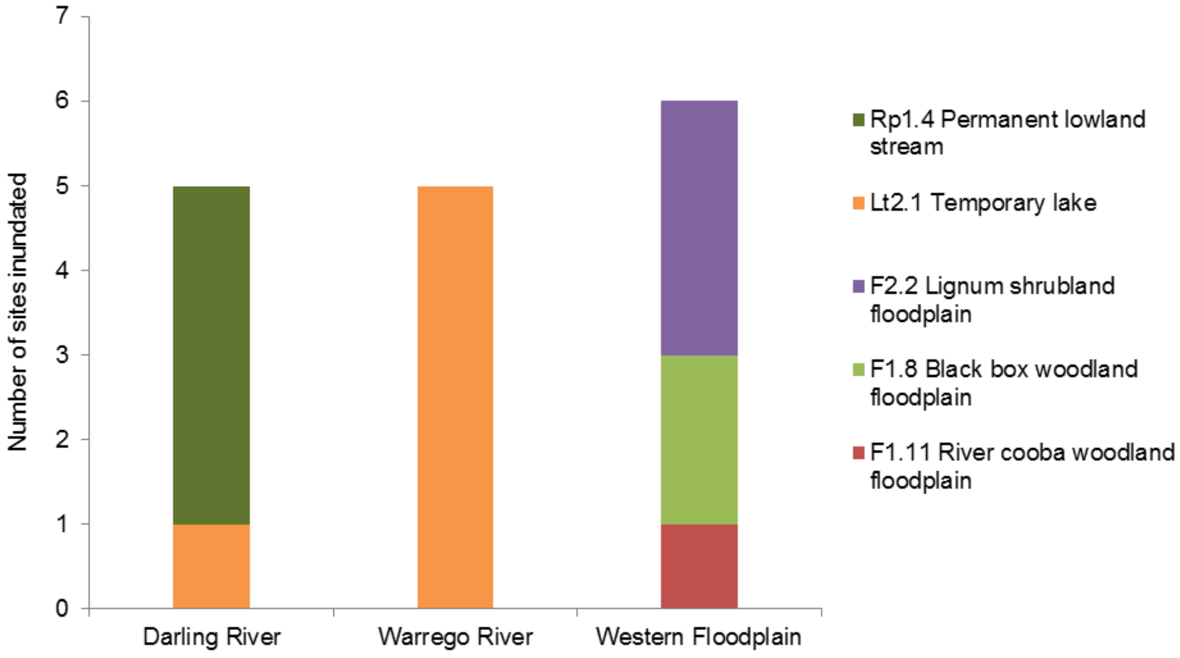


Figure J-3: Distribution of ANAE Ecosystem types inundated across the three monitoring zones within the Selected Area.

J.4 Discussion

The types of ecosystems monitored in this project are a reflection of the nature of the delivery of environmental water, and the indicators being assessed. While aquatic in-channel habitats are being monitored in the Darling and Warrego River zones, a broader suite of ecosystems including channels, waterholes and floodplains are being monitored on the Western Floodplain. This diversity is reflected in the greater number of Ecosystem types being monitored in this zone.

During the 2015-16 water year, Commonwealth environmental water influenced sites within the Warrego River and Darling River channels representing 2 of the 9 Ecosystem types monitored; permanent lowland streams (Rp1.4) and temporary Lakes (Lt2.1). Commonwealth environmental water did not contribute to inundation of Ecosystem types on the Western Floodplain, unlike the first year of the project where the management of Commonwealth environmental water inundated four ecosystem types on the Western Floodplain including temporary floodplain lakes (with and without aquatic beds), lignum shrubland floodplain and river cooba woodland floodplain types. While Commonwealth environmental water did not influence Western Floodplain ecosystem types in 2015-16, localised rainfall runoff did inundate some parts of the floodplain (Appendix E), sustaining a number of floodplain ecosystem types. Sustaining a range of different ecosystems is important for habitat availability and long term diversity within the Selected Area.

J.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*. Commonwealth of Australia, Canberra.

Appendix K Vegetation Diversity

K.1 Introduction

The Western Floodplain of the Warrego River supports predominantly continuous stands of floodplain species such as coolibah, black box and lignum (Hale *et al*. 2008) that have adapted to the increased inundation patterns as a result of the water management structures on Toorale (Capon 2009). These communities have been found to be in relatively good condition compared with communities in other intersecting streams in the northern basin (Hale *et al*. 2008). As such, they constitute a target for Commonwealth environmental water within the Junction of the Warrego and Darling rivers Selected Area (Selected Area). The vegetation diversity indicator aims to assess the contribution of Commonwealth environmental water to floodplain vegetation diversity, condition and extent. Several specific questions were addressed through the monitoring of vegetation diversity in the 2015-16 water year in the Selected Area:

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

K.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and providing connection to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year. (Figure K-1).

A moderate pulse in the Darling River began in June reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by the 30 June 2016, and peaking at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

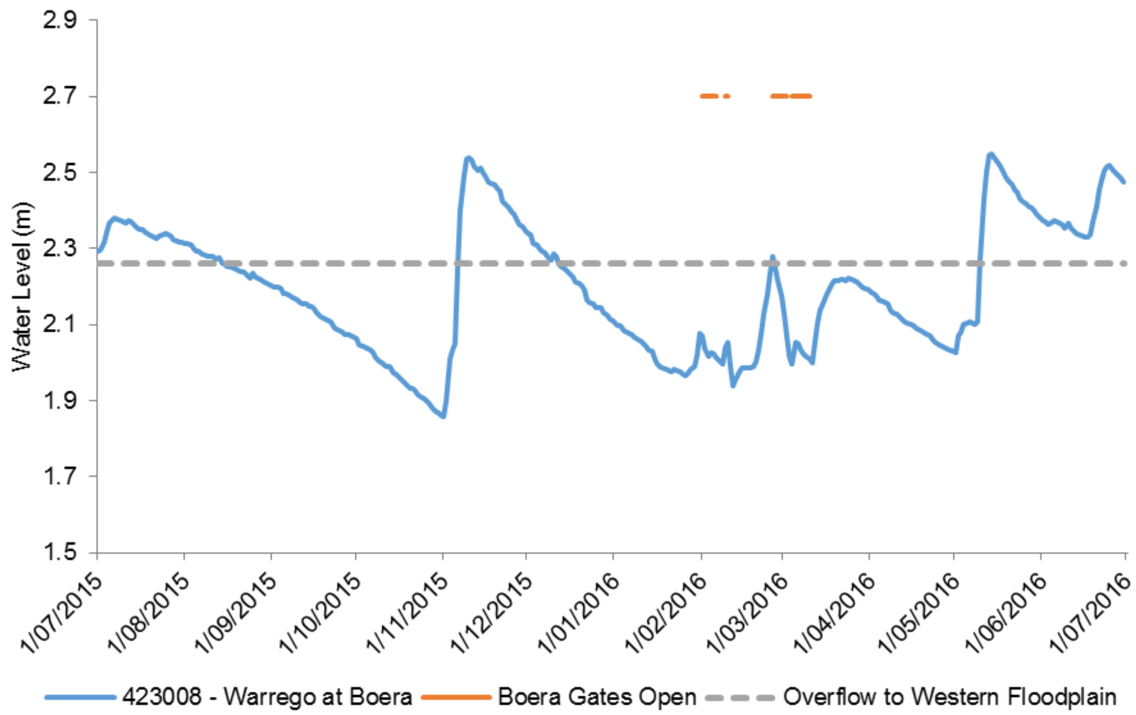


Figure K-1: Boera Dam levels during 2015-16 water year and flow to Western Floodplain and/or into lower Warrego channels (gates open)

K.1.2 2014-15 monitoring outcomes

Vegetation monitoring was undertaken during the 2014-15 water year as part of Year 1 of the LTIM project. This monitoring suggested that the presence of surface water during the February 2015 survey reduced the diversity of terrestrial species that tend not to cope well with periods of inundation. Species diversity at the four inundated sites increased in the May 2015 survey after the water had receded, indicating a positive causal link of species diversity with inundation. Forb species cover increased as these species are able to respond rapidly to changes in moisture condition.

K.2 Methods

K.2.1 2015-16 water year

Twenty-four plots were monitored at eight locations throughout the Western Floodplain during August 2015 and March 2016 (Table K-1; Figure K-2). These plots were located in four broad wetland vegetation communities, and experienced a range of inundation conditions (Table K-1). Sites that were classed as 'wet' for the March 2016 survey, were assessed using inundation mapping derived from Landsat 8 image analysis (Appendix E) to have been inundated prior to the survey. Vegetation surveys were completed following the standard vegetation diversity method (Commonwealth of Australia 2015; Hale *et al*. 2013), which recorded vegetation diversity and structure 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 factorial regression analysis to investigate the influence of inundation, sampling time and vegetation community. Where necessary, the data were transformed to meet model assumptions. To further explain changes in diversity, individual species were grouped into four functional groups (Brock and Cassanova 1997):

- Amphibious responders (AmR)—plants which change their growth form in response to flooding and drying cycles;
- Amphibious tolerators (AmT)—plants which tolerate flooding patterns without changing their growth form;
- Terrestrial damp plants (Tda)—plants which are terrestrial species but tend to grow close to the water margin on damp soils; and
- Terrestrial dry plants (Tdr)—those which 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 then compared between survey times using F-tests to test for equality of variances and then T-tests to test for differences in means.

Changes in vegetation cover were investigated using multivariate nMDS plots with differences between the presence of environmental water, survey time and vegetation community assessed using PERMANOVA in Primer 6. SIMPER analysis was used to identify the species that were most responsible for driving patterns in the data, and follow up descriptive univariate analysis of these species were then undertaken.

K.2.2 Multi-year comparison

Longer-term changes in vegetation species richness were investigated using factorial regression analysis on species richness data to investigate the influence of inundation, survey time (February 2015, May 2015, October 2015, March 2016), and vegetation community. Changes in vegetation cover over Year 1 and 2 of the LTIM project were investigated using multivariate nMDS plots with differences between inundation, survey time and vegetation community assessed using PERMANOVA in Primer 6.

Table K-1: Sites surveyed in August 2015 and March 2016 for vegetation diversity. Map projection GDA94 Zone 55.

Vegetation communities	Sites	Easting	Northing	Inundation	
				Aug-15	Mar-16
Coolibah-River Cooba-Lignum woodland	WD1.1	6668758	347881	Dry	Wet
Coolibah-River Cooba-Lignum woodland	WD1.2	6668663	347818	Dry	Dry
Coolibah-River Cooba-Lignum woodland	WD1.3	6668610	347776	Dry	Dry
Coolibah-River Cooba-Lignum woodland	WD2.1	6667219	347814	Dry	Dry
Coolibah-River Cooba-Lignum woodland	WD2.2	6667195	347764	Dry	Dry
Coolibah-River Cooba-Lignum woodland	WD2.3	6667165	347675	Dry	Dry
Chenopod shrubland	WD3.1	6658750	343962	Dry	Dry
Chenopod shrubland	WD3.2	6658762	343840	Dry	Dry
Chenopod shrubland	WD3.3	6658822	343729	Dry	Dry
Chenopod shrubland	WD4.1	6660934	347121	Dry	Dry
Chenopod shrubland	WD4.2	6661041	347292	Dry	Dry
Chenopod shrubland	WD4.3	6660788	347285	Dry	Dry
Coolibah woodland wetland	WD5.1	6654363	341209	Dry	Dry
Coolibah woodland wetland	WD5.2	6654290	341161	Dry	Dry
Coolibah woodland wetland	WD5.3	6654320	341268	Dry	Dry
Coolibah woodland wetland	WD6.1	6665179	347247	Dry	Wet
Coolibah woodland wetland	WD6.2	6665221	347382	Dry	Wet
Coolibah woodland wetland	WD6.3	6665082	347402	Dry	Dry
Lignum shrubland wetland	WD7.1	6668699	347679	Dry	Wet
Lignum shrubland wetland	WD7.2	6668693	347608	Wet	Wet
Lignum shrubland wetland	WD7.3	6668627	347613	Wet	Wet
Lignum shrubland wetland	WD8.1	6667685	348087	Dry	Dry
Lignum shrubland wetland	WD8.2	6667780	348055	Dry	Dry
Lignum shrubland wetland	WD8.3	6667585	348039	Dry	Dry

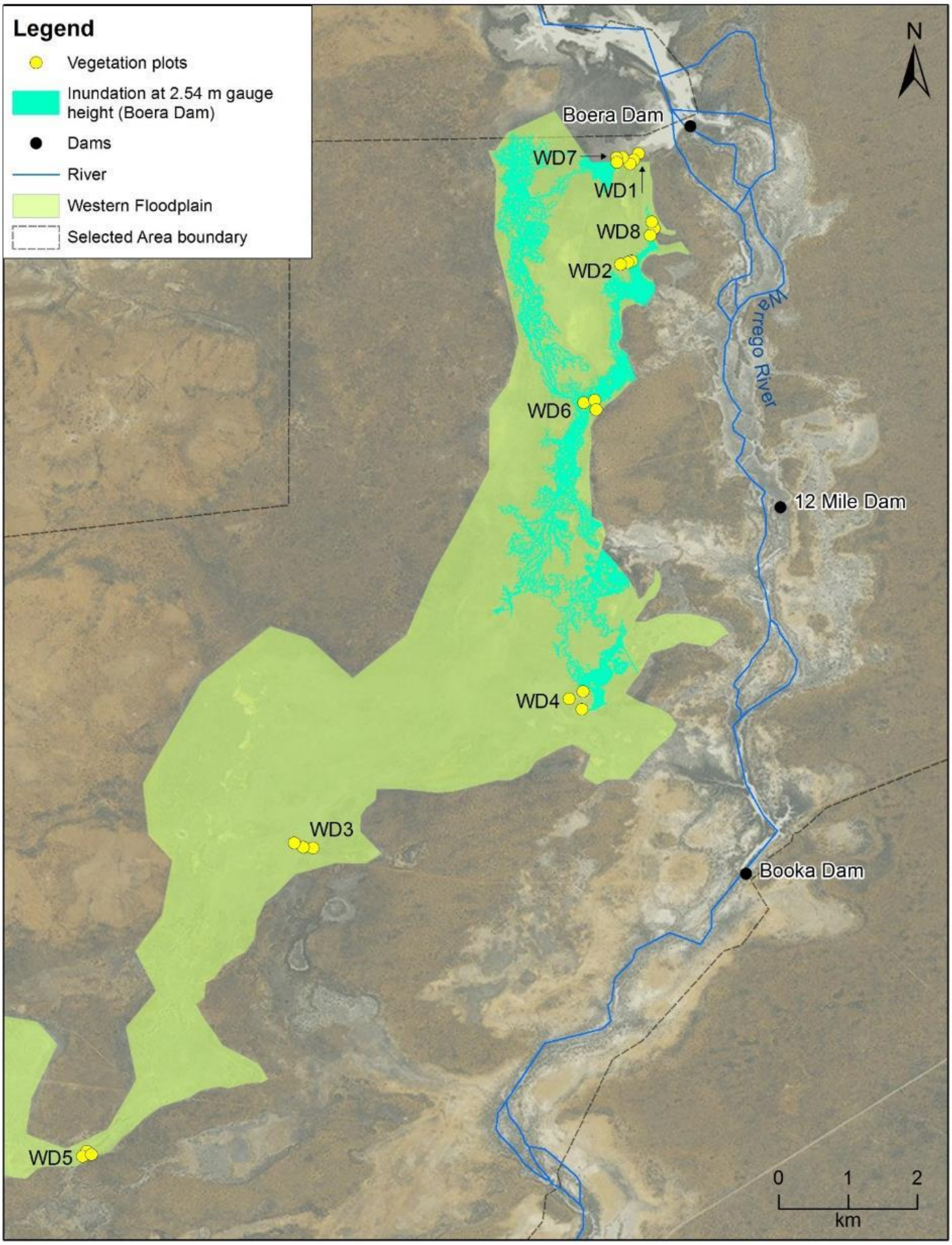


Figure K-2: Location of vegetation monitoring sites in the Western Floodplain zone. Maximum modelled inundation level (2.54 m at Boera Dam) also represented.

K.3 Results

K.3.1 2015-16 water year

Species richness

A total of 132 species from 38 families were recorded across all vegetation plots. The mean species richness recorded at each location during each survey period was 17.5. The lowest mean species richness was 10.7, recorded at WD5 in March 2016, while the highest was 27.3 species, recorded at WD8 in August 2015 (Figure K-3). Mean species richness was significantly higher in August 2015 (20.5 species), than in March 2016 (14.6 species; $F_{1,40}=29.607$, $p<0.005$). Plots located in the lignum shrubland wetland community had an average of 19.7 species, followed by chenopod shrubland (18.9 species), and coolibah - river cooba - lignum woodland (16.4 species). Coolibah woodland wetland communities had significantly lower mean species richness with 15.2 species per plot ($F_{3,40}=3.861$, $p<0.05$).

Sites that were wet during sampling had marginally lower mean species richness (16.6 species) than those that were dry (17.7), though this difference was non-significant ($t=0.90$, $p=0.38$). Inundated sites had a higher presence of species within the terrestrial damp plants (Tda) and amphibious tolerator (AmT) functional groups (Figure K-4). Sites that remained dry had a higher presence of species within the terrestrial dry plants (Tdr) functional group (Figure K-4). Changes within the amphibious responder (AmR) functional group were negligible across all sites regardless of time or inundation status. Sites that were dry during August 2015 and then wet in March 2016 decreased in species richness across the three functional groups present with time, however these decreases were non-significant ($t=1.09$, $p=0.32$; Figure K-5).

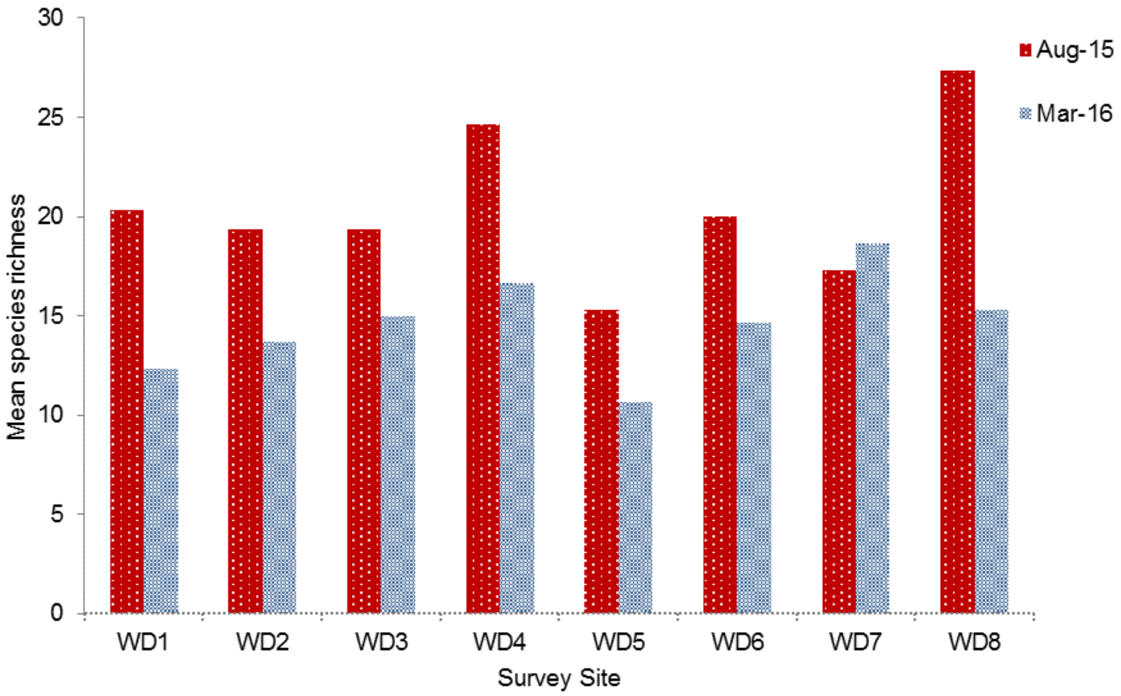


Figure K-3: Mean species richness recorded at each site during the August 2015 and March 2016 surveys.

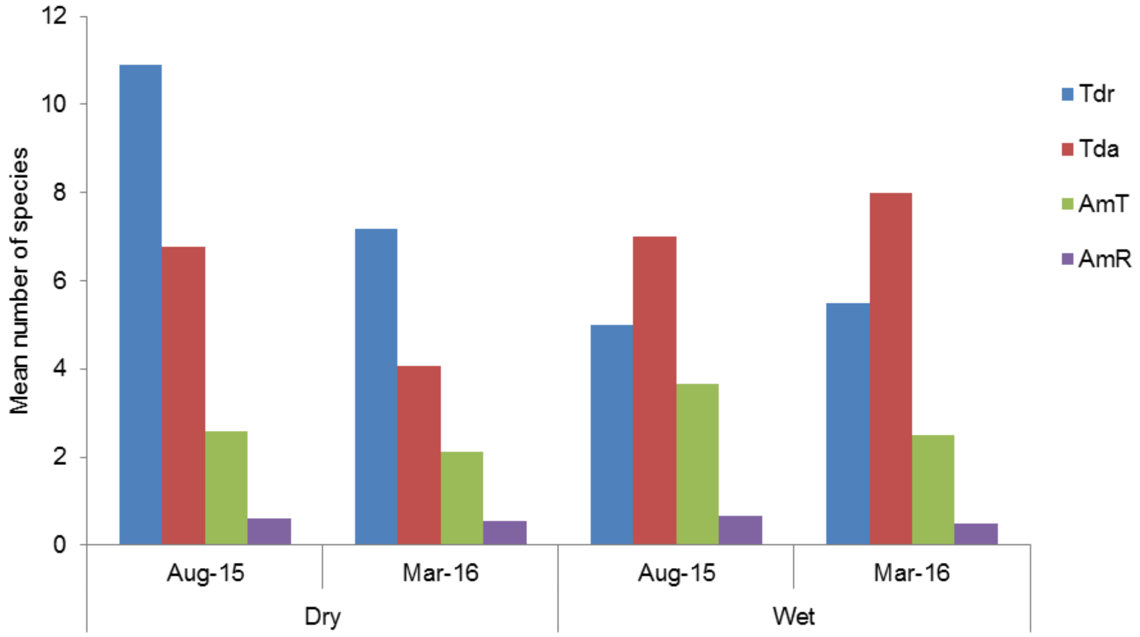


Figure K-4: Mean number of species recorded in each functional group during August 2015 and March 2016 survey periods at sites that were inundated versus those that remained dry. From left to right, Tdr = terrestrial dry plants, Tda = terrestrial damp plants, AmT = amphibious tolerator, AmR = amphibious responder.

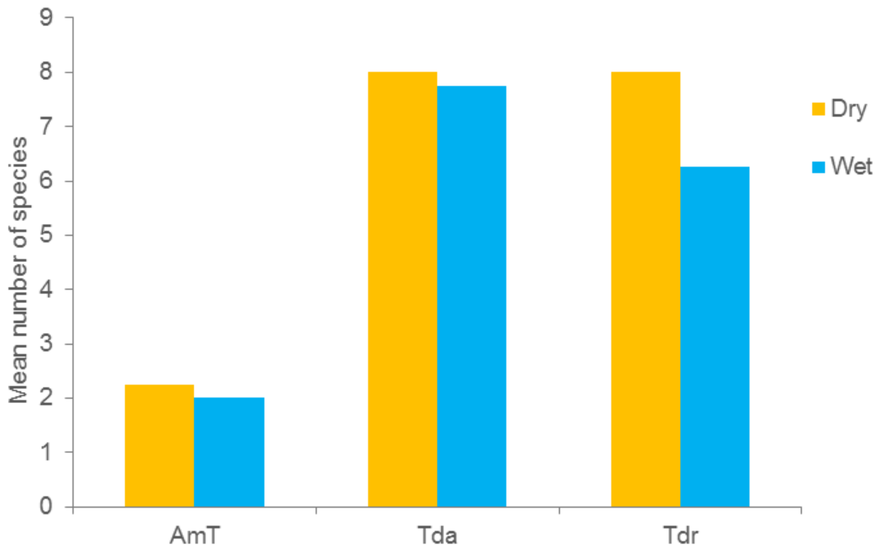


Figure K-5: Mean number of species recorded within each functional group at sites that were dry in August 2015 and wet in March 2016.

Forbs were the most abundant plant growth form across both survey periods; 74 species were recorded in August 2015 and 49 species were recorded in March 2016 (Figure K-6). Additionally, forb species diversity displayed the greatest reduction over the sampling period, falling by 25 species (34%). The reduction of forb species richness was largely driven by reductions in the Tdr and Tda functional groups (Figure K-7).

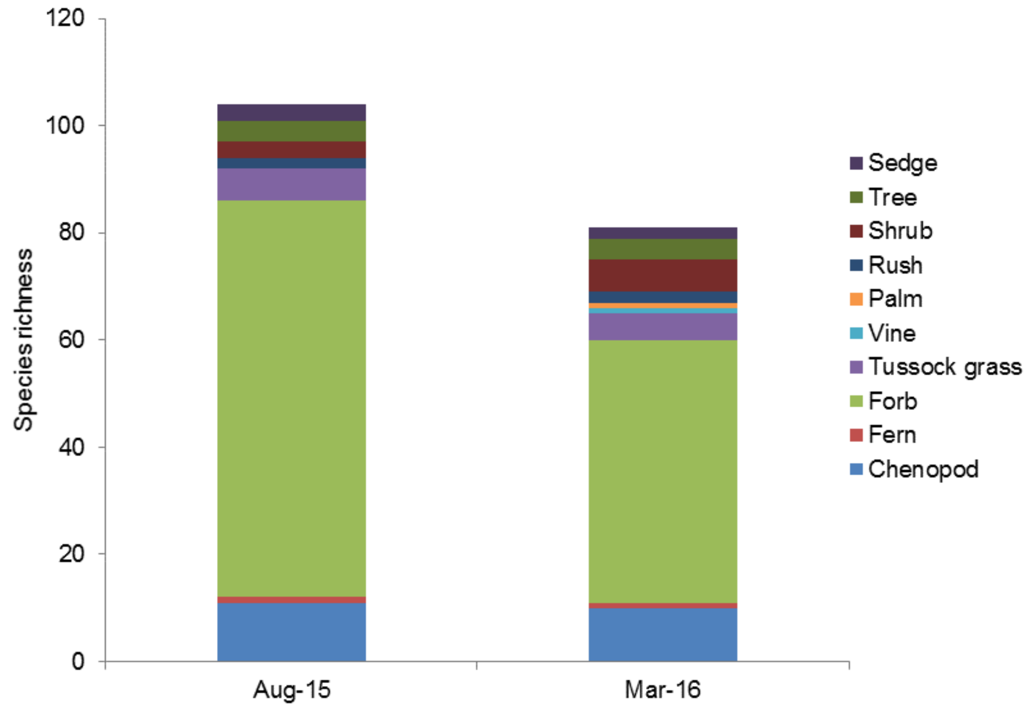


Figure K-6: Total number of species and the distribution of different growth forms recorded across all vegetation plots in August 2015 and March 2016.

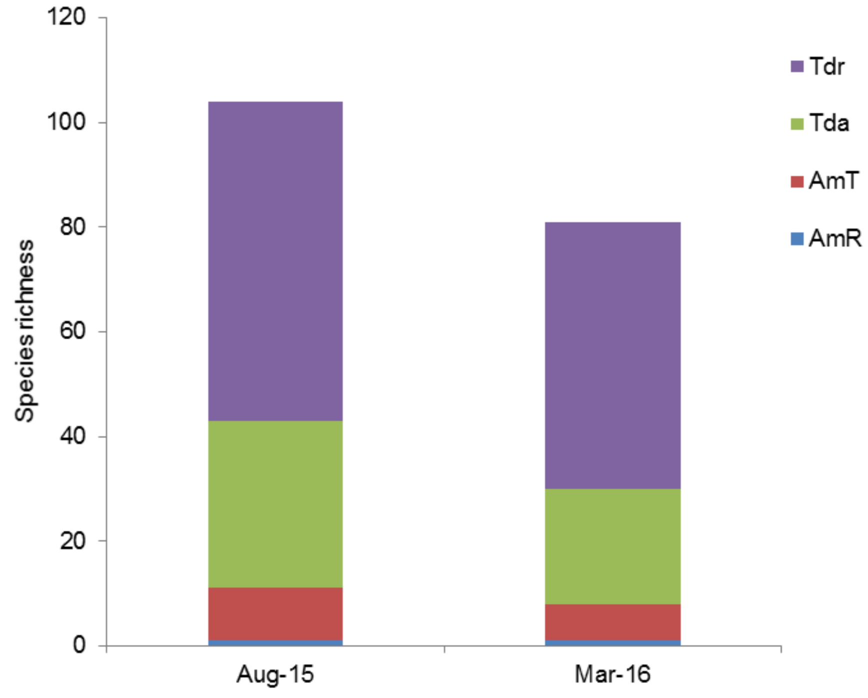


Figure K-7: Total number of species and the proportion of different functional groups recorded across all vegetation plots in August 2015 and March 2016.

Vegetation composition

To further describe patterns in vegetation community composition, multivariate analyses were undertaken on species abundance data. From the nMDS plots, there appeared to be separation of the data when grouped by vegetation type and inundation (Figure K-8), but little separation when grouped by survey time (Figure K-9). PERMANOVA analysis confirmed this, with significant differences existed between vegetation community (Pseudo-F=2.54, p<0.05) and inundation (Pseudo-F=4.306, Pr<0.005), but not survey time (P=0.499). There was a significant interaction between vegetation community and inundation (Pseudo-F=1.76, Pr<0.05), with differences observed between wet and dry lignum sites (t=2.27, Pr<0.01).

SIMPER analysis suggested that the percentage cover of tangled lignum *(Meuhlenbeckia florulenta)* and Coolibah *(Eucalyptus coolabah)* had a large influence on grouping the data by vegetation community and inundation (Table K-2). For the sites that were inundated, forb species such as common nardoo (*Marsilea drummondii*), Brassica species, spreading goodenia (*Goodenia heteromera*) and river mint (*Mentha australis*) influenced the grouping of inundated sites, along with Warrego grass (*Paspalidium jubiflorum*) that was the most abundant species recorded in the single river cooba site that was inundated (Table K-2).

Vegetation cover (excluding bare ground and litter cover) was generally low across most sites (mean 22.25%), ranging from 1-50% cover. Vegetation cover was significantly higher in August 2015 (T=3.785, Pr<0.005) than in March 2016 (Figure K-10), but there was no significant difference between wet and dry sites (Pr=0.177).

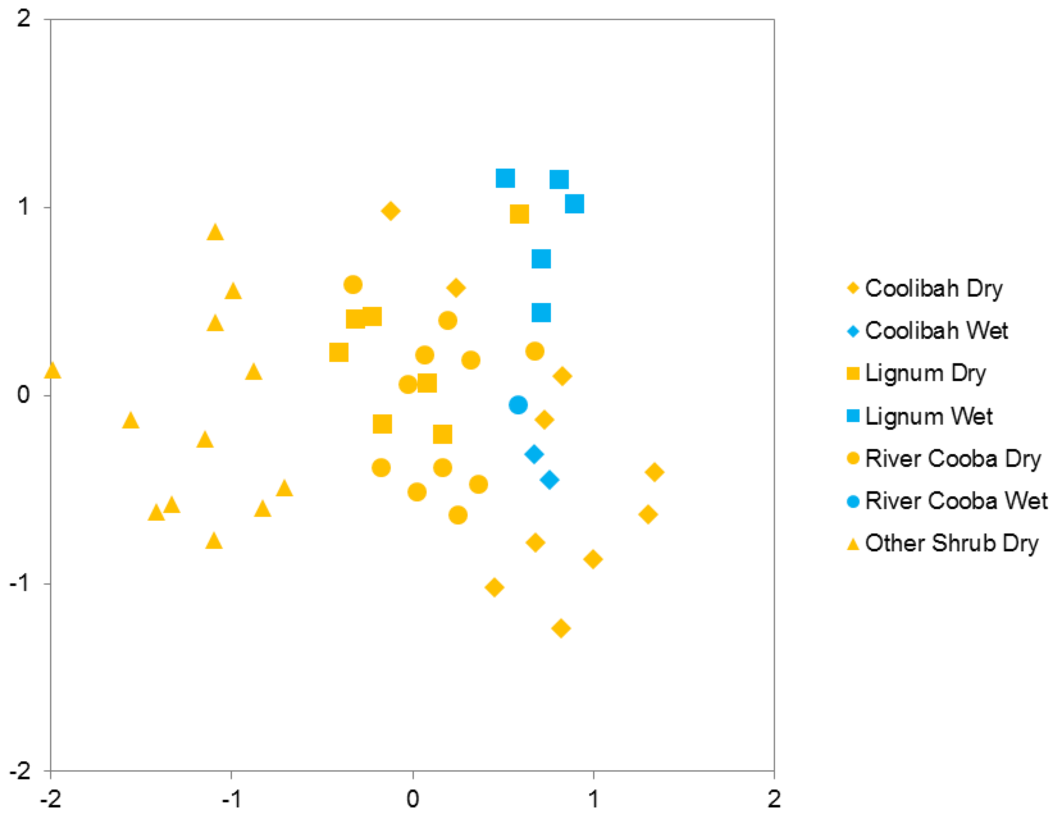


Figure K-8: nMDS plots with the data grouped by vegetation community and inundation status.

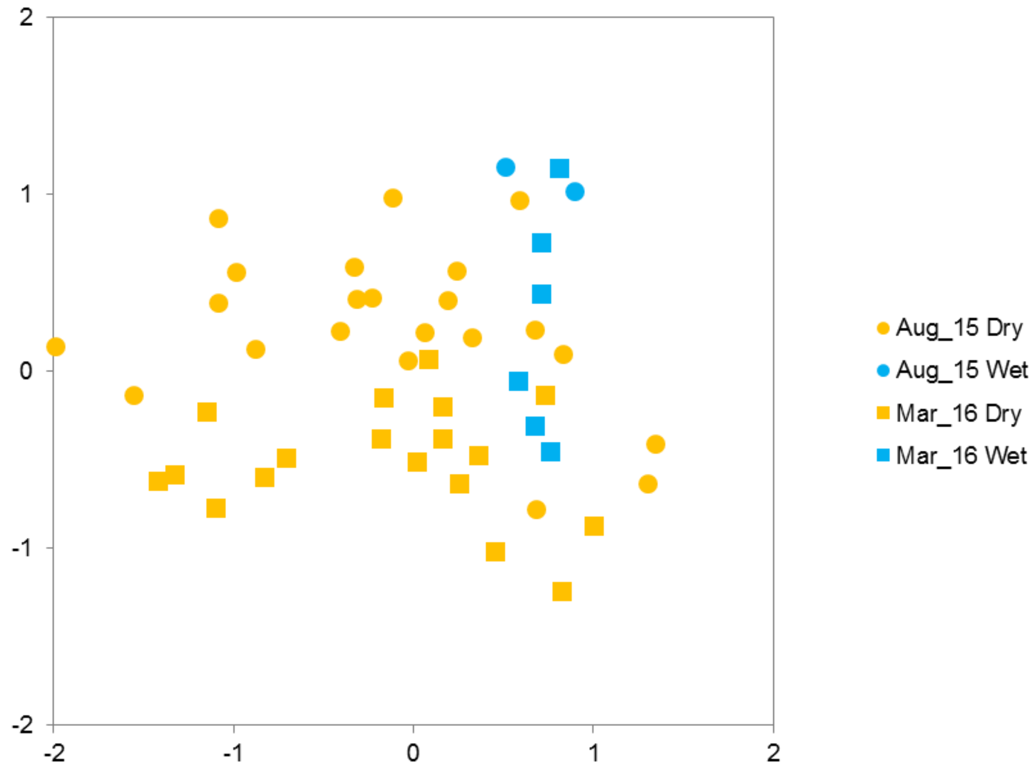


Figure K-9: nMDS plots with the data grouped by survey time and inundation status.

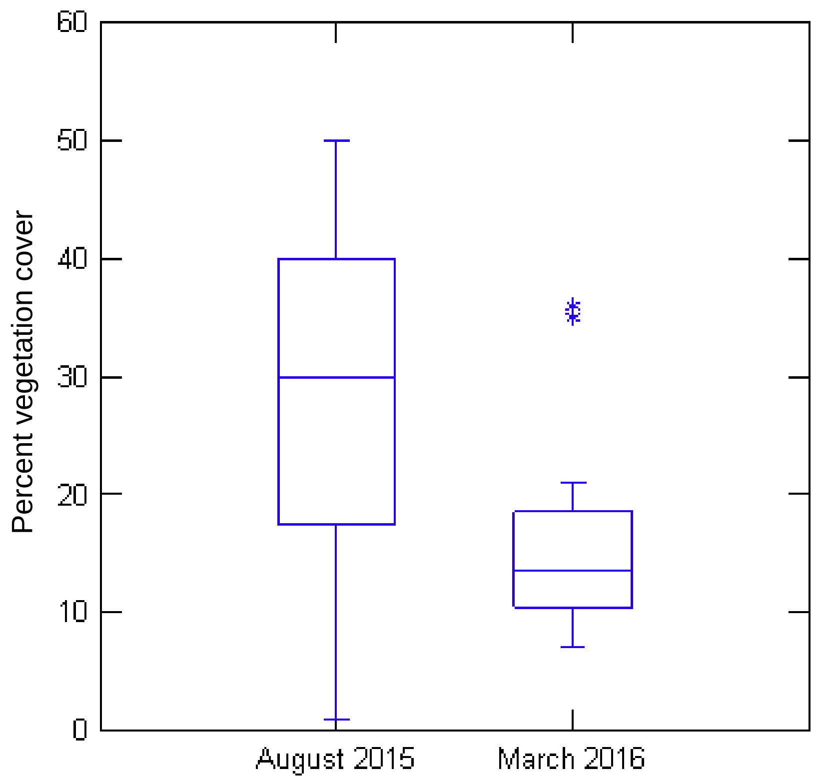


Figure K-10: Percent vegetation cover within monitoring plots surveyed in August 2015 and March 2016 on the Western Floodplain.

Table K-2: Vegetation species contributing most of the similarity between groups based on vegetation community and inundation.

Grouping	Species	% contribution	Cumulative % contribution
Coolibah x Dry	coolibah	23.56	23.56
	tangled lignum	15.47	39.03
	Warrego grass	9.68	48.71
	swamp starwort	6.43	55.14
Coolibah x Wet	tangled lignum	15.44	15.44
	coolibah	12.28	27.72
	river cooba	10.33	38.05
	brassica sp.	10.33	48.37
Lignum x Dry	tangled lignum	16.47	16.47
	coolibah	8.4	24.87
	spike-sedge	8.32	33.19
	swamp starwort	7.71	40.89
Lignum x Wet	tangled lignum	16.6	16.6
	spreading goodenia	9.75	26.35
	common nardoo	9.15	35.5
	river mint	9.15	44.66
River Cooba x Dry	tangled lignum	20.78	20.78
	river cooba	14.53	35.31
	Warrego grass	10.44	45.75
	swamp starwort	7.05	52.8
River Cooba x Wet	Warrego grass	10*	
	river cooba	6*	
	tangled lignum	5*	
	coolibah	4*	
Other Shrub x Dry	cotton fireweed	10.8	10.8
	black rolypoly	8.93	19.73
	Mexican poppy	8.68	28.4
	spike-sedge	7.79	36.2

* Values represent percentage cover of species within the single site in this grouping, where percentage contributions could not be calculated due to insufficient site numbers.

K.3.2 Multi-year Comparison

Species richness

When data from the four surveys conducted in Year 1 and 2 of the LTIM project was combined, species richness was shown to be significantly higher in the August 2015 survey time, compared to the other three survey periods ($F_{3,80}$=8.425, p<0.005; Figure K-11). Similarly, significant differences were noted between vegetation communities ($F_{3,80}$=5.88, p<0.005), with chenopod shrublands having significantly higher species richness than coolibah - river cooba - lignum woodlands and coolibah woodlands. Overall differences in species richness between wet and dry sites were non-significant (p=0.356).

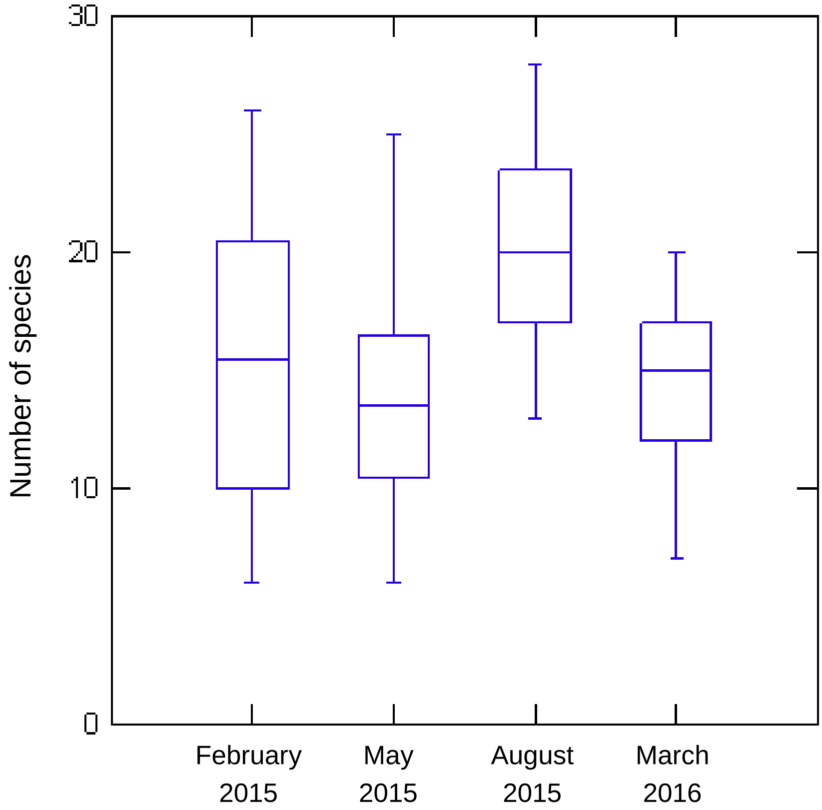


Figure K-11: Vegetation species richness recorded during surveys in year 1 and 2 of the project.

Vegetation composition

When the data collected in both Year 1 and 2 was plotted in multidimensional space, no significant grouping of the data was evident between sampling times (Figure K-12). Inundated sites tended to group closer together that suggests their species composition was more similar than sites that were not inundated. In contrast to the species richness results reported above, PERMANOVA model results identify that inundation was the only factor significantly influencing patterns in the data (Pseudo-F=3.08, Pr<0.005), with sampling time (Pr=0.48) and vegetation community (Pr= 0.11) returning a non-significant result. This suggests that overall it is changes in percentage cover of species, more than the number of species, driving patterns in the vegetation composition with respect to the presence of inundation.

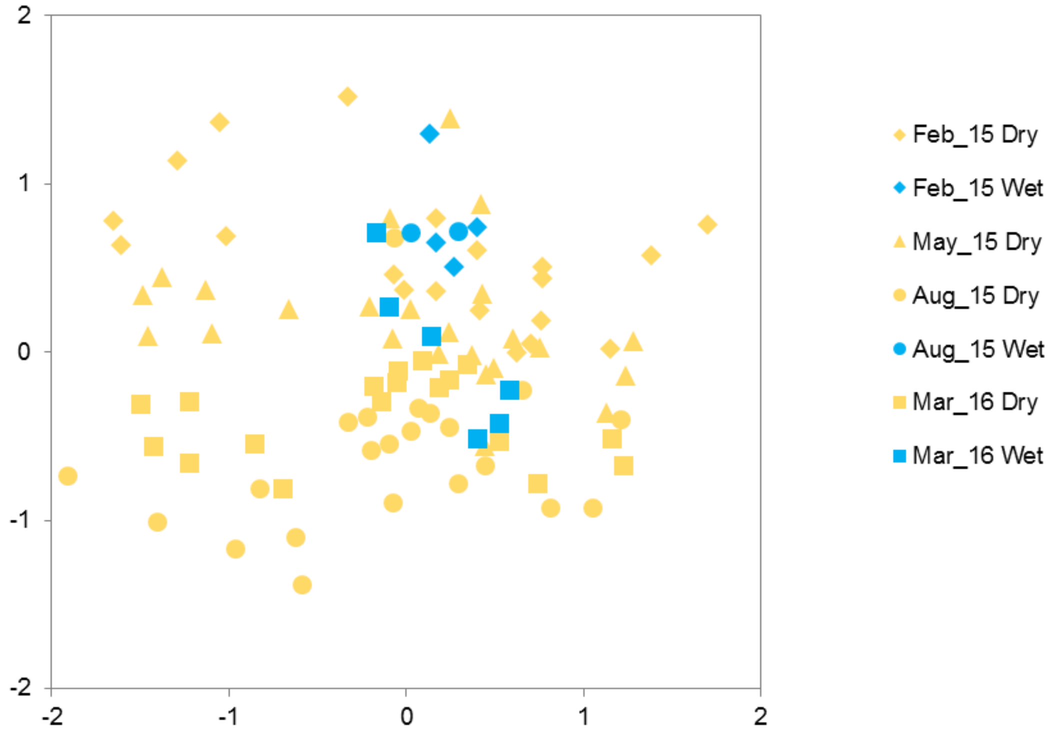


Figure K-12: nMDS plot of vegetation composition data grouped by the four sampling times surveyed and inundation on the Western Floodplain.

K.4 Discussion

Vegetation patterns within the Western Floodplain were driven by changes in terrestrial forb species in the 2015-16 water year. This is a similar result to patterns observed over the previous year (2014-15). In contrast to the previous year, sampling time was a significant influence on both the species richness of vegetation communities and the amount of vegetation present within survey sites as measured by percent vegetation cover. Similarly, significant variation was observed between sites within different vegetation communities. The influence of inundation on both species richness and vegetation cover was less pronounced, with only 17% of sites being inundated during the year.

The significant influence of sampling time was driven by higher species richness and cover during the August 2015 survey, which had the highest richness of any survey period conducted in the LTIM project. This is most likely a reflection of the higher than average local rainfall which fell in the two months preceding this survey. Rainfall in June 2015 was three times the long-term average at Bourke and likely stimulated growth of forb species at most sites compared to other sampling times. The March 2016 survey was undertaken following two month of very low rainfall, and limited inundation, hence the reduced species richness observed was expected.

While inundation did not appear to influence species richness and cover during the 2015-16 water year, multivariate analysis suggests that the composition of communities was different at sites that were inundated. This was particularly true within inundated lignum sites that contained forb species such as common nardoo and river mint, which tend to respond quickly to the moist conditions.

The influence of inundation was not found to be as strong as other factors such as vegetation community and survey time during the 2015-16 water year. As was the case during the previous water year, the low number of sites that were inundated on the Western Floodplain restricts our ability to fully assess the influence of inundation on vegetation patterns in the Selected Area, given the variation present between seasons and vegetation communities. However, the data collected so far in the LTIM project provides substantial baseline data with which to assess the influence of Commonwealth environmental water delivered to the Western Floodplain.

K.5 Conclusion

No Commonwealth environmental water was delivered to the Western Floodplain during the 2015-16 water year. A small number of sites were inundated from overflow to the floodplain from Boera Dam, and this influenced vegetation community composition at these sites. It appears that the above average rainfall that preceded vegetation surveys in August 2015 increased both species richness and vegetation cover at most sites, though these parameters returned to levels similar to those recorded in year 1 of the project later in the season. Given the limited inundation of the Western Floodplain during the first two years of the LTIM project, vegetation diversity data collected to date will form useful baseline data to compare the influence of future Commonwealth environmental water use and management in the future.

K.6 References

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Appendix L Fish (River)

L.1 Introduction

The aim of the Fish (river) indicator is to assess the effects of water releases on fish abundance, biomass and community health within the Junction of the Warrego and Darling rivers Selected Area (Selected Area). 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?

L.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January – March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year (Figure L-1).

A moderate pulse in the Darling River began in June 2016 reaching 4,818 ML/d at the Bourke Town gauge (NSW425003) by the 30 June 2016, and peaking at 8,542 ML/d on 7 July 2016. Flow events of this size occur less than 20% of the time. Given the reporting period for Year 2 of the LTIM project is the 2015-16 water year, the flow level at 30 June 2016 was considered as the maximum flow level for the associated analysis. Analysis for the full flow event will be undertaken in the 2016-17 annual report.

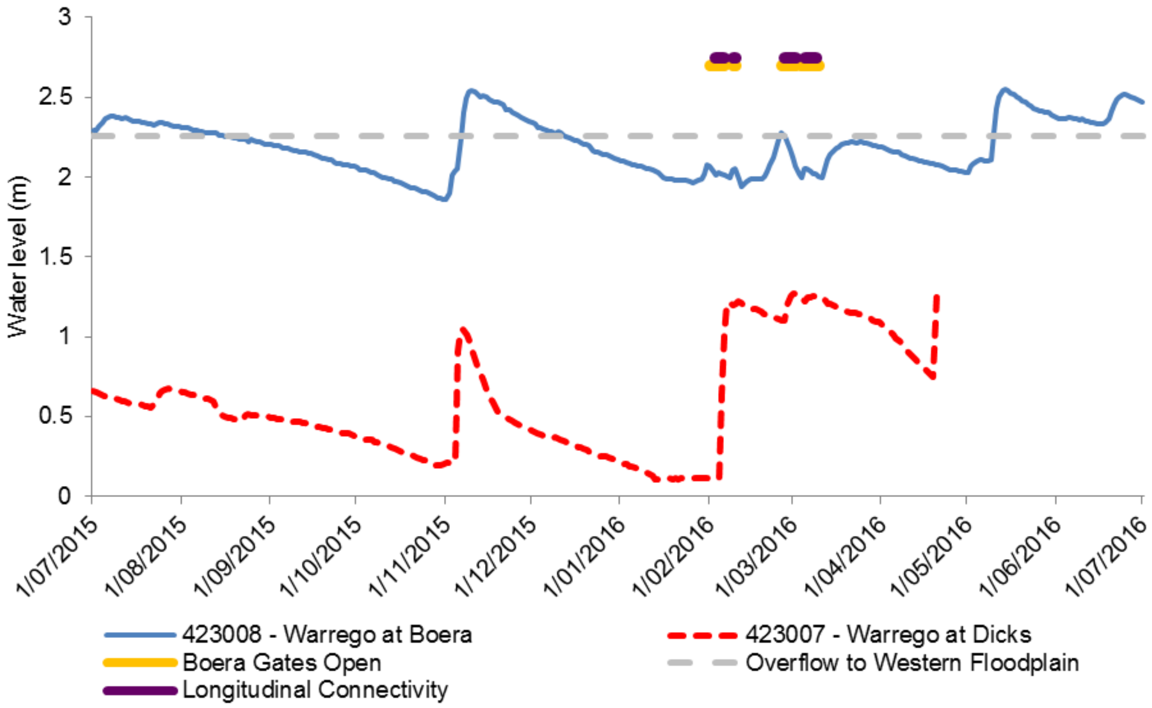

Figure L-1: Gauge heights in Boera and Dicks dam and periods of connection down the lower Warrego channel in 2015-16 water year. All available data plotted for Warrego at Dicks Dam gauging station.

L.1.2 Previous monitoring

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 Sustainable Rivers – Fish Index (SR-FI). In the SRA No. 2 report, the Warrego Valley scored an overall rating of 'Poor', primarily reflecting very poor recruitment and poor to very poor fish body condition (Murray-Darling Basin Authority 2012). However, indicators relating to native fish diversity and the extent to which pre-European fish assemblages remained intact returned more positive results. In particular, the Warrego Valley attained a 'Good' rating for 'Nativeness' (the proportion of total abundance, biomass, and species present that are native), although total biomass was dominated by alien species, particularly common carp (*Cyprinus carpio*). The number of native species observed during sampling from the SRA No. 2 report differed moderately from that expected under a pre-European reference condition. In summary, the SRA No. 2 report found that the contemporary presence of native species characteristic of the Warrego River's pre-European fish assemblages was outweighed by an apparent paucity of recent fish reproductive activity.

There have been limited studies of the fish communities within the Warrego River, particularly across the lower sections of the system. Balcombe *et al.* (2006) studied fish assemblages in 15 waterholes distributed along 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 watering events. All up, ten native species from eight families, and three alien species from two families were found. The most abundant and widespread species, under all watering conditions, was the bony herring (*Nematalosa erebi*). Hyrtl's tandan (*Neosilurus hyrtlii*) was also abundant, 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 fluctuations in abundance (Balcombe *et al.* 2006). For example, abundance of 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) study. In contrast, Hyrtl's tandan abundance underwent a 4,150% increase in abundance across the same three waterholes over the same period. Fish abundance appeared 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) is unclear. In particular, channel morphology varies markedly from the headwaters (i.e. above Cunnamulla in south-western Queensland) to the lower reaches, possibly driving differences in fish assemblages.

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, for all sites combined. Species sampled included three exotics and nine natives. Within the boundaries of the Selected Area, two of the species recorded upstream were not caught (freshwater catfish, *Tandanus* sp. and Australian smelt, *Retropinna semoni*). However, a small number of the endangered native silver perch (*Bidyanus bidyanus*) were caught at Dicks Dam, located at the lower end of the Selected Area, whilst none were caught upstream in NSW.

L.2 Methods

L.2.1 Sampling sites

Data were collected from five sites and over two sampling events (hereby referred to as Sample 1 and Sample 2) across the lower Warrego River Basin for *Cat 3 Fish River* analyses. The five sites were Ross Billabong, Dick's Dam, Toorale Homestead, Booka Dam and Boera Dam (Figure L-2; Figure L-3; Figure L-4; Table L-1). Sample 1 was undertaken from the 7 to the 11 of October 2015 and Sample 2 was undertaken from the 30 March to the 3 April 2016. The five sites were all located Within the Warrego River zone of the Selected Area. The lowest site (Ross Billabong) was approximately 5 km above the confluence of the Warrego and Darling rivers, whilst the top site (Boera Dam) was approximately 45 km upstream of the junction. The Warrego is considered intermittent and almost ephemeral across the lower end of the system, ending in a series of constructed water storages immediately upstream of the Warrego-Darling junction.

Of the five sampling sites, four were within water storages, with Ross Billabong the only natural section of the waterway sampled. Ross' Billabong is around 4-5 km in length and at its maximum holds around 13,000 ML. The four dams varied in size and capacity. No water was running through the system during either sampling event and all five sampling sites were in effect isolated pools. The water at all sites tended to be turbid and relatively shallow, ranging up to a maximum of only ~1-2 m in depth. In-stream habitat for fish was generally sparse, with mainly small and the occasional large woody debris, as well as fringing undercut banks, providing the majority of 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*) and small numbers of a variety of native shrubs <2 m in height.

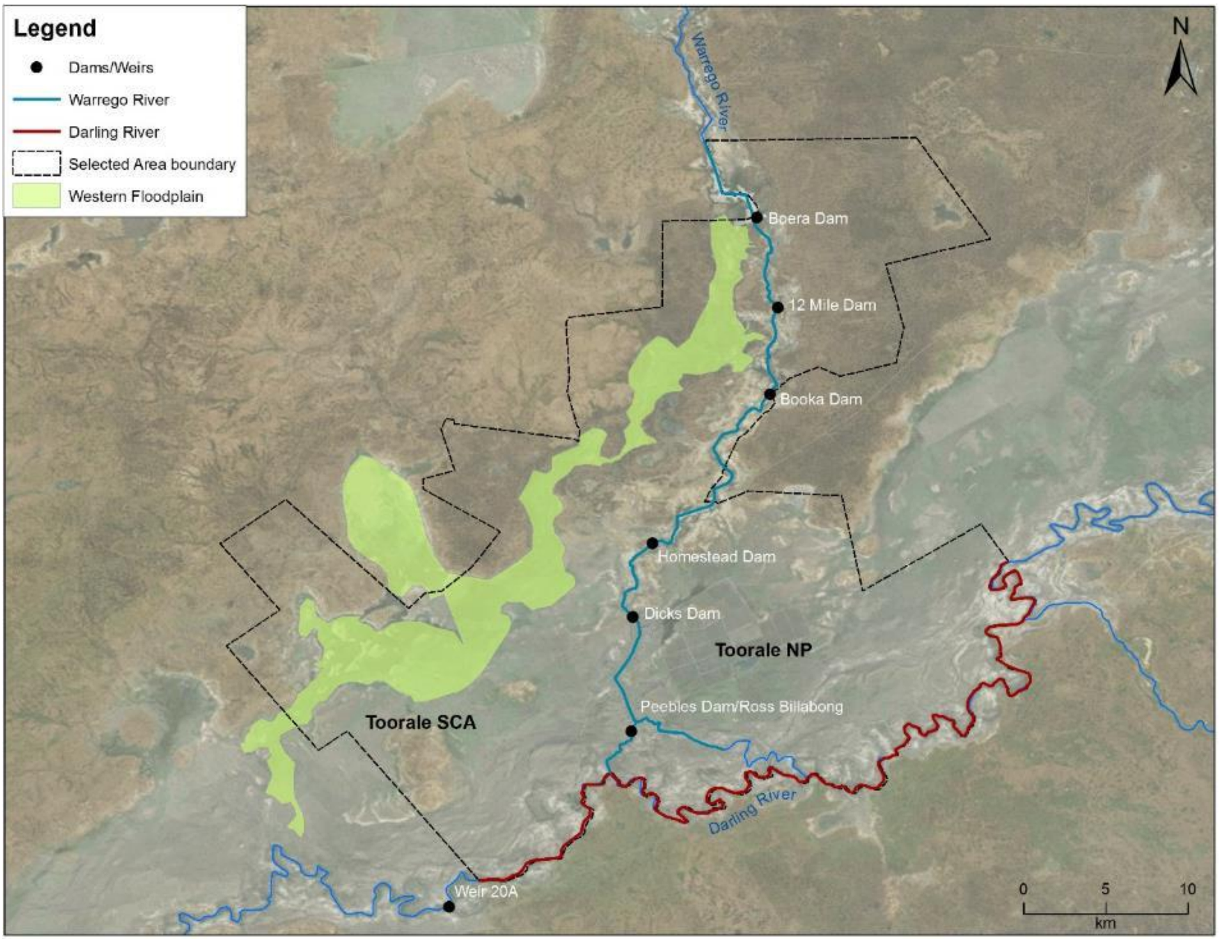

Figure L-2: Location of the dams in the lower Warrego River. See table L-1 for site locations.

Table L-1: Locations of the fish sampling sites in the lower Warrego River. Map projection GDA94 Zone 55.

Site name	Easting	Northing	Altitude	Zone	Electrofishing Effort
Ross Billabong	347066	6636891	103	Lowland	Small boat
Dick’s Dam	342373	6645027	99	Lowland	Backpack
Homestead	344068	6649148	98	Lowland	Backpack
Booka Dam	349784	6659072	98	Lowland	Small boat
Boera Dam	347722	6668881	104	Lowland	Small boat

Figure L-3: Ross Billabong sampling site.

Figure L-4: Booka Dam sampling site.

L.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 used either a small boat (3.5 kw Smith-Root electrofisher unit), backpack (Smith-Root model LR20), 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 was required, the number of operations of each method used was proportional to the area of navigable versus wadeable 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 before repeating the process. All boat and backpack electrofishing was undertaken by two operators.

Bait traps (n = 10 unbaited, n = 5 baited, 'opera house' style) were deployed haphazardly throughout the sites in depths of 0.5–1 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 in height 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 hours.

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 one species were captured by a given gear type within a site, only the first 50 of that species were measured, with any subsequent captures counted only. 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.

L.2.3 Data analyses

Fish community

Electrofishing and bait trapping data were combined for statistical analyses of the fish community. Non-parametric multivariate analysis of variances (PERMANOVA) was used to determine if there were differences between the fish assemblages in each of the four hydrological zones (PRIMER 6 & PERMANOVA; Anderson *et al*. 2008). Prior to analyses, the data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where differences were identified by PERMANOVA, pair-wise comparisons were 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 in the lengths of the six more abundant small- and large-bodied species in each of the four sub-catchments. Prior to analysis, the data was initially sorted into equal bins of 10 mm for small-bodied and 50 mm for large-bodied species. The results were then transformed to provide relative proportions (%) of each size class of fish for the four individual hydrological zones. Only zones where >20 individuals were sampled were included in the analyses. Species included in the analyses were: golden perch, spangled perch, bony herring, Hyrtl's tandan and common carp.

Health Metrics

Reference Condition

The predicted pre-European fish community of the lower Gwydir 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 L-2; Table L-3). The RC-F process involves using available 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 if it were sampled using the standard sampling protocol prior to 1770 (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 L-2).

The definition of a recruit was derived using a similar process as 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 that was not available (Table L-3).

Table L-2: Native freshwater fish species predicted to have occurred across the lower Warrego River prior to European colonisation. Descriptions of predominance (occurrence) correspond to RC-F categories for the Murray Darling Basins Sustainable Rivers Audit program 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	Un-specked 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. (MDB)	Freshwater catfish	Common

Table L-3: 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)	Sample 1		Sample 2	
		Adult	Juv.	Adult	Juv.
Native species					
Olive perchlet	26 mm (Pusey *et al*. 2004)				
Silver perch	75 mm (Mallen-Cooper 1996)				
Un-specked 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)				
Alien species					
Common carp	155 mm (Vilizzi and Walker 1999)		✓		✓
Eastern mosquitofish	20 mm (McDowall 1996)	✓		✓	✓
Common goldfish	127 mm (Lorenzoni *et al*. 2007)		✓		✓

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 rules sets developed by Davies *et al*. (2010).

The Expectedness Indicator (SR-FI_e) represents the proportion of native species that are now found within the basin, compared to that which was 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-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-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). The three 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-FI_e > SR-FI_r > SR-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).

L.3 Results

L.3.1 Abundance

In total, 616 fish were caught (n=597) or observed (n=19) across all sites and for all methods in Sample 1 and 2,653 were caught (n=2,592) or observed (n=61) in Sample 2. Species composition comprised nine species in Sample 1 (six native species and three exotic species) and eight in Sample 2 (five native species and three exotic species) (Figure L-5). In general, individual species tended to be locally abundant at the site scale and in some cases absent from other sites. In Sample 1, among the large-bodied species (those that grow to >100 mm), spangled perch (*Leiopotherapon unicolor*) was the most abundant species caught (n=260) for all sites combined, followed by Hyrtl's tandan (*Neosilurus hyrtlii*) (n=171) and golden perch (*Macquaria ambigua*) (n=37). In contrast, bony herring (*Nematolosa erebi*) (n=1,938) in Sample 2, totally dominated the catch both at the site scale as well as in overall numbers. Spangled perch (n=392) and golden perch (n=145) were also relatively abundant in Sample 2. Other species such as Hyrtl's tandan (n=43) (Figure L-6) and common carp (*Cyprinus carpio*) (Sample 1 n=33; Sample 2 n=14) declined in number. There were only two native small-bodied species caught in both Sample 1 and 2 and both were in low abundance. In Sample 1, carp gudgeon (*Hypseleotris* sp.) were more abundant but it was only caught at one site and none were caught in Sample 2. Similarly, Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) were only caught at one site in Sample 1, but in contrast they were caught at three sites in Sample 2. The exotic mosquitofish (*Gambusia holbrooki*) were also caught in low numbers in both samples (Booka Dam).

Despite the increase in abundance of fish between Sample 1 and 2, there was no significant difference in the fish assemblage between samples (Pseudo-$F_{1,8}$ =1.97, P=0.10).

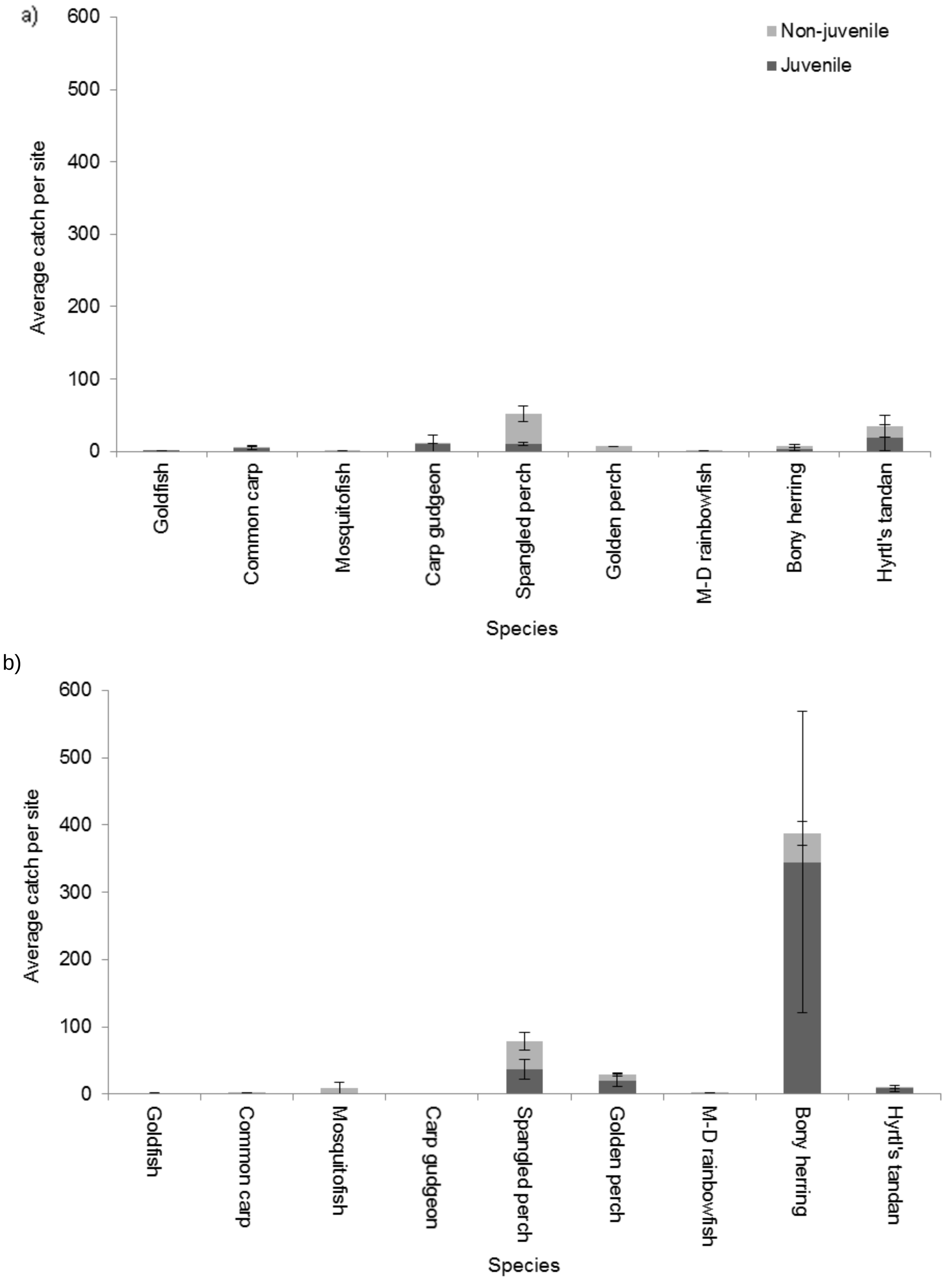

Figure L-5: Average catch per unit effort (CPUE) ± S.E. for the 9 fish species sampled in the 9 fish species sampled in the lower Warrego River, October 2015 (Sample 1 (a)) and April 2016 (Sample 2 (b)). NB*. Juveniles and non-juveniles estimates represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year (Table L-3).

Figure L-6: Hyrtl's tandan (*Neosilurus hyrtlii*) captured at Dick's Dam on the lower Warrego River; Sample 1 in October 2015.

L.3.2 Biomass

Based on estimated and measured weights, 19.431 kg of fish were recorded across all sites and methods in Sample 1, and 29.786 kg in Sample 2. In Sample 1, common carp had the highest overall biomass (*n*=8.215 kg) among the nine species sampled, followed by spangled perch (*n*=6.268 kg) and Hyrtl's tandan (*n*=2.23 kg) (Figure L-7). In contrast, spangled perch (*n*=10.91 kg) and bony herring (*n*=7.639 kg) had the first and second highest overall biomass in Sample 2, whilst common carp had the third highest (*n*=7.042 kg). Among the small-bodied species, carp gudgeon had the highest biomass in Sample 1 (*n*=14 g), whilst Murray-Darling rainbowfish had the highest in Sample 2 (*n*=14 g).

Despite the increase in the overall biomass of fish between Sample 1 to 2, there was no significant difference biomass between samples ($Pseudo\text{-}F_{1,8}$ =1.14, P=0.36).

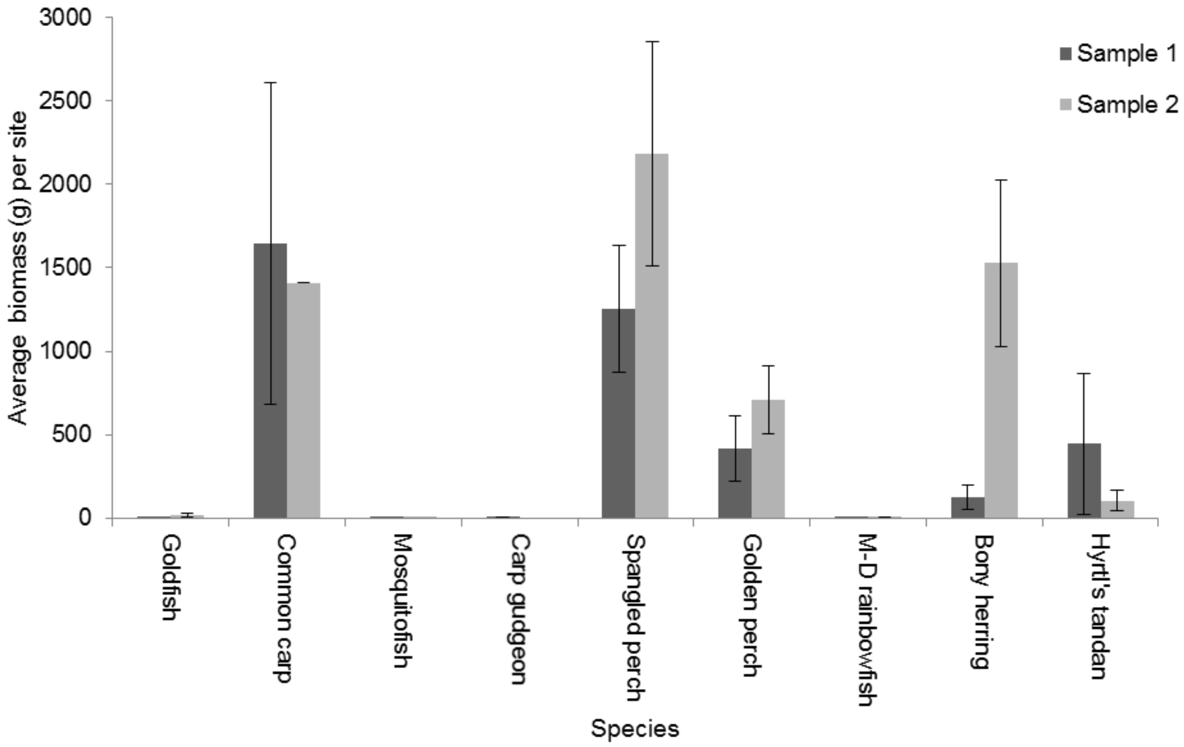

Figure L-7: Average biomass ± S.E. per site for the 9 fish species sampled across the lower Warrego River, October 2015 (Sample 1) and April 2016 (Sample 2).

L.3.3 Length frequency

There were significant differences in the length-frequency and in the general abundance between Sample 1 and Sample 2 among the five more abundant species caught (golden perch, spangled perch, bony herring, Hyrtl's tandan and common carp) (Table L-4; Figure L-8). Differences in length frequency distributions and in abundance were due to an increase in the number of young-of-year caught in Sample 2. For example, ~80% of golden perch caught in Sample 2 were <80 mm FL, whilst in Sample 1 all individuals caught were >80 mm FL. Similarly, > 40% of spangled perch and >80 % of bony herring caught in Sample 2 were <60 mm FL, compared to only ~10 % and ~35 % for the same two species, respectively, in Sample 1 (Figure L-9). For Hyrtl's tandan, the length structuring of the population in both samples was evenly distributed but as with the golden perch, spangled perch and bony herring, the population in Sample 2 was dominated by smaller individuals (Figure L-9).

The small numbers of common carp in Sample 2 meant statistical comparisons between samples could not be undertaken. In general there was little difference in the structure of the population between samples (Figure L-9), with the population dominated by individuals <200 mm FL in both samples. This same trend of populations dominated by smaller individuals and of very few larger individuals was the same for all five species. Only one golden perch >250 mm FL, as well as only one each bony herring and one Hyrtl's tandan >200 mm, were caught. Similarly, only five of the 604 spangled perch caught were <160 mm FL.

Table L-4: Kolmogorov-Smirnov test results of length frequency comparisons between the five most abundant species sampled in the lower Warrego River, October 2015 (Sample 1) and April 2016 (Sample 2). NB* Dark shading indicates significant difference <0.05.

		Zone				
		Golden perch	Spangled perch	Bony herring	Hyrtl's tandan	Common carp
Round 1 V Round 2	*Z*	5.543	2.278	3.344	2.868	--
	P	<0.001	<0.001	<0.001	<0.001	--

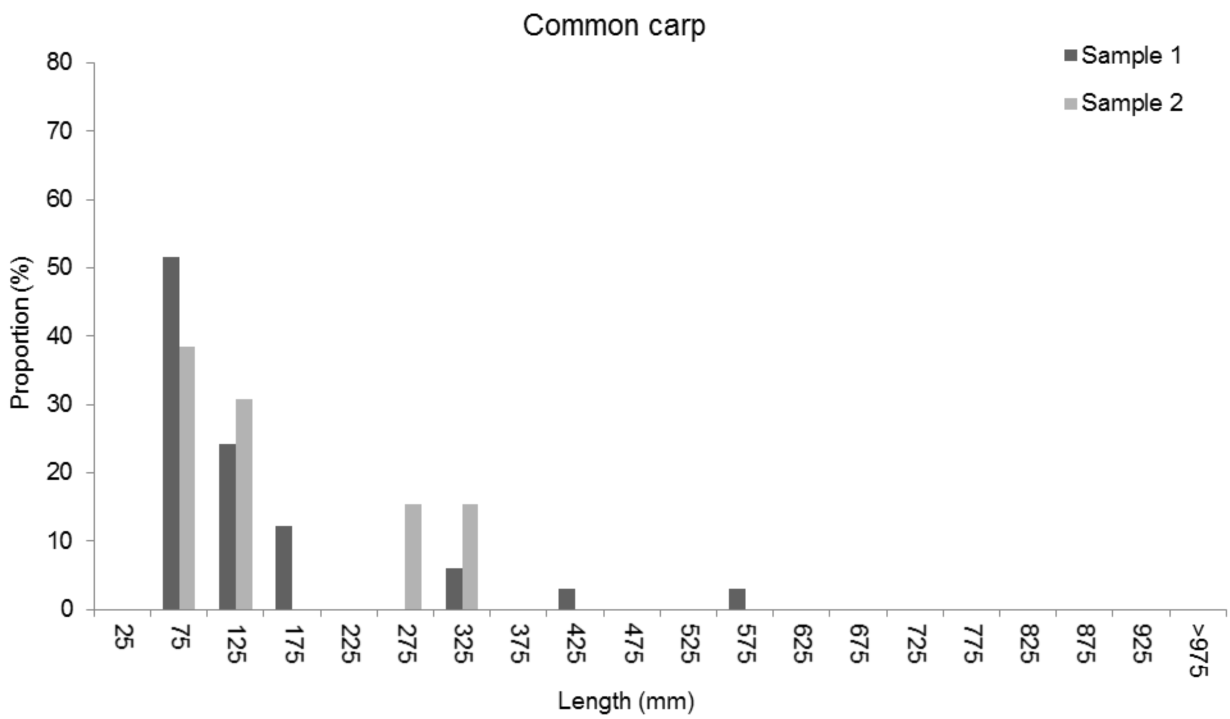

Figure L-8: Length frequency distribution (proportion (%)) of common carp sampled in the sampled in the lower Warrego River, October 2015 (Sample 1) and April 2016 (Sample 2). NB# Dashed line is approximate length of one-year-old individual.

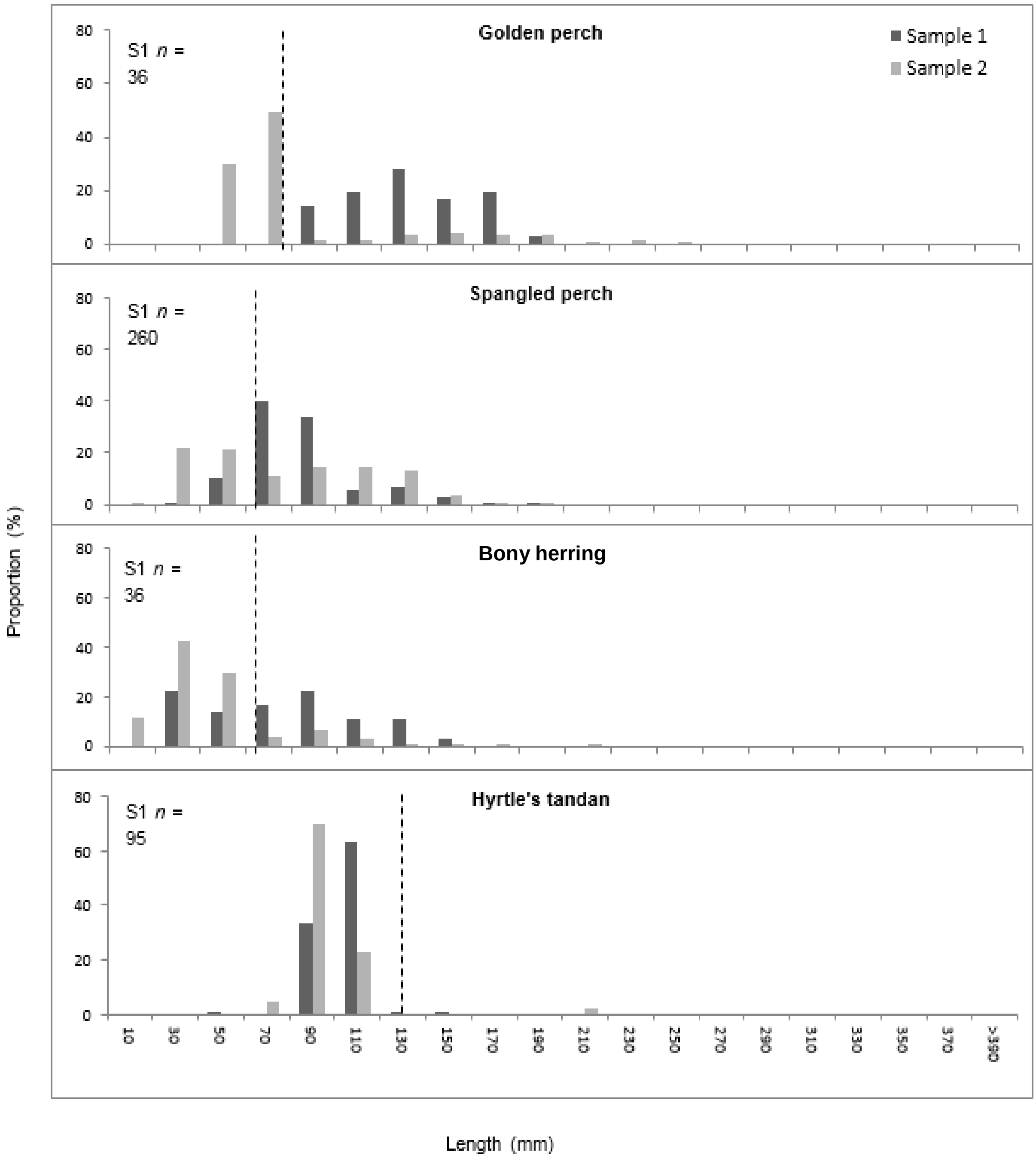

Figure L-9: Length frequency distribution (proportion (%)) of golden perch, spangled perch, bony herring and Hyrtl's tandan sampled in the lower Warrego River, October 2015 (Sample 1) and April 2016 (Sample 2). NB# Dashed line is approximate length of one-year-old individual.

L.3.4 Health Indicators

Expectedness

Of the 14 native fish species that have been previously sampled in or were thought to have historically occurred in the Warrego, six were caught at a minimum of one site in Sample 1 and five sites in Sample 2 (Table L-3). Carp Gudgeon were not caught in Sample 2 but caught in Sample 1. The eight species not caught in either sample were olive perchlet (*Ambassis agassizii*), silver perch (*Bidyanus bidyanus*), un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), desert rainbowfish (*Melanotaenia splendida tatei*), southern purple-spotted gudgeon (*Mogurnda adspersa*), Murray cod (*Maccullochella peelii*), Australian smelt (*Retropinna semoni*) and freshwater catfish (*Tandanus* sp. MDB). Of the eight, three were considered “rare” or “cryptic” meaning they are likely to only be collected in up to 20% of sites (un-specked hardyhead, desert rainbowfish and southern purple spotted gudgeon), and three as “occasional” (olive perchlet, silver perch and Murray cod) meaning they are only likely to be collected in 20-70% of sites within a zone (Robinson 2012). The remaining two species (Australian smelt and freshwater catfish) were considered as “common” and “abundant” in the past and would be expected to be caught at a minimum of 70% of sites within a zone (Robinson 2012).

In general, all five sites sampled rated low for Expectedness in both sampling rounds (Figure 6). In Sample 1, the highest rating was a “Poor” for the Boera Dam site (59.6), whilst Dick’s Dam rated the lowest at 22.9 or “Very Poor”. The three remaining sites (Ross Billabong, Toorale Homestead and Booka Dam) also all rated as “Very Poor”. In Sample 2, more native species were caught at the Toorale Homestead and Booka Dam sites lifting their rating from “Very Poor” to “Poor”, whilst Ross Billabong and Dick’s Dam maintained their rating of “Very Poor”. The Boera Dam site was the only one of the five to achieve a lower rating in Sample 2, with only three native species caught which resulted in it scoring 36.5 or “Very Poor”. The average (±S.E.) site score for Sample 1 for Expectedness was 37.3±5.91 or “Very Poor”, whilst for Sample 2 the average was 36.5±3.82 giving it the same overall rating of “Very Poor”.

Nativeness

Three of the nine fish species caught in the lower Warrego were exotic; eastern mosquitofish, goldfish and common carp (Figure L-10). All three species were caught in both sampling rounds but all were in low abundance. By number, common carp was the most abundant in Sample 1 (n=33), whilst mosquitofish were the most abundant in Sample 2 (n=44). Common carp were also the most widespread of the three, having been caught at four of the five sites surveyed in Sample 1 and at two of the same sites in Sample 2. Contrastingly, goldfish were only caught at two sites in both samples, whilst mosquitofish were only caught at the one site in both samples. Combined, exotics made up 42% of the total biomass of fish caught in Sample 1 and 24% in Sample 2.

The low abundance of exotic species is reflected in the high Nativeness scores for most sites. In Sample 1 four of the five sites rated as “Good”. Of these, Dicks Dam scored the highest with 98.4, with only one goldfish captured in total and no common carp or mosquitofish. Booka Dam was the only site rated as less than “Good”, scoring 53.5 giving it a rating of “Poor”. The low rating was due to the presence of a number of large common carp and the relatively low abundance of native species in the catch. All sites in Sample 2 rated as “Good”, ranging from as high as 100 for three sites where no exotics were sampled at all, down to 83.6 at Booka Dam, where low numbers of all three exotics were sampled but there were also high abundances native species in the sample. The average (±S.E.) score for Nativeness for Sample 1 was 84.2±7.86 giving the selected area an overall rating of “Good”, whilst for Sample 2 sites averaged 95.7±3.18 meaning the area again scored an overall rating of “Good” for Nativeness.

Recruitment

The Recruitment Indicator scores varied considerably between Sample 1 and Sample 2. For Sample 1 the selected area scored 39.3 or “Very Poor” for Recruitment, whilst for Sample 2 the score was 96.6 or “Good”. Based on the individual metrics calculated for the Recruitment Indicator: in Sample 1, 66% of the native fish sampled were recruiting at a minimum of one site compared to 100% in Sample 2; by number, recruits represented ~43% of the native fish caught in Sample 1 and ~72% in Sample 2; and the average proportion of sites with the selected area at which each species captured was recruiting was 47% in Sample 1 and 97% in Sample 2.

While not considered in the calculation of the Recruitment Indices, there was also evidence of recruitment among the three exotic species. Whilst only caught in low numbers, the large proportion of mosquitofish were was less than 25 mm suggesting recent breeding and recruitment. Similarly, all goldfish sampled were considered as potentially being less than 1 year old as no individuals >127 mm were caught. Again, while only relatively low in overall number, 75% and 78% of common carp caught in Sample 1 and Sample 2, respectively, were recruits. By site, common carp recruits were caught at three sites in Sample 1 (Booka Dam, Ross Billabong and Toorale Homestead) and one site (Booka Dam) in Sample 2.

Overall condition

The Overall Fish Condition (ndx-FS) scores for individual sites across the lower Warrego varied between sites but more so between samples. In Sample 1 all sites except Boera Dam, which rated “Poor”, rated at “Very Poor. Individual scores ranged from 22.9 at Dicks Dam up to 49.9 for Boera Dam. The site average (±S.E.) for Sample 1 was 33±4.53 giving the selected area an overall rating of “Very Poor” at the time. In contrast, no sites scored as “Very Poor” in Sample 2, with Toorale Homestead and Booka Dam achieving a rating of “Moderate”, whilst the remaining three rated as “Poor”. Individual sites ranged from 47.9 for Ross Billabong, up to 67.2 for the Toorale Homestead site. The site average for Sample 2 was 57.38±4.21, resulting in an overall rating of “Poor”.

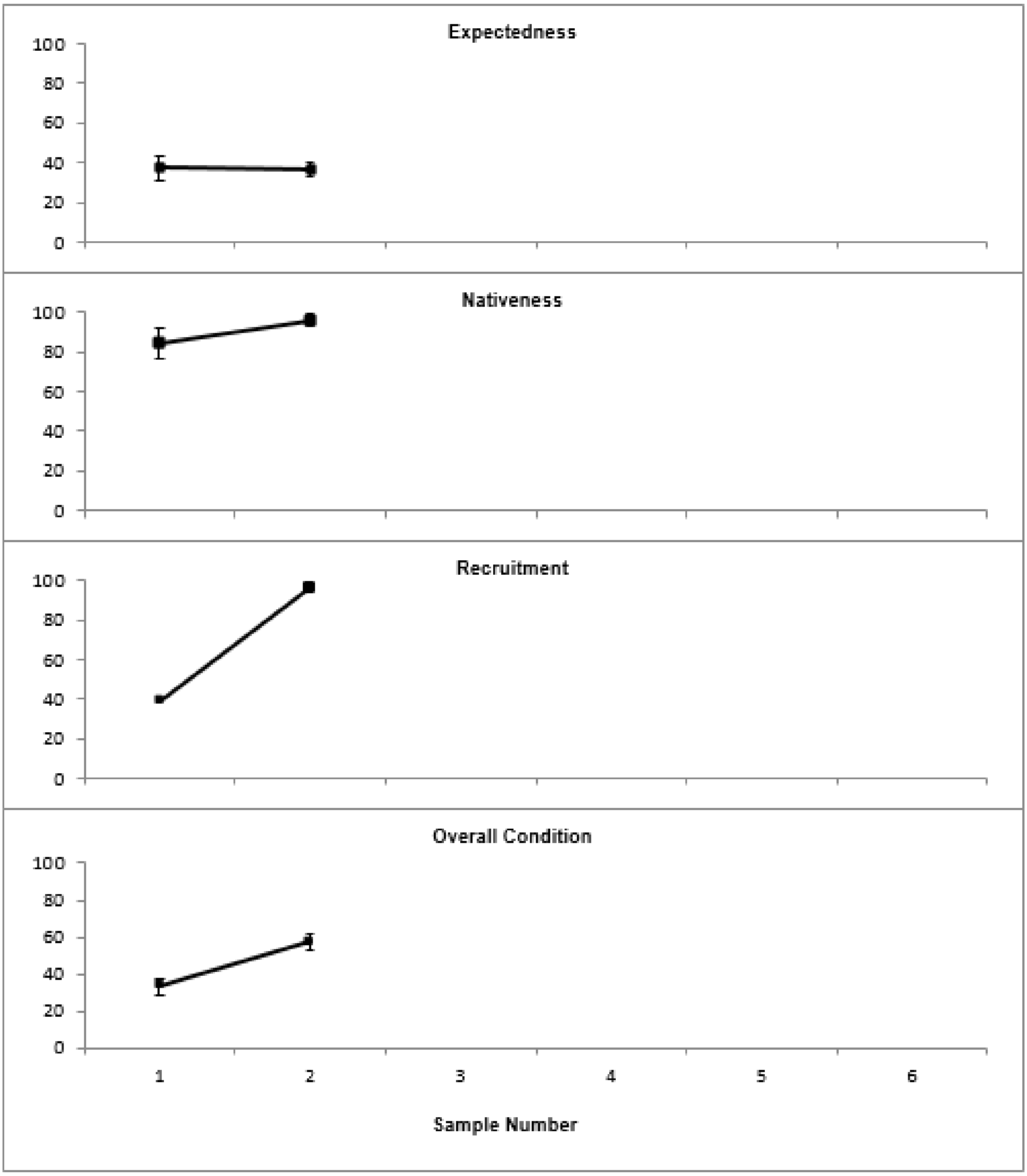

Figure L-10: *Expectedness Nativeness, Recruitment* and *ndxFS* Indicator values for fish at sites sampled in the lower Warrego River, October 2015 (Sample 1) and April 2016 (Sample 2).

L.4 Discussion

The results of the current sampling year suggest that the fish community appears to function as would be expected in a dryland floodplain river like the lower Warrego. Fish species that persist in hydrologically extreme river systems are often described as ecological generalist, which means they are adapted to survive even under the most extreme conditions and "boom" when conditions become favourable (Balcombe and Arthington 2009). The lower Warrego is best described as almost ephemeral in nature, in that in dry times which occur regularly, it can contract to a series of shallow waterholes with little or no connectivity and in some cases whole sections of the river for many kilometres can be dry. This means fish have to cope with the extremes of high water temperatures and low dissolved oxygen levels during spring and summer (e.g. Fords Bridge 20/12/2014: 29.7°C and 3.89 mg/l DO at 1 m (NSW DPI Freshwater Fish Database, unpublished data)) and cool often desert type temperatures in autumn and winter (e.g. Toorale Waterhole 05/05/2006: 11.8°C and 4.9 mg/l DO at 0.2 m (NSW DPI Freshwater Fish Database, unpublished data)). In contrast, during wet periods the river connects and the floodplain is inundated, allowing fishes to access previously unavailable habitats (Balcombe *et al*. 2006). Species such golden perch, spangled perch and bony herring, all of which were caught in relatively high numbers in the current sampling period, are well adapted to cope with these extremes of hydrological variability, in that they are highly mobile, readily utilise floodplain habitats for spawning and recruitment and in general can endure extremes in water quality (Balcombe and Arthington 2009; Balcombe *et al*. 2006; Puckridge *et al*. 2000).

The length-frequency of the more abundant large-bodied native species caught in the second sampling round suggests that breeding and recruitment is occurring regularly within the Warrego catchment for most species. In Sample 1, small numbers of young-of-year were caught among all the large-bodied species sampled except golden perch, whilst in Sample 2 young-of-year of all four species were caught, particularly golden perch, spangled perch and bony herring. Whilst young-of-year were relatively abundant among most species, based on reported length-at-age very few sexually mature individuals of any species were caught, including golden perch (sexual maturity >300 mm), bony herring (sexual maturity >130 mm) and Hyrtl's tandan (sexual maturity >135 mm) (in Pusey *et al*. 2004). The presence of young-of year and the absence of adults could be a result of a number of factors including the obvious explanation of upstream spawning and the downstream drift and settlement of larvae and/or juveniles. However, while this may have contributed to the phenomenon, the major cause is likely the effect the harsh environment has on the fish that reside in the lower Warrego. Severe resource limitation for food, space or habitat, not only leads to stunting in fish populations but can also lead to early maturation further exacerbating the issues of slow growth (Ylikarjula *et al*. 1999). Examination of golden perch otoliths collected from the lower Warrego as part of the current project support this hypothesis (Gavin Butler unpublished data) and it therefore seems likely that all long-lived (>3 yrs.) species that reside in the lower Warrego are growing slower and maturing earlier than the conspecifics in the wider Murray-Darling Basin.

The low *Expectedness* Indicator scores for all sites across both samples is most likely a realistic assessment of the state of the fish diversity in the lower Warrego and reflects the intermittent and harsh nature of the system as a whole. Fish communities in dryland rivers like the Warrego exhibit dramatic spatial and temporal variability in both abundance and assemblage structure (Balcombe *et al*. 2006). During dry periods when fish are confined to refugia pools, the structure of the community can vary markedly from one pool to the next and even more so from one section of the river to the next (Balcombe *et al*. 2006). An example of this in the current species is Murray-Darling rainbowfish and carp gudgeon, which were only in low numbers and at limited sites in both samples. In contrast, spangled perch were caught at all sites in both samples suggesting they are better adapted to cope with variable conditions experienced across the lower Warrego. Additionally, the complete absence of some species may in part be due to their rarity or cryptic nature but it may also be related to individual species life-history strategies, habitat requirements or feeding habits not being suited to the erratic nature of the system. An example of this would be Murray cod that are reported to prefer deep and flowing rivers and use large woody debris as resting and breeding habitat (Jones and Stuart 2007). Both the hydrology and habitat types are vastly different to this across the lower Warrego, meaning the area simply may not be suitable for the long-term persistence of cod. Similarly, olive perchlet, although a threatened species and in low numbers throughout most of the Murray-Darling Basin, is known to be particularly abundant and persist in areas of submerged macrophytes, filamentous algae and submerged bankside vegetation (Pusey *et al.* 2004). Again, these habitat types are rare or non-existent in the lower Warrego. As such, while the *Expectedness* values were low for all sites in both Sample 1 and 2, they may always remain at this level, with the fish that were missing if captured in the future possibly best considered more as “chance encounters” or “vagrants”.

The relatively high *Nativeness* scores for all sites suggest that introduced species are having little influence on the lower Warrego fish community as a whole. All three exotic species sampled were in relatively low abundance, no one species occurred at all sites sampled, and in general recent recruitment was also relatively low for all three. Sampling by Fisheries NSW within the boundaries of the Selected Area has returned similar results for mosquitofish and goldfish, with only low numbers caught, and only sporadically at a small number of sites (NSW DPI Freshwater Fish Database, unpublished data). In contrast, common carp were sampled in relatively high abundances at a number of sites across the wider Warrego catchment (NSW DPI Freshwater Fish Database, unpublished data), and the lower Warrego was also identified as a breeding hotspot for the species as part of the *Carp Hotspots Program* (Gilligan 2005). Considering that the floodplain was inundated between Sample 1 and Sample 2, which is a preferred spawning and recruitment habitat for common carp (Stuart and Jones 2006), and given the low numbers of adults and juveniles caught in Sample 2, it appears that the lower Warrego may not be so much a constant and consistent source of carp, but may be more an area used opportunistically. This may also have been influenced by changes to the management of Ross Billabong which historically received water pumped directly from the Darling River. This pumping not only created a more permanent refuge for carp in the system, but may have also provided a pathway for carp movement into the billabong (Baumgartner *et al.* 2007). Under current management conditions, carp, with their propensity to migrate upstream during high flow events (Stuart *et al.* 2006), may move up into the Warrego River during periods when the Warrego connects with the Darling to spawn and recruit. As such, in managing flow releases it is critical to ensure connectivity of the two rivers is carefully managed so that the opportunity for carp to move into the Warrego to spawn is minimised.

The rise in the *Recruitment* Index scores between Sample 1 and Sample 2 directly reflects the substantial increase in the number of recruits for most large-bodied native species caught in the later survey. This result is not unexpected given the inflows that occurred during November and December 2015 which was between the two samples. The flows resulted in longitudinal connection and riparian inundation along significant lengths of the Warrego River system and also spilling onto the Western Floodplain. While the majority of large-bodied species caught can reproduce and recruit in-channel during times of low discharge, they can also be called hydrological opportunist, in that overbank flooding and the inundation of the floodplain and in this case longitudinal connection of the river, can lead to booms in recruitment. This is due not only to an increase in available habitat, but is also due to an influx and release of nutrients, resulting in an increase in plankton and macroinvertebrate production, and subsequently increased food for fish larvae (Appendix H & I, Puckridge *et al*. 2000). Additionally, the benefits of increased primary production can also flow further up the food chain, resulting in healthier adult fish which can lead to enhanced reproductive output via increased fecundity and spawning frequency (Puckridge *et al.* 2000).

Based on the results of the current sampling round, the fish community across the lower Warrego could be said to be functioning and surviving, albeit in a constantly stressed and tenuous state. Unlike other sections of the Murray-Darling Basin that would benefit from remediation actions such as major habitat rehabilitation and restocking, these types of activities in the lower Warrego may result in little or no measurable improvement for native fish. By its very nature, the lower Warrego River is in a constant state of flux and as such the fish community experiences periods of both "boom" and "bust" and possibly only persist during dry periods because of the constructed dams found along its length. As such, ensuring water passes regularly through the system be it natural or environmental releases, is likely the most effective management action to ensure the health of fish in the system.

L.5 5 Conclusion

The current round of monitoring and reporting provides the first detailed information on the fish community in the lower Warrego catchment. The higher abundance of fish in general and an increase in the number of recruits in Sample 2 most certainly can be linked to the increased flows that occurred in late spring. While not a controlled or planned CEWH environmental release, it demonstrates that by increasing the amount and regularity of flows through the system the fish community as a whole across the entire region will likely benefit. The information gathered therefore not only provides an insight into what water can do for the fish in the system but also helps in justifying and planning for future releases of environmental water.

L.6 References

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Appendix M Frogs

M.1 Introduction

Frogs are a widespread and important taxon in inland rivers and floodplains and are sensitive to changes in hydrological regime including flooding frequency, inundation period and seasonality of flows (Wassens and Maher 2011). Little is known of frog communities and their responses to flow regulation in inland river systems, although the importance of both permanent and temporary wetland areas to sustain populations, facilitate successful reproduction, and provide refugial habitat in dry times is recognised, most particularly those with abundant littoral vegetation cover (Wassens and Maher 2011; Wassens *et al*. 2008; MacNally *et al*. 2009; Healey *et al*. 1997). Ongoing frog monitoring conducted as part of the LTIM program is helping to build an understanding of how frog communities respond to inundation in the Junction of the Warrego and Darling rivers Selected Area (Selected Area).

Several specific questions were addressed through the monitoring of frog diversity in the 2015-16 water year in the 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?

M.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016. While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened (Figure M-1) and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year (Figure M-1).

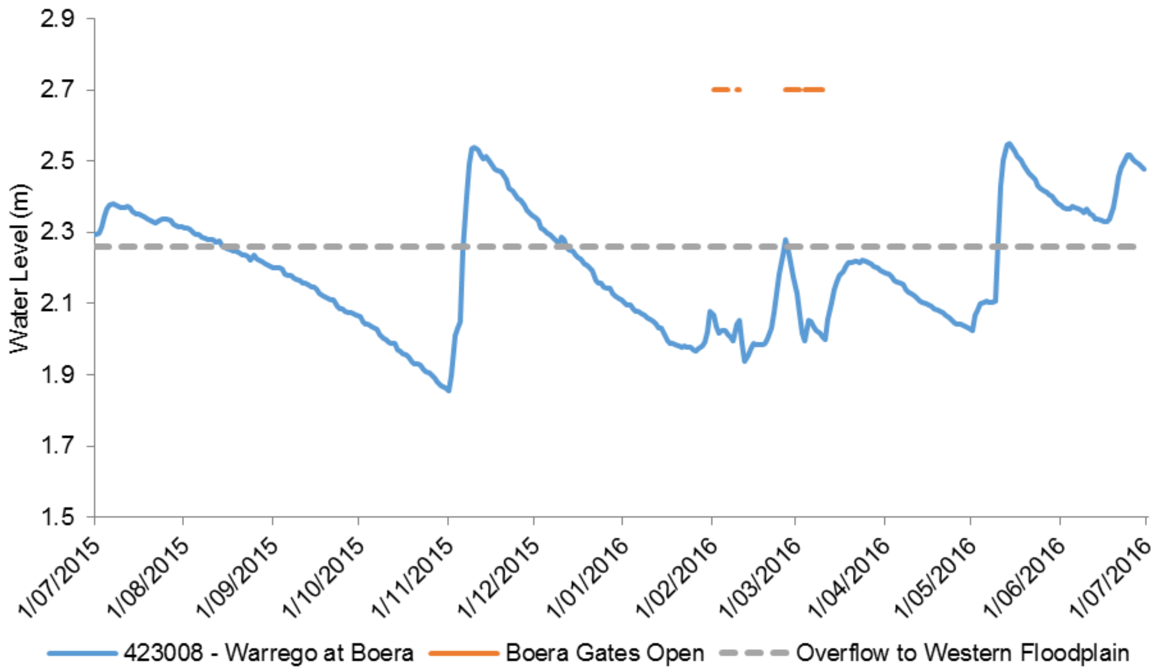

Figure M-1: Boera Dam levels during 2015-16 water year and flow to Western Floodplain (WF) and/or into lower Warrego channels (gates open)

M.1.2 2014-15 Monitoring outcomes

Frog surveys were conducted in February and May 2015 within the Selected Area to establish baseline data for the long term analysis of frog diversity, abundance and richness at three Warrego River channel sites and on the Western Floodplain. During these surveys, 10 frog species were observed, none of which are listed as threatened under the *Threatened Species Conservation Act* (NSW) (TSC Act) or the *Environment Conservation and Biodiversity Protection Act* 1999 (Cth) (EPBC Act). Abundance and richness did not differ significantly between survey periods, although community composition did.

A comparison of combined channel sites with the Western Floodplain site showed that mean abundance was higher in the channel sites but richness was highest on the Western Floodplain. Overall, changes in abundance and richness were not consistent across the Selected Area, with decreases in abundance at Boera Dam and Ross Billabong and increasing at Booka Dam and the Western Floodplain. However, these changes did appear consistent with habitat conditions. Water level receded at all sites between survey periods which reduced aquatic and riparian vegetation cover and increased exposed bank habitats at Boera Dam and Ross Billabong. Water level changes reduced habitat at Booka Dam and the Western Floodplain sites.

M.2 Methods

Frog monitoring was undertaken twice in the 2015-16 water year at three sites within the Warrego River and one in the Western Floodplain (Figure M-2; Table M-1). Surveys were undertaken in October 2015 and March 2016. Adult frogs were surveyed after dark using a 2 x 20-minute visual encounter (person minutes) and a 6 x 1-minute audio survey (Commonwealth of Australia 2014). 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 individuals observed were identified to species and the number recorded.

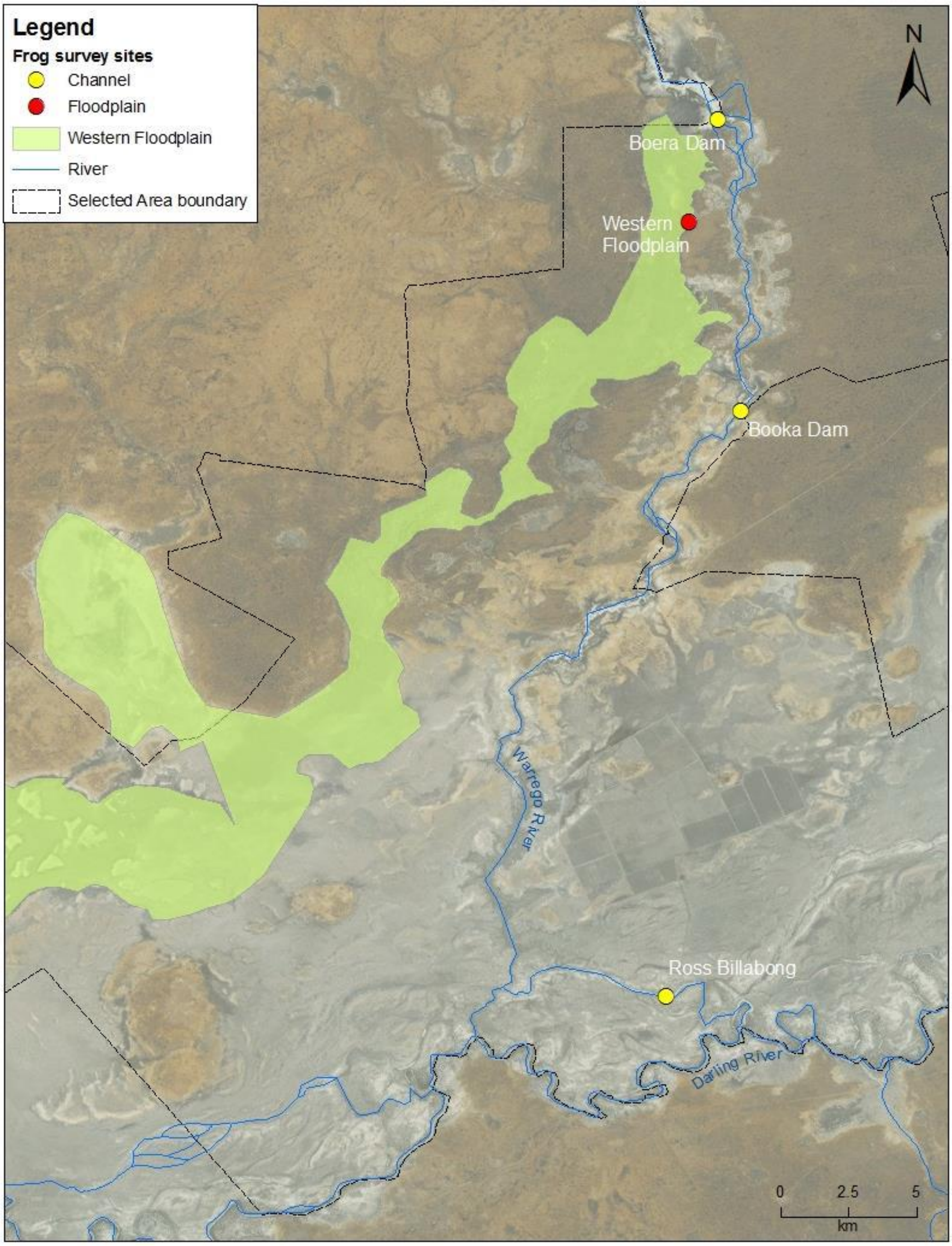

Figure M-2: Location of the Frog survey sites in the Junction of the Warrego and Darling rivers Selected Area.

Table M-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

M.3 Results

M.3.1 Abundance

A total of eight frog species were recorded within the Selected Area during the 2015-16 monitoring period; including five species in October 2015 and six species in March 2016 (Table M-2; Figure M-3). No frog species recorded are listed as threatened under the NSW TSC Act or the Commonwealth EPBC Act.

Mean abundance did not differ statistically between October 2015 survey (29.25 ± 33.27) and March 2016 survey (3.00 ± 2.45) with 117 individuals observed in October 2015 and 12 individuals observed in March 2016 (Table M-2; Figure M-4; $p=0.21$). Calling activity, which is generally indicative of active breeding, was highest in October 2015, with no calling recorded at any site in March 2016 (Table M-2). Mean richness per site differed between October 2015 (4.00) and March 2016 (1.50; $t= -2.61$, $p<0.05$) with a total of six species recorded across all sites in October 2015 and five species recorded across all sites in March 2016 (Figure M-6).

The highest abundance was recorded on the Western Floodplain in October 2015 with 78 individuals representing five species observed (Figure M-6). This is also the equal highest species richness observed throughout the monitoring period, with Booka Dam recording five species in the October 2015 surveys as well (Figure M-5; Table M-2). All sites decreased in abundance and richness between October 2015 and March 2016 with no frogs recorded at Ross Billabong in the March 2016 survey (Figure M-5; Figure M-6).

The Eastern sign-bearing froglet (*Crinia parinsignifera*), barking frog (*Limnodynastes fletcheri*) and Peron's tree frog (*Litoria peronii*) were absent from all sites in March 2016, although Peron's tree frog was the only species present across all four sites in the 2015-16 monitoring period (Table M-2). A comparison of floodplain and combined Warrego channel sites across the 2015-16 monitoring period indicated that mean abundance and richness did not differ by site type ($p= 0.13$ and $p= 0.90$ respectively) (Figure M-7).

Table M-2: Frog survey results for 2015-16.

Scientific Name	Common Name	Boera Dam		Booka Dam		Ross Billabong		Western Floodplain	
		Oct_15	Mar_16	Oct_15	Mar_16	Oct_15	Mar_16	Oct_15	Mar_16
Crinia deserticola	Desert Froglet				4				
Crinia parinsignifera	Eastern Sign-bearing Froglet	1^						17^	
Limnodynastes fletcheri	Barking Frog, Long-thumbed Frog, Marsh Frog	5^		3				13^	
Limnodynastes tasmaniensis	Spotted Grass Frog, Spotted Marsh Frog	1^	1	11				41^	3
Litoria caerulea	Green Tree Frog		2	3		3^			
Litoria peronii	Peron's Tree Frog	2^		1		4^		3^	
Litoria rubella	Desert Tree Frog, Red Tree Frog			5	1			4	
Uperoleia capitulata	Small-headed Toadlet				1				
	Individuals observed	2	3	23	6	2	0	35	3
	Individuals heard	7	0	0	0	5	0	43	0
	Total abundance	**9**	**3**	**23**	**6**	**7**	**0**	**78**	**3**
	Species richness (observed)	1	2	5	3	2	0	4	1
	Species richness (heard)	4	0	0	0	2	0	4	0
	Total species richness	**4**	**2**	**5**	**3**	**2**	**0**	**5**	**1**

Figure M-3: (a) Desert froglet seen at Booka Dam March 2016 b) Small headed toadlet seen at Booka Dam March 2016 (c) Green tree frog seen at Boera Dam in March 2016.

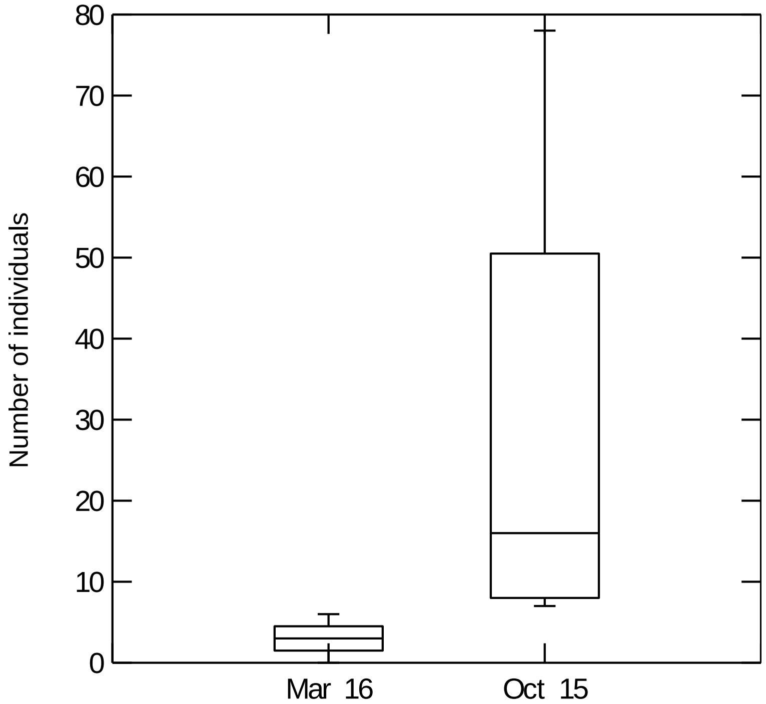

Figure M-4: Number of individuals observed overall in each season.

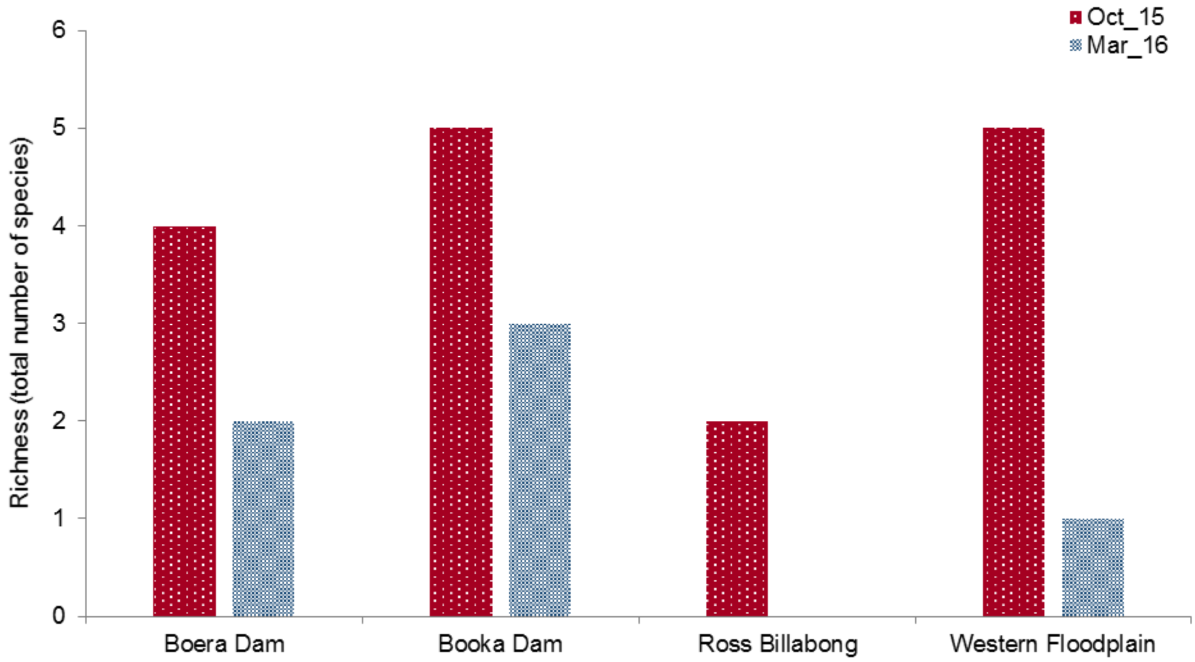

Figure M-5: Frog species richness recorded at survey sites along the Warrego River and the Western Floodplain during the 2015-16 water year.

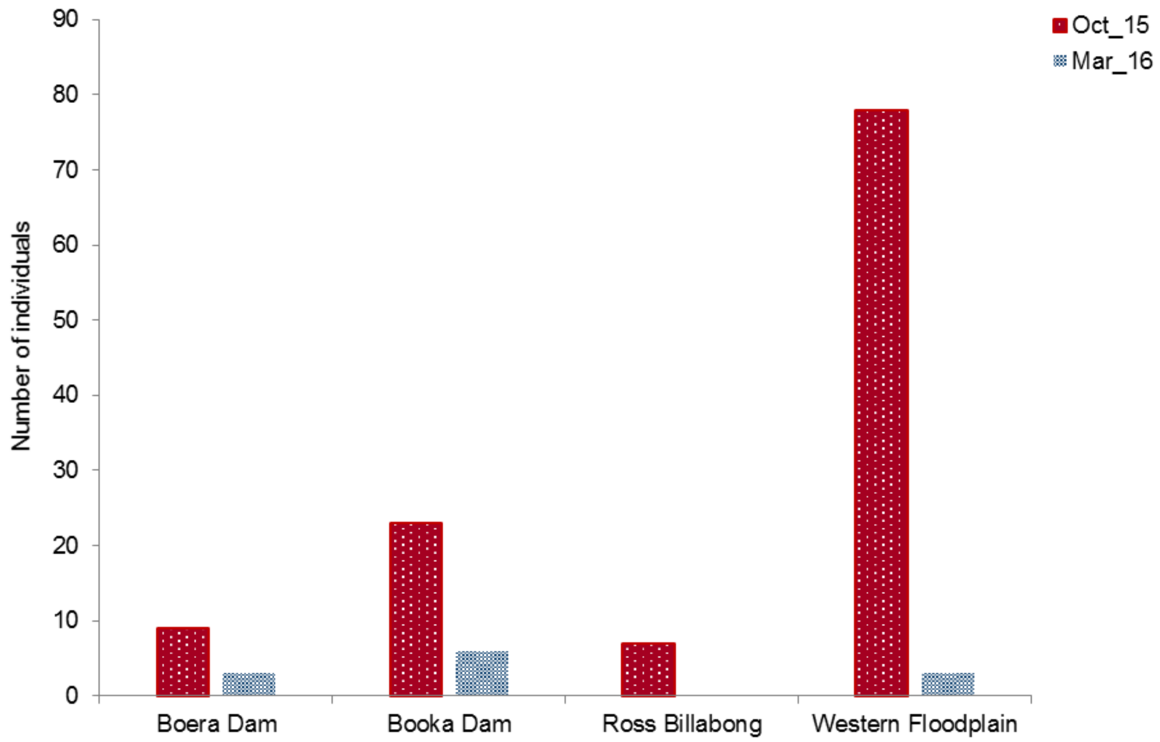

Figure M-6: Total frog abundance (including seen and heard animals) recorded at survey sites along the Warrego River and the Western Floodplain during the 2015-16 water year.

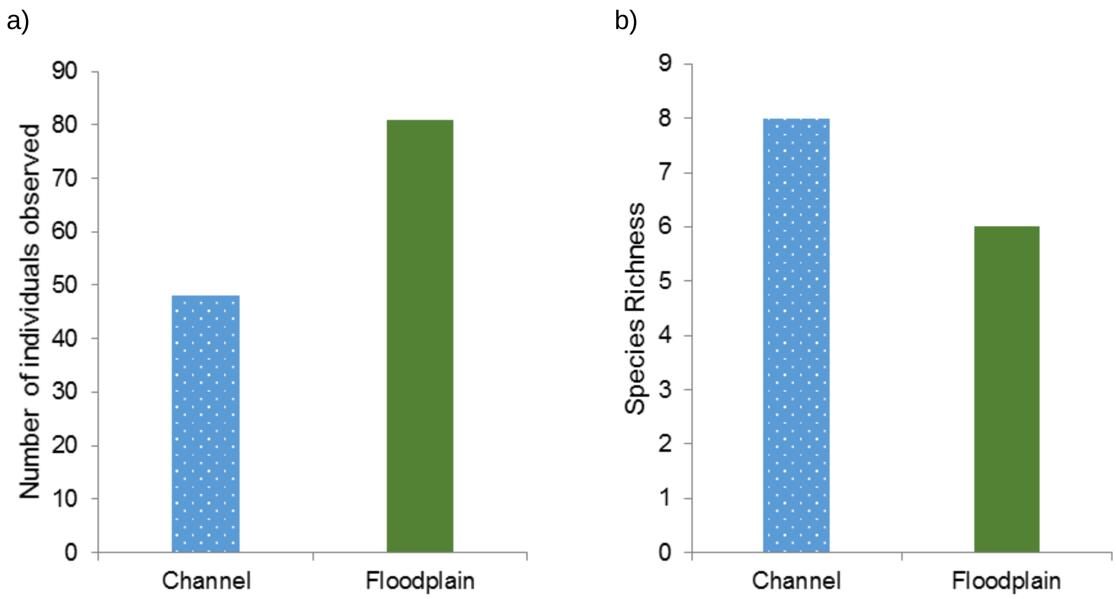

Figure M-7: Frog (a) total abundance and (b) species richness observed in the 2015-16 water year in river channel and floodplain sites along the Warrego River.

To further decipher patterns in frog community composition, multivariate analysis was undertaken on species abundance data. From the nMDS plot, there appeared to be separation of the data when grouped by survey time and site type (channel or floodplain) (Figure M-8). However, PERMANOVA analysis suggested there was no significant differences between either survey times (Pr=0.197) or site type (Pr=0.522). SIMPER analysis showed that different species were associated with each data grouping. Species that contributed to the grouping in the October 2015 data included the Peron's tree frog (41.2%), barking frog (20.48%) and spotted grass frog (Limnodynastes fletcheri) (18.34%). Similarly, the green tree frog (*Litoria caerulea*) (36.1%), Peron's tree frog (24.8%) and the spotted grass frog (24.2%), were responsible for the grouping of river sites. The spotted grass frog was 100% responsible for the grouping of both the March 2016 and floodplain site.

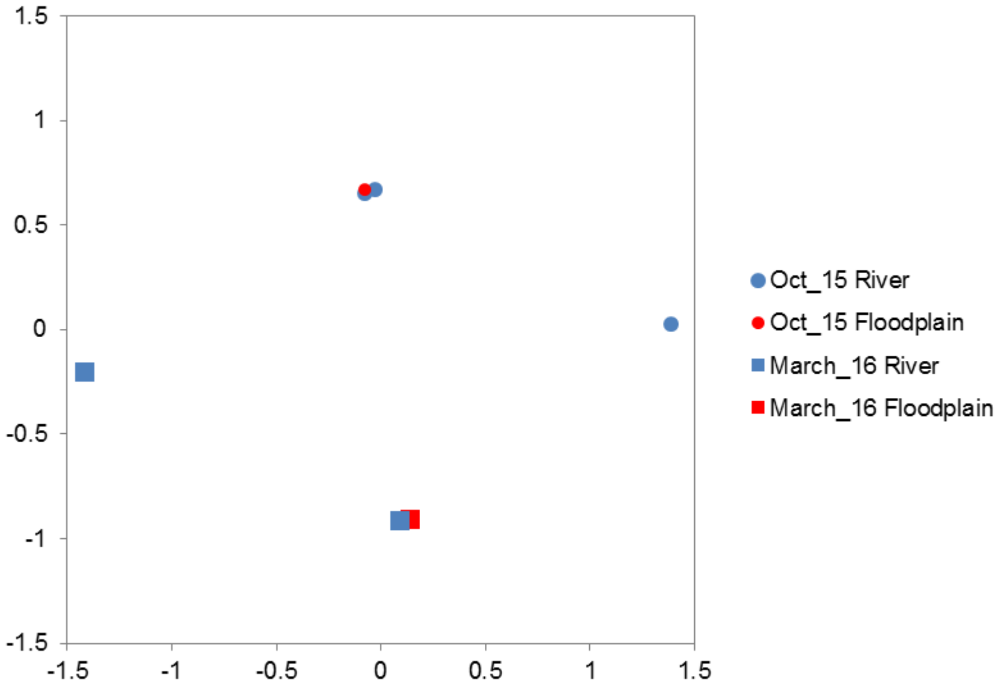

Figure M-8: nMDS plot of species abundance data grouped by sampling time and site type.

M.3.2 Multi-year Comparisons

Species assemblage was similar between water years, although four low abundance species present in the 2014-15 surveys were absent in 2015-16 - New Holland frog (*Cyclorana novaehollandiae*), rough frog (*C. verrucosa*), Sudell's frog (*Neobatrachus sudellae*) and wrinkled toadlet (*Uperoleia rugosa*). The Eastern sign-bearing froglet was recorded for the first time in the October 2015 surveys, although was absent from all sites in March 2016. Booka Dam and the Western Floodplain consistently had the highest diversity and abundance in all sampling periods (Figure M-9).

Overall, abundance did not differ significantly between sampling periods (p=0.13; Figure M-10). However, mean richness per site did, with a significant difference between the February 2015 and March 2016 surveys (Figure M-11). Although abundance did not differ significantly between seasons within water years, this is likely due to the high variation in total counts on the western floodplain between sampling periods in both years. Figure M-9 shows that the number of individuals, particularly heard individuals, was much higher on the Western Floodplain in both February 2015 and October 2015. In both instances the Western Floodplain was either receiving water (October 2015; Figure M-1) or had recently been inundated (February 2015 refer Commonwealth of Australia 2015). Abundance and richness were lower when the floodplain dried (Figure M-9).

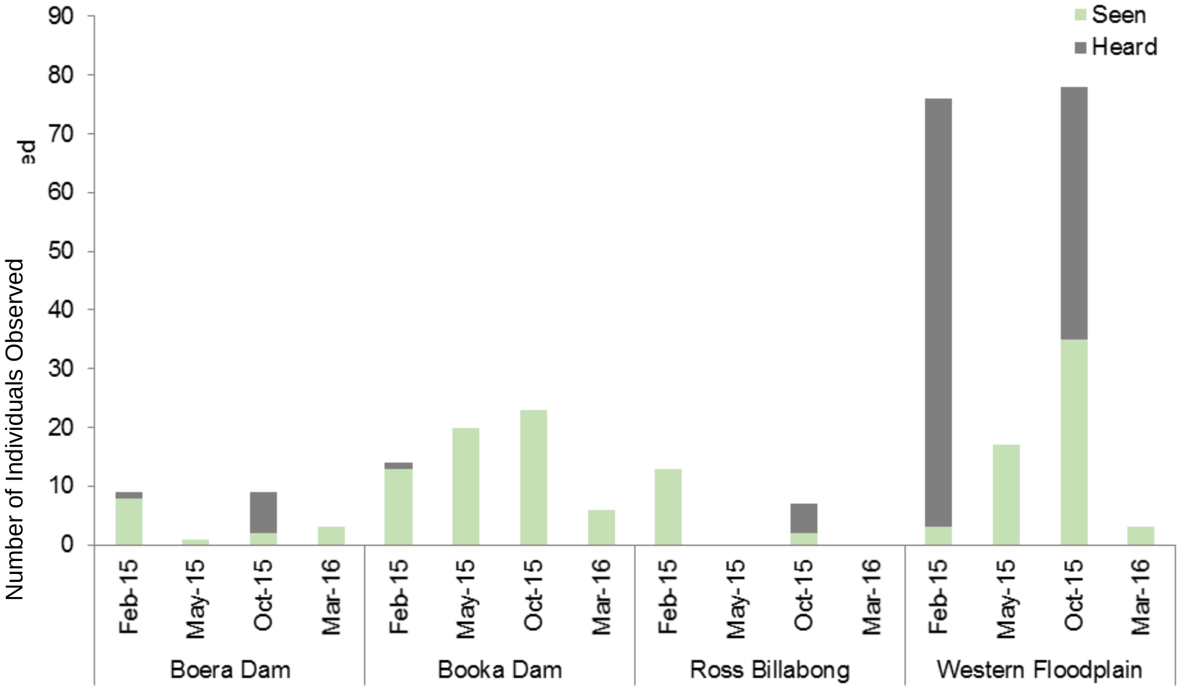

Figure M-9: Number of frogs observed and heard calling during the surveys undertaken in year 1 and 2 of the Junction of the Warrego and Darling rivers Selected Area LTIM project.

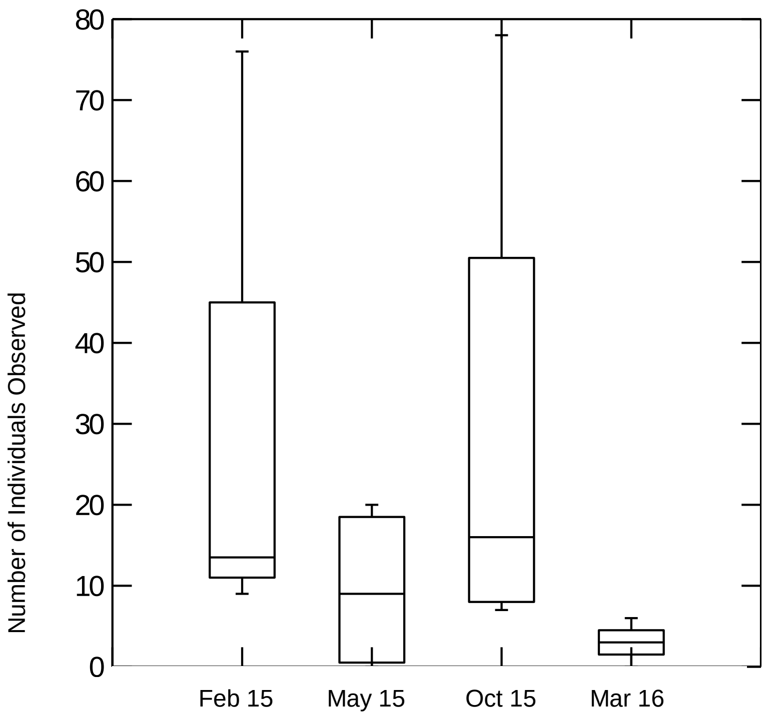

Figure M-10: Abundance across all sampling periods.

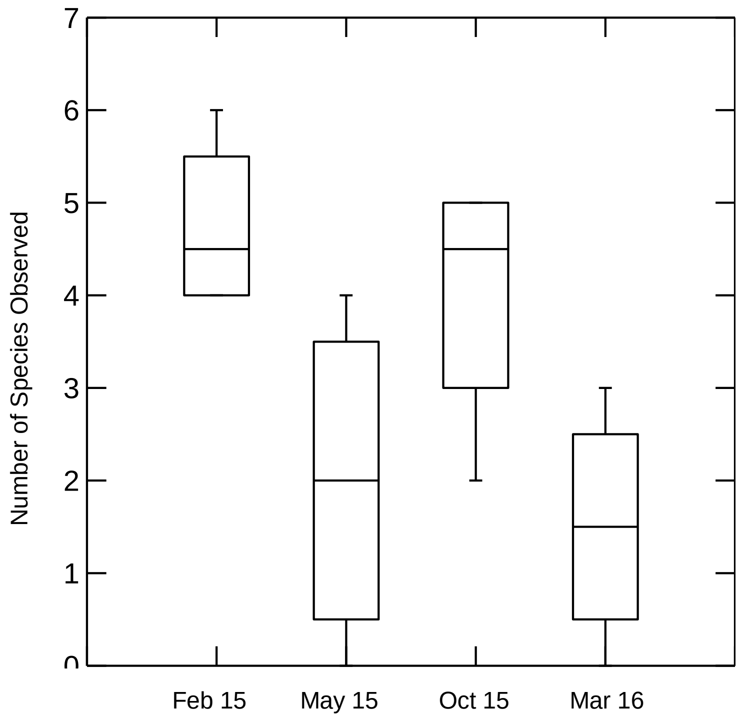

Figure M-11: Species Richness across all sampling periods

Multivariate analysis on species abundance data over the four sampling periods in year 1 and 2 of the project suggest that there was little separation of the data in terms of sampling time or site type (Figure M-12). PERMANOVA analysis confirmed this with non-significant differences between sampling times (Pr=0.131) or site type (Pr=0.301).

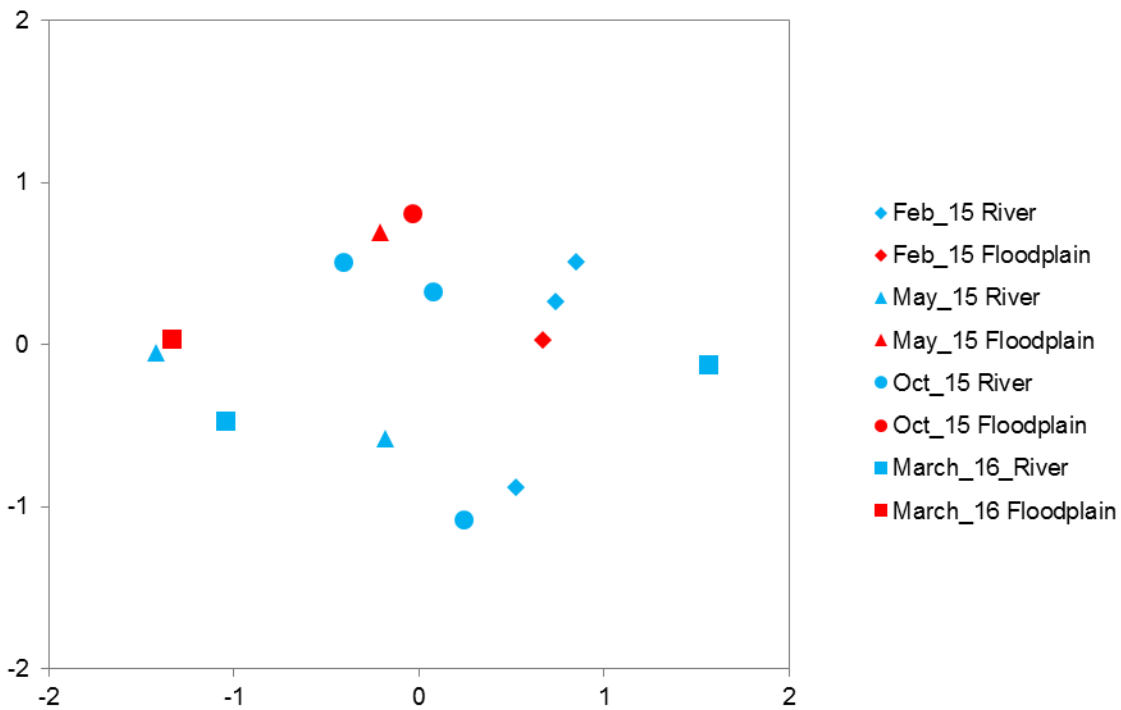

Figure M-12: nMDS plot of species abundance data from year 1 and 2 of the project grouped by sampling time and site type.

M.4 Discussion

Frog abundance and species richness was higher at all sites in October 2015 than in March 2016. The greatest difference in abundance and richness was observed on the Western Floodplain. This is likely due to the influence of flows onto the floodplain through July and August 2015 which would have increased suitable habitat availability and supported the growth of vegetation in and adjacent to the shallow wetland areas surveyed (Figure M-13). There is a recognised strong positive correlation between the presence of emergent aquatic and littoral zone terrestrial vegetation and the occurrence of frogs in wetland areas (Wassens and Maher 2011; Wassens *et al*. 2008; MacNally *et al*. 2009; Healey *et al*. 1997). The availability of such edge habitat is also increased when dam levels rise, reducing exposed bank areas. All Warrego River channel sites had exposed bank area >1m during the March 2016 surveys which may account for the limited number of observations.

Maximum and minimum daily temperatures in the October 2015 sampling period were several degrees higher than those recorded in the March 2016 sampling period (BoM 2016). Frogs such as those species observed within the Selected Area respond to seasonal conditions, generally with increased activity in winter and spring (MacNally *et al*. 2009).

The increases in frog abundance seen on the Western Floodplain over the first two years of the project, during or shortly after inundation indicates the value of temporary habitat for frog populations at the regional scale. Whilst the permanently wet waterhole sites support stable frog populations, periodic inundation of the floodplain attracts large numbers of frogs and stimulates breeding behaviour.

Previous studies investigating the influence of flow regulation on inland frog communities in the southern Murray-Darling Basin have shown that many of the frog species observed in the Selected Area show a preference for temporary sites over permanent sites. Similarly, higher rates of breeding activity have been observed at temporary versus permanent wetland sites, which are shallower and more heavily vegetated than permanent sites. Monitoring results from the 2014-15 and 2015-16 survey periods indicate a similar response in the frog communities of the Selected Area, with abundance and calling activity highest on the Western Floodplain during or shortly after inundation.

Figure M-13: Western Floodplain survey site during a) October 2015, and b) March 2016.

M.5 Conclusion

Patterns of abundance and behaviour in the frog communities of the Selected Area reflect the availability and type of habitat, and seasonal conditions. The permanent waterholes appear to offer stable habitat for local frog populations, and inundation of the Western Floodplain creates high productivity temporary habitat that supports higher frog abundance and breeding, in turn providing potential food for other animals such as birds, fish and reptiles. Continued management of water within the Selected Area to retain a mix of productive floodplain sites, as well as longer-term refugial channel sites is likely to be important to the persistence and diversity of frog populations within the selected area.

M.6 References

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Appendix N Waterbird Diversity

N.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 (Selected Area) but ongoing waterbird monitoring conducted as part of the LTIM program is helping to build an understanding of how waterbirds respond to environmental watering in this system.

Several specific questions were addressed through the monitoring of waterbird diversity in the 2015-16 water year in the Selected Area:

- 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?

N.1.1 Environmental watering in 2015-16

Unlike other Selected Areas, environmental water is not specifically delivered to the Junction of the Warrego and Darling Rivers Selected Area, rather, Commonwealth environmental water is held as unregulated entitlements and its use and influence is thus reliant on flows out of upstream catchments. Decisions surrounding the management of entitlements are as important as the amount of entitlements held in influencing ecological outcomes.

Four small to moderate flow events containing environmental water flowed down the Darling River during the 2015-16 water year. These occurred in July – October 2015, November 2015, January – March 2016 and June 2016. No environmental water was accounted for in the Warrego River or on the Western Floodplain in the Selected Area. However, a small flow event containing around 4% Commonwealth environmental water from the upper Warrego catchment flowed into the Selected Area during January-March 2016 (Appendix B). While this event was too small to trigger Toorale licences, the gates at Boera Dam were opened (Figure N-1) and water flowed through the lower Warrego channel refilling waterholes and connecting to the Darling River. Natural flows derived from localised rainfall, resulted in three separate inundation events on the Western Floodplain during the 2015-16 water year (Figure N-1).

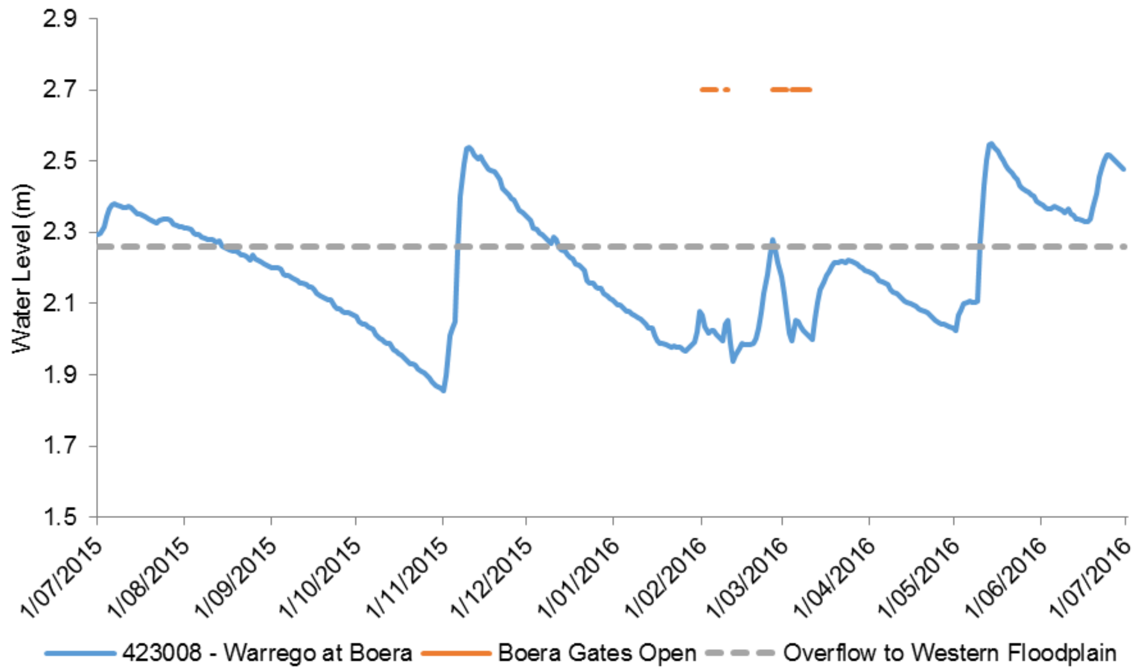

Figure N-1: Boera Dam levels during 2015-16 water year and flow to Western Floodplain and/or into lower Warrego channels (gates open).

N.1.2 2014-15 monitoring outcomes

Monitoring of waterbirds was undertaken in February and May 2015 to capture summer and autumn seasonal representation of waterbird communities. Four sites were surveyed, located along the Warrego River and Western Floodplain representing floodplain and channel sites. These surveys were conducted using ground survey methods (Commonwealth of Australia, 2015a).

The results of previous monitoring indicated that waterbird abundance and species richness corresponded to habitat and resource availability. Waterbird abundance per hectare declined across all sites from the February to May survey periods as flows and water levels reduced. In the 2014-15 water year a total of 86 bird species, including 31 waterbird species were recorded across the four sites including one waterbird species, the Eastern great egret (*Ardea alba*), listed under two international migratory bird agreements (JAMBA and CAMBA) and two threatened species listed under the NSW TSC Act: brolga *(Grus rubicunda*) and freckled duck *(Stictonetta naevosa)*. Waterbird breeding was observed at Boera Dam and Ross Billabong during the February 2015 survey for four waterbird species including Australasian darter *(Anhinga novaehollandiae)*, black-fronted dotterel (*Elseyornis melanops*), royal spoonbill *(Platalea regia)* and freckled duck.

N.2 Methods

Four sites were surveyed in both October 2015 and March 2016 (Table N-1; Figure N-2). These sites were located along the Warrego River and Western Floodplain monitoring zones representing channel and floodplain sites (Table N-1). Ground 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 2015b).

Point surveys were conducted from one or more points located to cover the largest possible area of each survey site. Where multiple points were surveyed for a single site, these points 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 at each survey point were recorded. In March 2016 Boera Dam survey point two received a second survey as the first survey was interrupted by disturbance to waterbirds when nearing completion. For this survey point, all species observed and the maximum abundance for each species observed were used in the analysis.

Factorial regression of species richness, abundance/ha and functional guild data was undertaken to compare between survey times and the Warrego River and Western Floodplain zones. F-tests were used to test for equality of variance, and appropriate t-tests were employed thereafter. Abundance/ha data were square root transformed prior to analysis to ensure model assumptions were met. Multivariate nMDS analyses were used to describe patterns of bird community composition.

Square-root or presence/absence transformations were 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 time and site type (river of floodplain). SIMPER tests were performed to assess the dominant species associated with each data grouping.

Table N-1: 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

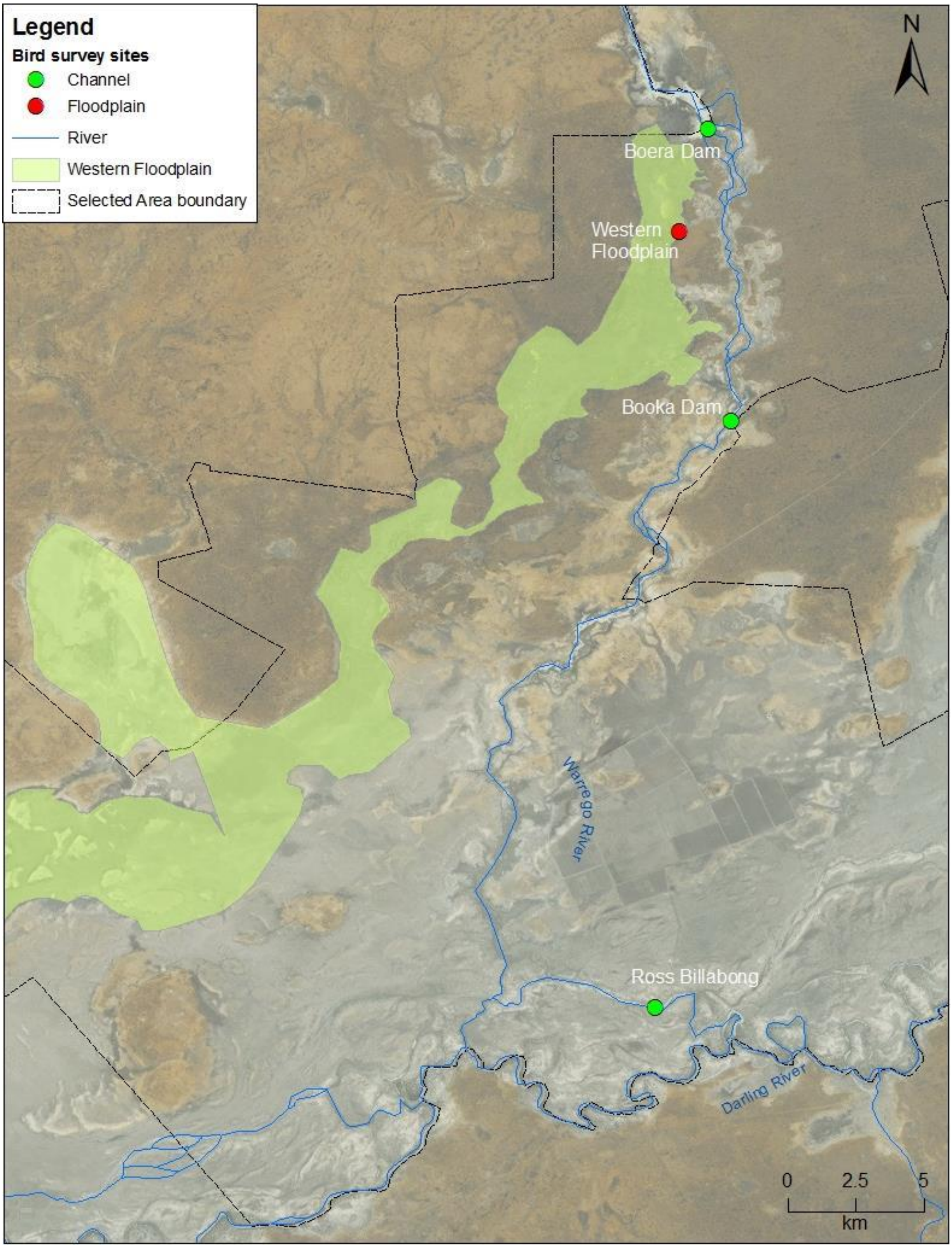

Figure N-2: Location of waterbird diversity monitoring sites within the Junction of the Warrego and Darling rivers Selected Area.

N.3 Results

N.3.1 2015-16 water year

Species richness and abundance

In total, 87 bird species were observed in the 2015-16 surveys in the Warrego River and Western Floodplain, of which 34 species were waterbirds (Figure N-3; Table N-2). This included three waterbird species listed under one or more international agreements: wood sandpiper (*Tringa glareola*) (JAMBA, CAMBA, ROKAMBA); common sandpiper (*Actitis hypoleucos*) (Figure N-3) (CAMBA and JAMBA) and; eastern great egret (*Ardea modesta*) (JAMBA). The wood and common sandpipers are non-breeding migrants to Australia during the northern hemisphere winter (Department of the Environment 2016), and the eastern great egret is listed as a marine and migratory species under the Environment Protection and Biodiversity Conservation Act 1999 with known breeding populations within Australia.

A total of 572 individual waterbirds were observed in October 2015 and 310 in March 2016 comprising 27 and 16 species respectively. Mean waterbird abundance/ha did not differ between October 2015 (4.6) and March 2016 (2.9; $p=0.71$). Similarly, mean richness per site did not differ between October 2015 (10) and March 2016 (7; $p=0.57$).

Boera Dam recorded the highest waterbird species richness and highest waterbird abundance/ha for the 2015-16 survey period, with 25 waterbird species recorded in October 2015 equating to 16 birds/ha (Figure N-3; Figure N-4; Table N-3). This survey accounted for 21% of total individuals seen across the 2015-16 monitoring period, and 53% of waterbird abundance/ha. Grey teal (*Anas gracilis*) were the most abundant waterbird species observed (Table N-3) with large flocks of 130 and 97 individuals observed during October 2015 surveys and a flock of 60 seen during March 2016 surveys. All of these observations occurred at Boera Dam. Australian wood duck (*Chenonetta jubata*) were the next most abundant waterbird species, with a flock of 42 birds observed at Boera Dam in March 2016. These two species accounted for 59% of all waterbird observations during the 2015-16 survey period.

A comparison of waterbird abundance and richness between the Warrego River and Western Floodplain showed that the Western Floodplain had significantly lower mean abundance/ha (0.02 birds/ha) than the Warrego River sites (5 birds/ha; $p<0.05$). The Western Floodplain also had lower mean richness (1) than the Warrego River sites (11.3; $p<0.05$), with no waterbirds recorded at all in the March 2016 survey of the Western Floodplain (Figure N-6; Figure N-7; Table N-3).

Figure N-3: (a) brolgas at Boera Dam and (b) Australasian darter and yellow-billed spoonbills at Boera Dam.

Figure N-4: (a) white-faced heron at Booka Dam and (b) common sandpiper at Boera Dam.

Figure N-5: white-bellied sea eagle at Ross Billabong.

Table N-2: Species richness, waterbird abundance/ha and the number of waterbird functional groups recorded at waterbird survey sites within the Selected Area in the 2015-16 monitoring period.

Monitoring Zone	Site Name	Waterbird species richness (maximum species count per site)		Waterbird abundance/ ha (maximum waterbird count per site/ ha)		Waterbird functional guilds	
		Oct-15	Mar-16	Oct-15	Mar-16	Oct-15	Mar-16
Warrego River	Boera Dam	25	10	15.97	6.35	8	6
	Booka Dam	5	11	1.28	3.98	4	6
	Ross Billabong	10	7	0.99	1.36	5	5
Western Floodplain	Western Floodplain	2	0	0.04	0.00	2	0
Mean		**10.5**	**7**	**5.00**	**4.57**	**2.92**	**4.25**
Std Dev		**10.21**	**4.97**	**7.35**	**7.62**	**2.82**	**2.87**

Table N-3: Total counts and percent occurrence of the 34 waterbird species recorded in the Selected Area in 2015-16.

Monitoring Zone		Warrego River			Western Floodplain	
Functional Guild	Common Name	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain	% Occurrence
Australian-breeding Charadriiform shorebirds	black-fronted dotterel*	25	18	9	4	100
	black-winged stilt	16				25
	masked lapwing	11		1		50
	red-capped plover	12				25
	red-kneed dotterel	20				25
	red-necked avocet	4				25
Dabbling and filter-feeding ducks	Australasian shoveler	2				25
	freckled duck	1				25
	grey teal	365	6	50		75
Dabbling and filter-feeding ducks cont.	Pacific black duck	25	2	6		75
	pink-eared duck	42				25
Diving ducks, aquatic gallinules and swans	black swan			6		25
	Eurasian coot		2			25
Grazing ducks and geese	Australian wood duck	76	21	5		75
	plumed whistling-duck			8		25

Monitoring Zone		Warrego River			Western Floodplain	
Functional Guild	Common Name	Boera Dam	Booka Dam	Ross Billabong	Western Floodplain	% Occurrence
Migratory Charadriiform shorebirds	common sandpiper[CJ]	1				25
	wood sandpiper[CJR]	1				25
Piscivores	Australasian darter	5		1		50
	Australian pelican	26	11	1		75
	Eastern great egret[J]		1			25
	hoary-headed grebe	5				25
	pied cormorant	3				25
	sacred kingfisher*	1	5	1	3	100
	whiskered tern	1				25
	white-faced heron	2	1	1		75
	white-necked heron		1			25
Rails and shoreline gallinules	black-tailed native-hen	55				25
Raptor	black kite	1		2		50
	nankeen kestrel			3		25
	whistling kite	2	2	1		75
Large wading birds	Australian white ibis	1				25
	brolga	2				25
	yellow-billed spoonbill	5				25

[J]= listed under JAMBA; [C]= listed under CAMBA; [R]= listed under ROKAMBA; [V]=Vulnerable (NSW TSC Act); [E]= Endangered (NSW TSC Act);

*= breeding activity observed

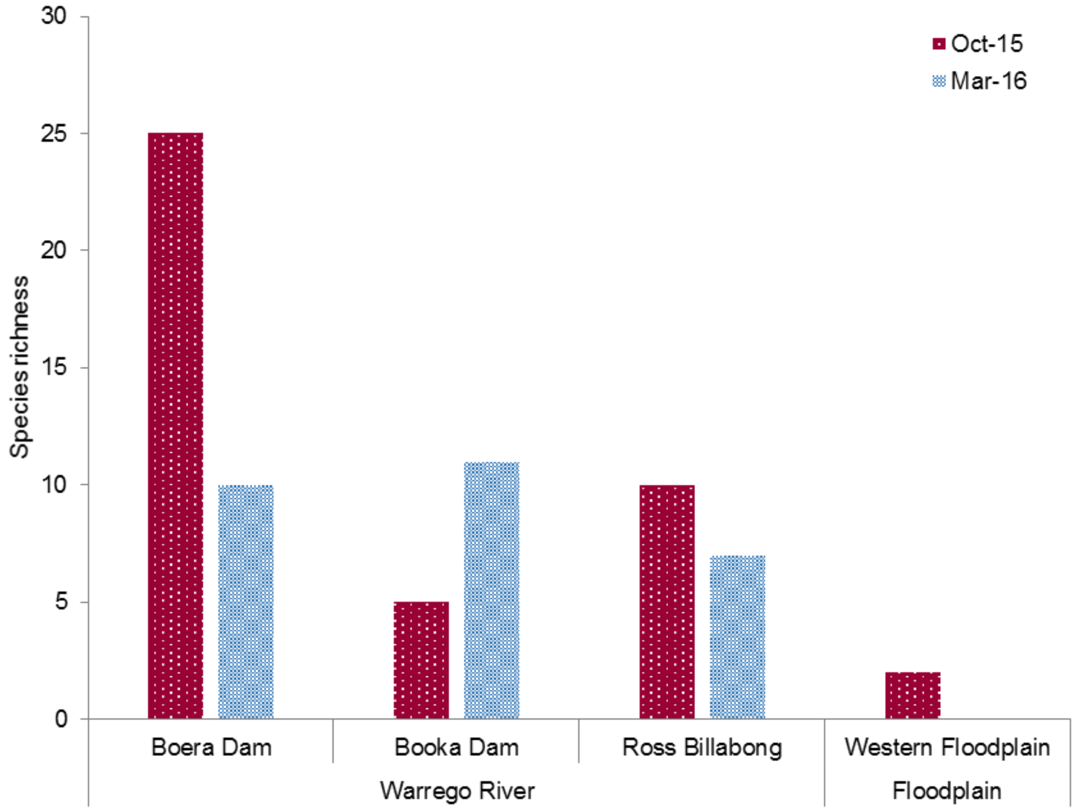

Figure N-6: Species richness recorded across sites in 2015-16 monitoring period.

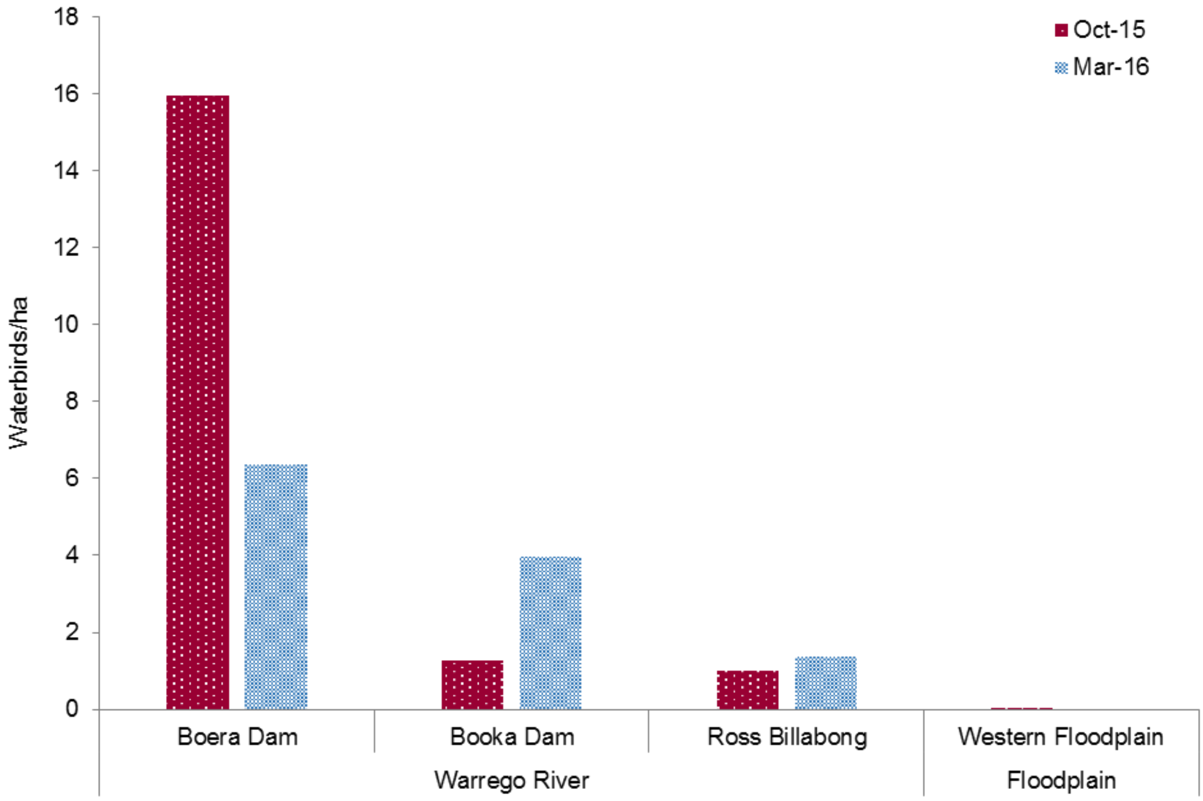

Figure N-7: Number of waterbirds/ha recorded across sites in 2015-16 monitoring period.

To further describe patterns in bird community composition, multivariate analysis was undertaken on species abundance data. From the nMDS plots, there appeared to be separation of the data when grouped by season and zone (Figure N-8). However, PERMANOVA analysis suggested these differences were non-significant. While the differences between groups were non-significant, SIMPER analysis suggested that different species were associated with each grouping (Table N-4).

Australian wood duck, sacred kingfisher (*Todiramphus sanctus*) and black-fronted dotterel contributed to the variation within the October 2015 sampling sites, while the grey teal, Pacific black duck (*Anas superciliosa*), Australian pelican (*Pelecanus conspicillatus*), white-faced heron (*Egretta novaehollandiae*) and whistling kite *(Haliastur sphenurus)* contributed to the grouping of the March 2016 sampling sites. In the Warrego channel, the grey teal, whistling kite, Australian wood duck, Australian pelican and Pacific black duck contributed to the variation, while the black-fronted dotterel and sacred kingfisher were the only species recorded in the Western Floodplain site.

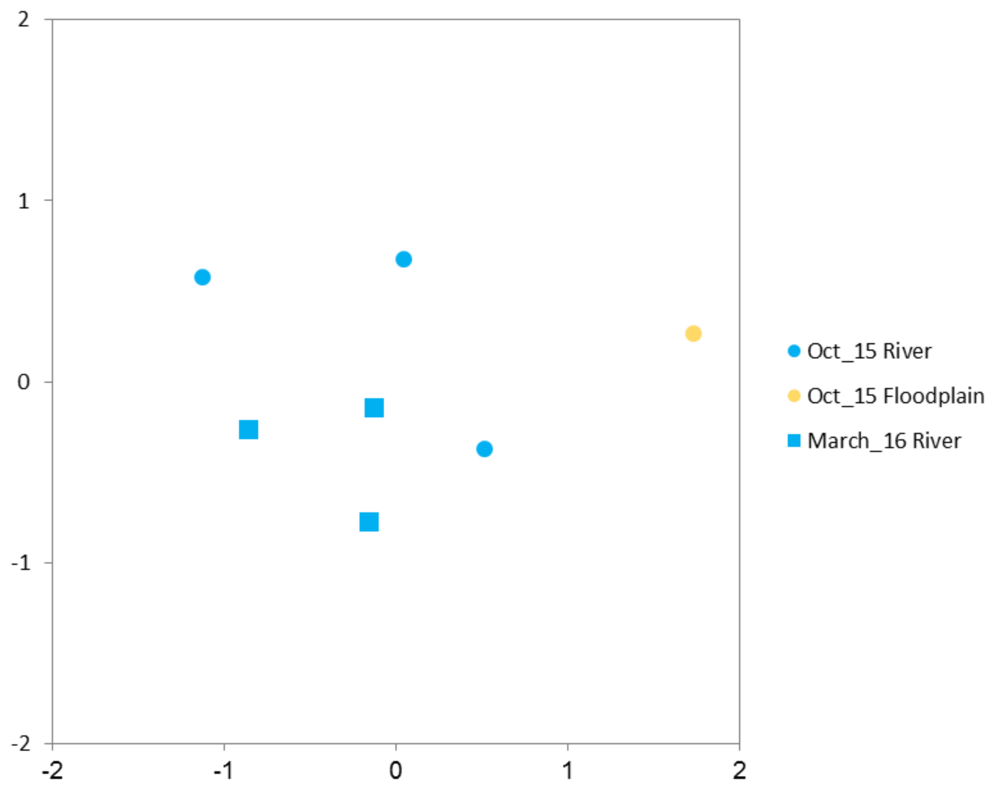

Figure N-8: nMDS plot of waterbird abundance data grouped by sampling time and zone.

Table N-4: SIMPER results of species contributions to groupings in community composition data. Contributions of species for the floodplain sites could not be calculated due to only one site containing data. All species present at this site are listed.

Grouping	Species	Contribution to grouping (%)
October 2015	black-fronted dotterel	35.35
	sacred kingfisher	30.06
	Australian wood duck	14.6
March 2016	grey teal	26.58
	Pacific black duck	16.67
	Australian pelican	16.11
	white-faced heron	12.9
	whistling kite	12.23
River	grey teal	19.14
	black-fronted dotterel	15.66
	Australian wood duck	15.53
	Australian pelican	13.57
	Pacific black duck	12.25
Floodplain	black-fronted dotterel	-
	sacred kingfisher	-

Waterbird breeding and functional guilds

Waterbird breeding was only observed in two species in the 2015-16 monitoring period; the black-fronted dotterel (Australian-breeding charadriiform shorebird) at Boera Dam in October 2015 and sacred kingfisher (piscivore) at Booka Dam in March 2016.

Nine of the ten functional guilds were represented in the Selected Area in the 2015-16 monitoring period with reed-inhabiting passerines absent in both monitoring periods. Eight guilds were represented in October 2015 and seven guilds were represented in March 2016 (Figure N-9). Dabbling and filter-feeding ducks, which includes grey teal, the most abundant waterbird species observed in the 2015-16 monitoring period were dominant in both survey periods. This functional group showed the largest decline in abundance per hectare between survey periods. Most other functional groups also declined in abundance/ha between survey periods, apart from diving ducks, aquatic gallinules and swans; grazing ducks and geese and piscivores which all increased from October 2015 to March 2016.

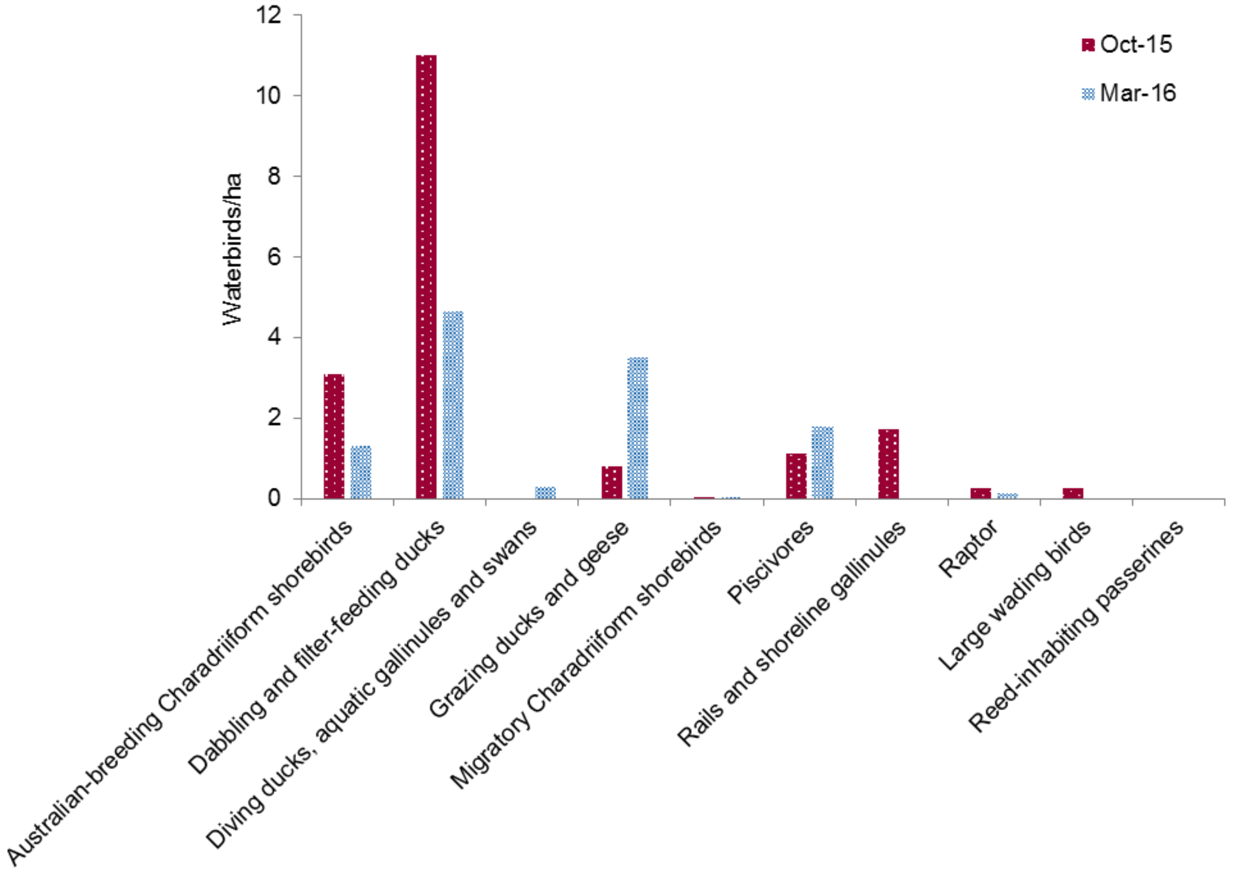

Figure N-9: Waterbird count /ha for each functional group observed throughout the 2015-16 monitoring period across all sites.

N.3.2 Multi-year comparison

Species richness and abundance

Abundance and species richness did not differ significantly between sampling periods across year 1 and year 2 ($p=0.495$ and $p=0.302$ respectively). However, both abundance and richness differed significantly between channel and floodplain sites ($p<0.05$). There was no significant interaction between sampling period and site type for either abundance or richness ($p=0.339$ and $p=0.135$ respectively). Within periods, there was no consistent difference between channel and floodplain sites with a significant difference observed only in the March 2016 survey ($p=0.045$).

Community composition

Multivariate analysis undertaken on the community composition data from both year 1 and year 2 of the project suggests that zone is the main factor driving separation in the data (Figure N-10), as significant results were observed between Warrego channel and Western Floodplain sites (PERMANOVA, pseudo-F=2.60, P<0.05). Differences between sampling times were non-significant.

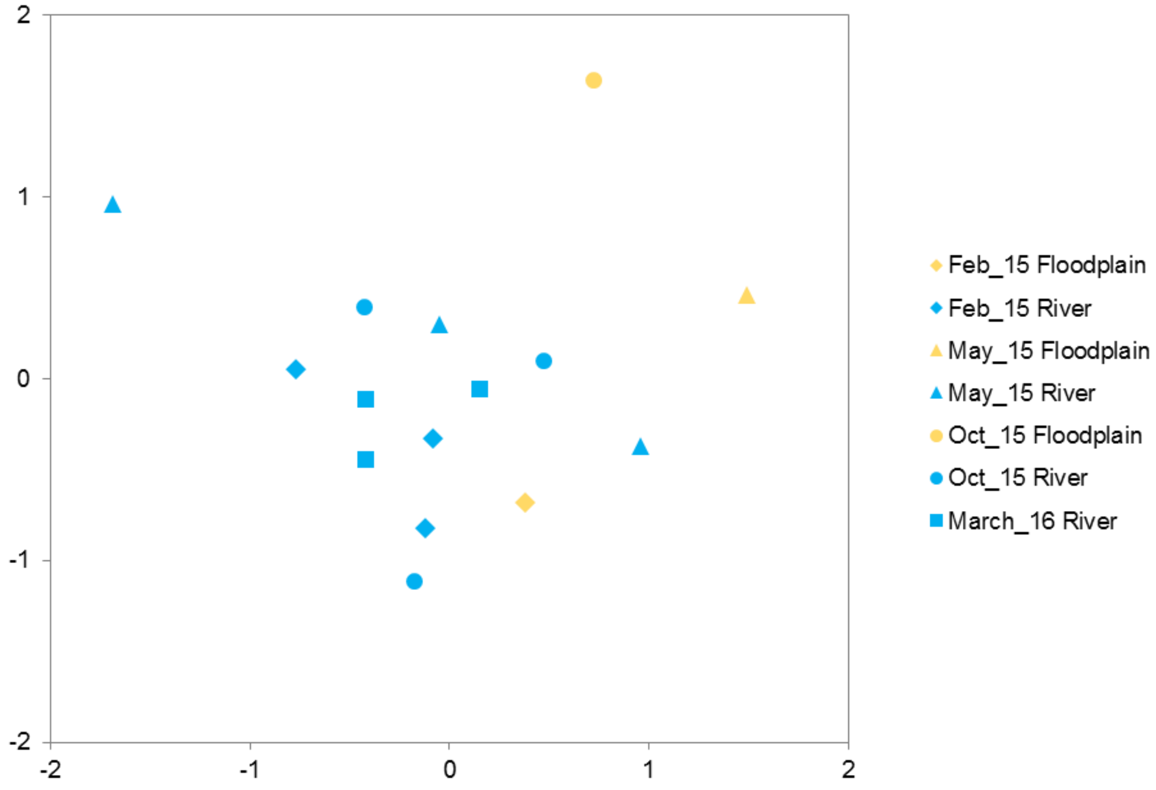

Figure N-10: nMDS plot of waterbird community composition data grouped by sampling time and monitoring zone.

N.4 Discussion

Boera Dam, one of the largest and most permanent waterbodies in the lower Warrego River, recorded the highest waterbird abundance across all surveys throughout the 2014-15 and 2015-16 water years. This underlines the importance of this permanent waterhole as a refugial habitat that supports a locally significant waterbird population. In the 2014-15 water year, inundation of the Western Floodplain through the management of Commonwealth environmental water resulted in an increase in productivity that saw higher mean waterbird abundance and richness on the Floodplain than at combined channel sites, likely as a result of dispersal to the newly created habitat by waterbirds from within and beyond the catchment. The same results were not seen in the 2015-16 water year most likely because survey times did not coincide with floodplain inundation events.

There was little seasonal difference in waterbird abundance and richness between October 2015 and March 2016, and a comparison of year 1 and year 2 data indicates that seasonality is not driving patterns in waterbird abundance and richness within the Selected Area. Differences in waterbird abundance and richness seen in the 2014-15 water year were linked to inundation of the Western Floodplain. The results indicate that those species present during surveys in 2015-16 have retracted to the more permanent sites where habitat and resource abundance were sufficient to maintain populations although not support widespread breeding.

Dabbling and filter-feeding ducks, which feed on invertebrates and zooplankton, remained the dominant functional group present, although abundance dropped between survey periods. This is likely to reflect a reduction in available resources, as the abundance of macroinvertebrates was also shown to be lower in March 2016 (Appendix I) or the migration of waterbirds to other, more productive catchments at the time of survey (Roshier *et al*. 2002). A small increase in piscivores, grazing ducks and geese and diving ducks, aquatic gallinules and swans is likely to also be indicative of the availability of resources. The diving ducks, aquatic gallinules and swans functional group was represented by Eurasian coot and black swan which are herbivorous and omnivorous respectively and which may have benefited from a stable food resource in aquatic macrophytes, increased littoral algal production (Appendix H), encroaching terrestrial vegetation on wetland edges, and small fish (Kingsford *et al*. 2010). Similarly, piscivores may have benefitted from the increased number of small fish observed in the March 2016 survey period (Appendix L).

N.5 Conclusion

Monitoring of waterbird diversity in 2015-16 suggested that the waterholes along the Warrego River channel provide effective refugial habitat for waterbirds, important in the arid landscape of north western New South Wales. Monitoring outcomes from the 2014-15 water year indicate that inundation of the Western Floodplain supports an increase in waterbird abundance and richness. Continued management of water within the Selected Area to retain a mix of productive floodplain sites, as well as longer-term refugial channel sites is likely to be important to the persistence of waterbird populations regionally (Bino *et al.* 2015).

N.6 References

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