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 several other indicators measured in the Gwydir River system Selected Area (Gwydir Selected Area) including Water Quality, Vegetation, Waterbirds, Fish, Microinvertebrates and Macroinvertebrates. The influence of hydrology on these indicators will be addressed under their respective sections. The Hydrology (River) indicator will also provide information on the degree of hydrological connection maintained through the Gwydir Selected Area during the LTIM project (2014-19). Several specific questions were addressed in relation to this indicator:

- What did Commonwealth environmental water contribute to hydrological connectivity?
- What did Commonwealth environmental water contribute to hydrological connectivity of the Gwydir Selected Area channels?

A.2 Methods

A.2.1 Hydrological connectivity

An assessment of the hydrological connectivity experienced throughout the monitoring zones of the Gwydir Selected Area was undertaken following the methods outlined in Commonwealth of Australia (2014). Here, flow thresholds measured at upstream gauging stations were identified that would ensure flow through the length of channel in each zone. These thresholds were estimated through an analysis of historical flow records (from 1990-2014) whereby corresponding peaks of small flow events were observed at both upstream and downstream gauging sites, suggesting connection throughout the length of the channel (Figure A-1). These thresholds were then compared with known average stream losses provided by WaterNSW. Due to the off-river abstraction of flows in some channels, flows passing the downstream gauges were also quantified to confirm connectivity through the system. Here an arbitrary 5 ML/d level was used to indicate through flow connection. The gauging stations used for this analysis are presented in Figure A-1 and Table A-1 outlines the thresholds estimated to provide longitudinal connectivity.

Once the thresholds were identified, a spells analysis (Gordon *et al.* 1992) was undertaken to assess the total duration and frequency of flows passing the gauge. Results for downstream gauges were then subtracted from those at upstream gauges to provide an estimate of full longitudinal connectivity along channels throughout the LTIM project.

No downstream gauge exists in the Mallowa system, making an assessment of hydrological connectivity impossible. To determine duration of wet and dry spells a minimum figure of 5 ML/d entering the system through the Regulator (Figure A-1) was used to indicate a connected period.

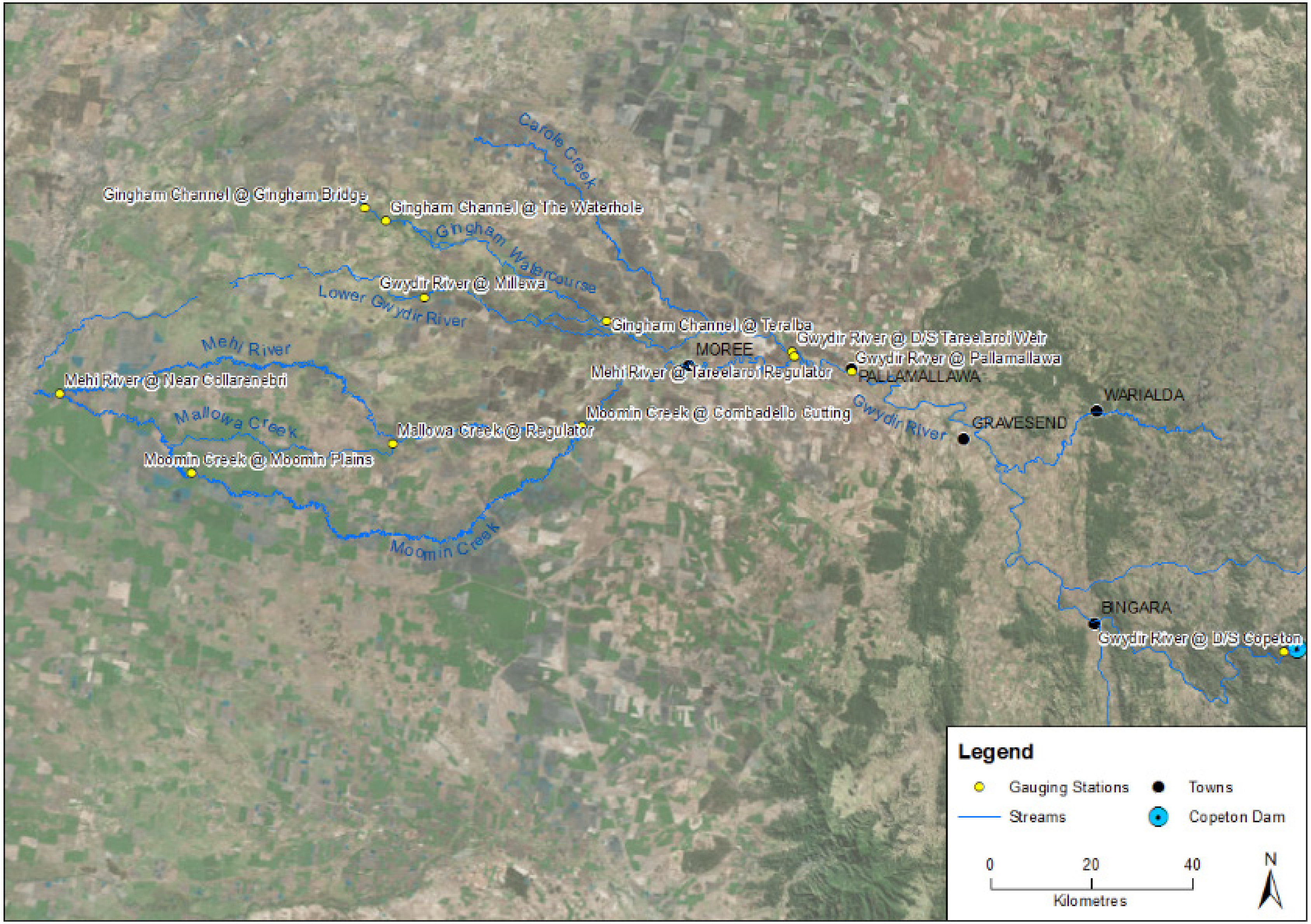

Figure A-1: Location of flow gauging stations used in the hydrological connectivity analysis.

Table A-1: Thresholds at gauging stations used to determine hydrological connectivity.

Zone	Channel	Gauging station (upstream or downstream)	Gauging station number	Threshold for longitudinal connectivity
Gwydir River	Gwydir	Gwydir DS Copeton Dam (U/S)	418026	100 ML/d
		Gwydir River @ Pallamallawa (D/S)	418001	5 ML/d
Gingham-Gwydir Watercourse	Lower Gwydir	Gwydir (south arm) DS Tyreel regulator (U/S)	418063	40 ML/d
		Gwydir @ Millewa (D/S)	418066	5 ML/d
	Gingham	Gingham channel @ Teralba (U/S)	418074	50 ML/d
		Gingham channel @ Gingham bridge (D/S)	418079	5 ML/d
Mehi-Moomin	Mehi	Mehi River @ D/S Tareelaroi Regulator (U/S)	418044	300 ML/d
		Mehi River @ near Collarenebri (D/S)	418055	5 ML/d
	Moomin	Moomin @ Combadello Cutting (U/S)	418048	30 ML/d
		Moomin @ Moomin plains (D/S)	418070	5 ML/d
	Mallowa	Mallowa @ Regulator (U/S)	418049	5 ML/d

A.3 Results

A.3.1 Longitudinal connectivity

During the LTIM project, the longest percentage time of longitudinal connectivity was experienced in the Gwydir and Lower Gwydir channels, with connection achieved 54% of the time (i.e. 54% of days were above the relevant connection thresholds at both gauges in each channel; Table A-2). The Gingham Watercourse was the next most connected (25% connection), followed by Mallowa Creek (23%). The Mehi River and Moomin Creek had the lowest longitudinal connection with 18% of days being above the connection thresholds analysed. The Lower Gwydir channel showed the highest frequency of connection with 51 individual connection events (average duration 20 days), with the Mallowa Creek showing the lowest frequency of connection (15 events; Table A-2). In line with this, the Mallowa system displayed the longest dry spell between connection events, of 381 days from September 2017 to September 2018, and the Lower Gwydir the shortest maximum dry period of 146 days. In contrast, the Gwydir River showed the longest single period of connection, being connected for a 224-day period from July 2018 to February 2019. Moomin Creek had the shortest maximum wet period or 23 days but displayed a relatively high number of connection events with an average of 8 days connection duration for each event (Table A-2).

Table A-2: Variables describing the duration and character of hydrological connectivity in the channels of the Gwydir River system Selected Area over the duration of the LTIM project.

Monitoring Zone	Channel	Days connected (%)	No. of times connected	Average duration of connection events (days)	Maximum wet (days)	Maximum dry (days)
Gwydir River	Gwydir River	54	20	49	224	216
Lower Gwydir River and Gingham Watercourse	Lower Gwydir River	54	51	20	164	146
	Gingham Watercourse	25	25	18	133	354
Mehi River and Moomin Creek	Mehi River	18	22	15	48	208
	Moomin Creek	18	40	8	23	167
	Mallowa Creek	23	15	29	147	381

Gwydir River channel

Flows through the Gwydir River channel were influenced by both regulated releases from Copeton Dam, and unregulated inflows from tributaries below the dam over the duration of the LTIM project (Figure A-2). As the uppermost gauge used in the analysis was directly downstream of the dam, periods of connection were shown to be highly associated with dam releases. Overall, the greatest magnitude of flow measured at the downstream gauge (Pallamallawa) occurred in September to November 2016, during an unregulated flow event that reached near bankfull stage (Figure A-2). Smaller but relatively consistent unregulated flows occurred throughout the first four years of the project, with the only flows through this channel being regulated deliveries from November 2017 onwards.

Connection in the Gwydir River channel over the 2014-15 water year was dominated by two events of relatively long duration (39 and 129 days) during September 2014 to March 2015 (Figure A-2). These were dominated by environmental water deliveries to downstream channels. Several flow events were seen later in the water year, produced by significant rainfall events in tributaries that enter this reach downstream of Copeton Dam. While these events provided connection along the lower sections of this reach, they were not captured in this analysis that assumed full connection of this reach from Copeton Dam downstream to Pallamallawa.

Connection in the Gwydir River channel during 2015-16 was dominated by a 71-day connection event over the summer period (Figure A-2). Three separate environmental flows were released during this period that helped to maintain connectivity. The third flow in this series, delivered in late January, restored connectivity after a brief disconnection of two days to provide another short connection event lasting 11 days. Four other periods of connection, lasting between six and 21 days occurred during the 2015-16 water year, primarily driven by environmental water deliveries. Connectivity in this channel occurred through spring, summer and autumn with no connectivity recorded in winter.

During 2016-17, connection in the Gwydir River channel was dominated by a 101-day connection event over the summer period (Figure A-2). Two separate environmental flows were released during this period that helped to maintain connectivity. A brief period of connectivity of four days was experienced in mid-July, however, this was due to localised rainfall rather than environmental flows. While significant flows occurred in the mid and lower reaches of the Gwydir River due to high tributary inputs in August-October 2016, this did not show up as full hydrological connectivity as flows below Copeton Dam remained below the connectivity threshold. Regardless, substantial connection was observed in the downstream reaches of the Gwydir in winter and spring 2016.

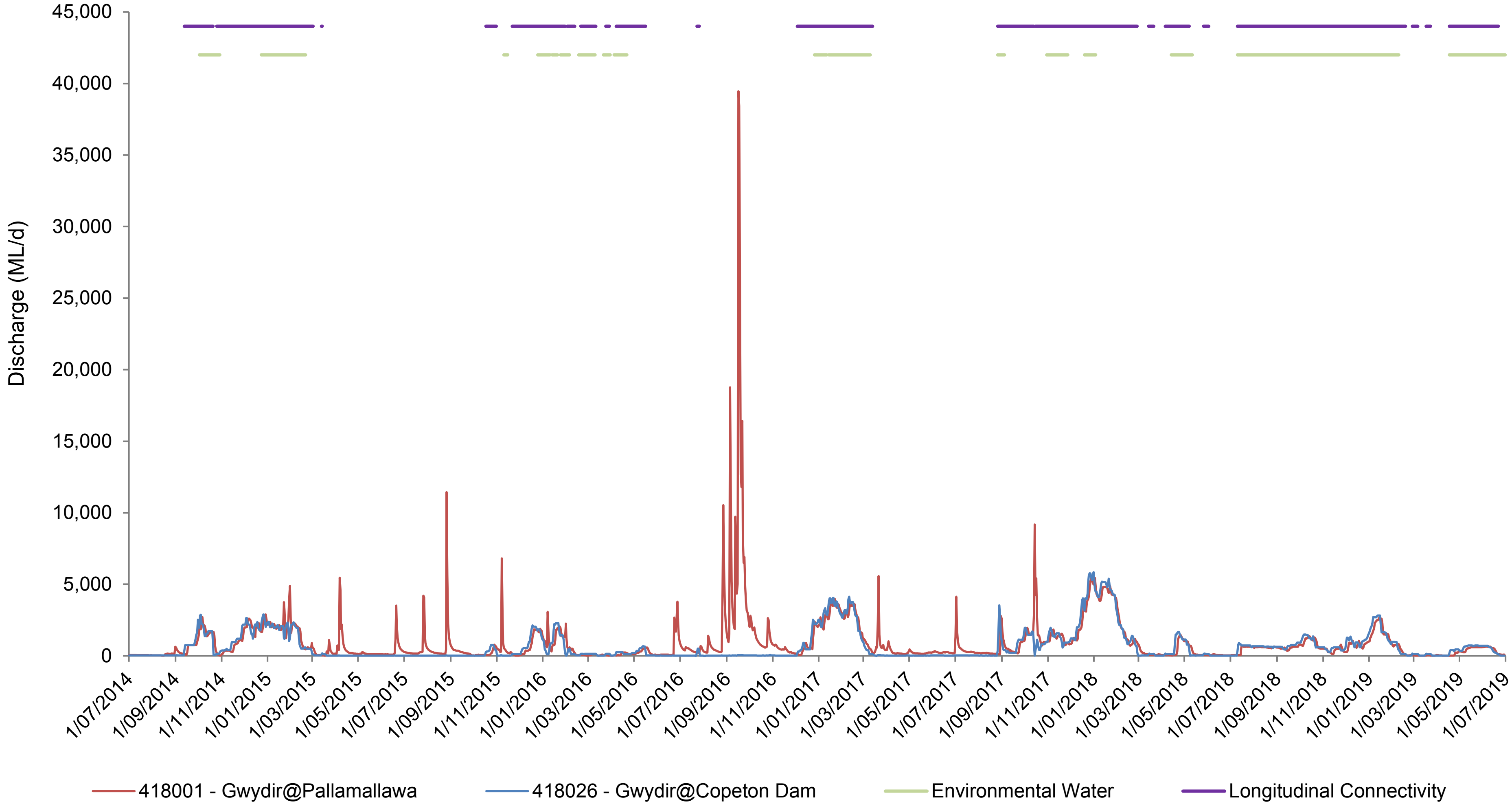

Figure A-2: River flows in the Gwydir River (Copeton to Pallamallawa) and the timing of environmental water releases and longitudinal connectivity down this channel.

Connection in the Gwydir River channel during 2017-18 was dominated by a nearly continuous 185-day connection event over the spring-summer period (Figure A-2). Three separate environmental flows were released during this period that helped to maintain connectivity. A brief period of connectivity of eight days was experienced in mid-March, due to localised rainfall rather than environmental flows. Connectivity was recorded again in early-April and was sustained until early-May by environmental flows delivered to the Barwon River. Whilst flow between Copeton Dam and Pallamallawa was consistent for most of the 2017-18 water year, a flow peak recorded downstream at Pallamallawa in mid-October was due to unregulated inflows from Myall Creek and Warialda Creek entering the Gwydir River upstream of Gravesend. During this time flows immediately downstream of Copeton Dam had declined to 6.31 ML/d, below the connectivity threshold used in this analysis.

The longest period of connection (224 days) for the LTIM project occurred from July 2018 to February 2019 down the Gwydir River. This was driven by extended deliveries of environmental water into the downstream wetlands. A second extended period of connection was experienced in May-June 2019 associated with the delivery of the Northern Fish Flow. This lasted for 66 days (Figure A-2).

Lower Gwydir River channel

Connection down the Lower Gwydir River channel was episodic throughout the LTIM project, with the largest magnitude connection event occurring in September 2016 (Figure A-3). Environmental water contributed significantly to connection through this channel in the 2014-15 and 2018-19 water years, during periods of wetland wetting.

Longitudinal connectivity down the Lower Gwydir channel in 2014-15 was dominated by environmental water delivered through the September to March period (Figure A-3). While flows in the upstream section of this reach were pulsed during this period, longitudinal connectivity was maintained through to the wetlands for 164 days, representing the longest period of connection over the LTIM project. In addition, several shorter connection events were experienced as a result of the rainfall generated flows towards the end of the water year.

Connectivity in the Lower Gwydir River channel during 2015-16 was characterised by multiple short to moderate length connection events ranging from three to 30 days (Figure A-3). The longest periods of connectivity occurred during winter and spring (July 2015-October 2015) with three separate events of 22-, 29- and 30-day durations, separated by small disconnection periods of two and three days. The earliest of these connection events was a continuation of a rainfall driven event that occurred in late June 2015. Environmental water contributed to one short period of connectivity in late January to early February 2016 that aimed to reinstate supplementary flow extracted from this channel.

Similarly, in 2016-17, connectivity in the Lower Gwydir River channel was characterised by multiple periods of connectivity ranging from one to 79 days (Figure A-3). The longest periods of connectivity occurred during winter and spring (July-November 2016) with two separate events of 79 days and 67 days duration, separated by a small disconnection period of three days. A third long period of connectivity occurred during summer (December 2016-February 2017) for 62 days. In this period, environmental water contributed to connectivity in late December 2016 to early February 2017 for two periods that aimed to maintain water levels in the Gingham/Gwydir wetlands.

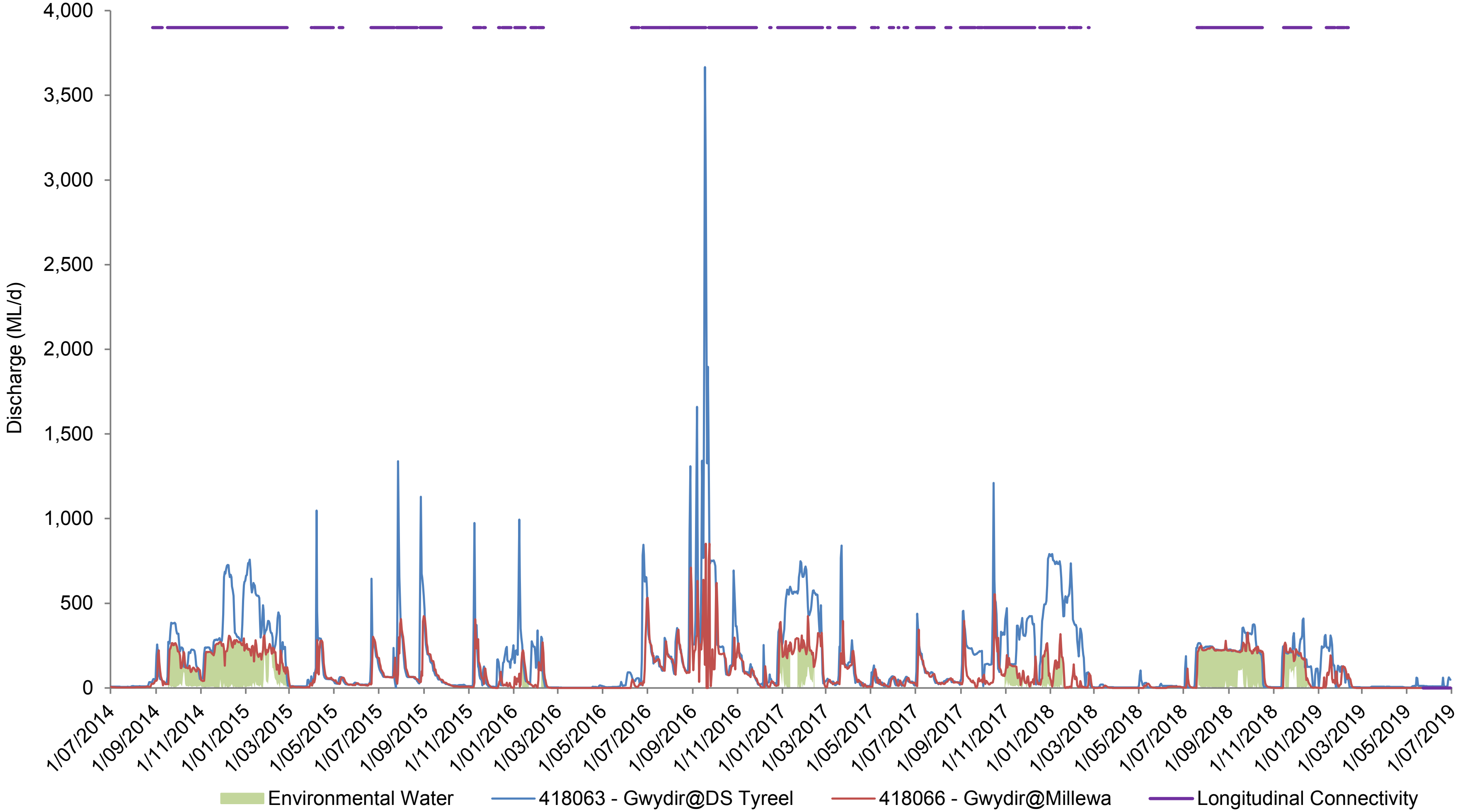

Figure A-3: River flows in the Lower Gwydir River and the timing of environmental water releases and longitudinal connectivity down this channel

In 2017-18, the longest periods of connectivity occurred during spring and summer (September 2017-January 2018) down the Lower Gwydir channel with three separate events of eight to 74 days duration, separated by three small disconnection periods of one and two days (Figure A-3). This was preceded by a 25-day period of connection in June 2017 and followed by another longer period of connectivity during summer (December 2017-January 2018) of 34 days. Environmental water contributed to connectivity in November 2017, and late December to mid-January 2018 which was delivered after an announced Supplementary Flow event under the 'Restoring Natural Flows' planning principle that seeks to return the portion of natural flows extracted from upstream irrigation.

In 2018-19, connection down the Lower Gwydir River was driven by deliveries of environmental water, during July-September 2018 (90 days connection) and then November-December 2018 (38 days connection). Additional environmental water deliveries were made for pool maintenance in May 2019, however, these were not of sufficient size or volume to provide connection all the way along this channel (Figure A-3).

Gingham Watercourse

As with the other channels in the system, connection down the Gingham Watercourse was dominated by the September-November 2016 flow event (Figure A-4). This event produced flows past Gingham Bridge at the lower end of the system that were around two orders of magnitude larger than most flows past this point during the LTIM project. Unlike other channels, connection along the Gingham Watercourse driven by rainfall rather than regulated deliveries, except during the 2018-19 water year where the delivery of environmental water provided the only connection.

During the 2014-15 water year, instances of longitudinal connection along the Gingham Watercourse were short in duration and influenced by both environmental water and rainfall generated flow events (Figure A-4). Environmental water was delivered to the Gingham in two discrete parcels during September 2014 and November 2014 through to March 2015. The September delivery provided full connection of this channel through the wetlands, for a total of 5 days, before flows at Gingham Bridge fell to below 5 ML/d. Flows through to Gingham Bridge were not reinstated for around three months, before environmental water once again increased flows at this gauge. Several short periods of connection were observed in this channel towards the end of the season, again driven by rainfall generated flow events.

There was limited connectivity in the Gingham Watercourse during the 2015-16 water year (Figure A-4). The earliest event of five days duration in July 2015 was a continuation of a rainfall driven event that occurred in late June of 2015. Two other periods of connection occurred in late July-August 2015 and late August-September 2015 of 19- and 23-days duration respectively which were also rainfall driven. There was a single environmental release in January 2016 that was accounted for in the Gingham Watercourse. While this did not connect the system all the way to Gingham Bridge it provided flow through the system, increasing water levels in Gingham Waterhole around 4.5 km upstream of Gingham Bridge.

Connectivity in the Gingham Watercourse in the 2016-17 water year was the greatest in the LTIM project, characterised by a 114-day long period of connection (August 2016-November 2016) and nine short periods in April and June 2017 (Figure A-4). In autumn, periods of connection ranged from two days to six days, separated by small disconnection periods of one to 11 days. All periods of connection were rainfall driven and no connection was recorded during December 2016 and February 2017 when environmental water was delivered to the Gingham Watercourse. Like the previous year, these environmental releases did not connect the system all the way to Gingham Bridge. However, they increased flow through the system and increased water levels in Gingham Waterhole.

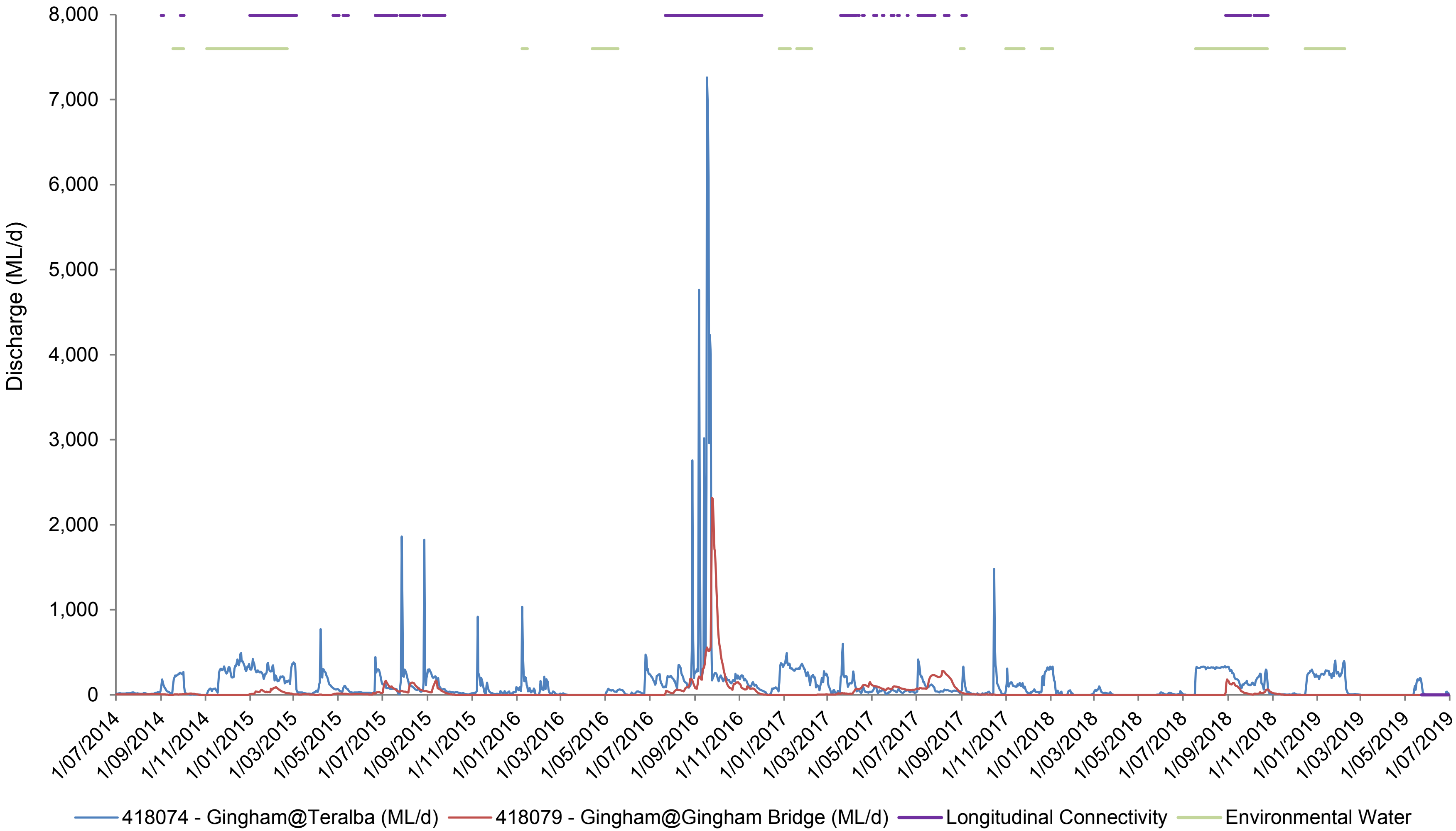

Figure A-4: River flows in the Gingham Watercourse and the timing of environmental water releases and longitudinal connectivity down this channel.

Connectivity in the Gingham Watercourse in the 2017-18 water year was characterised by two moderate periods of connection (Figure A-4). The first period of 44 days (July-August 2017) was rainfall driven. However, the second period of connection was for 31 days and was influenced by environmental water released in early September of which 1,014 ML was delivered to the Gingham Watercourse. Two environmental water releases occurred in November and December 2017 that were accounted for in the Gingham Watercourse, however, these events did not connect the system all the way to Gingham Bridge.

In 2018-19 connectivity down the Gingham Watercourse was restricted to two periods of 35- and 20-days during September-October 2018, separated by a 4-day period of disconnection (Figure A-4). This connection was provided directly through the delivery of environmental water to the wetlands. Environmental water was also delivered in December 2018-February 2019; however, these flows did not make it all the way to Gingham Bridge, with the flow ending in Gingham Waterhole.

Mehi River channel

Longitudinal connectivity in the Mehi River channel was driven by both rainfall generated flows, and regulated flows throughout the LTIM project (Figure A-5). Owing to the presence of irrigated agriculture and some larger off-channel wetland systems like the Mallowa, many flow events that occur through the upstream gauge, do not make it down the length of the system to provide full connection.

During 2014-15 longitudinal connectivity in the Mehi channel was characterized by shorter, relatively frequent events (Figure A-5). Three in-channel flows of environmental water were delivered down the Mehi channel, one specifically for the Mehi channel in October 2014, and two in October 2014 and February-March 2015 that were delivered to the Mallowa system. The initial environmental flow delivered in conjunction with stock and domestic water produced connection through the Mehi to near Collarenebri, with a noticeable peak evident at both the upstream and downstream gauges (Figure A-5). While the two Mallowa environmental flows produced rises in the upstream sections of the Mehi, they had little influence on flows below the Mallowa Creek offtake. During these periods, localized rainfall events aided longitudinal connectivity through the Mehi channel. The last period of connection down the Mehi channel was in April 2015 resulting from rainfall in the upper catchment.

Connectivity in the Mehi River during 2015-16 was restricted to two short events of three and 15 days in late August 2015 and late January 2016 respectively (Figure A-5). Environmental water released in late January 2016 contributed to the second connection event. Other environmental water releases in November 2015 and early January 2016 had no direct impact on full connectivity in the Mehi River due to diversion of this water into the Mallowa system.

Connectivity in the Mehi River occurred in spring, summer and autumn during 2016-17 (Figure A-5). In late August 2016 to late October 2016 the Mehi River was connected for three periods of 15-, 30- and 6-days each. Following 83 days of disconnection the Mehi River was again connected from January 2017 to March 2017 for two periods of 49 days and 4 days, separated by 9 days of disconnection. Whilst environmental water was released in mid-January 2017 it did not have a direct impact on full connectivity of the Mehi River as it was diverted into Mallowa Creek at the Gundare Regulator.

In late September to late December 2017, the Mehi River was connected for five periods ranging in length from one to 42 days duration. Following 29 days of disconnection, the Mehi River was again connected from January 2018 to late-February for three short periods of up to 22 days, separated by several days of disconnection. In late October 2017, 10,000 ML of environmental water was delivered into the Gwydir River, Mehi River and Carole Creek systems to provide conditions conducive for fish spawning and recruitment. This flow event contributed to connectivity during late spring and early summer. However, connectivity in late summer was driven by stock and domestic releases from Copeton Dam.

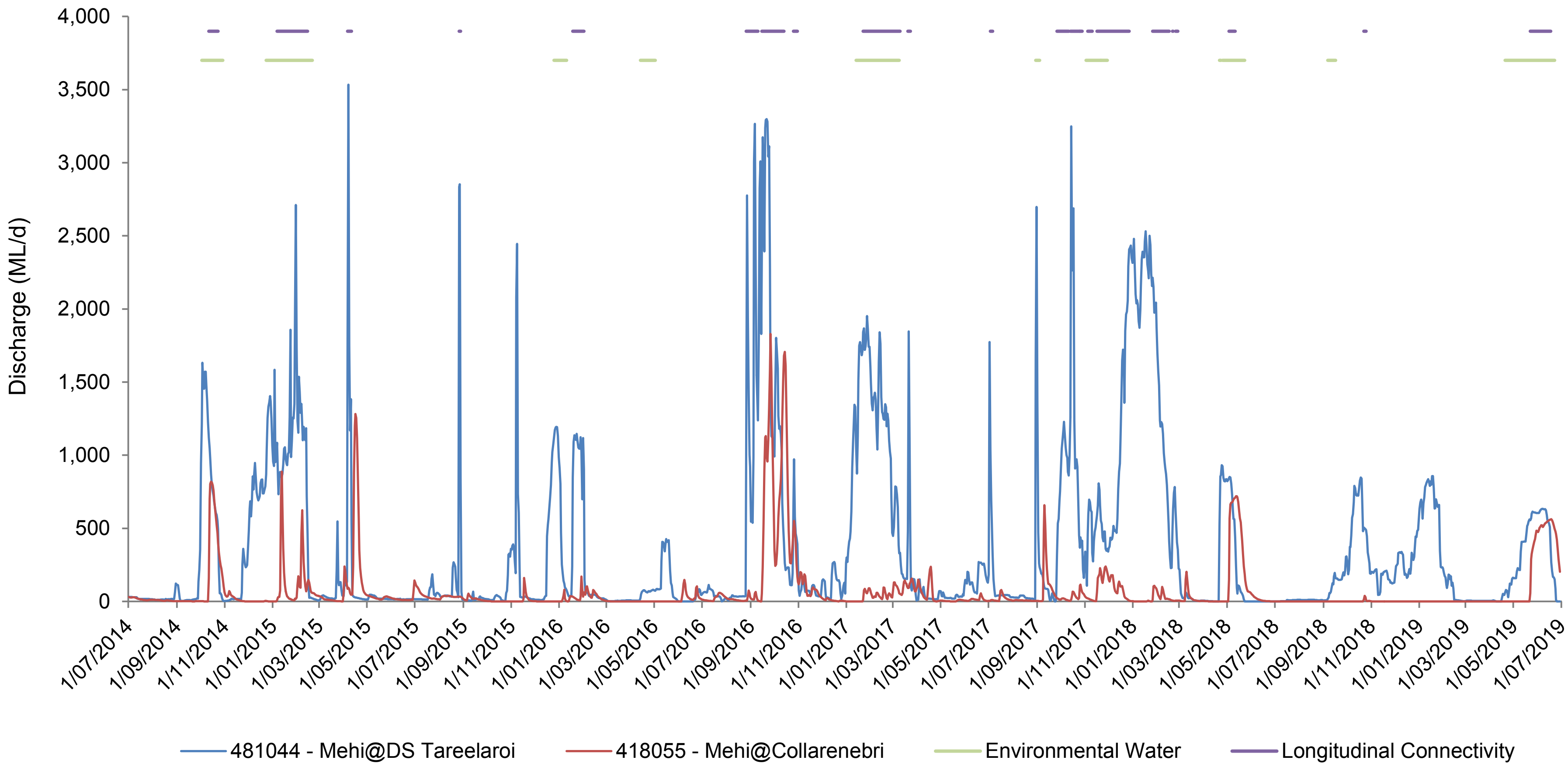

Figure A-5: River flows in the Mehi River and the timing of environmental water releases and longitudinal connectivity down this channel.

Environmental water released as part of the Northern Connectivity Event in April – May 2018 resulted in longitudinal connection for nine days.

Only two periods of connection were recorded down the Mehi River during 2018-19: a four-day event in October 2018, and a 27-day event during June 2019 (Figure A-5). These events were separated by a 208-day period which was the longest period of disconnection in the Mehi River over the LTIM project. During this time, the majority of the lower Mehi River below Gundare Regulator was dry, with only several isolated waterholes present around Bronte (M. Southwell pers obs). Reconnection of the Mehi channel was achieved during June 2019 as a result of environmental water released as part of the Northern Fish Flow. This was preceded by the delivery of a pool replenishment flow down the Mehi River.

Moomin Creek channel

At the time of writing, Moomin Creek is not a current target for environmental water, and as such, flows down this system are typically generated by local rainfall, or are regulated deliveries from Copeton Dam for irrigation or stock and domestic purposes. As a result, connection events occur sporadically and are short in duration (8 days on average, Table A-2; Figure A-6). Connectivity along the Moomin channel was provided by environmental water on two occasions. In April 2017, 380 ML was pushed into the system during delivery of the Northern Connectivity Event providing 4 days of longitudinal connection. In May-June 2019, 2,500 ML flowed down the Moomin channel during delivery of the pool maintenance and Northern Fish Flow events producing 3 days of connection (Figure A-6). As flows down the Moomin are controlled by water levels in Combadello Weir pool, during the delivery of higher magnitude flows, some water makes its way into the Moomin, of which a small amount may return to the Mehi River at their downstream confluence.

Mallowa Creek channel

Environmental water played a large role in providing connection through the Mallowa Creek system throughout the LTIM project, contributing to connectivity in every year except 2017-18 (Figure A-7). During 2014-15, two major periods of environmental water delivery contributed to connectivity. During October-November 2014, 1,116 ML of environmental water was delivered, producing connection for 26 days. A 50-day period of disconnection followed before another 9,560 ML of environmental water was again delivered down the channel. This provided 72 days of connection through the December 2014 – March 2015 period. Environmental water was delivered to Mallowa Creek on three occasions in the 2015-16 water year (Figure A-7). These environmental flows were the main contribution of flow to the Mallowa system during this water year.

During 2016-17, Mallowa Creek was connected for two short periods in September 2016 for 2 and 4 days in duration. A long period of connectivity occurred from December 2016 to May 2017 for 101 days, followed by a 10-day connection period. Environmental water was delivered to Mallowa Creek on one occasion in the 2016-17 water year (Figure A-7). These environmental flows were the main contribution of flow to the Mallowa system in December 2016 to March 2017. Other periods of connection including the last event in the 2016-17 water year were rainfall driven. Mallowa Creek was connected for two consecutive days in early-September 2017. This unusually short connection event which peaked at 10.78 ML/d on September 2017, was the result of limited diversion from the Mehi River. No environmental water was delivered to Mallowa Creek in the 2017-18 water year. The longest period of disconnection down the Mallowa system was experienced from September 2017 to September 2018, with a total duration of 381 days. This was the longest period of disconnection of any channel monitored during the LTIM project. Environmental flows delivered in September 2018 broke this dry spell, with a continual flow down the Mallowa for 147 days until February 2019.

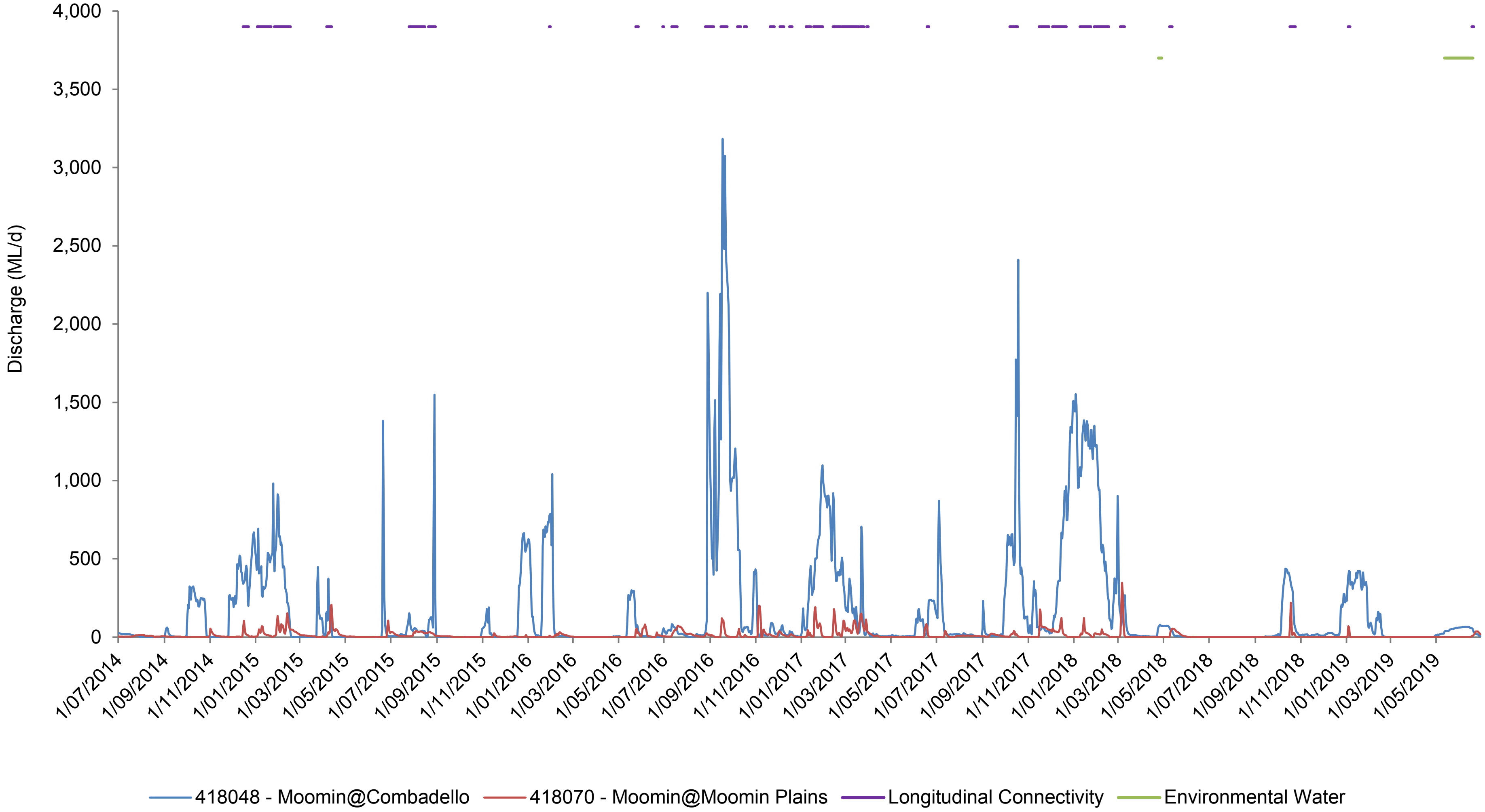

Figure A-6: River flows in Moomin Creek and the timing of environmental water releases and longitudinal connectivity down this channel.

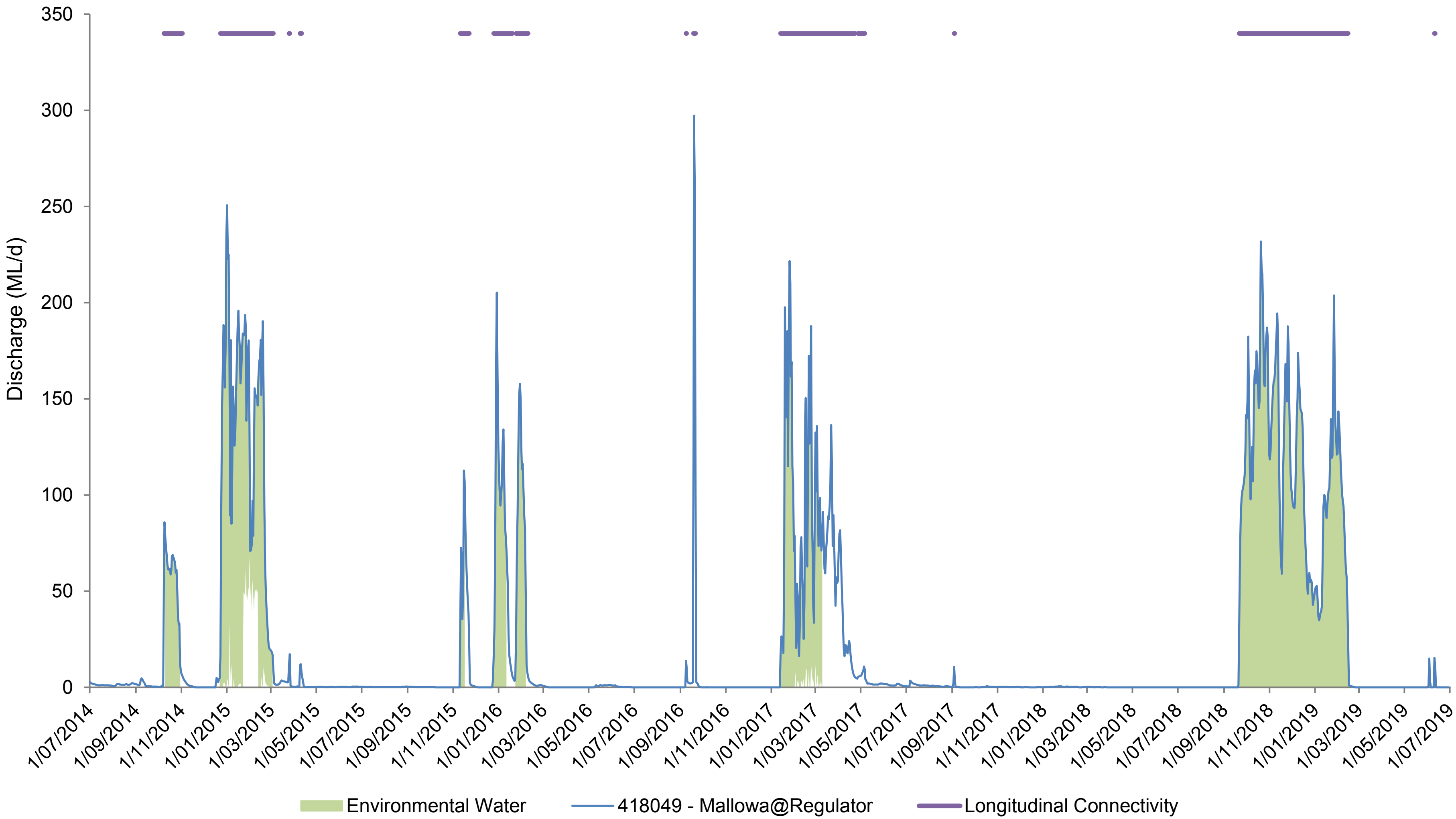

Figure A-7: River flows in Mallowa Creek and the timing of environmental water releases and longitudinal connectivity down this channel.

A.4 Discussion

Approximately 301 GL of environmental water was delivered to the Gwydir River system during the LTIM project to provide for a range of positive environmental outcomes. These included:

- wetland watering to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands,
- in-channel stimulus flows to promote productivity,
- pool replenishment flows delivered during dry times to reconnect isolated waterholes,
- connectivity flows delivered from the Gwydir catchment to provide connection within the broader Barwon-Darling catchment; and
- the replacement of supplementary water take to support the benefits of natural flow events.

These deliveries undoubtedly increased hydrological connectivity within the channels of the Gwydir system, with maximum connection achieved through the Gwydir River reach, as this reach is the conduit that passes all downstream environmental water deliveries. Connectivity in the Lower Gwydir channel was also relatively high, with environmental flows contributing to this channel being inundated for 54% of the time. Significant delivery of environmental water down the Lower Gwydir in the planned ‘wet’ years of 2014-15 and 2018-19 constituted 73% and 90% of the total flows down this system respectively. Environmental water deliveries down the Gingham Watercourse were of a similar magnitude, however, the recorded connectivity through the system was less (25% of days connected). This is due to the downstream gauge in the Gingham being downstream of the bulk of the wetland areas in this system. On-ground works within these wetlands to slow water flow through the channel and increase the lateral movement of water has been undertaken, which has likely impacted on the longitudinal connectivity in this system. This is not necessarily a negative, given most environmental flows are targeted at wetland outcomes in this system. During larger-scale inundation events like those observed in late 2016, considerable water still made it through the wetlands in the mid reaches of the Gingham Watercourse to provide connection and inundation of wetland areas downstream. Similarly, environmental water played a significant role in the connectivity through the Mallowa Creek system. When delivered, environmental water contributed between 86% and 96% of the total flow down the system. This was key to maintaining the condition of vegetation and habitat for other wetland animals (Appendix H and Appendix K).

Pool replenishment flows were delivered during dry times, especially during 2017-2019, to reconnect isolated waterholes along the channels that were disconnected for some time. These within channel connections were not always captured in the current analysis as it focused on longitudinal connectivity down the majority of each river channel. While these flows do not always provide full system connection, their importance in connecting and rejuvenating pools is important at the local scale. Monitoring of other indicators suggests that as water levels recede and pools become disconnected, their water quality deteriorates, with increasing chlorophyll *a* and nutrient concentrations, and increasing pH, and conductivity (Appendix C). Providing connecting flows to these pools to improve or at least stabilise the water quality is critical to maintain populations of aquatic species such as fish, whose populations are showing stress across the Gwydir system (Appendix I).

In developed catchments such as the Gwydir, hydrology is dominated by regulated deliveries of irrigation and stock and domestic water that are extracted at various distances downstream. In addition, many unregulated flow events also get extracted, limiting their benefit to connectivity. While these deliveries and flow events provide some connection, and hence ecological benefit for a portion of the channel’s length, providing environmental flows that connect much longer lengths of channel are critical. There have been a number of environmental flow releases targeted at improving connectivity delivered down the channels of the Lower Gwydir system over the duration of the LTIM project. Not only have these deliveries improved connectivity along channels in the Gwydir River, but they have also influenced water levels in downstream catchments. The flow event delivered in October 2014 aimed to stimulate productivity within the Mehi River and Carole Creek. This flow increased connectivity in these channels through to the Barwon River, and a noticeable peak was also tracked as far downstream as Bourke on the Darling River. Two additional flow events, the Northern Connectivity Event and the Northern Fish Flow delivered in 2018 and 2019 respectively, were successful in improving connectivity through the channels of the Lower Gwydir system, and also improved flow conditions along the Barwon-Darling River. These flows highlight the additional benefits of delivering targeted flow pulses to the Gwydir, which extend outside of the catchment and into the receiving rivers downstream. Given the propensity of fish and other aquatic animals to migrate through the Murray-Darling Basin (Reynolds 1983; DPI Fisheries 2015), delivering flows such as these should be a focus of environmental flow planning in the future.

A.5 Conclusion

Environmental water contributed to connectivity in all the monitored river channels throughout the LTIM project, with maximum delivery of environmental water occurring during the 2018-19 water year. Maximum connectivity was achieved through the Gwydir and Lower Gwydir River channels with connection occurring around 54% of the time in both channels. The relative contribution of environmental water to connectivity was greatest in the Mallowa Creek channel, with environmental water contributing between 86% to 96% of the total flow in years when it was delivered. Connectivity in the Lower Gwydir River was greatest during the delivery of environmental water to the wetlands in 2014-15, a planned ‘wet’ year. In the Gingham Watercourse, connectivity was greatest during the larger unregulated flow event that occurred in late 2016. Pool replenishment flows were used in 2017-19 to reconnect isolated pools along most monitored channels. These flows are likely to be important for maintaining water quality and access to habitat for aquatic fauna at the local scale. Environmental flows that aimed to provide connectivity through the Gwydir and into the Barwon River were effective at doing so, with the influence of some of these flows noted all the way to Bourke on the Darling River. Delivering flows such as these that provide broader basin scale connectivity should be a focus of environmental flow planning in the future.

A.6 References

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Appendix B Hydrology (Watercourse)

B.1 Introduction

The Lower Gwydir wetlands have long been a target for environmental water due to their extensive wetland vegetation communities and waterholes that support many important species (DECCW 2011). Watering targets for the wetlands tend to specify the inundation of particular extents and vegetation communities. Therefore, knowledge of the extent and volume of water held in the wetlands throughout each watering season is essential base information from which to evaluate the success of environmental watering. The hydrology (Watercourse) 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 Lower Gwydir, Gingham and Mallowa wetlands. Specifically, this chapter addresses the following question:

- What did Commonwealth environmental water contribute to hydrological connectivity of the Gingham, Gwydir and Mallowa wetlands?

B.1.1 Environmental watering over the LTIM project

A total of 301,172 ML of environmental water was delivered through the Gwydir River system during the LTIM project, making up 23% of the total water that flowed down the Gwydir River channel during that time (Table B-1). The highest volume occurred during the 2018-19 water year when 62,150 ML of Commonwealth and 52,000 ML of NSW environmental water was used. The lowest volume was in the 2015-16 water year where 13,250 ML of environmental water was delivered.

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system. In-channel flow pulses were delivered down the Mehi River and Carole Creek channels to enhance in-stream ecological function, nutrient cycling, water quality and fish spawning conditions. In addition, flows were delivered to the Lower Gwydir wetlands, Gingham wetlands and Mallowa Creek to provide for wetlands inundation.

During 2015-16 environmental water was delivered to a number of assets within the Gwydir Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for, with 964 ML of this water flowing down the Mehi River and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW water bulk water deliveries. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse in February 2016 to replace flows that were extracted in a supplementary flow event. Due to critically low flows experienced in the Lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April 2016. This followed a period of 30 to 40 days of nil flow conditions across the catchment.

During 2016-17, a flow event occurred down the Mehi River in September 2016 and supplementary water licences owned by the CEWO were triggered. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however, very little of the moderate flows were diverted into the Mallowa wetlands. In January to March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse to build upon moderate winter/spring flows. From January to March 2017, 30,000 ML was delivered, aiming to inundate broad areas of semi-permanent wetland vegetation. During 2016-17, no environmental water was delivered to Moomin Creek.

A delivery of 8,000 ML, including both State and Commonwealth environmental water, was made to the Lower Gwydir and Gingham wetlands from mid-December 2017 to late January 2018 to replace supplementary take from a small flow event that occurred in the previous months. This aimed to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands.

In 2018-19 environmental water made up 53% of the total flow down the Gwydir River channel (Table B-1). Sixty gigalitres of environmental water was delivered to the Lower Gwydir and Gingham wetlands to support wetland vegetation and channel processes. Deliveries to the wetlands began in July 2018 and finished in February 2019. In both systems deliveries were stopped in October/November for harvest. Over the November 2018 to February 2019 period, environmental water was also delivered to the Mallowa wetlands to support wetland vegetation, waterbirds and native fauna. During this event 16,950 ML of Commonwealth environmental water was delivered. A trial delivery of 600 ML was delivered to the Ballin Boora system in January to February 2019 to support wetland and riparian vegetation.

Table B-1: Environmental water use in the Gwydir River system during the LTIM project (2014-19). This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW State governments.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2014-15				
Gwydir River*	56,534	29,895	302,043	29
Gingham Watercourse	15,000	14,868	46,711	64
Lower Gwydir	15,000	15,027	41,171	73
Carole Creek	3,656	-	48,670	8
Mehi River	13,316	-	123,480	11
Mallowa Creek	9,667	-	11,281	86
2014-15 total	***56,534***	***29,895***	***302,043***	***29***
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River	20,404	5,046 GS	213,134	12
Moomin Creek#	324	175	104,075	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434,462***	***11***
2018-19				
Gwydir River*	63,416	43,941	205,520	53
Gingham Watercourse	20,000	15,000	40,443	87
Lower Gwydir	11,314	16,032	30,254	90
Carole Creek	300	300	16,865	4
Mehi River^	10,430	16,545	82,262	33
Mallowa Creek	16,950	-	17,230	98
2018-19 total	***63,416***	***43,941***	***205,520***	***52***
Grand total	**179,592**	**118,434**	**1,327,700**	**22**

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 14,160 ML delivered as part of the Northern Connectivity Event. The total volume for the NSW component also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system. Also includes 23,051 ML delivered as part of the Northern Fish Flow

+Includes 4,758 ML delivered as part of the Northern Connectivity Event

B.2 Methods

Four data sources were used to describe inundation extent and volume in the Lower Gwydir, Gingham and Mallowa wetland systems (Commonwealth of Australia 2015). These included:

- Landsat imagery;
- Existing vegetation mapping;
- Water level records associated with remote cameras; and
- Point water level observations throughout the water year.

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 and volume of inundation associated with each vegetation community in all three wetland systems (Figure B-1).

B.2.1 Inundation mapping

All available Landsat 8 images captured during the LTIM project were accessed via the USGS Glovis website (http://glovis.usgs.gov/). Those with minimal cloud cover and no other problems were chosen for further analysis. Twenty-four images spanning the LTIM project were acquired and analysed (Figure B-2).

The extent of inundation within each image was classified using density slicing of band 6 as described in Frazier and Page (2000). A maximum wetland extent layer was then used to exclude waterbodies such as irrigation storages and farm dams outside of the target wetland area. The final inundation extent file for each capture time was then intersected with Gwydir vegetation community layers (Commonwealth of Australia 2015) to determine the extent of inundation within each vegetation community.

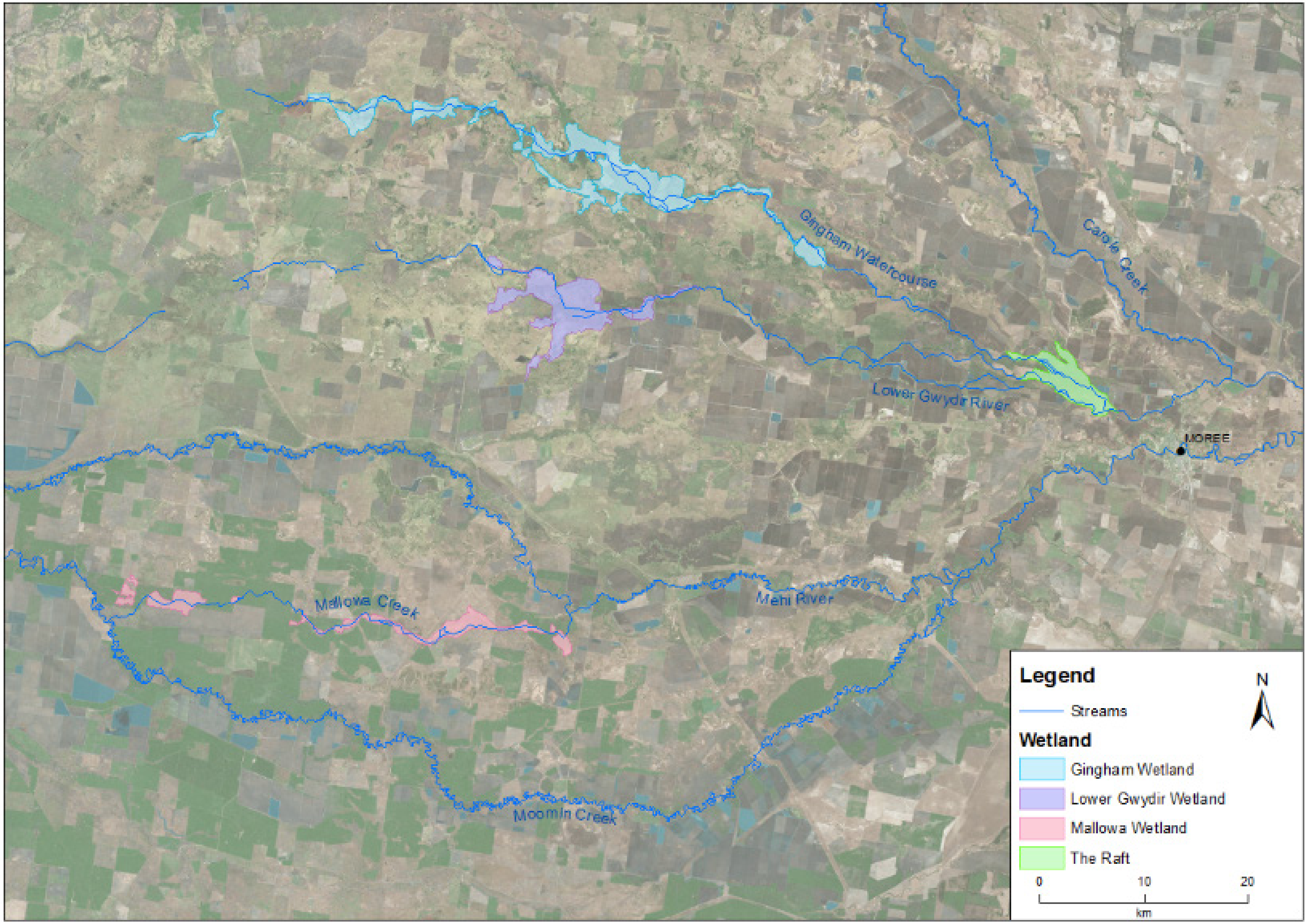

Figure B-1: Extent of Lower Gwydir, Gingham and Mallowa wetlands in the Gwydir river system Selected Area.

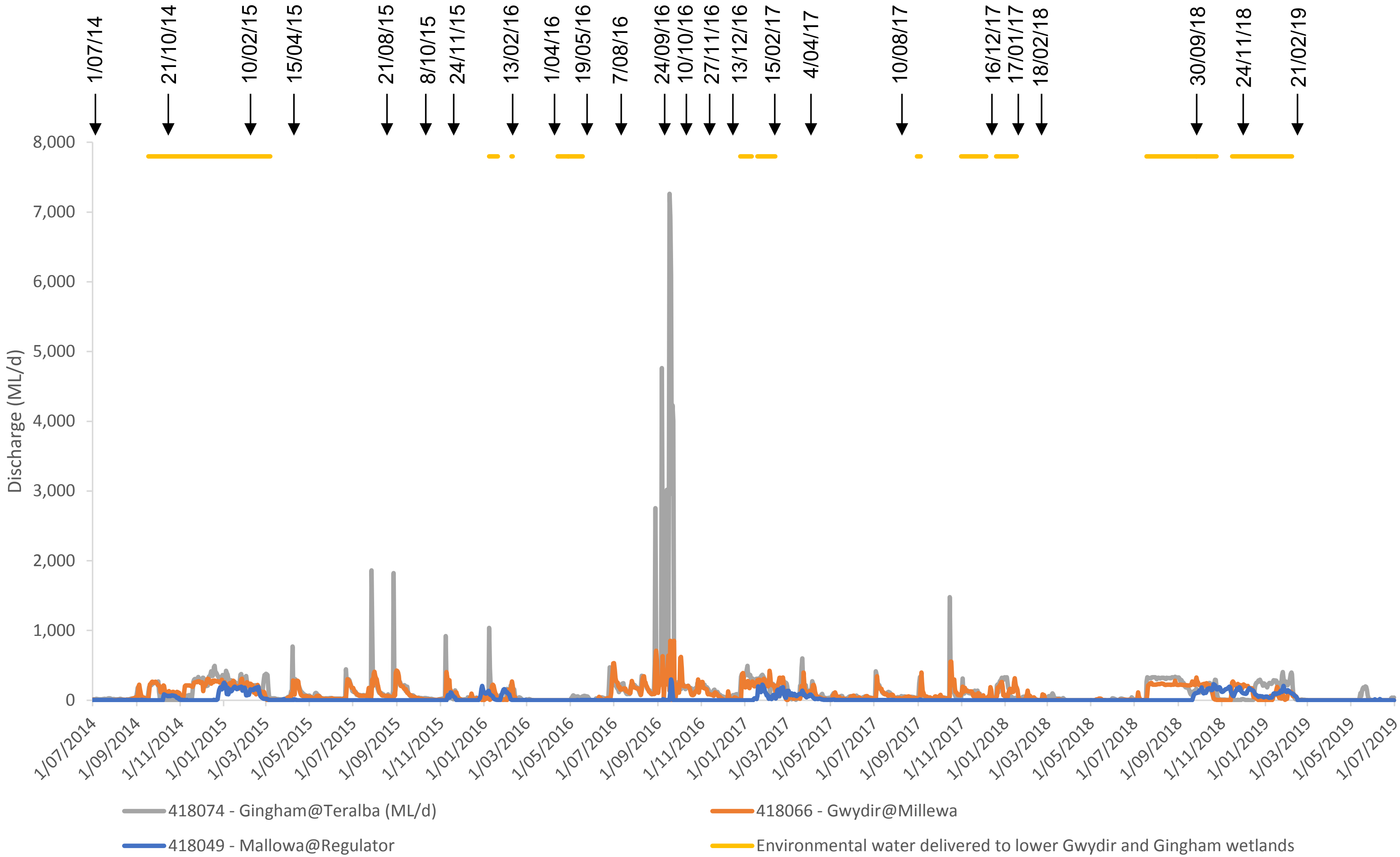

Figure B-2: Hydrology through the Gingham, Lower Gwydir and Mallowa wetlands and the timing of Image capture used to assess wetland inundation

B.2.2 Calculation of inundation volumes

Volumes of inundation for each vegetation community within the Lower Gwydir and Gingham wetlands were estimated for each of the Landsat image dates (Table B-2). This was done using water depth information from a level logger at the Old Dromana remote camera site in the Gwydir wetlands (Figure B-3) and water depth estimates within vegetation plots surveyed throughout the project. Due to technical difficulties in 2017-19, water depths were not monitored at Bunnor Bird Hide or Old Dromana. Point depth measurements were taken at specific points in time, so water level data from the remote camera site were used to adjust these measurements and provide average depth estimates for each image capture date. Average depths for each vegetation community were estimated to the nearest 0.05 m. These were then multiplied by the area of each vegetation community to provide an estimate of the volume of surface water contained within each vegetation community. Lack of water depth reference data in the Mallowa wetlands precluded calculation of inundation volumes in this system.

Figure B-3: Remote monitoring station at Old Dromana wetland.

Table B-2: Average depth (m) of inundation for vegetation communities during the twenty-three image capture times in the Lower Gwydir and Gingham wetlands zone.

Wetland	Vegetation community	Estimated average depth of inundation (m)																						
		2014-15				2015-16						2016-17						2017-18				2018-19		
		1-Jul-14	21-Oct-14	10-Feb-15	15-Apr-15	21-Aug-15	8-Oct-15	24-Nov-15	13-Feb-16	1-Apr-16	19-May-16	7-Aug-16	24-Sep-16	10-Oct-16	27-Nov-16	13-Dec-16	15-Feb-17	10-Aug-17	16-Dec-17	24-Sep-16	18-Feb-18	30-Sep-18	24-Nov-18	21-Feb-19
Lower Gwydir	Common Reed - Marsh Club-rush	0.05	0.1	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.15	0.2	0.2	0.1	0.05	0.15	0	0	0.15	0	0.2	0	0.00
	Common Reed - Tussock Sedge	0.05	0.1	0.2	0.2	0	0	0	0	0	0.05	0	0	0.2	0.1	0.05	0	0	0	0	0	0.2	0	0
	Coolibah - River Red Gum Association	0.05	0.2	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.05	0.05	0.1	0	0	0.1	0	0.2	0	0.05
	Coolibah woodland	0	0.1	0.2	0.2	0.05	0	0.05	0.05	0	0	0.05	0.1	0.1	0.15	0.05	0.1	0	0	0	0	0.2	0	0
	Cumbungi - Marsh Club-rush	0	0.05	0.1	0.2	0	0	0.05	0	0	0.05	0.15	0.2	0.2	0.1	0.05	0.15	0	0.05	0.15	0	0.2	0.15	0.05
	River Cooba - Lignum Association	0.1	0.2	0.2	0.2	0.1	0.05	0.1	0.05	0	0.05	0	0	0.15	0.1	0.05	0.1	0	0	0.1	0	0.2	0.1	0.10
	Water Couch - Spike-rush - Tussock Rush	0.1	0.2	0.2	0.2	0.1	0.05	0.1	0.05	0.05	0.05	0.15	0.2	0.2	0.15	0.05	0.15	0.05	0.05	0.15	0.05	0.25	0.15	0.10
	Natural Water Body	0.5	0.6	0.6	0.6	0.4	0.5	0	0	0.5	0	0.45	0.5	0.5	0.4	0.4	0.45	0	0.45	0	0	1	0.45	0
	Cultivated Land	0.01	0.1	0.2	0.2	0.05		0.05	0	0	0	0.05	0.1	0.1	0.05	0.05	0.1	0	0.05	0	0	0	0.10	0
	Farm Dam	1	1.1	1.1	1.1	0.8	1	1	0.8	1	0.7	0.9	1	1	0.8	0.8	0.9	0.8	0.8	0.9	0.8	0.90	0.90	0.90
Gingham	Baradine Red Gum shrubby open forest	0.05	0.2	0.2	0.05	0	0.05	0	0.05	0.05	0.05	0	0	0	0.1	0	0	0	0	0	0	0	0.15	0
	Belah grassy woodland	0.1	0.2	0.2	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.05	0.1	0.15	0.05	0.1	0	0.1	0	0.1	0.15	0
	Carbeen grassy woodland		0.1	0.1		0	0	0	0.05	0.05	0.05	0	0	0	0.1	0	0	0	0	0	0	0	0.1	0
	Cleared land		0.1	0.1		0.05	0.05	0	0	0	0	0.05	0.15	0.05	0.1	0	0.05	0.05	0	0	0	0.1	0.1	0
	Coolibah - River Cooba grassy woodland	0.05	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.05	0.1	0.15	0.05	0.15	0.05	0.1	0.05	0.1	0.2	0.05
	Cultivated land	0.05	0.2	0.2	0.05	0.05	0.05	0.05	0	0	0	0.05	0.2	0.05	0.1	0.15	0.05	0.15	0.05	0.1	0.05	0.1	0.2	0.05
	Cumbungi swamp rushland	0.3	0.4	0.4	0.3	0.2	0.2	0.2	0.25	0.05	0.2	0.15	0.35	0.2	0.2	0.3	0.2	0.3	0.15	0.25	0.15	0.15	0.4	0.15
	Derived grasslands	0.05	0.2	0.2	0.05	0.05	0	0	0	0.05	0.05	0.05	0.05	0.1	0.05	0	0	0	0	0	0	0	0.2	0
	dry wetland with rehabilitation potential		0.1	0.2		0.05	0.05	0	0	0.05	0.05	0.05	0.25	0.1	0.05	0.2	0.1	0.15	0	0.1	0.05	0.1	0.1	0.05
	Marsh Club-rush swamp sedgeland		0.1	0.2		0	0	0	0	0	0	0	0.25	0.1	0.05	0.2	0	0.15	0	0	0	0.1	0.1	0
	Myall - Rosewood shrubby woodland	0.05	0.1	0.2		0.05	0	0	0	0	0	0	0.2	0.05	0.1	0.15	0	0.05	0	0	0.05	0.1	0.2	0
	Paleo-channel: Coolibah - River Cooba woodland	0.05	0.2	0.2	0.05	0	0	0	0	0	0	0	0.2	0.05	0.1	0.15	0	0	0	0	0	0	0	0
	Paleo-channel: cultivated land	0	0	0	0	0	0	0	0	0	0	0	0.2	0.05	0.1	0.15	0	0	0	0	0	0	0	0
	Paleo-channel: dry wetland with rehabilitation potential	0.05	0.1	0.2	0	0	0	0	0	0	0	0	0.25	0.1	0.05	0.2	0.1	0.1	0	0	0	0.1	0.1	0
	Paleo-channel: Water Couch - Spike-rush	0.1	0.2	0.2	0.05	0	0	0	0	0	0	0	0.25	0.1	0.05	0.2	0.1	0.1	0.05	0.1	0.05	0.15	0.2	0.1
	Poplar Box shrubby woodland	0	0.1	0.1	0	0	0	0	0.05	0.05	0.05	0	0.15	0.05	0.1	0	0	0	0	0	0	0	0.1	0
	Quinine Bush - Cooba tall shrubland	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	River Cooba - Lignum Association	0.2	0.3	0.3	0.2	0.05	0.05	0.05	0.1	0.05	0.05	0	0.25	0.1	0.05	0.2	0.1	0	0	0.1	0.05	0.2	0.3	0.15
	River Cooba - Lignum swamp shrubland	0.2	0.3	0.3	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.25	0.1	0.05	0.2	0.1	0.2	0.05	0.15	0.05	0.2	0.3	0.15
	River Red Gum - Coolibah open forest	0.05	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.1	0.05	0.15	0.1	0.15	0.05	0.1	0.05	0.15	0.2	0.1
	Spike-rush - Cumbungi swamp sedgeland		0.1	0.2		0	0	0.05	0	0	0	0	0	0	0.15	0	0	0.15	0	0.1	0.05	0	0.1	0
	Tussock Rush swamp rushland	0.1	0.2	0.2	0.1	0.05	0.05	0	0	0	0	0.05	0.25	0.1	0.05	0.2	0.1	0.15	0	0	0	0.15	0.2	0
	Water Couch - Spike-rush - Tussock Rush marsh grassland/sedgeland	0.1	0.2	0.2	0.05	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.25	0.1	0.05	0.2	0.1	0.1	0.05	0.1	0.05	0.1	0.2	0.1
	Natural water body	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.45	0.2	0.4	0.35	0.5	0.4	0.4	0.6	0.4	0.6	0.3	0.6	0.3	0.6	0.5	0.4
	Farm dam	0.1	1.1	1.1	1	1	1	1	0.9	0.7	1	0.9	1.1	1	1	1.1	0.8	1	0.8	1	0.8	1	1.1	0.9

B.2.3 Average monthly rainfall

Historically, spring and summer are the wetter seasons, although rainfall has varied over the course of the LTIM project (Figure B-4). During the 2014-15 water year, rainfall was above average in August, January, March, April, May and June. During the 2015-16 water year, rainfall was above average in January, May and June. The 2016-17 water year was the wettest year of the project, with March recording the highest monthly rainfall of the project (156.2 mm) and above average rainfall in August, September, October, April and May. During the 2017-18 water year, rainfall was above average in October, November, February and March. The 2018-19 water year was a particularly dry year with an accumulated total of just 300.2 mm of rainfall, and only October recording above average rainfall (Figure B-4).

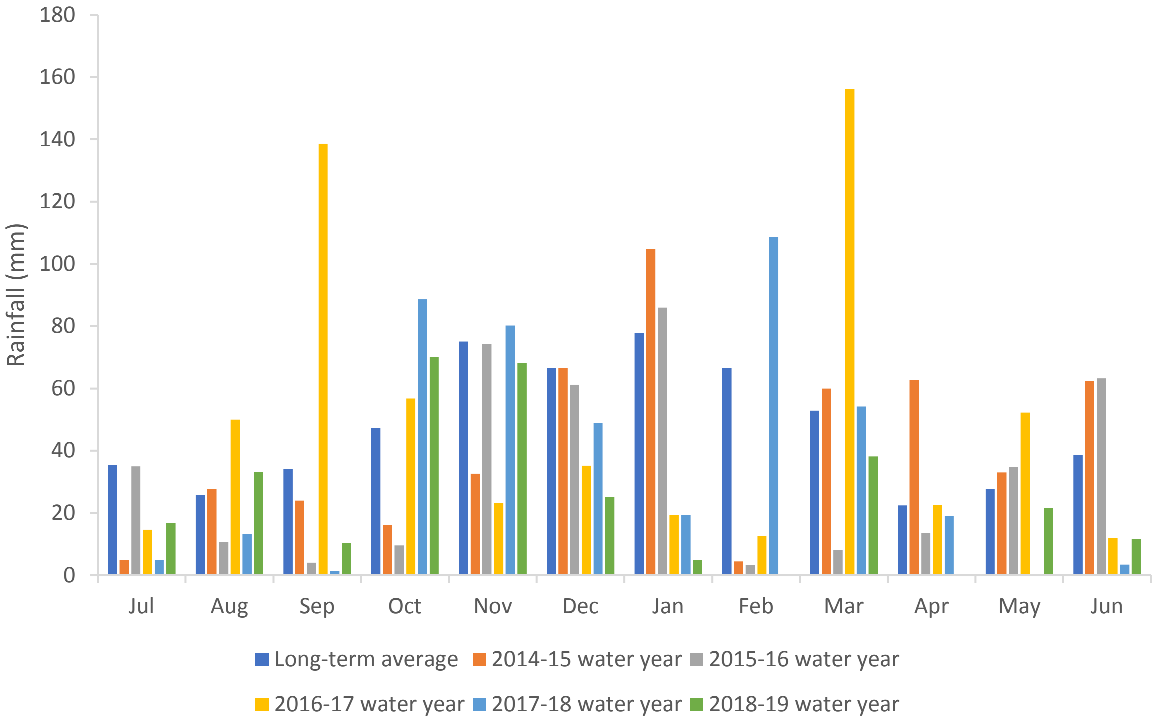

Figure B-4 Monthly rainfall for 2014-2019 water years and long-term average (Moree Aero - 053115)

B.3 Results and Discussion

B.3.1 Inundation extent and volume modelling

Inundation extent varied over time in all three wetlands. In the Gingham and Lower Gwydir wetlands, maximum inundation extent was achieved during the 2014-15 year in response to environmental watering (Table B-3; Figure B-5). In the Mallowa wetlands, maximum inundation was achieved in the 2018-19 water year, coinciding with the maximum volume of environmental water delivered throughout the project (Table B-4; Figure B-14).

During the 2014-15 water year, total inundation extent varied throughout the season in both the Gingham and Lower Gwydir wetlands. In the Lower Gwydir there was an increase from 20 ha of inundated area in July 2014 to 1,779 ha in October 2014 within inundation peaking at 2,433 ha in February 2015 (Table B-3; Figure B-5). Water levels then receded to 444 ha in April 2015. In the Gingham, the extent of inundation was around 96 ha in July 2014, and initially increased more slowly than the Lower Gwydir reaching an area of 179 ha in October 2014 (Figure B-5). Inundation extent reached a maximum of 3,908 ha in February 2015, before falling to 1,398 ha in April 2015.

Table B-3: Cumulative inflows, inundation extent and volume of water in the Gingham and Lower Gwydir wetlands measured during the LTIM project

Water year	Date	Gingham			Lower Gwydir		
		Cumulative inflows (ML)	Inundation Extent (ha)	Inundation volume (ML)	Cumulative inflows (ML)	Inundation Extent (ha)	Inundation volume (ML)
2014-15	1/07/2014	0	96	190	0	20	21
	21/10/2014	3,697	179	583	724	1,779	3,292
	10/02/2015	25,237	3,909	8,977	25,236	2,434	4,829
	15/04/2015	32,471	1,398	3,505	35,152	444	879
2015-16	21/08/2015	6,315	575	354	6,191	149	140
	8/10/2015	12,301	592	418	11,800	106	63
	24/11/2015	14,718	247	344	14,559	162	149
	13/02/2016	18,921	188	260	18,476	84	41
	1/04/2016	19,069	52	38	18,514	48	2
	19/05/2016	19,460	60	91	18,514	67	33
2016-17	7/08/2016	7,215	1,056	564	6,824	796	1,020
	24/09/2016	65,406	2,844	6,603	19,841	279	482
	10/10/2016	69,014	1,445	1,380	23,882	390	742
	27/11/2016	77,650	567	843	29,939	173	227
	13/12/2016	78,142	292	689	30,299	90	49
	15/02/2017	94,713	322	419	43,215	127	160
2017-18	10/08/2017	4,457	364	639	3,435	32	15
	16/12/2017	14,141	81	89	13,800	7	7
	17/01/2018	19,242	267	478	18,237	119	147
	18/02/2018	19,485	55	39	19,157	7	1
2018-19	30/09/2018	19,765	913	1,329	17,162	1,317	3,151
	24/11/2018	24,156	1,133	2,763	23,560	886	1,200
	21/02/2019	38,534	179	242	30,254	27	24

Table B-4: Cumulative inflows, inundation extent and volume of water in the Mallowa wetlands measured during the LTIM project

Water Year	Date	Cumulative inflows in water year (ML)	Inundation Extent (ha)
2014-15	21/10/2014	1,066	57
	22/11/2014	1,531	19
	10/02/2015	9,212	734
	15/04/2015	11,262	55
2015-16	21/08/2015	11	11
	8/10/2015	23	13
	24/11/2015	23	24
	13/02/2016	4,406	205
	1/04/2016	4,428	64
	19/05/2016	4,438	18
2016-17	7/08/2016	0	1
	10/10/2016	832	8
	27/11/2016	833	67
	13/12/2016	833	6
	15/02/2017	3,985	168
	4/04/2017	8,168	901
2017-18	29/10/2017	50	11
	16/12/2017	98	18
	17/01/2018	104	8
	23/04/2018	115	2
2018-19	19/12/2018	12,368	817
	4/01/2019	13,207	331
	9/03/2019	17,184	73
	26/04/2019	17,184	62

In 2014-15, patterns in inundation volume followed inundation extent, with the maximum calculated volume being 4,829 ML in the Lower Gwydir wetlands and 8,977 ML in the Gingham wetlands during February 2015 (Table B-3). Notably, total wetland inundation and volume appeared to reduce faster in the Lower Gwydir (444 ha, 879 ML) compared to the Gingham Watercourse (1,398 ha, 3,505 ML) towards the end of the water year. In the Mallowa wetlands, inundation extent reached a maximum of 734 ha measured on 10 February 2015 image (Table B-4: Figure B-10). This was following almost three months of inundation with environmental water that began on 18 December 2014 (Appendix A). By 15 April, this extent had reduced to 55 ha (Table B-4).

Inundation extent was 149.19 ha in the Lower Gwydir at the start of the 2015-16 water year (Table B-3; Figure B-6). While this followed a period of connectivity in the Lower Gwydir that commenced in late June 2015 and continued into October 2015 (Appendix A), the fragmented inundation pattern suggests that the extent of inundation may not have been a result of this flow connection alone, being more reflective of drying down from flooding experienced in 2014-15. Inundation extent dropped slightly in October and increased again in November 2015 to the highest extent recorded for the water year, reaching 162 ha. This also followed a period of connection driven by local rainfall in early November 2015, and inundation patterns indicate that channel flow was likely responsible for this increase (Appendix A). Inundation extent dropped through the remainder of the water year, reaching the lowest levels in April 2016. There was a slight increase in inundation area shown in the May 2016 image, most likely associated with local rainfall in early May (Figure B-7). Similar inundation patterns were observed in the Gingham wetland system with 575.38 ha of inundation at the start of the 2015-16 water year (Table B-3; Figure B-7). Again, this was likely from residual water from extensive flooding in 2014-15. There was a brief period of connection in the Gingham Watercourse from late June to early July 2015 (Appendix A) but inundation patterns suggest that the extent of inundation captured in this image was not influenced greatly by this flow. Inundation extent increased marginally in October 2015 reaching the largest extent for the water year at 592 ha. Inundation then declined steadily for the remainder of the water year with the smallest extent (52.34 ha) recorded in April 2016. There was a slight increase in inundation extent in May 2016 most likely associated with local rainfall in early May (Figure B-7). Inundation in the Mallowa wetlands at the start of the 2015-16 water year was the lowest recorded at 10.73 ha (Table B-4). Inundation extent shown in the October and November images reached a peak in February 2016 with 205 ha of inundation (Figure B-11). The inundation extent increases observed in the November and February images are related to environmental flows delivered to the Mallowa over the summer period (Appendix A). Flows in Mallowa Creek were almost entirely dependent on environmental water in the 2015-16 water year and when environmental deliveries ceased after February 2016 inundation extent dropped over the remainder of the season.

Patterns in inundation volume generally followed inundation extent, with maximum volume and inundation occurring in the Lower Gwydir wetlands in November 2015 and in the Gingham wetlands in October 2015 (Table B 2; Table B 3). Between years, the pattern of wetland drying was reversed. In 2015-16, inundation extent and volume dropped much more sharply in the Gingham wetlands than the Lower Gwydir wetlands from peak inundation to the end of the water year.

Inundation extent in the Lower Gwydir for the 2016-17 water year was lowest in July (6 ha) and increased to its maximum in August with 796 ha. Inundation extent fluctuated in September and October, in response to local rainfall events, before decreasing to 90 ha in December. Inundated extent increased to 127 ha in February after the delivery of environmental water (Table B-3; Figure B-7). Inundation extent in the Gingham wetlands for the 2016-17 water year was lowest in July (43 ha), while maximum mapped inundation occurred in September (2,844 ha). Inundation extent retreated steadily throughout the rest of the year to 292 ha by December 2016. Inundated area then increased to 322 ha in February following environmental flow delivery (Table B-3; Figure B-7). Rainfall contributed to inundation extent in the Lower Gwydir and the Gingham wetlands during late winter and early to mid-spring 2016, particularly the 139 mm received in September. Earlier in the 2016-17 water year, inundation extent in the Mallowa wetlands was below 10 ha. This increased to 67 ha in November (67 ha) and peaked at 901 ha in April as a result of inundation resulting from environmental water delivery (Table B-4; Figure B-12). This was the greatest inundation recorded during the LTIM project.

Inundation extent in the Lower Gwydir for the 2017-18 water year was below 35 ha in all images analysed except for January, where 119 ha was inundated following environmental water deliveries (Figure B-8; Table B-3). This inundation was confined to the eastern and central parts of the Lower Gwydir wetlands (Figure B-8). Inundation extent in the Gingham wetlands for the 2017-18 water year was lowest in February (6.69 ha), while maximum mapped inundation occurred in August (364 ha). Inundation extent was greatest in August 2017, presumably because of early season inflows and residual water from 2016-17. This inundation had retreated in December 2017 to 81 ha, before deliveries of environmental water then increased inundation in the eastern Gingham to 267 ha in January (Figure B-8, Table B-3). Cumulative inflows to the Mallowa wetlands system were very low in 2017-18 with no environmental water being delivered to this system (Table B-4). As a result, mapped inundation in all images analysed was very low, being less than 20 ha throughout the year. Maximum inundation was detected in December (18 ha), with inundation patterns suggesting this was the result of remnant water in farm dams and rainfall generated inundation away from the river channel (Figure B-13).

During 2018-19 maximum inundation in the Lower Gwydir wetlands peaked earlier with a maximum of 1,317 ha inundated on 30 September 2018, following the delivery of 17,162 ML of environmental water (Table B-3; Figure B-9). As deliveries to the Lower Gwydir ended in December 2018, inundation extent had dropped to 27 ha by February 2019. Inundation extent during the 2018-19 water year in the Gingham wetlands peaked at 1,133 ha on the 24 November 2018 (Figure B-9; Table B-3). This had reduced to 179 ha by 21 February 2019 as environmental water deliveries had ceased. During December 2018, inundation extent in the Mallowa wetlands peaked at 817 ha (Table B-4: Figure B-14). 331 ha of the Mallowa wetlands remained inundated in February 2019, and this dropped to 62 ha by 26 April 2019 (Figure B-14).

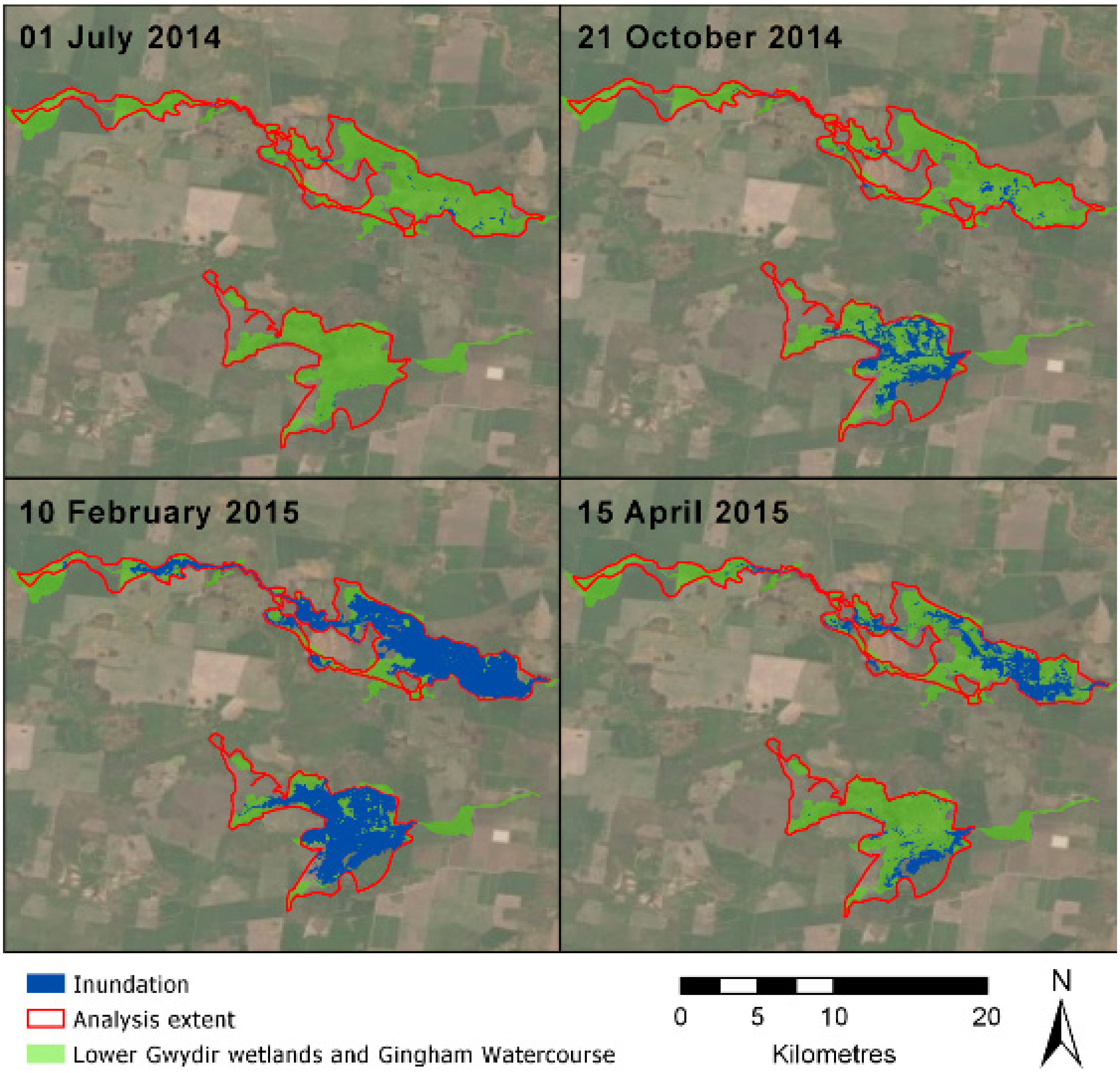

Figure B-5: Inundation recorded in the Gingham and Lower Gwydir wetlands during 2014-15

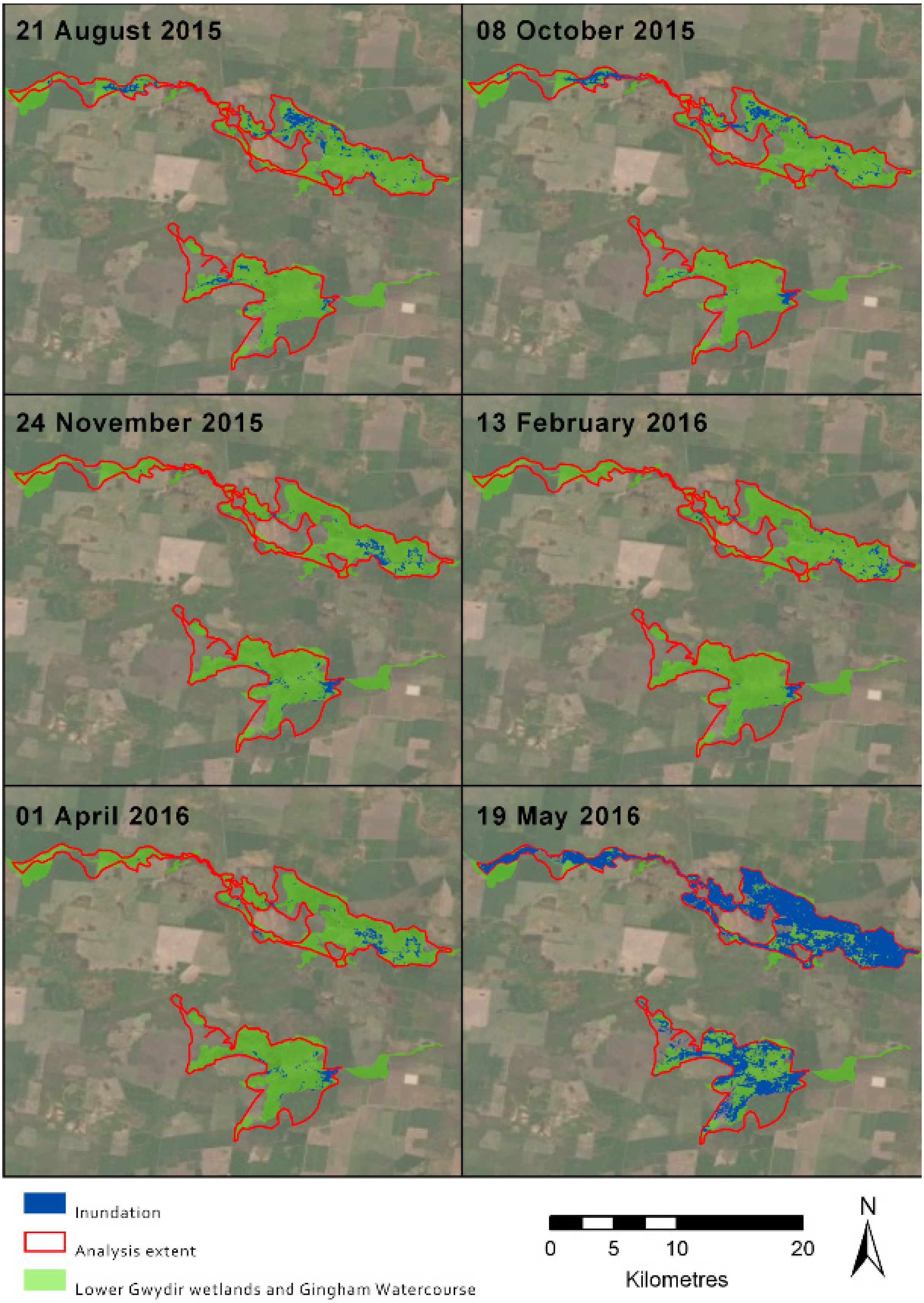

Figure B-6: Inundation recorded in the Gingham and Lower Gwydir wetlands during 2015-16

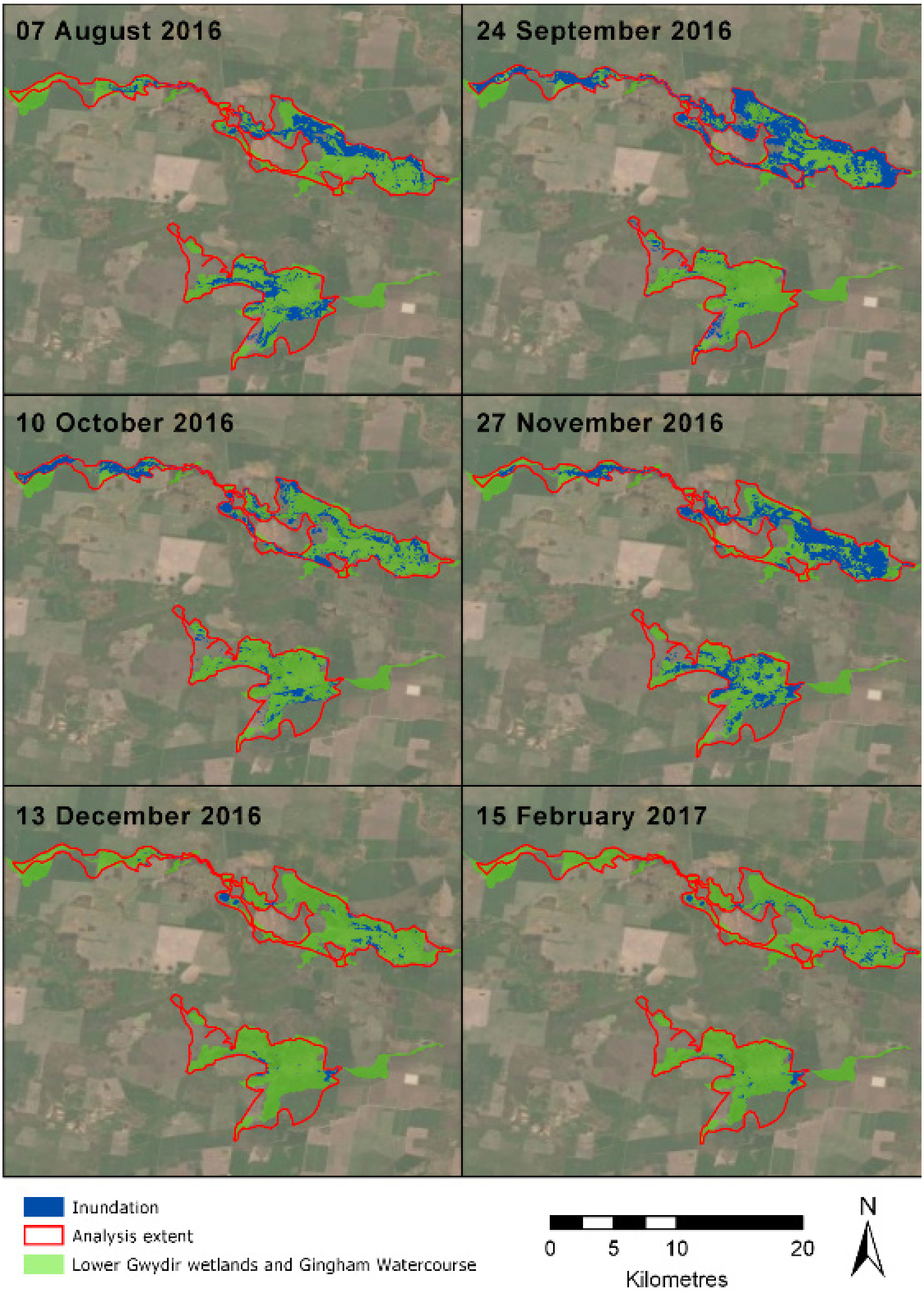

Figure B-7: Inundation recorded in the Gingham and Lower Gwydir wetlands during 2016-17

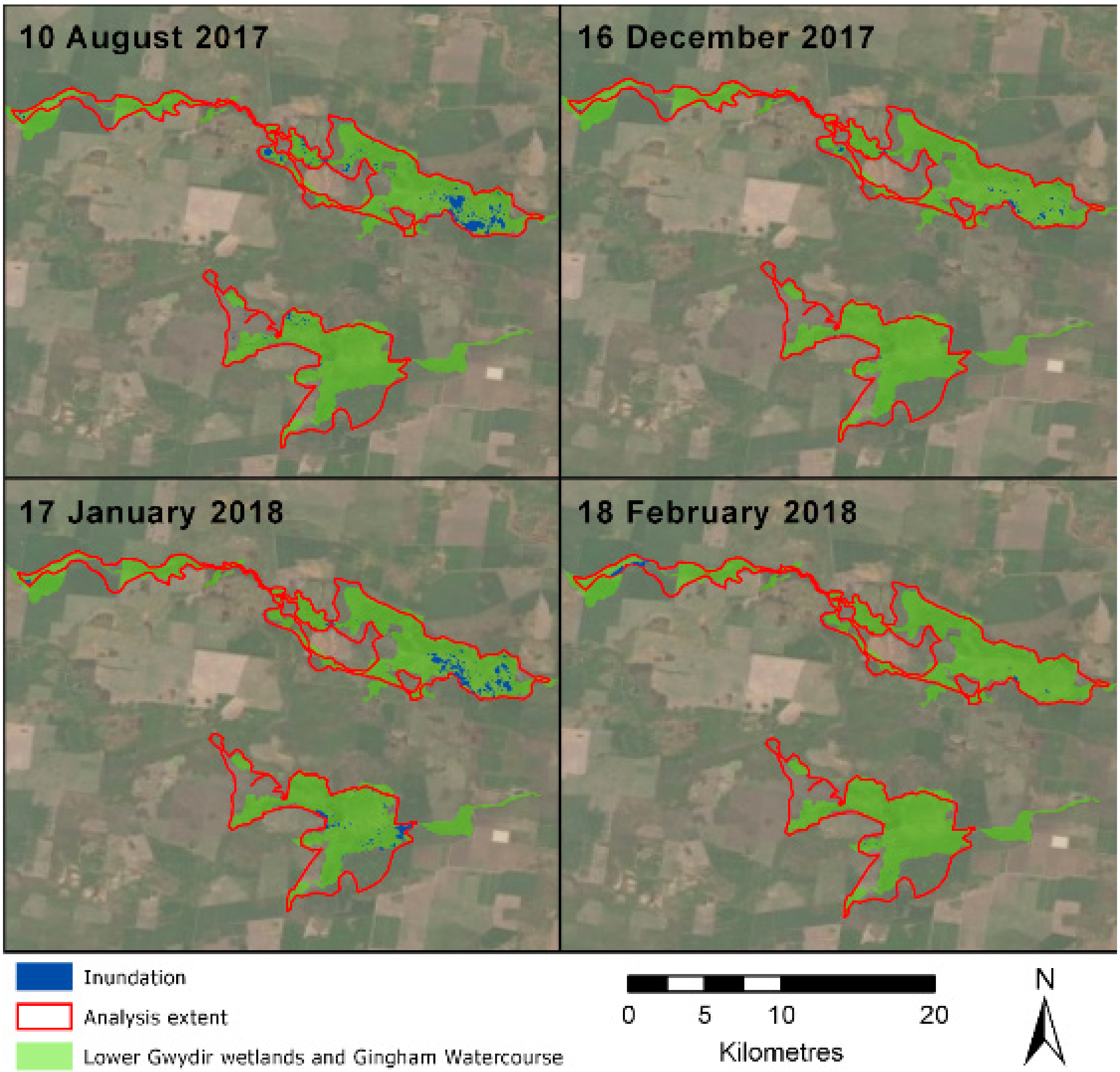

Figure B-8: Inundation recorded in the Gingham and Lower Gwydir wetlands during 2017-18

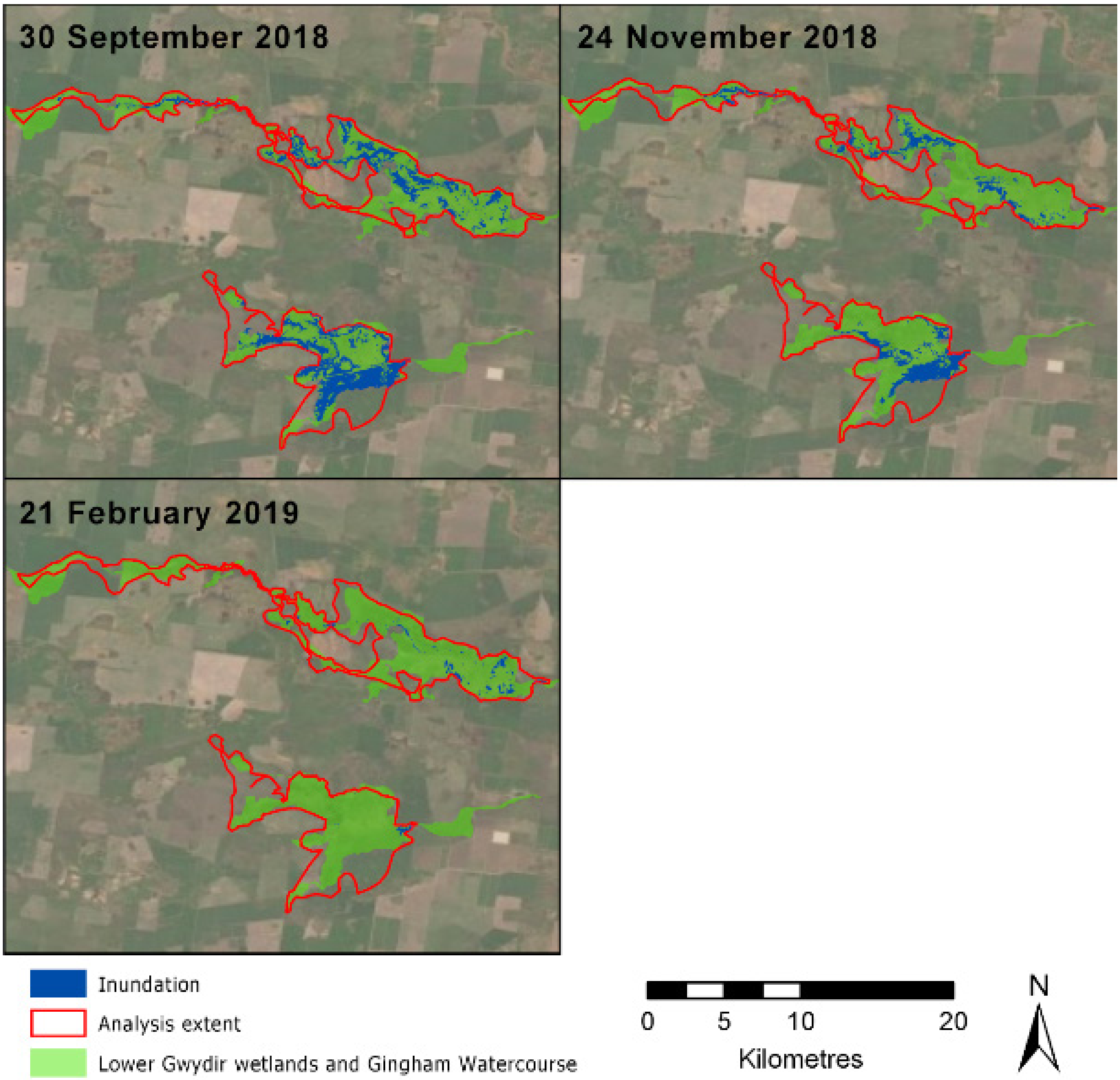

Figure B-9: Inundation recorded in the Gingham and Lower Gwydir wetlands during 2018-19

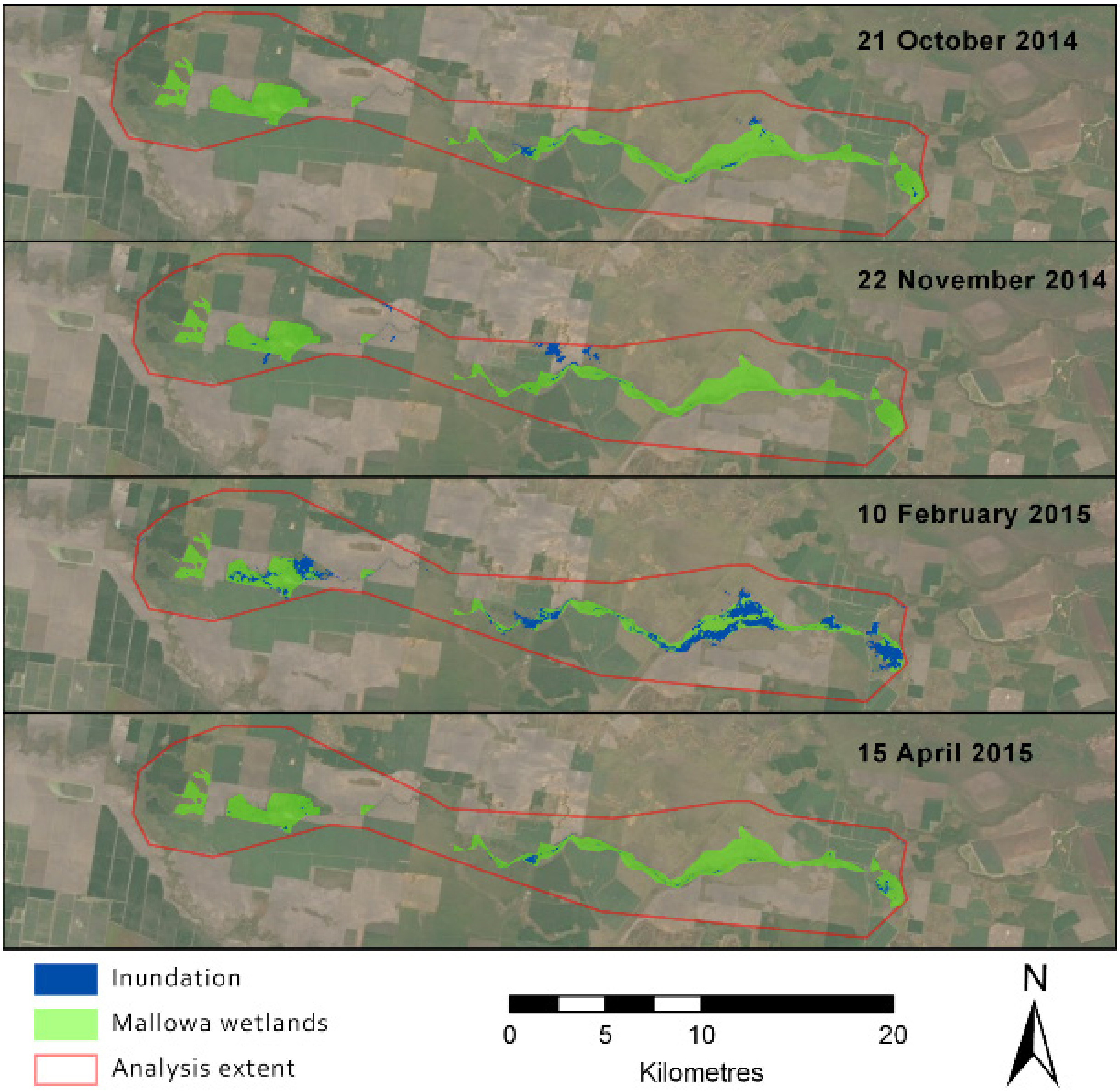

Figure B-10: Inundation recorded in the Mallowa wetlands during 2014-15

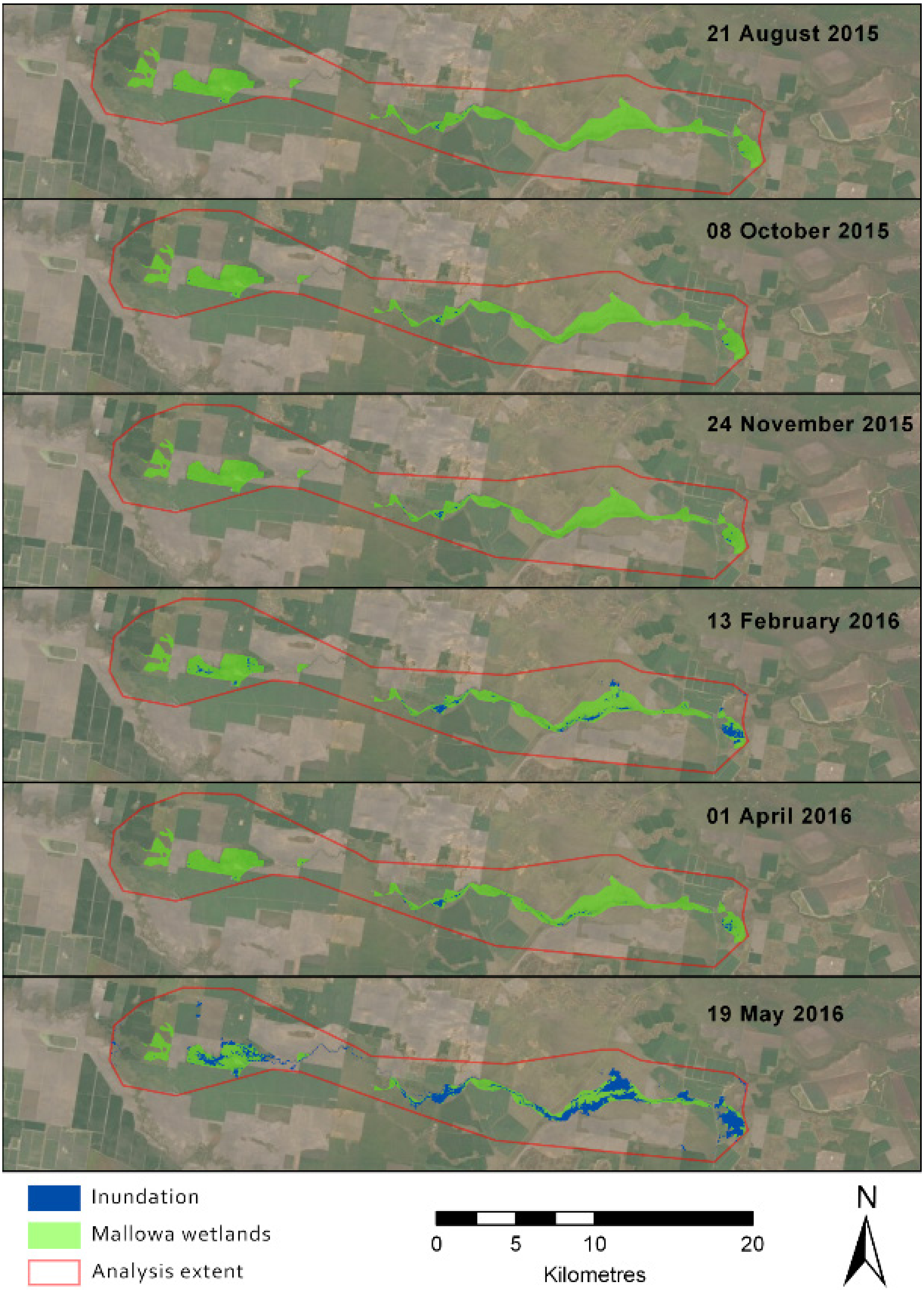

Figure B-11: Inundation recorded in the Mallowa wetlands during and 2015-16

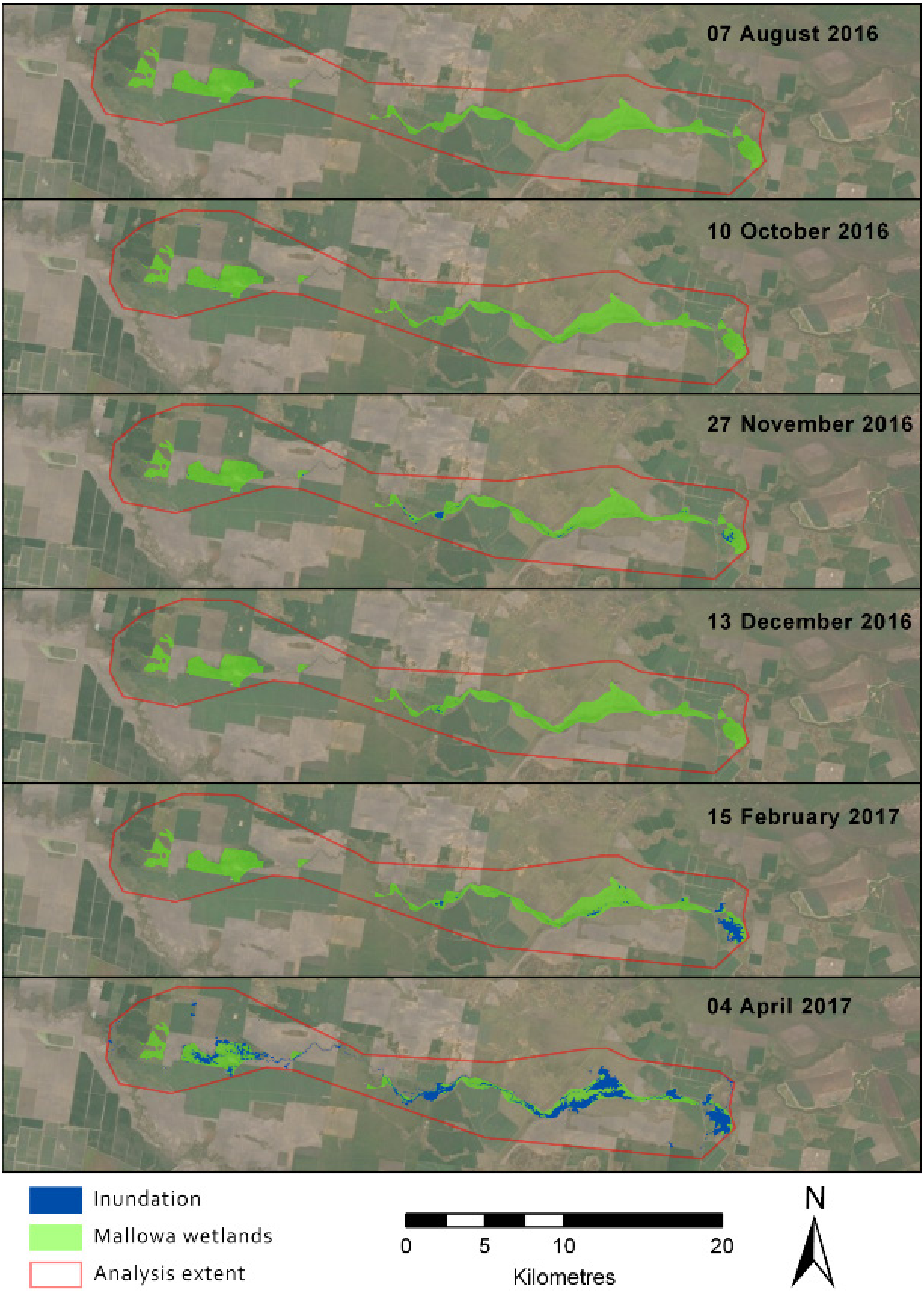

Figure B-12: Inundation recorded in the Mallowa wetlands during 2016-17

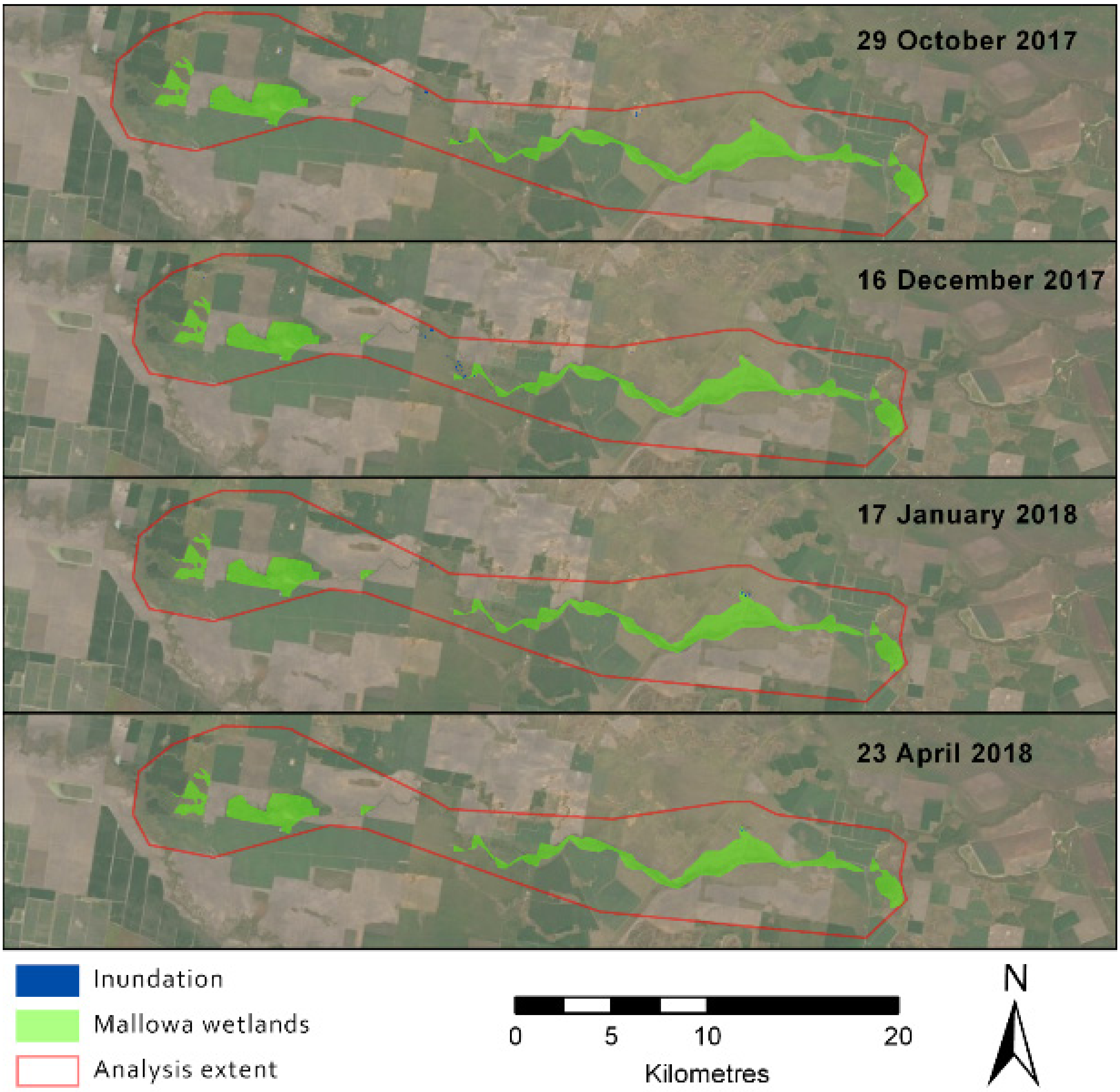

Figure B-13: Inundation recorded in the Mallowa wetlands during 2017-18

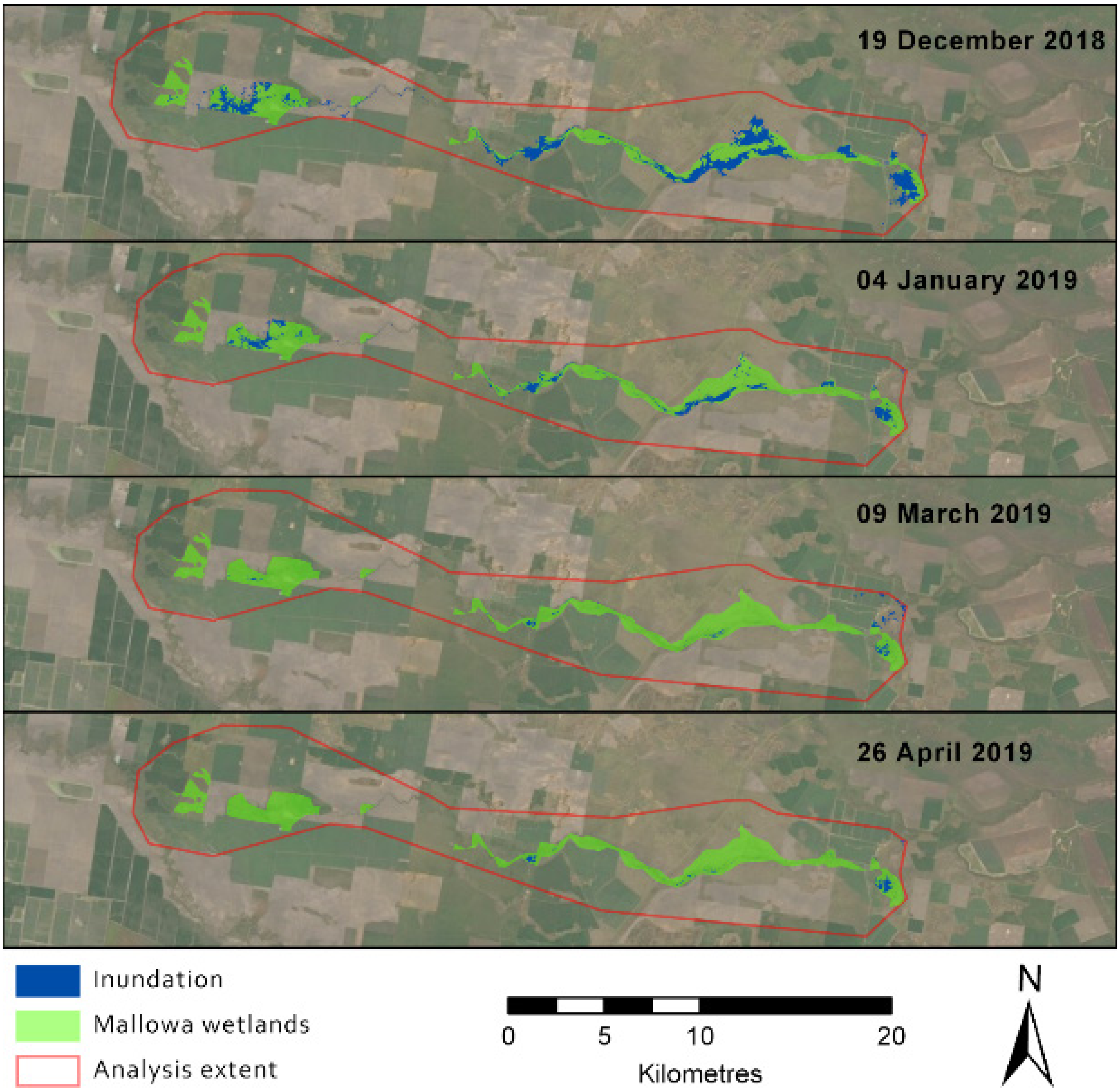

Figure B-14: Inundation recorded in the Mallowa wetlands during 2018-19

B.3.2 Vegetation community inundation

In the Lower Gwydir and Gingham wetlands, the most commonly inundated vegetation community over the LTIM project was the water couch – spike rush – tussock rush marsh grassland community (Table B-5 - Table B-7). In the Gingham wetlands, cumbungi swamp rushland was also a major community to be inundated. In the Mallowa wetlands the dominant community inundated was the coolibah – river cooba – lignum association (Table B-8).

During 2014-15 in the Lower Gwydir, water couch – spike-rush – tussock rush marsh grassland (33-76%), and river cooba – lignum association (4-18%) were the most commonly inundated vegetation communities, along with cultivated land (3-34%; Table B-5). At the peak of the inundation extent (February 2015) seven different vegetation communities were inundated to some degree, along with areas of cultivated land, natural water bodies and some farm dams.

In the Gingham wetlands, cumbungi swamp rushland had the greatest area inundated early in the season (32-49%), where water was confined to natural water bodies and vegetation communities lining channels and depressions. As inundation increased in early 2015, greater proportions of water couch – spike-rush – tussock rush marsh grassland (38-43%) and river cooba – lignum swamp shrubland (18%) becoming inundated (Table B-5). Within the Gingham a total of 16 different vegetation communities were inundated to some degree during the season, while land mapped as cultivated land constituted only a relatively small proportion (2-16%) of the total inundated extent throughout the year. During 2014-15, coolibah – river cooba – lignum association was the most commonly inundated vegetation community in the Mallowa wetlands accounting for more than 90% of the total area inundated (Table B-8). Both cultivated and non-cultivated coolibah communities were also inundated in the water year, along with small (<2 ha) areas of river Cooba-lignum association communities.

In the Lower Gwydir wetlands during 2015-16, river cooba – lignum association (0-67% of inundated area) and water couch – spike rush – tussock rush (1-73% of inundated area) were the most commonly inundated vegetation communities throughout the 2015-16 water year (Figure B-11). At the peak inundation extent in November 2015, six different vegetation communities were inundated to some degree (Figure B-11), although this was not the maximum number of inundated vegetation communities. In May 2016, seven communities were inundated, including the same six inundated in November 2015 plus a small area (3 ha) of common reed – tussock sedge. In the Gingham wetlands, water couch – spike-rush – tussock rush marsh grassland (1-53% of inundated area) and river cooba – lignum swamp shrubland (2-39% of inundated area) were the most commonly inundated vegetation communities (Figure B-11). The river cooba – lignum swamp shrubland vegetation community was extensively inundated early in the water year (169 ha in August 2015 and 230 ha in October 2015) but this extent decreased sharply at all other image capture times (1-7 ha for the remainder of the water year). The low-lying water couch – spike rush – tussock rush marsh grassland was inundated for the majority of the year. This community accounted for only 1% of inundated area in April 2016, but at all other times accounted for between 22% and 53% of inundated area. At the peak inundation extent in October 2015, 13 different vegetation communities were inundated (Figure B-11), which was the maximum number of vegetation communities inundated in the Gingham wetlands in the 2015-16 water year.

During 2015-16 within the Mallowa wetlands, coolibah – river cooba – lignum association was the most commonly inundated vegetation community, accounting for between 93% and 100% of inundated area across the water year (Table B-8). At the peak inundation extent in February 2016 four different vegetation communities were inundated. Being fringing wetlands adjacent to the river channel, rather than terminal wetlands such as those in the Gwydir and Gingham systems, inundation along the Mallowa Creek is generally restricted to these areas immediately adjacent the main channel. Therefore, inundation does not tend to be as broad in the landscape and it is to be expected that fewer vegetation communities are inundated.

During 2016-17 in the Lower Gwydir wetlands, water couch – spike rush – tussock rush marsh grassland was the most frequently inundated vegetation community. This vegetation community also had the largest area and greatest volume of inundation mapped for all image capture dates, with the maximum being in August 2016 (796 ha, 1,020 ML; Table B-6). During August 2016 (the period with the largest extent of inundation) all eight vegetation communities mapped in the Lower Gwydir wetlands were inundated (≥0.1 ha; Figure B-11). During December 2016 (the period with the smallest extent of inundation) only five communities were inundated (≥0.1 ha; Table B-6). In the Gingham wetlands, Water couch – spike-rush – tussock rush marsh grassland had the largest area and greatest volume of inundation mapped for all image capture dates, with the maximum being in September 2016 (1,004 ha, 2,510 ML; Table B-6).

During maximum inundation in September 2016 (2,844 ha), 19 of 24 vegetation communities were inundated; while in December 2016 that had the least inundation (292 ha), only 10 vegetation communities were inundated (≥0.1 ha; Table B-6). In the Mallowa wetlands, coolibah – river cooba – lignum association had the largest area and greatest volume of inundation mapped for all image capture dates during 2016-17, with the maximum in April 2017 (774.2 ha; Table B-8). This was the largest area of any vegetation community inundated in this wetland for the LTIM project (Table B-8). Coolabah woodlands was the second most inundated community in 2016-17, with an area of 69.4 ha being inundated in April 2017.

In the Lower Gwydir wetlands during 2017-18, water couch – spike rush – tussock rush marsh grassland was the most frequently inundated vegetation community and had the greatest volume of inundation mapped in January 2018 (75 ML; Table B-6). River-cooba lignum association had the largest area inundated in any single image capture date with 51 ha being mapped in January 2018 (Table B-6). During January 2018 (the period with the largest extent of inundation) five of the eight vegetation communities mapped in the Lower Gwydir wetlands were inundated. During February 2018 (the period with the smallest extent of inundation) only two communities were inundated (Table B-6). In the Gingham wetlands, water couch – spike-rush – tussock rush marsh grassland had the largest area of inundation mapped for all image capture dates, with the maximum being in July (172 ha; Table B-6), whereas cumbungi swamp rushland had the greatest volume of inundation, also in July (284 ML; Table B-6). During maximum inundation in July (364 ha), 12 of 24 vegetation communities were inundated; while in February with the least inundation (55 ha), only six vegetation communities were inundated (Table B-6). Since no environmental water was delivered into the Mallowa, no inundation was caused by environmental water and further analysis was not undertaken.

During 2018-19, 1,122 ha of water couch – spike rush – tussock rush marsh grassland was inundated in the Lower Gwydir wetlands during September 2018, with a volume of 2,804 ML estimated to have inundated this community (Table B-7). The river cooba-lignum association was the second largest community inundated with 98 ha becoming inundated in November 2018. During maximum inundation, all vegetation communities were inundated to some degree (Table B-7). By February 2019 total inundation was 27 ha across three vegetation communities. In the Gingham system, maximum inundation for 2018-19 was recorded in November with the 359 ha of river cooba - lignum swamp shrubland, 370 ha of water couch – spike rush – tussock rush marsh grassland and 156 ha of cleared land being the predominant vegetation communities inundated (Table B-7). During this time, 15 of the 24 vegetation communities were inundated. In the Mallowa wetland during 2018-19, 718 ha of coolibah – river cooba – lignum association were inundated in December 2019. During this period, all four wetland communities in the Mallowa wetlands became inundated.

Table B-5: Area inundated, including percentage of total extent inundated at the time, for different vegetation communities in the Lower Gwydir and Gingham wetlands in 2014-15 and 2015-16. * Farm dams were not included in volume calculations

Wetland	Vegetation community	2014-15								2015-16											
		Area inundated (ha)				Volume (ML)				Area inundated - ha (%)						Volume - ML (%)					
		1-Jul-14	21-Oct-14	10-Feb-15	15-Apr-15	1-Jul-14	21-Oct-14	10-Feb-15	15-Apr-15	21-Aug-15	8-Oct-15	24-Nov-15	13-Feb-16	1-Apr-16	19-May-16	21-Aug-15	8-Oct-15	24-Nov-15	13-Feb-16	1-Apr-16	19-May-16
Lower Gwydir	Common Reed - Marsh Club-rush	0 (0)	44 (2)	56 (2)	5 (1)	0 (0)	44 (1)	111 (2)	10 (1)	0 (0)	0 (0)	4 (2)	5 (5)	0 (0)	15 (23)	0 (0)	0 (0)	2 (1)	2 (6)	0 (3)	8 (23)
	Common Reed - Tussock Sedge	0 (0)	44 (2)	38 (2)	1 (0)	0 (0)	44 (1)	75 (2)	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)
	Coolibah - River Red Gum Association	1 (5)	16 (1)	15 (1)	8 (2)	1 (3)	32 (1)	30 (1)	15 (2)	2 (2)	9 (9)	10 (6)	0 (0)	3 (5)	1 (2)	1 (1)	5 (7)	5 (3)	0 (0)	1 (80)	1 (2)
	Coolibah woodland	0 (0)	39 (2)	67 (3)	6 (1)	0 (0)	39 (1)	133 (3)	12 (1)	8 (5)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	4 (3)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)
	Cumbungi-Marsh Club Rush	0 (0)	62 (3)	36 (1)	6 (1)	0 (0)	31 (1)	36 (1)	11 (1)	0 (0)	0 (0)	7 (4)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	3 (2)	0 (0)	0 (0)	0 (1)
	River Cooba - Lignum Association	2 (11)	166 (9)	100 (4)	81 (18)	2 (11)	331 (10)	199 (4)	160 (18)	28 (19)	62 (59)	73 (45)	56 (67)	42 (89)	26 (39)	28 (20)	31 (49)	73 (49)	28 (68)	0 (0)	13 (40)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	6 (33)	1,345 (76)	1,849 (76)	180 (41)	6 (31)	2,689 (82)	3,698 (77)	360 (41)	102 (68)	30 (29)	66 (41)	21 (25)	1 (1)	19 (29)	102 (73)	15 (24)	66 (44)	10 (26)	0 (17)	10 (29)
	Natural Water Body	2 (11)	5 (0)	3 (0)	1 (0)	11 (53)	33 (1)	17 (0)	6 (1)	0 (0)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	12 (20)	0 (0)	0 (0)	0 (0)	0 (0)
	Cultivated Land	4 (21)	49 (3)	264 (11)	151 (34)	0 (2)	49 (1)	528 (11)	302 (34)	7 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Farm Dam*	4 (19)	9 (0)	6 (0)	5 (1)					2 (1)	2 (2)	3 (2)	2 (2)	2 (4)	1 (1)						
	Total	**19**	**1,779**	**2,434**	**444**	**20**	**3,292**	**4,827**	**879**	**149**	**106**	**162**	**84**	**48**	**67**	**140**	**63**	**149**	**41**	**2**	**33**
Gingham	Baradine Red Gum shrubby open forest	0 (0)	7 (4)	37 (1)	17 (1)	17 (1)	14 (2)	74 (1)	35 (1)	0 (0)	2 (0)	0 (0)	2 (1)	8 (16)	4 (7)	0 (0)	1 (0)	0 (0)	1 (0)	4 (11)	2 (2)
	Belah grassy woodland	1 (1)	4 (2)	299 (8)	31 (2)	31 (2)	8 (1)	598 (7)	62 (2)	9 (2)	10 (2)	1 (0)	2 (1)	5 (10)	1 (2)	5 (1)	5 (1)	0 (0)	1 (0)	3 (7)	1 (1)
	Carbeen grassy woodland	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Cleared land	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05	0.05	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Coolibah - River Cooba grassy woodland	1 (1)	5 (3)	433 (11)	79 (6)	79 (6)	9 (2)	866 (10)	158 (5)	45 (8)	16 (3)	1 (1)	13 (7)	9 (17)	6 (11)	22 (6)	8 (2)	1 (0)	7 (3)	4 (12)	3 (3)
	Cumbungi swamp rushland	31 (32)	88 (49)	274 (7)	244 (17)	244 (17)	351 (60)	1,098 (12)	974 (28)	18 (3)	46 (8)	119 (48)	31 (16)	12 (22)	22 (36)	35 (10)	92 (22)	238 (69)	76 (29)	6 (15)	43 (47)
	Derived grasslands	0 (0)	0 (0)	11 (0)	0 (0)	0 (0)	0 (0)	23 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	dry wetland with rehabilitation potential	0 (0)	0 (0)	281 (7)	15 (1)	15 (1)	0 (0)	561 (6)	15 (0)	36 (6)	11 (2)	0 (0)	0 (0)	0 (0)	0 (0)	18 (5)	5 (1)	0 (0)	0 (0)	0 (0)	0 (0)
	Marsh Club-rush swamp sedgeland	0 (0)	0 (0)	10 (0)	8 (1)	8 (1)	0 (0)	19 (0)	8 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Myall - Rosewood shrubby woodland	0 (0)	0 (0)	13 (0)	24 (2)	24 (2)	0 (0)	25 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: Coolibah - River Cooba woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Wetland	Vegetation community	2014-15								2015-16											
		Area inundated (ha)				Volume (ML)				Area inundated - ha (%)						Volume - ML (%)					
		1-Jul-14	21-Oct-14	10-Feb-15	15-Apr-15	1-Jul-14	21-Oct-14	10-Feb-15	15-Apr-15	21-Aug-15	8-Oct-15	24-Nov-15	13-Feb-16	1-Apr-16	19-May-16	21-Aug-15	8-Oct-15	24-Nov-15	13-Feb-16	1-Apr-16	19-May-16
	Paleo-channel: cultivated land	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: dry wetland with rehabilitation potential	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: Water Couch - Spike-rush	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Poplar Box shrubby woodland	0 (0)	2 (1)	43 (1)	5 (0)	5 (0)	2 (0)	43 (0)	5 (0)	0 (0)	0 (0)	0 (0)	1 (1)	2 (3)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (2)	0 (0)
	Quinine Bush - Cooba tall shrubland	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	River Cooba - Lignum Association	8 (9)	0 (0)	42 (1)	32 (2)	32 (2)	1 (0)	127 (1)	96 (3)	1 (0)	3 (0)	3 (1)	12 (6)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	12 (5)	0 (0)	0 (0)
	River Cooba - Lignum swamp shrubland	0 (0)	13 (7)	689 (18)	247 (18)	247 (18)	38 (6)	2,067 (23)	740 (21)	169 (29)	230 (39)	7 (3)	6 (3)	2 (4)	1 (2)	84 (24)	115 (27)	4 (1)	3 (1)	1 (2)	0 (1)
	River Red Gum - Coolibah open forest	3 (3)	5 (3)	21 (1)	16 (1)	16 (1)	9 (2)	42 (0)	33 (1)	4 (1)	8 (1)	2 (1)	4 (2)	4 (8)	2 (3)	2 (1)	4 (1)	1 (0)	2 (1)	2 (5)	1 (1)
	Spike-rush - Cumbungi swamp sedgeland	0 (0)	2 (1)	8 (0)	7 (0)	7 (0)	2 (0)	15 (0)	7 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Tussock Rush swamp rushland	0 (0)	0 (0)	4 (0)	4 (0)	4 (0)	1 (0)	8 (0)	8 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	19 (20)	34 (19)	1,485 (38)	607 (43)	607 (43)	68 (12)	2,970 (33)	1,214 (35)	190 (33)	185 (31)	98 (40)	100 (53)	1 (1)	13 (22)	95 (27)	92 (22)	49 (14)	100 (39)	0 (1)	7 (7)
	Cultivated land	15 (16)	3 (2)	226 (6)	40 (3)	40 (3)	6 (1)	332 (4)	65 (2)	88 (15)	63 (11)	3 (1)	1 (1)	0 (0)	0 (0)	44 (12)	32 (8)	1 (0)	0 (0)	0 (0)	0 (0)
	Natural water body	13 (13)	15 (8)	21 (1)	17 (1)	17 (1)	74 (13)	105 (1)	85 (2)	12 (2)	16 (3)	12 (5)	13 (7)	8 (16)	9 (14)	48 (14)	63 (15)	49 (14)	57 (22)	17 (44)	34 (38)
	Farm dam*	3 (3)	2 (1)	9 (0)	5 (0)					3 (1)	4 (1)	2 (1)	2 (1)	1 (2)	1 (2)						
	Total	**94**	**180**	**3,908**	**1,398**	**191**	**583**	**8,975**	**3,505**	**575**	**592**	**247**	**188**	**52**	**60**	**354**	**418**	**344**	**260**	**38**	**91**

Table B-6: Area inundated, including percentage of total extent inundated at the time, for different vegetation communities in the Lower Gwydir and Gingham wetlands in 2016-17 and 2017-18. * Farm dams were not included in volume calculations

Wetland	Vegetation community	2016-17												2017-18							
		Area inundated - ha (%)						Volume - ML (%)						Area inundated - ha (%)				Volume - ML (%)			
		7-Aug-16	24-Sep-16	10-Oct-16	27-Nov-16	13-Dec-16	15-Feb-17	7-Aug-16	24-Sep-16	10-Oct-16	27-Nov-16	13-Dec-16	15-Feb-17	10-Aug-17	16-Dec-17	24-Sep-16	18-Feb-18	10-Aug-17	16-Dec-17	17-Jan-18	18-Feb-18
	Common Reed - Marsh Club-rush	27 (3)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	40 (4)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)
	Common Reed - Tussock Sedge	4 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Coolibah - River Red Gum Association	4 (0)	0 (0)	1 (0)	5 (3)	4 (4)	4 (3)	2 (0)	0 (0)	1 (0)	2 (1)	2 (4)	4 (3)	0 (0)	0 (0)	5 (4)	0 (0)	0 (0)	0 (0)	5 (3)	0 (0)
	Coolibah woodland	21 (3)	4 (1)	4 (1)	4 (2)	1 (1)	7 (5)	11 (1)	4 (1)	4 (1)	6 (3)	1 (1)	7 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Cumbungi-Marsh Club Rush	14 (2)	1 (0)	9 (2)	9 (5)	9 (10)	2 (1)	21 (2)	2 (0)	19 (3)	9 (4)	4 (9)	2 (1)	0 (0)	0 (3)	10 (9)	0 (0)	0 (0)	0 (1)	15 (10)	0 (0)
Lower Gwydir	River Cooba - Lignum Association	66 (8)	0 (0)	20 (5)	36 (21)	42 (46)	51 (40)	0 (0)	0 (0)	30 (4)	36 (16)	21 (43)	51 (32)	0 (0)	0 (0)	51 (43)	0 (0)	0 (0)	0 (0)	51 (35)	0 (0)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	607 (76)	193 (69)	331 (85)	114 (66)	29 (32)	59 (46)	910 (89)	385 (80)	662 (89)	171 (75)	14 (29)	88 (55)	30 (94)	6 (79)	50 (42)	2 (23)	15 (100)	3 (41)	75 (51)	1 (100)
	Natural Water Body	3 (0)	3 (1)	2 (0)	1 (0)	2 (2)	2 (1)	13 (1)	13 (3)	9 (1)	2 (1)	7 (14)	8 (5)	0 (0)	1 (13)	0 (0)	0 (0)	0 (0)	4 (58)	0 (0)	0 (0)
	Cultivated Land	46 (6)	78 (28)	16 (4)	0 (0)	0 (0)	0 (0)	23 (2)	78 (16)	16 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Farm Dam	5 (1)	1 (0)	6 (1)	4 (2)	3 (4)	2 (2)							2 (6)	0 (6)	2 (1)	5 (77)				
	Total	**796**	**279**	**390**	**173**	**90**	**127**	**1,020**	**482**	**742**	**227**	**49**	**160**	**32**	**7**	**119**	**7**	**15**	**7**	**147**	**1**
	Baradine Red Gum shrubby open forest	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Belah grassy woodland	22 (2)	62 (2)	13 (1)	1 (0)	1 (0)	0 (0)	11 (2)	125 (2)	6 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Carbeen grassy woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Cleared land	63 (6)	287 (10)	131 (9)	0 (0)	0 (0)	0 (0)	32 (6)	430 (7)	66 (5)	0 (0)	0 (0)	0 (0)	6 (2)	0 (0)	0 (0)	0 (0)	3 (0)	0 (0)	0 (0)	0 (0)
	Coolibah - River Cooba grassy woodland	98 (9)	280 (10)	85 (6)	10 (2)	4 (1)	2 (0)	49 (9)	559 (8)	43 (3)	10 (1)	6 (1)	1 (0)	4 (1)	0 (0)	0 (0)	1 (1)	6 (1)	0 (0)	0 (0)	0 (1)
Gingham	Cumbungi swamp rushland	9 (1)	64 (2)	64 (4)	64 (11)	58 (20)	63 (20)	14 (2)	224 (3)	128 (9)	128 (15)	175 (25)	126 (30)	95 (26)	28 (35)	108 (40)	8 (15)	284 (44)	42 (47)	269 (56)	13 (33)
	Derived grasslands	3 (0)	21 (1)	15 (1)	0 (0)	0 (0)	0 (0)	2 (0)	10 (0)	15 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	dry wetland with rehabilitation potential	73 (7)	310 (11)	76 (5)	6 (1)	0 (0)	0 (0)	37 (7)	774 (12)	76 (5)	3 (0)	1 (0)	0 (0)	8 (2)	0 (0)	1 (0)	13 (23)	12 (2)	0 (0)	1 (0)	6 (17)
	Marsh Club-rush swamp sedgeland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	9 (2)	0 (0)	0 (0)	0 (0)	13 (2)	0 (0)	0 (0)	0 (0)
	Myall - Rosewood shrubby woodland	0 (0)	7 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	15 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: Coolibah - River Cooba woodland	0 (0)	1 (0)	5 (0)	41 (7)	0 (0)	0 (0)	0 (0)	2 (0)	2 (0)	41 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Wetland	Vegetation community	2016-17												2017-18							
		Area inundated - ha (%)						Volume - ML (%)						Area inundated - ha (%)				Volume - ML (%)			
		7-Aug-16	24-Sep-16	10-Oct-16	27-Nov-16	13-Dec-16	15-Feb-17	7-Aug-16	24-Sep-16	10-Oct-16	27-Nov-16	13-Dec-16	15-Feb-17	10-Aug-17	16-Dec-17	24-Sep-16	18-Feb-18	10-Aug-17	16-Dec-17	17-Jan-18	18-Feb-18
	Paleo-channel: cultivated land	0 (0)	53 (2)	49 (3)	0 (0)	4 (1)	0 (0)	0 (0)	105 (2)	25 (2)	0 (0)	6 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: dry wetland with rehabilitation potential	5 (1)	64 (2)	47 (3)	0 (0)	40 (14)	18 (6)	0 (0)	160 (2)	47 (3)	0 (0)	79 (11)	18 (4)	20 (6)	0 (0)	0 (0)	0 (0)	20 (3)	0 (0)	0 (0)	0 (0)
	Paleo-channel: Water Couch - Spike-rush	0 (0)	46 (2)	36 (2)	2 (0)	0 (0)	0 (0)	0 (0)	116 (2)	36 (3)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Poplar Box shrubby woodland	1 (0)	2 (0)	0 (0)	61 (11)	0 (0)	0 (0)	0 (0)	3 (0)	0 (0)	61 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Quinine Bush - Cooba tall shrubland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	River Cooba - Lignum Association	0 (0)	44 (2)	4 (0)	3 (0)	1 (0)	10 (3)	0 (0)	110 (2)	4 (0)	1 (0)	2 (0)	10 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	River Cooba - Lignum swamp shrubland	416 (39)	450 (16)	229 (16)	0 (0)	38 (13)	53 (16)	208 (37)	1,125 (17)	229 (17)	0 (0)	75 (11)	53 (13)	21 (6)	1 (2)	1 (0)	0 (0)	42 (7)	1 (1)	2 (0)	0 (0)
	River Red Gum - Coolibah open forest	9 (1)	10 (0)	2 (0)	1 (0)	4 (1)	2 (1)	5 (1)	21 (0)	2 (0)	1 (0)	5 (1)	2 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
	Spike-rush - Cumbungi swamp sedgeland	0 (0)	0 (0)	0 (0)	333 (59)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	500 (59)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Tussock Rush swamp rushland	2 (0)	3 (0)	2 (0)	15 (3)	1 (0)	1 (0)	1 (0)	7 (0)	2 (0)	7 (1)	2 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	332 (31)	1,004 (35)	608 (42)	4 (1)	121 (41)	152 (47)	166 (29)	2,510 (38)	608 (44)	2 (0)	242 (35)	152 (36)	172 (47)	40 (49)	137 (51)	27 (48)	172 (27)	20 (22)	137 (29)	13 (34)
	Cultivated land	5 (0)	115 (4)	55 (4)	4 (1)	2 (1)	3 (1)	2 (0)	230 (3)	28 (2)	4 (0)	2 (0)	2 (0)	17 (5)	1 (2)	8 (3)	5 (9)	25 (4)	1 (1)	8 (2)	3 (7)
	Natural water body	11 (1)	15 (1)	15 (1)	20 (4)	15 (5)	13 (4)	38 (7)	75 (1)	62 (4)	81 (10)	92 (13)	53 (13)	10 (3)	9 (11)	10 (4)	1 (2)	60 (9)	26 (29)	61 (13)	3 (8)
	Farm dam	4 (0)	6 (0)	5 (0)	0 (0)	4 (1)	3 (1)						25 (6)	1 (0)	2 (2)	2 (1)	0 (0)	13 (2)	12 (14)	16 (3)	1 (3)
	Total	**1,056**	**2,844**	**1,445**	**567**	**292**	**322**	**564**	**6,603**	**1,380**	**843**	**689**	**419**	**364**	**81**	**267**	**55**	**639**	**89**	**478**	**39**

Table B-7: Area inundated, including percentage of total extent inundated at the time, for different vegetation communities in the Lower Gwydir and Gingham wetlands in 2018-19. *Farm dams were not included in volume calculations

Wetland	Vegetation community	2018-19					
		Area inundated - ha (%)			Volume - ML (%)		
		30-Sep-18	24-Nov-18	21-Feb-19	30-Sep-18	24-Nov-18	21-Feb-19
Lower Gwydir	Common Reed - Marsh Club-rush	31 (2)	44 (5)	0 (0)	62 (2)	66 (6)	0 (0)
	Common Reed - Tussock Sedge	4 (0)	11 (1)	0 (0)	8 (0)	6 (0)	0 (0)
	Coolibah - River Red Gum Association	6 (0)	9 (1)	2 (7)	13 (0)	4 (0)	1 (4)
	Coolibah woodland	35 (3)	9 (1)	0 (0)	69 (2)	5 (0)	0 (0)
	Cumbungi-Marsh Club Rush	8 (1)	35 (4)	0 (1)	12 (0)	52 (4)	0 (1)
	River Cooba - Lignum Association	86 (7)	98 (11)	22 (81)	129 (4)	49 (4)	22 (89)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	1,122 (85)	668 (75)	1 (5)	2,804 (89)	1,003 (84)	1 (6)
	Natural Water Body	3 (0)	3 (0)	0 (0)	17 (1)	11 (1)	0 (0)
	Cultivated Land	19 (1)	4 (0)	0 (0)	38 (1)	4 (0)	0 (0)
	Farm Dam*	4 (0)	5 (1)	1 (5)			
	Total	**1,317**	**886**	**27**	**3,151**	**1,200**	**24**
Gingham	Baradine Red Gum shrubby open forest	0 (0)	5 (0)	0 (0)	0 (0)	8 (0)	0 (0)
	Belah grassy woodland	1 (0)	10 (1)	0 (0)	1 (0)	15 (1)	0 (0)
	Carbeen grassy woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Cleared land	81 (9)	156 (14)	0 (0)	81 (6)	156 (6)	0 (0)
	Coolibah - River Cooba grassy woodland	15 (2)	40 (4)	0 (0)	15 (1)	81 (3)	0 (0)
	Cumbungi swamp rushland	66 (7)	137 (12)	40 (23)	99 (7)	549 (20)	61 (25)
	Derived grasslands	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	dry wetland with rehabilitation potential	31 (3)	18 (2)	0 (0)	31 (2)	18 (1)	0 (0)
	Marsh Club-rush swamp sedgeland	0 (0)	2 (0)	0 (0)	0 (0)	2 (0)	0 (0)
	Myall - Rosewood shrubby woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: Coolibah - River Cooba woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: cultivated land	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Paleo-channel: dry wetland with rehabilitation potential	10 (1)	3 (0)	0 (0)	10 (1)	3 (0)	0 (0)
	Paleo-channel: Water Couch - Spike-rush	0 (0)	1 (0)	0 (0)	0 (0)	1 (0)	0 (0)

Wetland	Vegetation community	2018-19					
		Area inundated - ha (%)			Volume - ML (%)		
		30-Sep-18	24-Nov-18	21-Feb-19	30-Sep-18	24-Nov-18	21-Feb-19
	Poplar Box shrubby woodland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Quinine Bush - Cooba tall shrubland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	River Cooba - Lignum Association	1 (0)	21 (2)	6 (4)	1 (0)	63 (2)	10 (4)
	River Cooba - Lignum swamp shrubland	313 (34)	359 (32)	15 (8)	627 (47)	1,077 (39)	23 (9)
	River Red Gum - Coolibah open forest	3 (0)	10 (1)	1 (1)	5 (0)	20 (1)	1 (1)
	Spike-rush - Cumbungi swamp sedgeland	0 (0)	5 (0)	0 (0)	0 (0)	5 (0)	0 (0)
	Tussock Rush swamp rushland	1 (0)	0 (0)	0 (0)	2 (0)	0 (0)	0 (0)
	Water Couch - Spike-rush - Tussock Rush marsh grassland	370 (41)	317 (28)	99 (56)	370 (28)	634 (23)	99 (41)
	Cultivated land	3 (0)	29 (3)	1 (1)	3 (0)	58 (2)	1 (0)
	Natural water body	14 (2)	15 (1)	12 (7)	84 (6)	73 (3)	48 (20)
	Farm dam*	4 (0)	4 (0)	3 (2)			
	Total	**913**	**1,133**	**179**	**1,329**	**2,763**	**242**

Table B-8: Area inundated (ha), including percentage of total extent inundated at the time, for different vegetation communities in the Mallowa wetlands over the LTIM project.

Water year*	Image Date	Coolibah - cultivated	Coolibah - River Cooba - Lignum Association	Coolibah woodlands	River Cooba - Lignum Association	Total
2014-15	21-Oct-14	0.3 (0.5)	56.2 (98.4)	0.4 (0.6)	0.3 (0.5)	57.1
	22-Nov-14	0.2 (1)	17.7 (98)	0.2 (1)	0 (0)	18.1
	10-Feb-15	33.5 (4.6)	664.3 (90.5)	34.6 (4.7)	1.8 (0.2)	734.2
	15-Apr-15	0.2 (0.3)	53.6 (98.2)	0.6 (1.1)	0.2 (0.3)	54.5
2015-16	21-Aug-15	0.1 (0.8)	10.7 (99.2)	0 (0)	0 (0)	10.8
	08-Oct-15	0 (0)	13.1 (100)	0 (0)	0 (0)	13.1
	24-Nov-15	0.6 (2.5)	24 (96.4)	0.1 (0.4)	0.2 (0.7)	24.9
	13-Feb-16	5.8 (2.8)	201.6 (95.7)	2.8 (1.3)	0.4 (0.2)	210.7
	01-Apr-16	0.8 (1.2)	64.1 (98.3)	0.3 (0.5)	0 (0)	65.3
	19-May-16	0.6 (3.4)	17 (92.6)	0.6 (3.4)	0.1 (0.5)	18.4
2016-17	07-Aug-16	0.1 (11.1)	0.4 (44.4)	0.3 (33.3)	0.1 (11.1)	0.8
	10-Oct-16	0.6 (7.7)	5.8 (70.8)	1.8 (21.5)	0 (0)	8.2
	27-Nov-16	0.5 (0.7)	64.3 (96)	1.7 (2.5)	0.5 (0.8)	67.0
	13-Dec-16	0 (0)	5.3 (90.8)	0.3 (4.6)	0.3 (4.6)	5.8
	15-Feb-17	23.6 (14.1)	133.6 (79.7)	10.4 (6.2)	0 (0)	167.6
	4-Apr-17	40.3 (4.5)	774.2 (85.9)	82.4 (9.1)	3.9 (0.4)	900.8
2018-19	19-Dec-18	25.9 (3.2)	718.3 (88)	69.4 (8.5)	3 (0.4)	816.7
	04-Jan-19	5.9 (1.8)	299.9 (90.6)	24 (7.3)	1 (0.3)	330.9
	09-Mar-19	17.8 (24.5)	49.5 (68.2)	5 (6.8)	0.3 (0.5)	72.6
	26-Apr-19	1 (1.6)	60.2 (97.4)	0.2 (0.4)	0.4 (0.6)	61.8

* inundation in 2017-18 was not influenced by river flow so was excluded from analysis

B.4 Conclusion

Environmental water deliveries within all three monitored wetlands improved the extent and volume of wetland inundation. Maximum inundation in the Lower Gwydir and Gingham wetlands was achieved in the first year of the LTIM project provided by environmental watering and supported by local rainfall. In the Gingham system, natural inflows during 2016-17 again provided significant wetland inundation. While environmental water delivered to the Lower Gwydir and Gingham wetlands in 2018-19 were of similar magnitude to those delivered in 2014-15, wetland inundation was lower due to antecedent conditions. The extremely dry conditions being experienced throughout the catchment during these deliveries likely reduced the extent of this water. In the Mallowa wetlands, environmental water deliveries drove wetland inundation with maximum areas of coolibah – river cooba – lignum communities inundated during the 2016-17 water year.

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Appendix C Category II Water Quality

C.1 Introduction

The Category II Water Quality indicator aimed to assess the contribution of Commonwealth environmental water to the improved quality of water in the Gwydir River system Selected Area (Gwydir Selected Area). As such, this indicator is linked to Fish (Channel), Stream Metabolism, Waterbird Diversity, Microinvertebrates, Macroinvertebrates, Frogs and Hydrology (River and Watercourse) indicators. Several specific questions were addressed through this indicator for 2014-19:

- What did Commonwealth environmental water contribute to temperature regimes?
- What did Commonwealth environmental water contribute to pH levels?
- What did Commonwealth environmental water contribute to turbidity regimes?
- What did Commonwealth environmental water contribute to salinity regimes?
- What did Commonwealth environmental water contribute to dissolved oxygen levels?
- What did Commonwealth environmental water contribute to patterns and rates of primary productivity?
- What did Commonwealth environmental water contribute to patterns and rates of decomposition?

C.2 Methods

C.2.1 Gwydir River long-term station

The category II Water Quality indicator was monitored at a single station at Pallamallawa near the WaterNSW gauge (NSW418001) in the Gwydir River between Copeton Dam and Tareelaroi Weir (Commonwealth of Australia, 2015). This single station has permanent surface water connectivity in a defined channel and all environmental water delivered to the lower Gwydir system must pass through this reach (Figure C-1). It has been labelled GW1 in the following analysis.

Continuous monitoring of dependant indicators temperature (°C), pH, turbidity (NTU), conductivity (mS/cm), and dissolved oxygen (%) occurred at this station using a Hydrolab DS5-X Probe and logger (Table C-1). The probe was permanently mounted mid-water below the low flow water height. The probe was then connected via a 3-G telemetered system in the hydrometric station to an RMTek website for data monitoring and download. Each water quality indicator was logged at a 10-minute interval. Due to issues with power supply and instrument failure, datasets were partly discontinuous, and no data was available in the 2018-19 water year.

Daily mean values (midnight to midnight) for each water quality indicator were calculated from 10-minute interval data, with analyses based on the temporally independent mean values (Table C-1). There were 18 recorded environmental water flow events/periods in the Gwydir River in 2014-19 (Appendix A). These flow events varied in magnitude, duration and variability in discharge. Regression analyses were used to explore relationships between discharge (ML/d) and each water quality indicator to separate the time/season of delivery from the discharge volume.

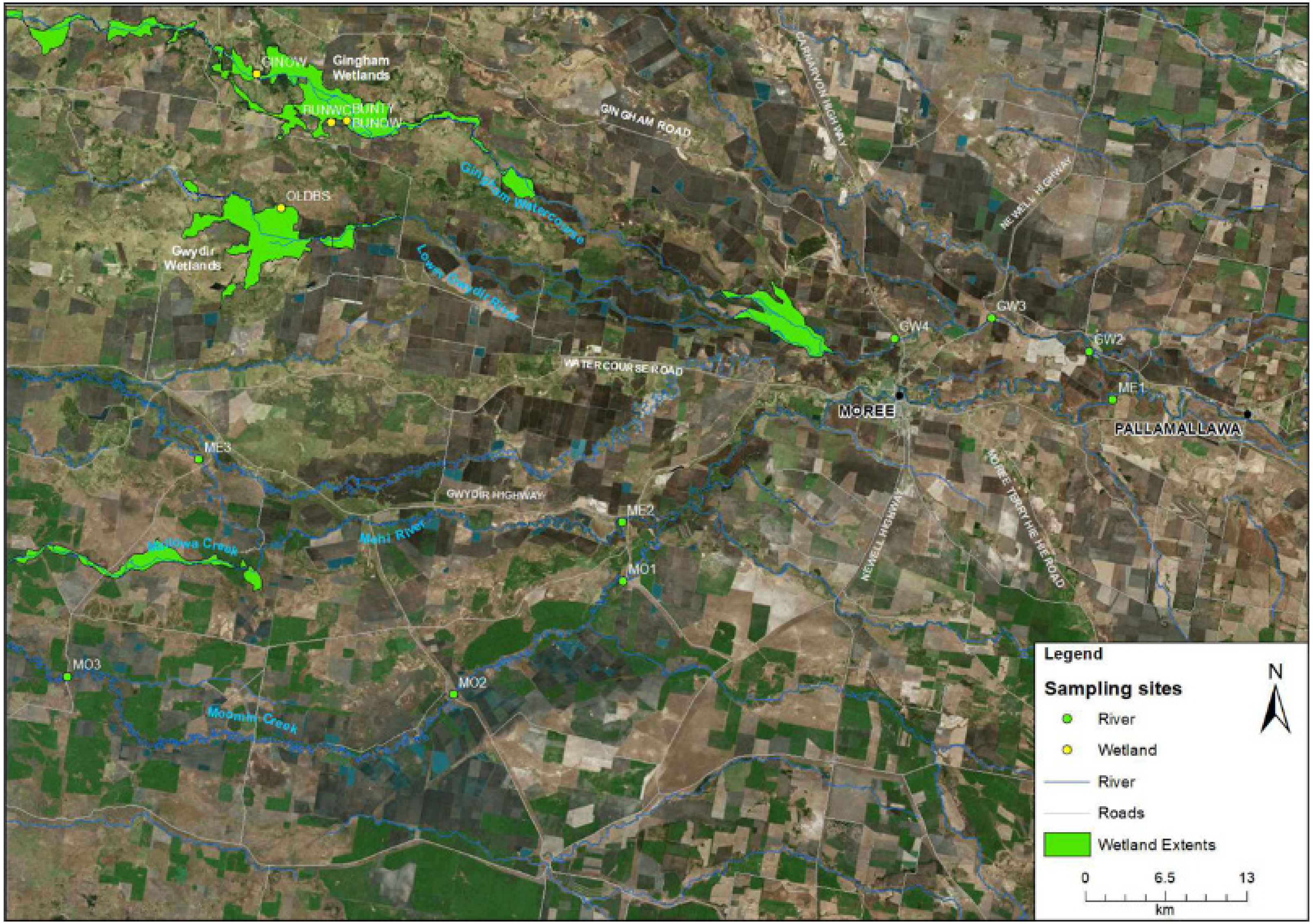


Figure C-1: Location of water quality station and four additional stream metabolism stations in the Gwydir Selected Area in 2014-19. See Table C-2 for site codes.

Table C-1: Category II Water Quality indicators measured at one station and four additional stream metabolism sites in 2014-19.

Indicators	Variables		Units
Water quality	i.	Temperature	°C
	ii.	pH	-
	iii.	Turbidity	NTU
	iv.	Conductivity	mS/cm
	v.	Dissolved Oxygen	%
Stream metabolism	i.	Gross Primary Production	mg O_2/L/day
	ii.	Ecosystem Respiration	mg O_2/L/day
	iii.	Net Primary Production	mg O_2/L/day

C.2.2 Stream metabolism monitoring in four additional stations

To explore the patterns and rates of stream metabolism within the Gwydir Selected Area, four additional stations were selected from Category III microinvertebrate/macroinvertebrate/water quality sites along the Gwydir and Mehi Rivers to monitor temperature (°C) and dissolved oxygen (%) at a 10-minute interval using D-Opto loggers from September 2017 to June 2019 (Figure C-1 and Table C-2). Photosynthetically active radiation (PAR) and barometric pressure were also logged at 10-minute intervals.

Daily means (midnight to midnight) of dissolved oxygen (DO) were calculated from 10-minute interval data, with analyses based on temporally independent mean values (Table C-1). Daily rates of gross primary production (GPP), ecosystem respiration (ER) and net primary production (NPP) in mg O_2/L/d were calculated using the BASE v2 modelling package (Grace *et al.*, 2015). A new metric to estimate the amount of organic carbon produced per day per one-kilometre stream reach (kg C/km/d) was calculated by multiplying the daily rate of GPP (mg O_2/L/d) by the cross-sectional stream area (m^2) at the nearest gauge station with a conversion factor of 12/32 to convert oxygen gas (O_2) molecular mass to carbon (C) atomic mass. Discharge data was collated from the nearest WaterNSW gauge station (Table C-2).

Table C-2: Gwydir River long-term station and four additional stream metabolism sites with the nearest gauge stations within the Gwydir Selected Area in 2014-19.

Site	Easting	Northing	WaterNSW gauge station	Distance from gauge station
GW1	222146	6735701	418001 (Gwydir @Pallamallawa)	0 km
GW2	790876	6740455	418042 (Gwydir D/S Tareelaroi)	6 km downstream
GW4	775597	6741491	418004 (Gwydir @ Yarraman Br)	0 km
GW6	735918	6751398	418078 (Gwydir @ Allambie Br)	0 km
ME1	211342	6736610	418044 (Mehi D/S Tareelaroi)	3 km downstream

C.3 Results and Discussion

C.3.1 Hydrological patterns

Throughout the LTIM project, 18 in-channel flow pulses containing environmental water were recorded and used to examine responses in water quality parameters (Table C-3; Figure C-2). The contributions of environmental water in each year ranged between 7% and 53% (Table C-3). The magnitude of flow events in 2016-17 ('wet year'), a bank full event with peak flow around 39,000 ML/d was much higher than other years ('dry year') due to high catchment rainfall. All environmental water flow events were freshes with peaks less than 5,000 ML/d (Figure C-2). As a consequence, water quality indicators were highly variable in response to a large range of event volumes.

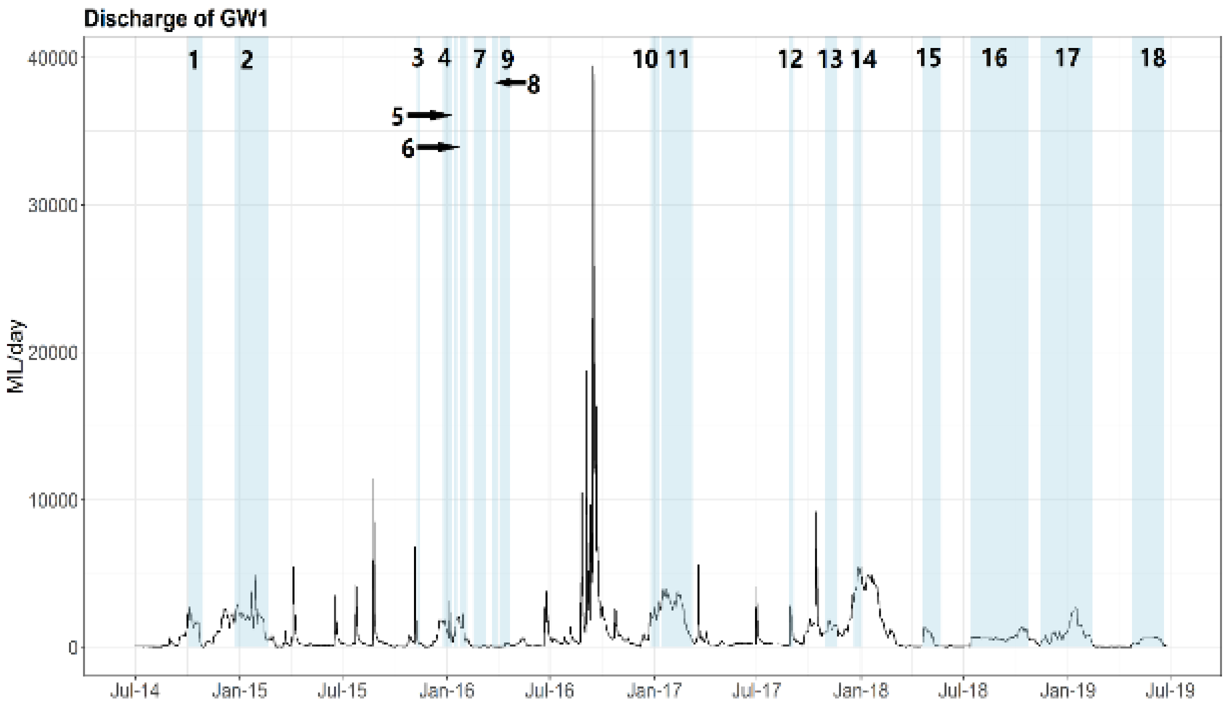


Figure C-2: Mean daily discharge (ML/d) at Gwydir @ Pallamallawa (NSW418001) at GW1 Gwydir River long-term station with shaded areas representing 18 environmental water events (Table C-3).

Table C-3: Environmental water (EW) events in the Gwydir Selected Area during the LTIM project (2014-19).

EW event	Water Year	Event	Start date	End date	Flow by Water Year (ML)		
					Total	EW	EW (%)
1	2014-15	Event 1	2/10/2014	29/10/2014	302,043	87,592	29
2		Event 2	23/12/2014	20/02/2015			
3	2015-16	Event 1	10/11/2015	15/11/2015	184,759	12,933	7
4		Event 2	25/12/2015	10/01/2016			
5		Event 3	13/01/2016	20/01/2016			
6		Event 4	24/01/2016	5/02/2016			
7		Event 5	17/02/2016	10/03/2016			
8		Event 6	21/03/2016	30/03/2016			
9		Event 7	4/04/2016	21/04/2016			
10	2016-17	Event 1	26/12/2016	11/01/2017	614,484	43,013	7
11		Event 2	14/01/2017	10/03/2017			
12	2017-18	Event 1	26/08/2017	4/09/2017	434,462	47,790	11
13		Event 2	30/10/2017	20/11/2017			
14		Event 3	19/12/2017	3/01/2018			
15		Event 4	20/04/2018	23/05/2018			
16	2018-19	Event 1	14/07/2018	24/10/2018	205,520	108,925	53
17		Event 2	14/11/2018	14/02/2019			
18		Event 3	25/04/2019	19/06/2019			

C.3.2 Temperature regime

Water temperature was predictably higher in summer than in winter (Figure C-3, Table C-4). Temperature did not show a relationship to discharge, highlighting that environmental water did not contribute to changes in water temperature. Water temperature variation was attributed to seasonal patterns rather than flow or other environmental conditions.

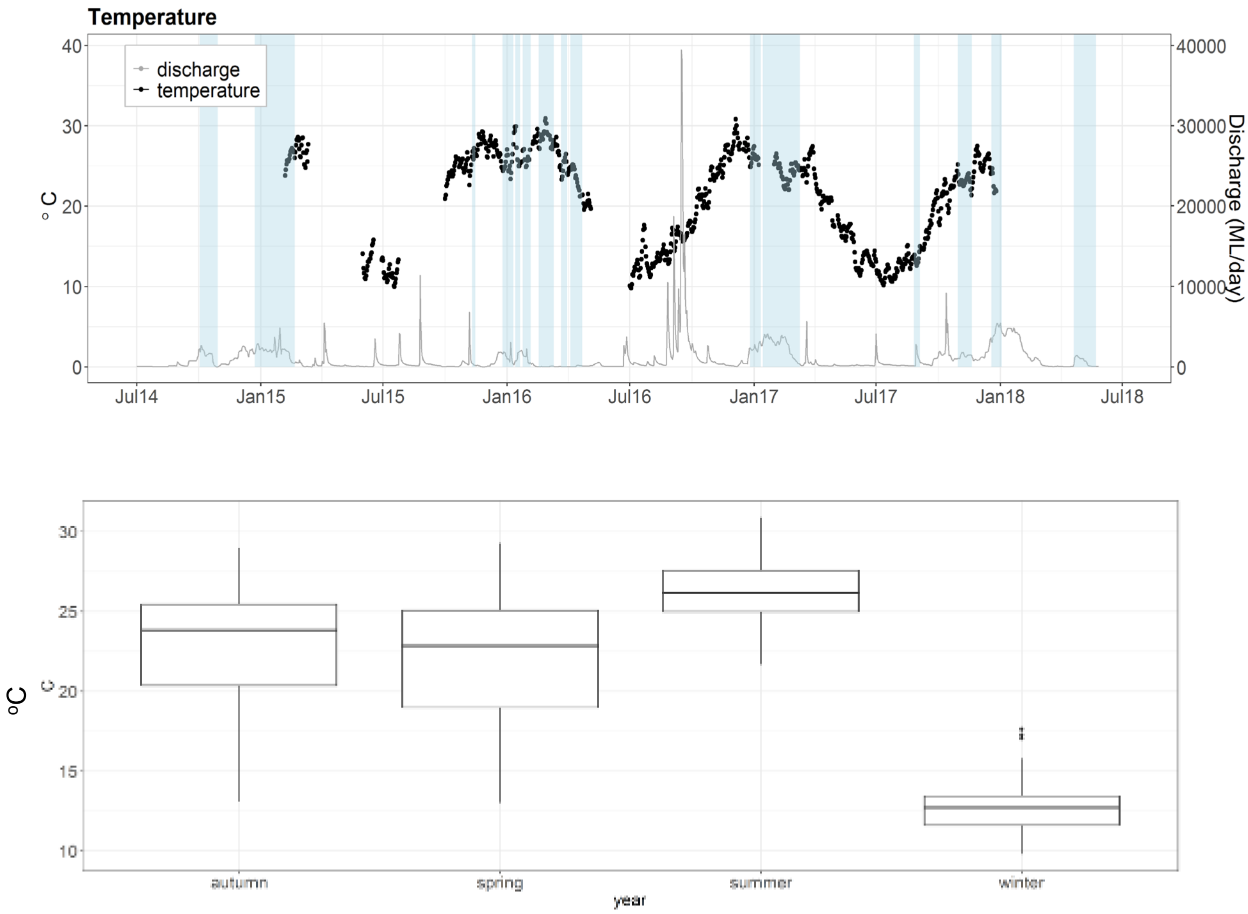


Figure C-3: (Top) Mean daily temperature at the station with black line represents discharge. (Bottom) Boxplot of average temperature by season in 2014-18.

Table C-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicators between 2014 and 2019 within the Gwydir Selected Area with water quality guideline trigger values from ANZECC (2000).

Water quality indicator	ANZECC	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
Temperature (°C)	-	9.79	13.79	22.78	26.33	30.89	803
pH	6.5 - 8	7.11	7.65	8.03	8.25	8.75	803
Turbidity (NTU)	6 - 50	0.00	3.08	13.16	30.66	81.26	253
Conductivity (mS/cm)	0.125 - 2.2	0.15	0.23	0.42	0.65	0.85	803
Dissolved Oxygen (%)	85 - 110	52.62	83.81	89.79	97.51	159.70	803

Table C-5: Summary of regression results between continuous hydrological factors and microinvertebrate indicators within the Gwydir Selected Area in 2014-19.

Water quality indicator	Regression				
	F	df	p-value	R^2	model
Temperature (°C)	0.66	1,801	0.418	0.001	log
pH	34.86	1,801	***<0.001****	0.042	log
Turbidity (NTU)	30.67	1,251	***<0.001****	0.109	log
Conductivity (mS/cm)	877.90	1,801	***<0.001****	0.523	log
Dissolved Oxygen (%)	44.22	1,801	***<0.001****	0.052	log

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

'log' represents logistic regression model.

C.3.3 pH regime

The pH was consistently alkaline and occasionally exceeded ANZECC guideline trigger values (Table C-4). Values were generally highly variable during base/low flow conditions when discharge was below 5,000 ML/d (Figure C-4), reducing under the ANZECC upper guideline value (pH <8) when discharge was above 5,000 ML/d. This discharge may be a potential flow threshold for the inundation or connection of geomorphic features that subsequently increase ions and suspended sediment inputs in the Gwydir River. There was no strong predictable relationship with discharge, suggesting the discharge threshold may be a better approach to understand pH patterns (Table C-5).

pH was significantly lower during environmental water periods. In the 2017-18 events (12 and 13), mean daily pH decreased to within the ANZECC guideline trigger value four and six days after the events commenced. Increases in flow variability and magnitude augmented by environmental water reduced pH. The pH increased during non-environmental water periods, possibly from sustained elevated primary production and increased residence time for water in the channel.

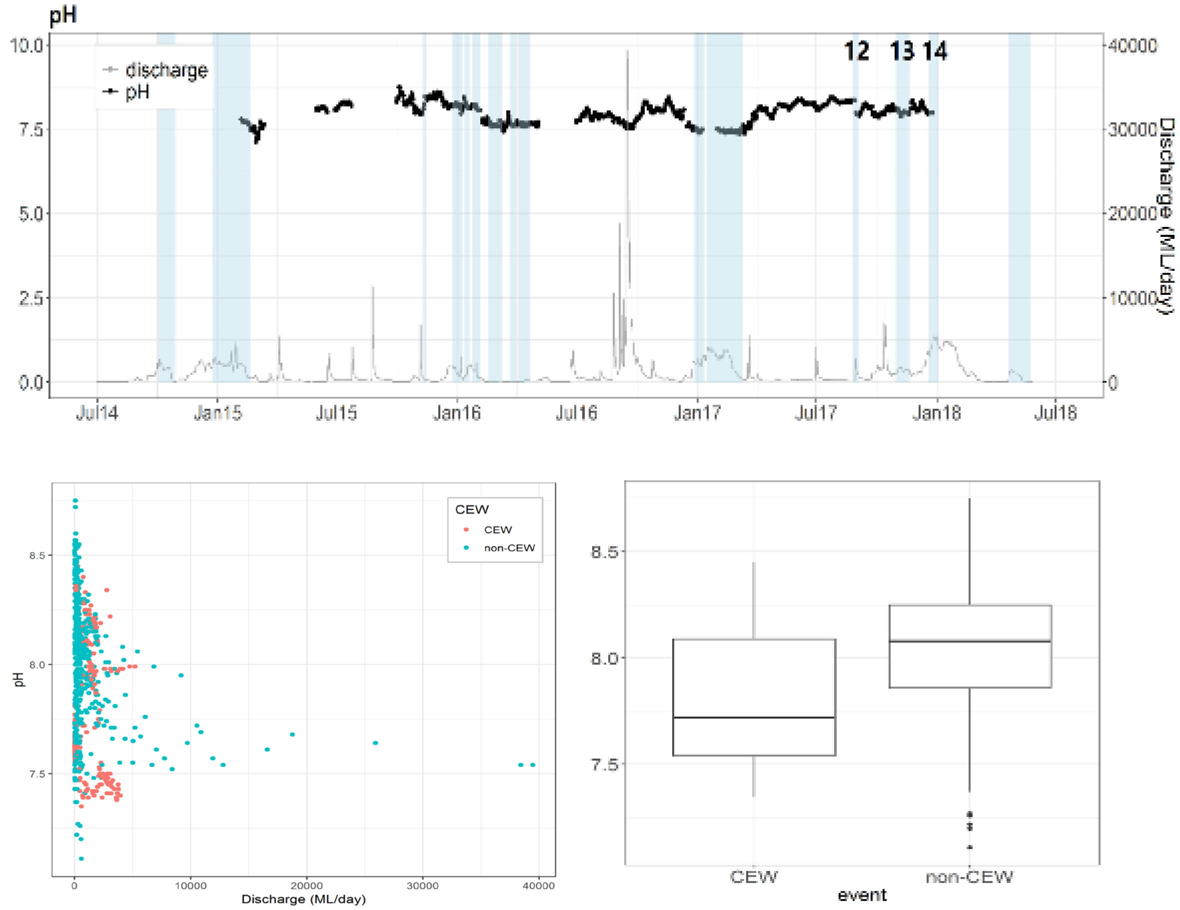


Figure C-4: (Top) Mean daily pH with black line represents discharge. (Bottom left) Regression between discharge and pH in 2014-18. (Bottom right) Boxplot of average pH by events in 2014-18.

C.3.4 Turbidity regime

Turbidity was generally within the ANZECC guideline trigger range from 2014-16 (Table C-4). Turbidity levels were highly variable during base flow conditions and generally below 30 NTU when discharge was above 100 ML/d (Figure C-5). There was no strong predictable relationship with discharge (Table C-5). The higher turbidity levels recorded during base flow conditions could confine primary production in the channel to the shallow edge habitats and limit oxygen production.

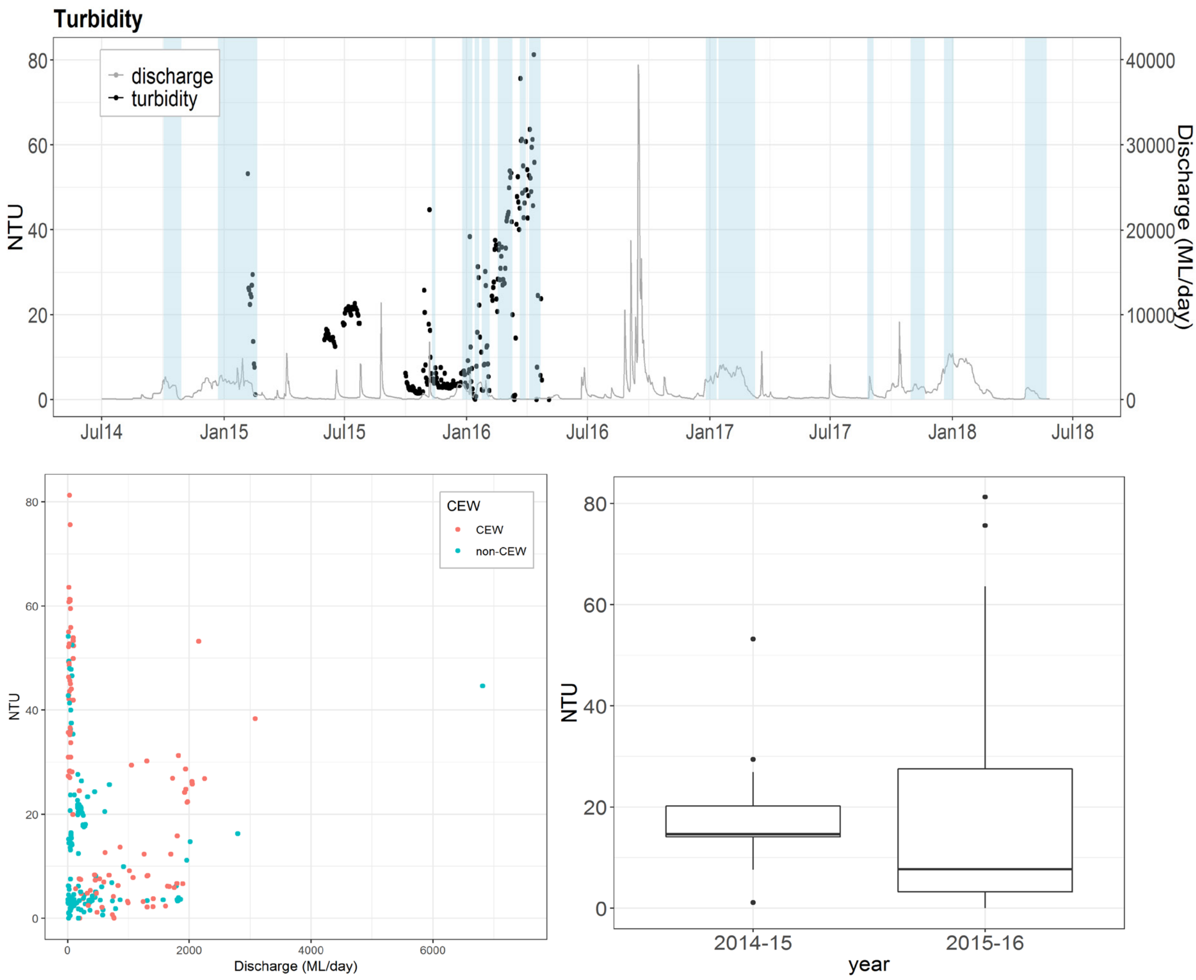


Figure C-5: (Top) Mean daily turbidity with black line represents discharge. (Bottom left) Regression between discharge and turbidity in 2014-18. (Bottom right) Boxplot of average turbidity by year in 2014-16.

C.3.5 Salinity regime

Conductivity was consistently within the ANZECC guideline trigger range (Table C-4 and Figure C-6). There was a clear relationship with discharge (Table C-5). The delivery of environmental water and increases in discharge generally led to a significant reduction in conductivity. These processes reflect a dilution effect provided by flow events including environmental water, and the changes in water chemistry associated with the increase in discharge and wetted area of channels. Conductivity reduced to below 0.3 mS/cm when discharge was above 5,000 ML/d, suggesting that this may be a key high-flow threshold. Similarly, a consistent increase in conductivity was recorded with prolonged low flow events.

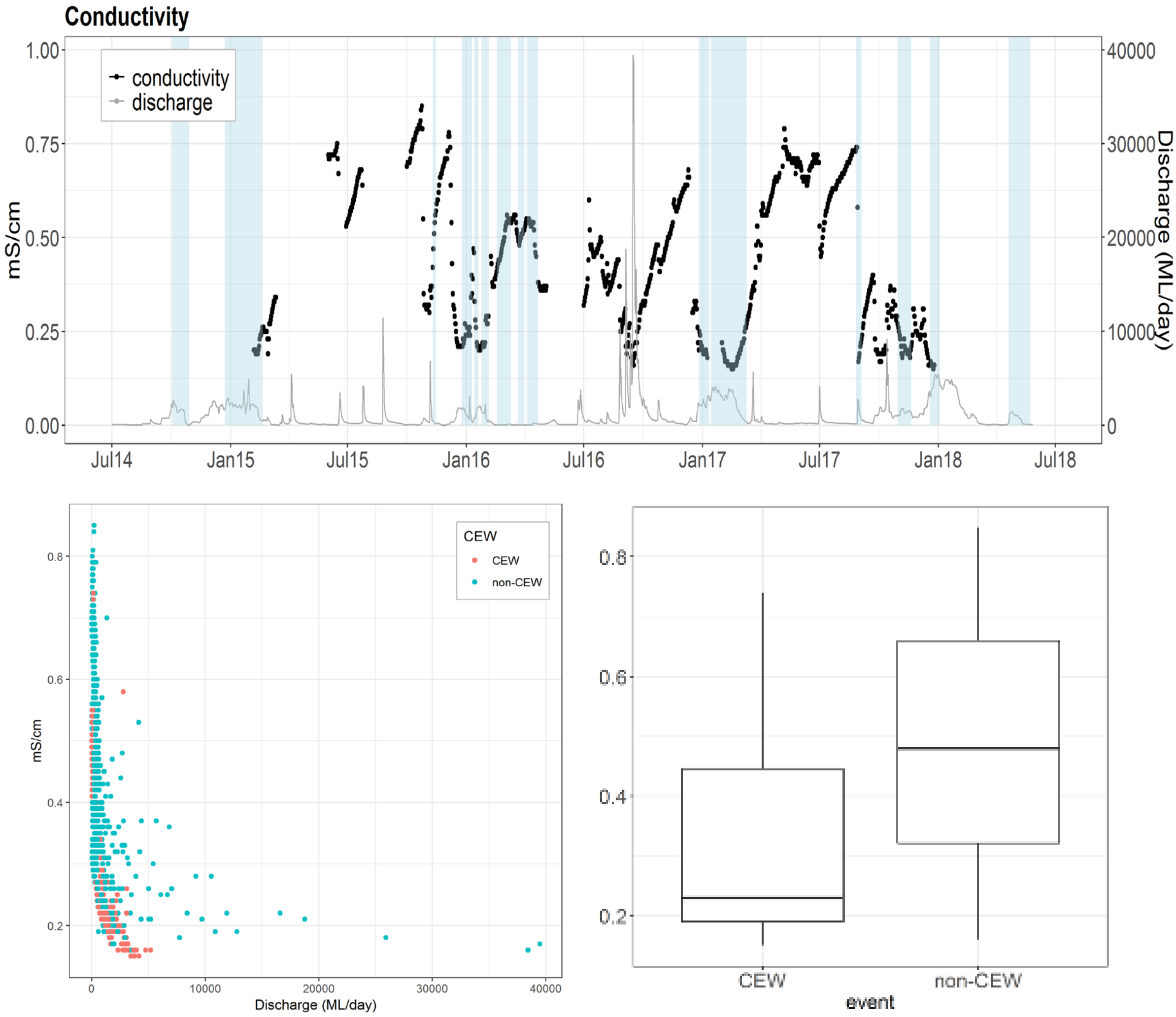


Figure C-6: (Top) Mean daily conductivity with black line represents discharge. (Bottom left) Regression between discharge and conductivity in 2014-18. (Bottom right) Boxplot of average conductivity by year in 2014-18.

C.3.6 Dissolved oxygen regime

Mean daily dissolved oxygen was highly variable and was occasionally outside the ANZECC water quality guideline trigger values (Table C-4 and Figure C-7). Dissolved oxygen was most variable during base flow and low flow conditions (discharge 0 to 2,500 ML/d) and remained between 65% and 100% saturation when discharge was above 2,500 ML/d (Figure C-7). Dissolved oxygen had a poor correlation with discharge (Table C-5). There are several explanations, including;

- differences in upstream water sources of differing water quality,
- antecedent flow conditions associated with time since flow recession, and,
- phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015).

Dissolved oxygen concentrations were lower in autumn/winter, reflecting cooler water temperatures regulating the metabolism of primary producers (Figure C-7).

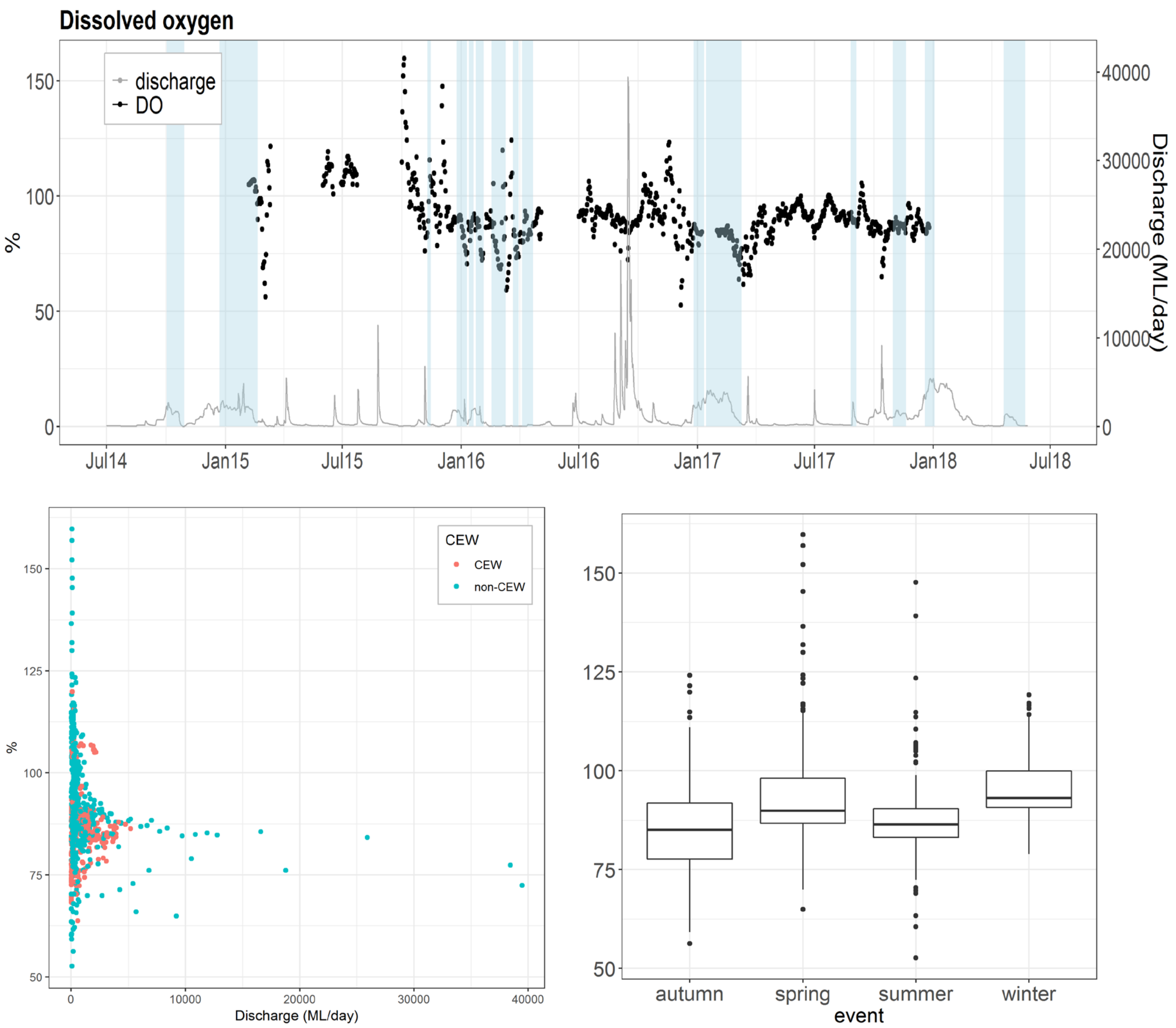


Figure C-7: (Top) Mean daily dissolved oxygen with black line represents discharge. (Bottom left) Regression between discharge and dissolved oxygen in 2014-18. (Bottom right) Boxplot of average dissolved oxygen by year in 2014-18.

C.3.7 Stream metabolism regime

In 2017-19, six in-channel flow pulses containing environmental water (event 12 – event 17) were used to examine responses in stream metabolism to discharge events (Table C-3). All stations exhibited similar patterns of discharge with different magnitudes and short time lags in discharge to downstream stations (Figure C-8). The magnitude of flow in environmental water events in 2017-19 was predominantly small freshes with peak flow less than 5,000 ML/d, with exception of a single natural flow pulse event of 9,200 ML/d in mid-October 2017. Water temperature variations were similar in all stations, attributed to seasonal patterns rather than flow or other environmental conditions (Figure C-8). Mean daily dissolved oxygen concentrations were highly variable and were different between stations (Figure C-8).

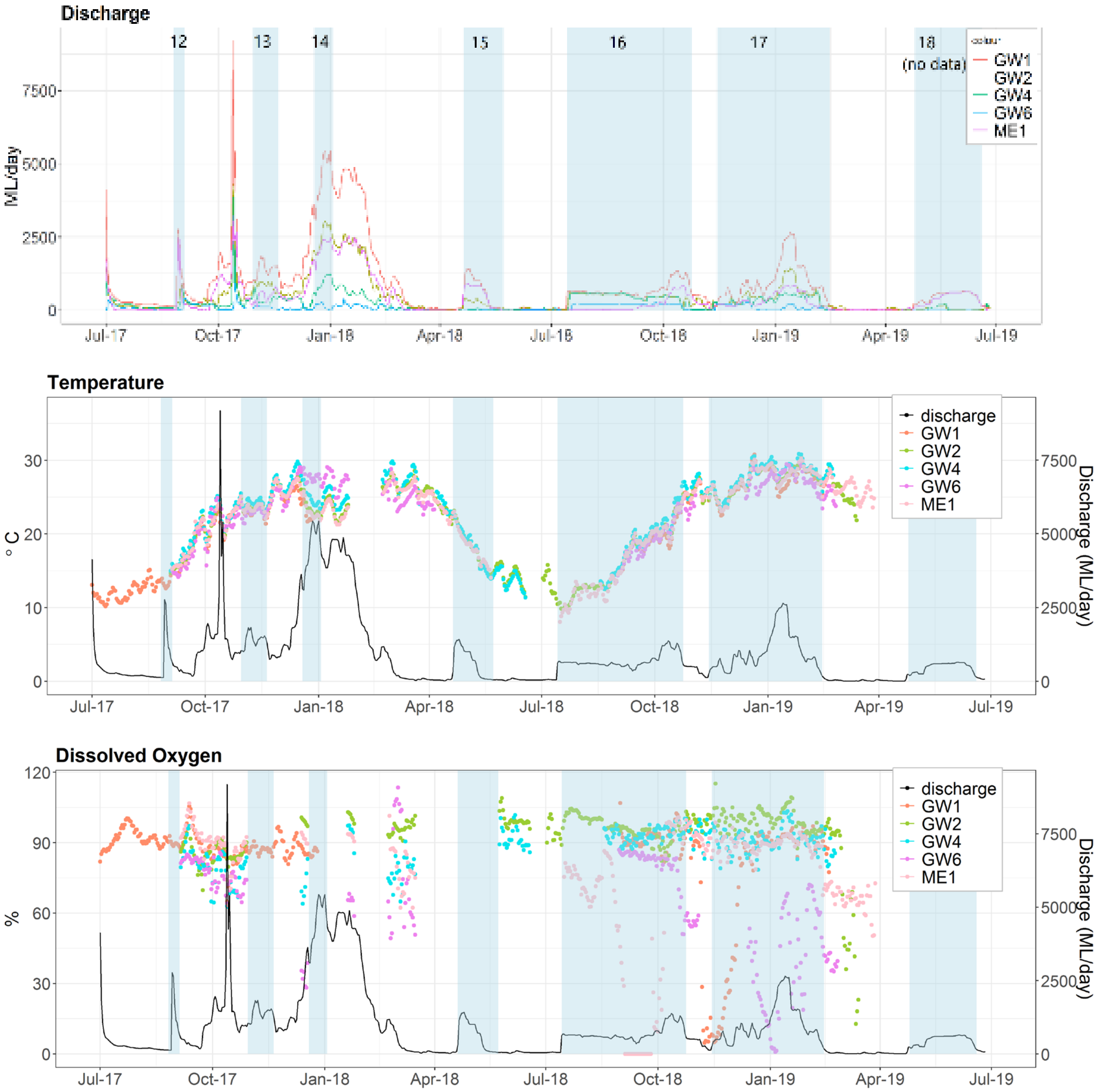


Figure C-8: Mean daily discharge (ML/d), temperature and dissolved oxygen concentrations at long-term station and four additional stream metabolism sites with shaded areas representing 7 environmental water events details in Table C-3.

A total of 769 daily stream metabolism records (Table C-6) showed stream metabolism rates were highly variable in the Gwydir River (Figure C-9). The highest rates of GPP and ER were recorded in the Mehi River (ME1) station in late August 2018 during an extended period of low flows (Figure C-9). Generally, the Gwydir River zone was a carbon sink with more net carbon consumed than produced (Figure C-10). The major reason for heterotrophy in this system was consistently low rates of GPP and high rates of ER (Figure C-9). Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which dissolved and particulate organic matter are consumed by detritivores that then fuel the invertebrate, fish and waterbird food webs (Kobayashi *et al.* 2009).

GPP rates were highly variable during base flow conditions and were constrained to below 5 mg/O_2/L/d when discharge was above 1,700 ML/d (Figure C-11). ER rates showed a similar pattern and were constrained to below 10 mg/O_2/L/d when discharge was above 1,700 ML/d (Figure C-11). Flow events generally led to a reduction in net carbon production and consumption. Moreover, GPP rates increased with increasing temperature with rates above 5 mg/O_2/L/day only occurring when temperature was above 18 °C and rates above 10 mg/O_2/L/day only occurred when temperature was above 23 °C (Figure C-11). This reflects that rates of primary production were also driven by increased water temperature. It is proposed that metabolism indicators respond to threshold changes in discharge, rather than a linear trend. Complex interactions between stream metabolism, discharge, conductivity, turbidity and chlorophyll *a* concentrations were observed in the LTIM Gwydir project in 2017-19 and need further investigation to be better understood.

Table C-6: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each stream metabolism indicators at five stations between 2017 and 2019 within the Gwydir Selected Area.

Variable	Station	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
GPP	GW1	0.32	2.40	4.24	9.48	19.30	125
	GW2	0.15	1.68	2.79	5.25	15.77	303
	GW4	0.65	2.48	5.00	8.94	15.02	161
	GW6	0.25	0.62	0.85	1.38	6.23	56
	ME1	0.06	0.97	2.11	3.87	26.13	124
ER	GW1	2.28	4.38	8.92	15.15	26.14	125
	GW2	0.01	2.06	4.32	5.96	40.83	303
	GW4	1.97	4.92	8.51	12.30	20.27	161
	GW6	1.80	3.23	4.42	6.56	31.40	56
	ME1	0.37	2.68	5.26	7.35	188.90	124
NPP	GW1	-23.26	-5.78	-2.87	-1.78	0.55	125
	GW2	-25.06	-2.01	-0.47	0.68	6.97	303
	GW4	-12.29	-4.02	-2.44	-1.36	1.96	161
	GW6	-30.60	-4.98	-3.56	-2.59	0.06	56
	ME1	-162.80	-4.45	-2.87	-0.74	1.05	124

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

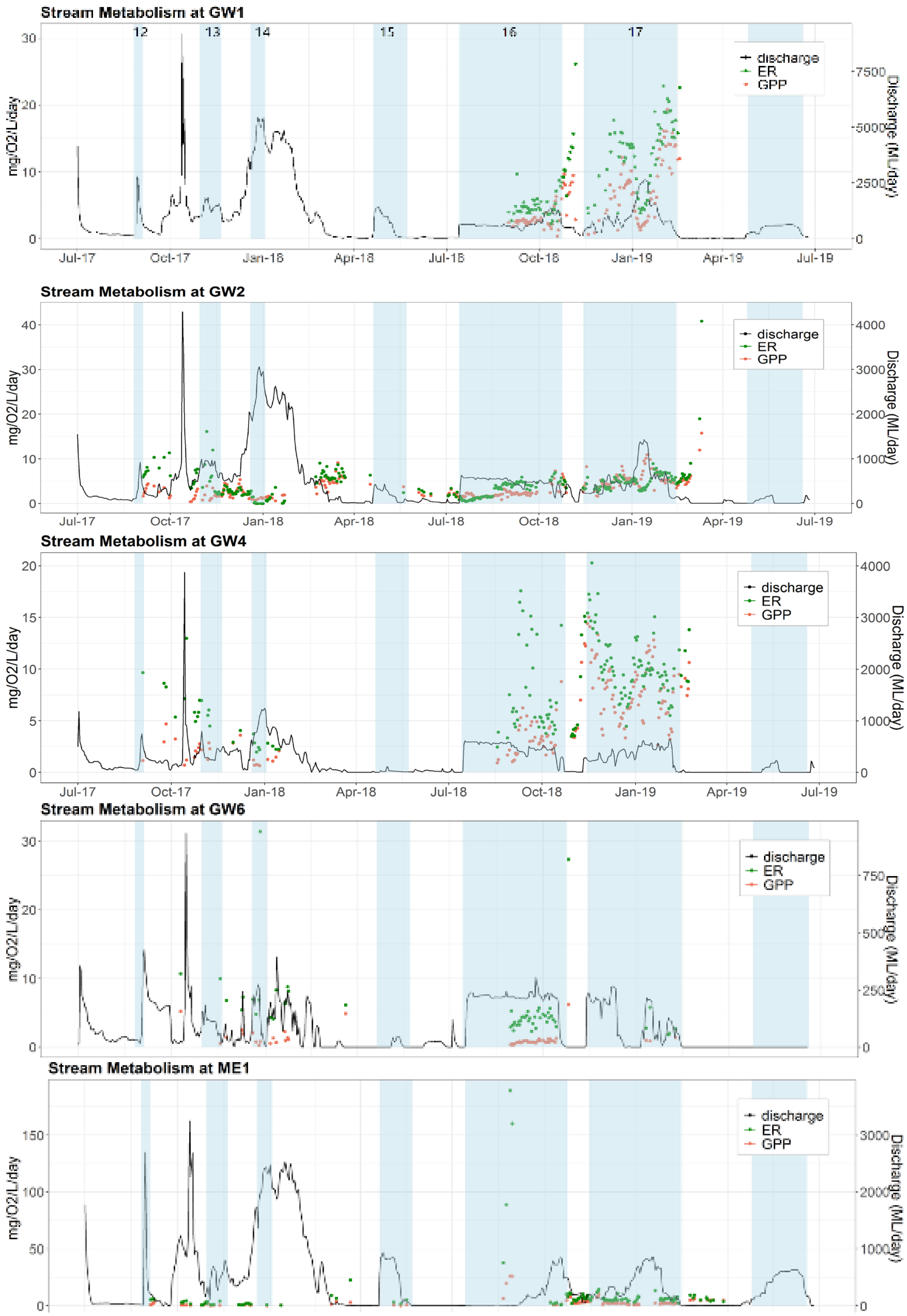


Figure C-9: Daily GPP and ER at five stations with black line represents discharge at the nearest gauge stations. Shaded areas representing 7 environmental water events in 2017-19 details in Table C-3.

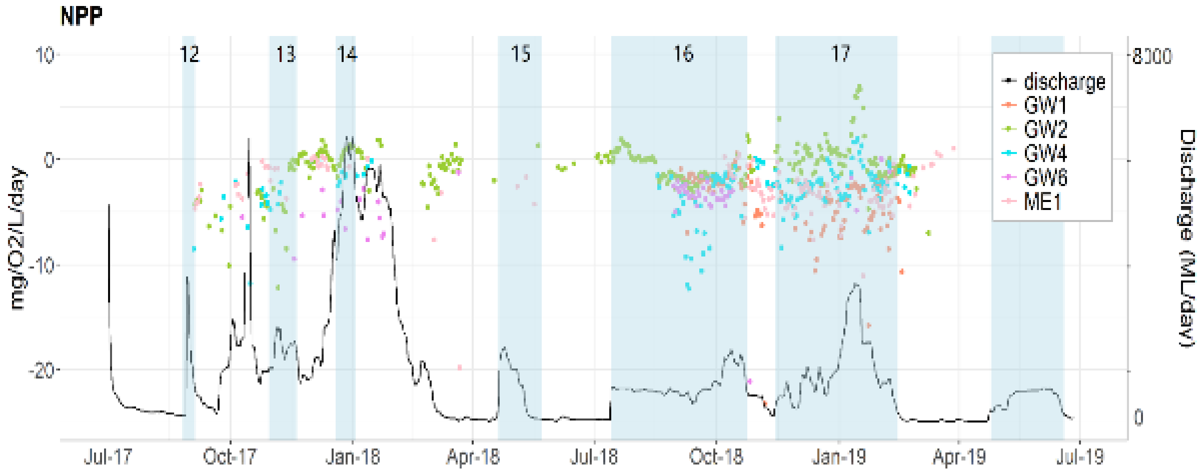


Figure C-10: Daily NPP at five stations with black line represents discharge at GW1 gauge station. Shaded areas representing 7 environmental water events in 2017-19 details in Table C-3.

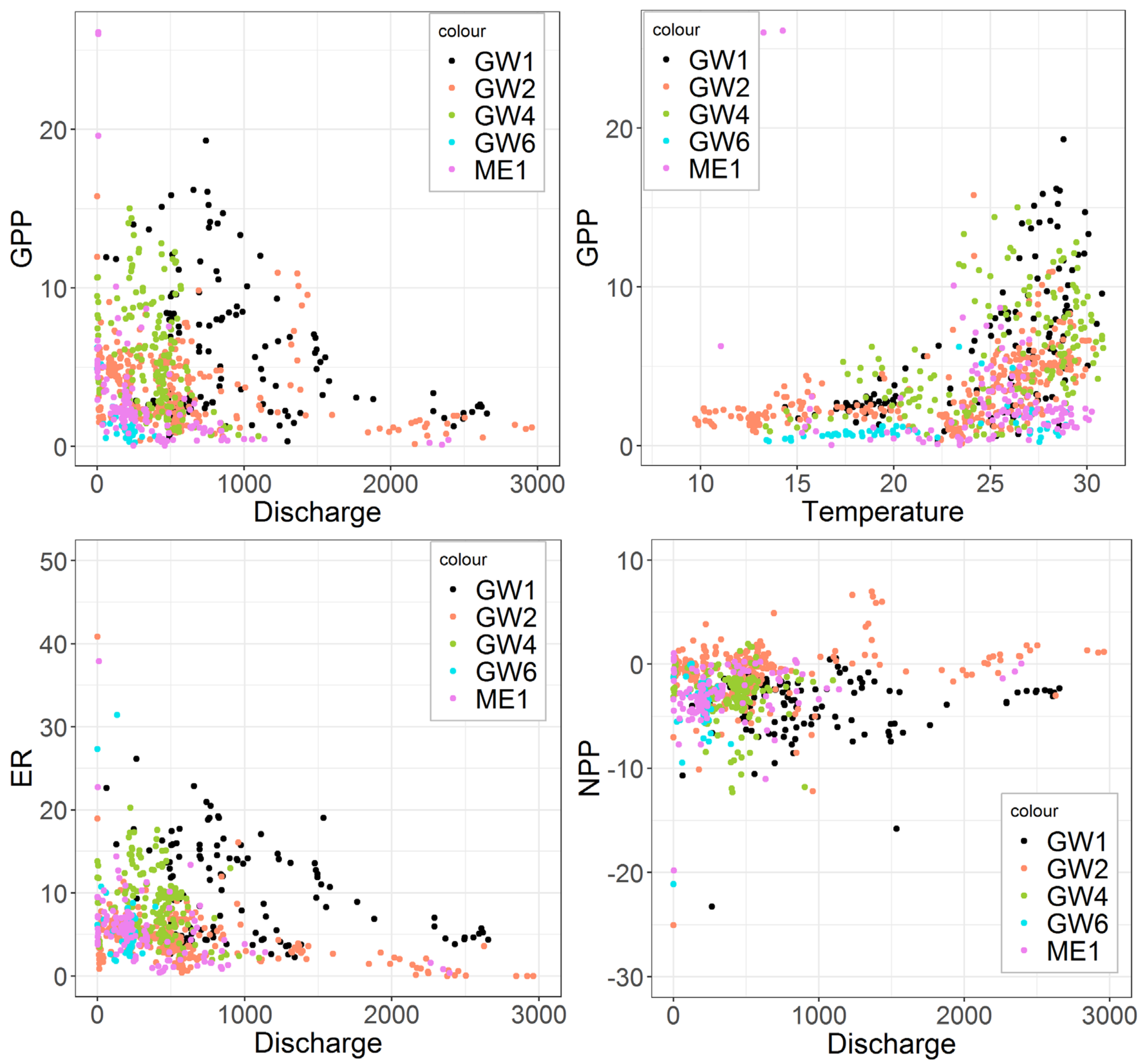
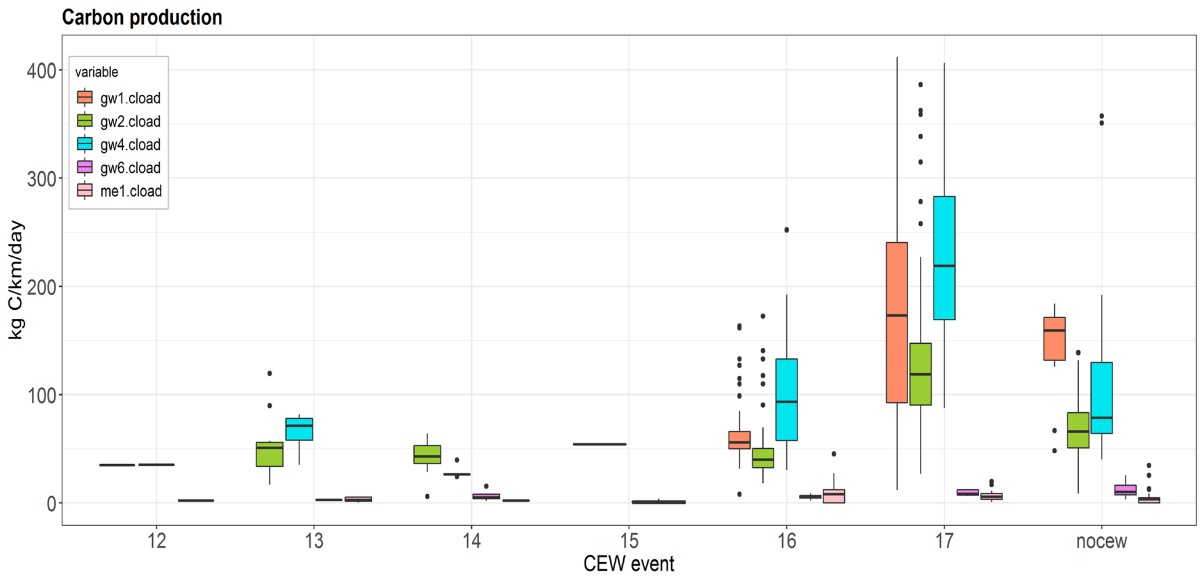


Figure C-11: Regressions between discharge and stream metabolism within the Gwydir Selected Area in 2017-19. Units are mg/O_2/L/day.

C.3.8 Carbon production

The estimated production of carbon ranged from 0.1 to 411.9 kg C/km/d (Table C-7). In general, GW1, GW2 and GW4 stations had a higher carbon production than GW6 and ME1 stations due to larger channel cross sectional area leading to a higher carbon production (Figure C-12). Seasonal changes in temperature exert a strong influence on carbon production with generally lower carbon production in autumn and winter across all five stations from lower rates of GPP in cooler seasons with lower water temperature (Figure C-12).



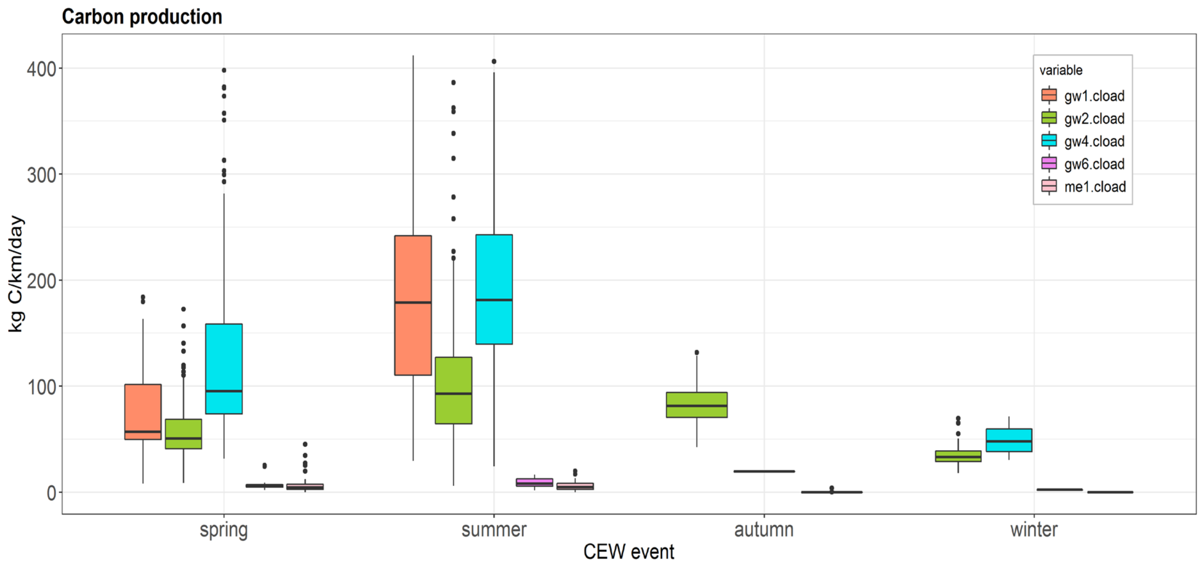


Figure C-12: Boxplots of carbon production by environmental water events and by season within the Gwydir Selected Area in 2017-19.

Table C-7: Average carbon production (kg C/km/day) of each station between 2017 and 2019 within the Gwydir Selected Area.

Variable	Station	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
Carbon production	GW1	8.3	54.1	110.6	199.8	411.9	125
	GW2	6.2	37.4	64.2	109.9	386.4	303
	GW4	24.5	75.1	145.7	247.4	406.3	161
	GW6	1.8	4.7	6.2	8.9	25.4	56
	ME1	0.0	1.2	4.4	8.6	45.4	124

C.4 Conclusion

Eighteen in-channel flow pulses containing environmental water were recorded in the Gwydir Selected Area. In 2016-17, a bankfull event recorded a peak flow around 39,000 ML/d. All other environmental water flow events had peak flows less than 5,000 ML/d. Water quality monitoring between 2014 and 2018 at the Gwydir station showed the delivery of environmental water contributed to consistent improvements in water quality. The most consistent pattern was a significant reduction in mean daily pH, conductivity and turbidity when compared to periods without environmental water. This reflected dilution provided by environmental water, and the changes in water chemistry associated with the increase in discharge and wetted area of channels. In particular, a potential discharge threshold around 5,000 ML/d was observed in pH and conductivity. Water temperature followed a predictable pattern with seasonal changes exerting a strong influence on many other water quality parameters. Dissolved oxygen concentrations were highly variable during base flow and low flow conditions (0 - 2,500 ML/d) and reduced with increasing discharge up to 25,000 ML/d. It is likely that phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence. Similarly, prolonged low flow events resulted in a consistent increase in conductivity and pH.

Additional stream metabolism monitoring in 2017-19 identified the Gwydir River as a carbon sink. Stream metabolism rates were highly variable with higher rates of GPP with increasing water temperature reflected in increased rates of primary production. On the other hand, an increase in discharge also led to an increase in turbidity, which conversely limited GPP. It is proposed that rates of metabolism respond to threshold changes in discharge rather than following a linear trend.

C.5 References

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Appendix D Category III Water Quality

D.1 Introduction

The Category III Water Quality indicator aimed to assess the contribution of Commonwealth environmental water to the improved quality of water within the Gwydir River system Selected Area (Gwydir Selected Area). As such this indicator is linked to Fish (Channel), Waterbird Diversity, Microinvertebrates, Macroinvertebrates and Hydrology (River, Watercourse) indicators. Several specific questions were addressed through this indicator in the 5-year monitoring period:

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

D.2 Methods

D.2.1 Sampling sites and parameters

Category III Water Quality indicators were measured in association with Category III Microinvertebrate (Appendix E) and Macroinvertebrate (Appendix F) indicators on twenty sampling occasions between 2014 and 2019. Sampling sites were located in five Sampling zones within the Gwydir Selected Area: Gwydir River, Mehi River, Moomin Creek, Gingham Watercourse and Lower Gwydir wetlands (Figure D-1).

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

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

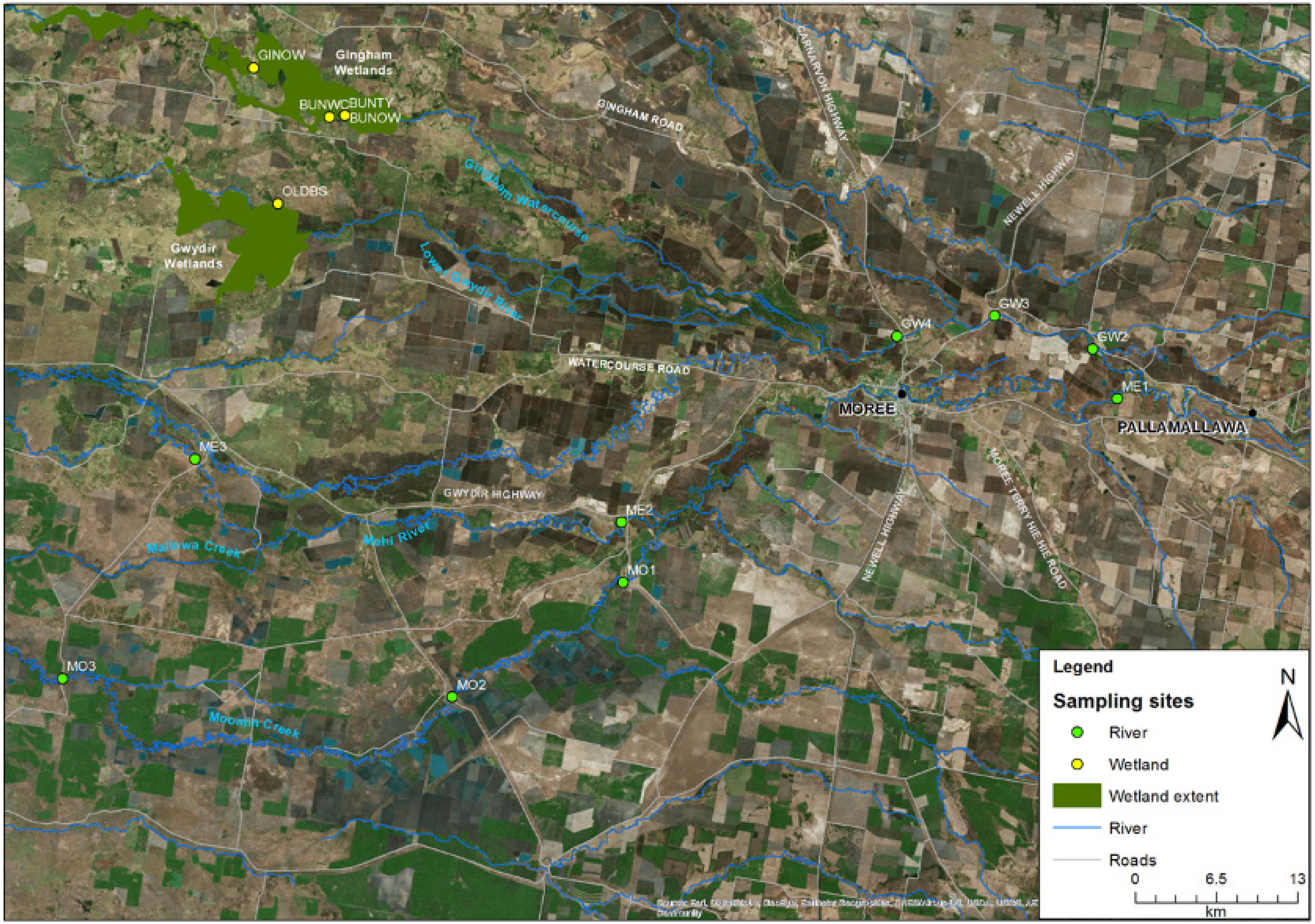

Figure D-1: Location of water quality sites (Cat III Water Quality) within the Gwydir Selected Area between 2014 and 2019.

Table D-1: Category III Water Quality (water chemistry and nutrient) indicators and stream metabolism indicators measured in twenty sampling occasions in 2014-19.

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

D.2.2 Explanatory (spatial, temporal and hydrological) factors

Spatial and temporal factors were used to test if water quality indicators were spatially or temporally dependent. Seventeen sampling sites were categorised in two ecosystems: channel and wetland (Table D-2). Twenty sampling occasions were categorised into five years and two seasons (i.e. summer from October to April and winter from May to September; Table D-3).

Hydrological data were used to test the influence of environmental water and natural flow events. In all channel sites, daily discharge (ML/d) data was collated from the nearest WaterNSW gauge to determine hydrological thresholds for each water quality indicator (Table D-2 and Figure D-2). In all wetland sites, time since connection was identified and calculated using data from the nearest WaterNSW gauge (Table D-2 and Figure D-3). In Gingham wetland sites (i.e. BUNOW, BUNTY and BUNWC), time since connection was calculated using the days between when Gingham@Tillaloo gauge dropped below 10 ML/d and the first day of the next sampling trip (Figure D-3). At 10 ML/d at Tillaloo it was assumed water would cease to flow into the wetlands. For Gingham site (GINWH), time since connection was calculated using days between when Gingham@Waterhole gauge level began to recede and the first day of the next sampling trip (Figure D-3). In the Lower Gwydir sites (OLDBS, OLDCB, OLDTY and OLDWC), connection was identified when Gwydir@Millewa gauge water level rose above 1.5 m and the first day of the next sampling trip (Figure D-3). 1.5 m on the Millewa gauge was considered to be the point at which water flowed into the Lower Gwydir wetlands.

Continuous hydrological factors (i.e. discharge in channel and time since connection in wetland) were further transformed into categorical hydrological factors (discharge groups in channel and time since connection group in wetland) to infer patterns in statistical analyses.

Table D-2: Location of seventeen water quality sites (Cat III Water Quality) and the nearest gauge stations within the Gwydir Selected Area. Map projection GDA94 Zone 55

Ecosystem	Sampling Zone	Site	Easting	Northing	WaterNSW gauge station	Distance from gauge station (downstream)
Channel	Gwydir River (GW)	Gwydir River Site 2 (GW2)	791299	6740442	418042 (Gwydir D/S Tareelaroi)	6 km
		Gwydir River Site 3 (GW3)	783417	6743136		11 km
		Gwydir River Site 4 (GW4)	775598	6741492	418004 (Gwydir @ Yarraman Br)	0 km
	Mehi River (ME)	Mehi River Site 1 (ME1)	793235	6736492	418044 (Mehi D/S Tareelaroi)	3 km
		Mehi River Site 2 (ME2)	753567	6726597	418037 (Mehi D/S Combadello)	7 km
		Mehi River Site 3 (ME3)	719420	6731644	418085 (Mehi D/S Gundare Reg)	15 km
	Moomin Creek (MO)	Moomin Creek Site 1 (MO1)	753679	6721789	418048 (Moomin@Combadello)	10 km
		Moomin Creek Site 2 (MO2)	740017	6712591	418060 (Moomin@Glendello)	0 km
		Moomin Creek Site 3 (MO3)	708808	6714077	418061 (Moomin@Alma Br)	0 km
Wetland	Gingham wetland (GIN)	Bunnor Open Water (BUNOW)	731409	6759165	418076 Gingham@Tillaloo Br	8 km
		Bunnor Typha (BUNTY)	731394	6759148		
		Bunnor Water Couch (BUNWC)	730157	6759022		
		Gingham Waterhole (GINWH)	724103	6762962	418077 Gingham @ Water Hole	0 km
	Lower Gwydir wetland (OLD)	Old Dromana Bolboschoenus (OLDBS)	726067	6752088	418066 GWYDIR@MILLEWA	3 km
		Old Dromana Coolibah (OLDCB)	727611	6750685		
		Old Dromana Typha (OLDTY)	726680	6751125		
		Old Dromana water Couch (OLDWC)	726664	6751404		

Table D-3: Explanatory (temporal) factors to infer Category III Water Quality patterns in statistical analyses

Year	Sampling occasion	Month	Season	Number of sites
2014-15	1	2014-12	summer	7
	2	2015-02	summer	7
	3	2015-03	summer	6
	4	2015-04	summer	5
2015-16	5	2015-09	winter	12
	6	2016-02	summer	12
	7	2016-03	summer	12
	8	2016-04	summer	11
2016-17	9	2016-10	summer	15
	10	2016-12	summer	12
	11	2017-02	summer	13
	12	2017-05	winter	13
2017-18	13	2017-09	winter	13
	14	2017-11	summer	13
	15	2018-02	summer	13
	16	2018-04	summer	12
2018-19	17	2018-08	winter	16
	18	2018-12	summer	16
	19	2019-01	summer	12
	20	2019-03	summer	11

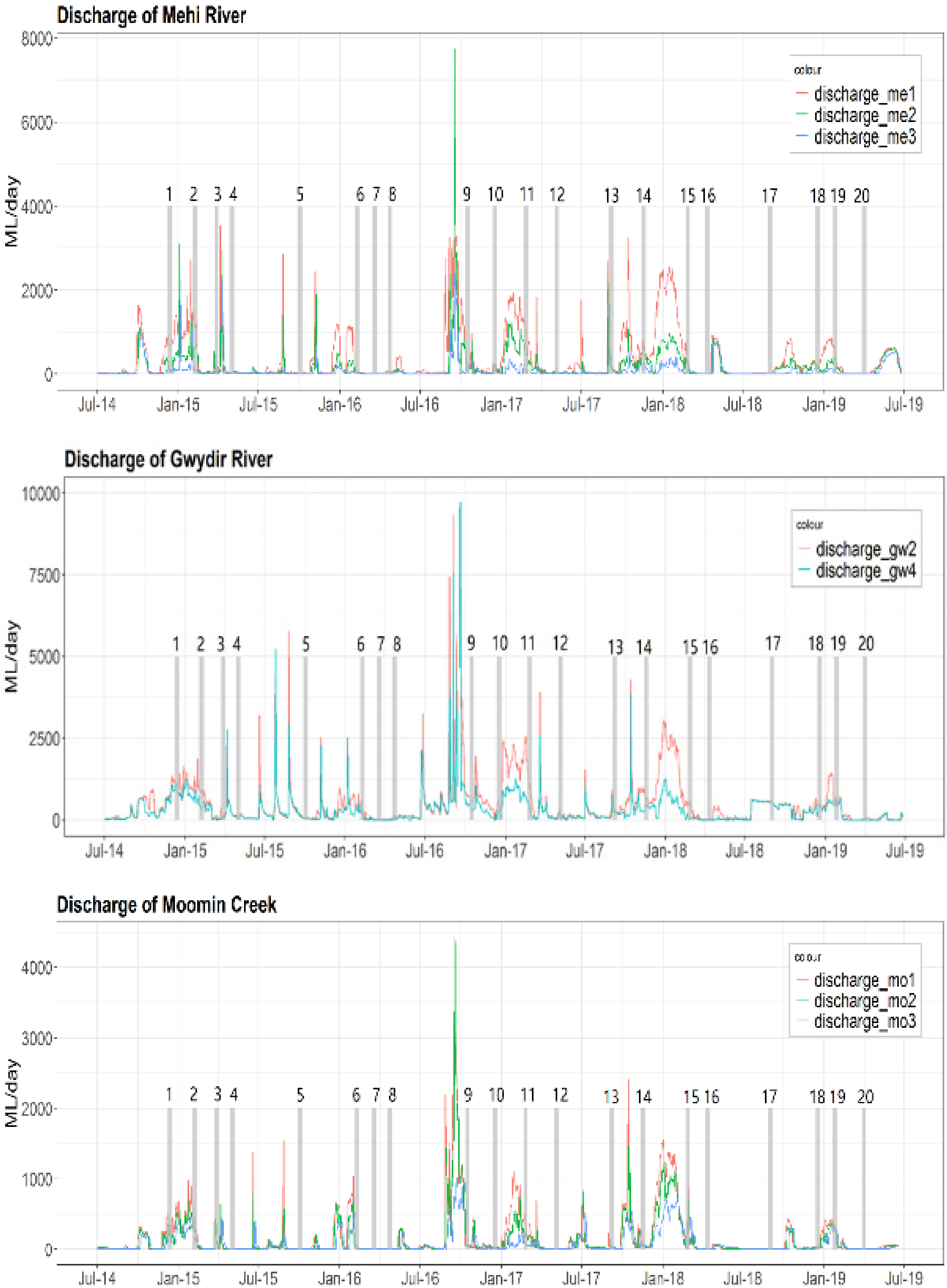

Figure D-2: Mean daily discharge in the Gwydir River, Mehi River and Moomin Creek with sampling occasions (numbered grey bars). Water gauge stations information in Table D-2.

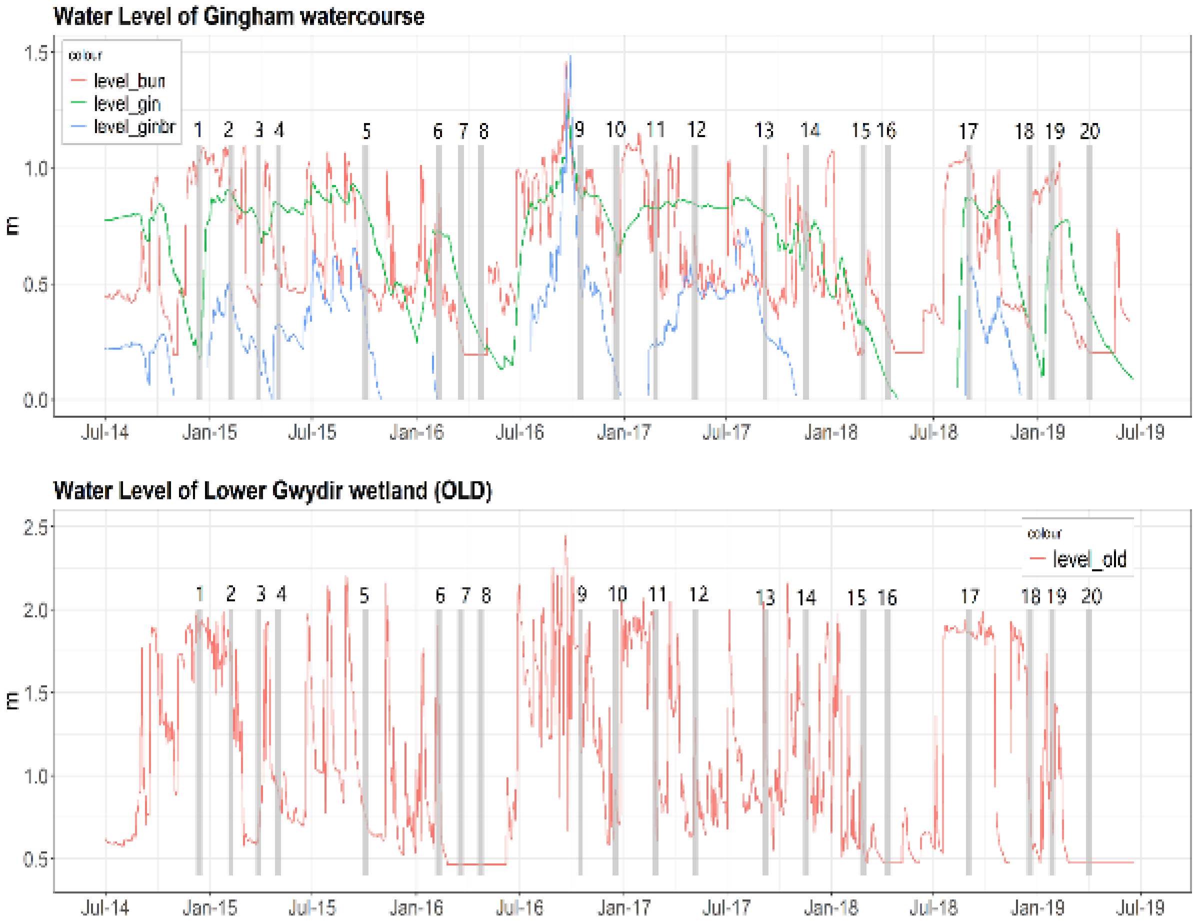

Figure D-3: Mean daily water level in the Gingham and Lower Gwydir wetlands with sampling occasions (numbered grey bars). Water gauge stations information in Table D-2

D.2.3 Statistical methods

Principal Components Analysis

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

Summary statistics and water quality guidelines

The minimum, 20th, 50th (median) and 80th percentile and maximum values for each water quality indicator were calculated relative to ANZECC South-East Australia lowland river water quality trigger values (ANZECC, 2000).

PERMANOVA

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

PERMANOVA was used to test the overall difference in water quality indicators between ecosystem, year and season and their interactions. Within ecosystems, water quality patterns were mainly driven by discrete hydrological events and therefore were analysed separately. In the channel ecosystem, PERMANOVA was used to test the difference in water quality indicators between discharge categories. In the wetland ecosystem, PERMANOVA was used to test the difference in water quality indicators between time since connection categories.

Regression

Relationships between water quality indicators and continuous hydrological factors were analysed using non-linear polynomial regression. In the channel ecosystem, regression was used to explore the relationships between water quality indicators and discharge (ML/d). In the wetland ecosystem, regression was used to explore the relationships between water quality indicators and time since connection (days). Regression outputs of F-statistic, degree of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

D.3 Results and Discussion

D.3.1 Overall patterns

A PCA of water quality parameters (Figure D-4) showed that the complex spatial and temporal patterns in water quality were driven primarily by hydrological conditions. PC1 (axis-x) explained 26.8% of the variance with total nutrients, dissolved organic carbon and chlorophyll *a* concentrations as dominant explanatory variables (Figure D-4). PC2 (axis-y) explained 17.1% of the variance with dissolved oxygen and pH being positively aligned, and filterable reactive phosphorus negatively correlated (Figure D-4).

As expected, water quality differed between the river channels and wetland environments, evidenced by marked differences in water column pH, turbidity, conductivity and nutrient concentrations. The spatial pattern identified that the three channel zones (i.e. Gwydir, Mehi and Moomin) had relatively similar environmental conditions (Figure D-4a). On the other hand, the Gingham and Lower Gwydir wetland samples were the most disperse along the PC1 axis, reflecting that the environmental conditions were highly variable within two wetland zones, between sample occasions and highly depending on vegetation types (Figure D-4a).

There was a temporal (year) pattern in water quality condition (Figure D-4b). In particular, exceptionally high dissolved oxygen concentrations and pH were observed in the Gingham wetland in 2017-18 and in the Lower Gwydir wetlands in 2018-19 during the retention/contraction phase in late summer (Figure D-4b). In general, extended dry periods with a long period from time since connection for wetlands led to poor water quality in channel and wetland ecosystems.

Seasonal change exerts a strong influence on temperature as expected, with PERMANOVA analysis showing a significant difference between seasons (Table D-4, 5 and Figure D-5). Variations in water temperature were attributed to broader seasonal patterns rather than flow or other environmental conditions.

The pH values were consistently alkaline and occasionally exceeded the upper ANZECC guideline (Table D-4). Lower pH was generally found in wetland sites as leachates derived from rewetted organic matter lowers the pH (Figure D-5). In comparison, channels consistently had relatively higher pH (Figure D-5). A three-way PERMANOVA showed a significant interaction between ecosystem and year (Table D-5). For example, in 2016-17, pH was significantly lower ($p<0.05$, Figure D-5), reflecting a dilution effect provided by several flow pulses in this 'wet year' lowering pH to more neutral levels.

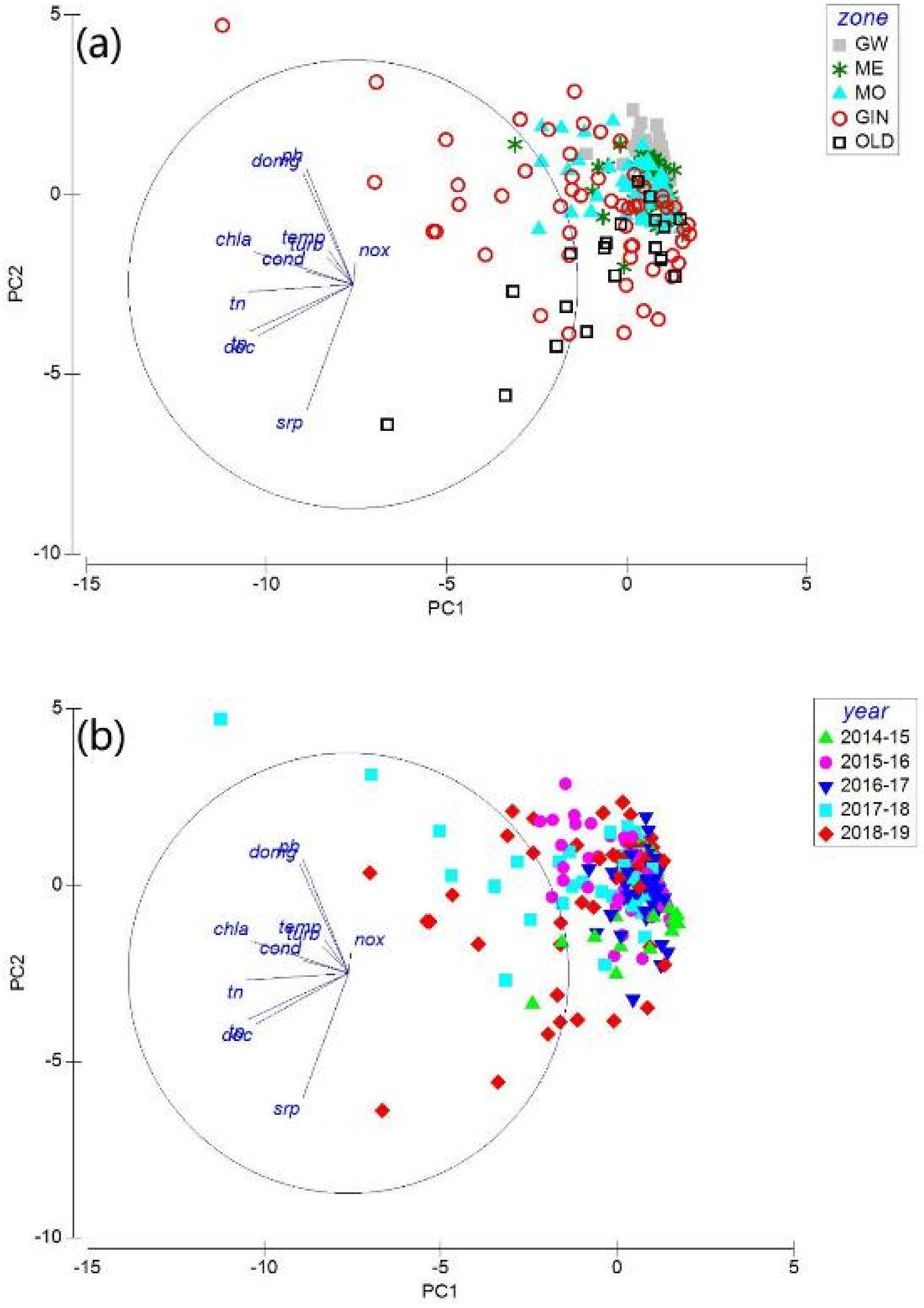

Figure D-4: Principal components analysis (PCA) bi-plot of Category III Water Quality indicators showing spatial (zone) and temporal (year) patterns with vectors of eleven water quality indicators (normalised data, Spearman correlation) which underlie the environmental patterns.

Table D-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each water quality indicator with water quality guidelines from ANZECC (2000).

Variable	ANZECC (2000)	Zone	Minimum	Percentile			Maximum	Number of samples
				20th	50th	80th		
Temperature (°C)	-	GW	14.8	20.7	25.9	28.2	32.3	60
		ME	10.3	19.0	23.8	26.6	33.4	48
		MO	11.8	19.2	23.8	27.1	30.0	48
		GIN	10.7	20.7	23.6	30.0	35.2	55
		OLD	11.8	15.9	22.5	24.7	32.9	20
pH	6.5 - 8	GW	7.3	7.7	8.2	8.6	9.5	60
		ME	7.3	7.6	7.9	8.4	8.8	48
		MO	7.3	7.5	7.9	8.5	9.1	48
		GIN	6.7	7.5	7.8	8.5	9.9	55
		OLD	6.7	7.2	7.4	7.6	8.2	20
Turbidity (NTU)	6 - 50	GW	0.0	13.1	43.8	91.3	551.0	60
		ME	0.0	22.1	56.2	138.0	377.0	48
		MO	19.6	57.7	102.0	219.0	660.0	48
		GIN	0.0	16.6	47.1	99.6	462.0	55
		OLD	0.0	2.0	6.3	20.5	124.0	20
Conductivity (mS/cm)	0.125 - 2.2	GW	0.1	0.2	0.3	0.5	0.6	60
		ME	0.2	0.2	0.3	0.5	0.8	48
		MO	0.2	0.2	0.4	0.5	0.7	48
		GIN	0.2	0.3	0.5	0.6	0.9	55
		OLD	0.2	0.3	0.4	0.4	0.7	20
Dissolved oxygen (mg/L)	85 – 110 (in %)	GW	3.3	6.2	8.6	9.7	11.9	60
		ME	3.0	6.0	7.6	9.7	11.2	48
		MO	3.0	6.0	7.3	9.7	13.0	48
		GIN	2.0	3.7	6.8	10.9	20.0	55
		OLD	1.8	2.7	5.1	8.6	11.8	20
Chlorophyll *a* (µg/L)	5	GW	0.0	2.9	7.0	10.9	92.4	60
		ME	0.3	3.7	8.9	14.7	117.9	48
		MO	2.5	8.3	15.0	28.6	159.1	48
		GIN	0.0	2.6	8.9	58.4	268.0	55
		OLD	1.8	4.5	8.8	23.5	82.3	20
Dissolved organic carbon (mg/L)	-	GW	4.5	7.4	10.4	11.3	16.5	60
		ME	4.1	8.0	11.0	12.3	29.5	48
		MO	3.5	8.5	11.4	14.6	75.6	48
		GIN	9.2	12.3	18.4	30.5	49.2	55
		OLD	9.1	12.7	14.6	27.0	47.6	20

Variable	ANZECC (2000)	Zone	Minimum	Percentile			Maximum	Number of samples
				20th	50th	80th		
Total nitrogen (µg/L)	500	GW	114.5	412.0	598.0	991.0	1,957.7	60
		ME	66.2	465.0	623.0	1,000.0	2,164.5	48
		MO	34.0	486.0	639.0	1,079.0	1,736.8	48
		GIN	257.5	623.0	1,161.0	2,563.0	8,379.5	55
		OLD	443.5	930.0	1,249.0	2,220.0	5,823.3	20
Total phosphorus (µg/L)	40	GW	29.8	60.6	100.0	150.0	268.0	60
		ME	34.0	81.3	132.0	240.0	808.8	48
		MO	66.2	110.0	199.0	333.0	1,041.6	48
		GIN	36.1	102.0	189.0	594.0	1,377.6	55
		OLD	58.0	167.0	289.0	699.0	1,230.0	20
Nitrate-nitrite (µg/L)	50	GW	0.0	77.4	144.0	322.0	698.6	60
		ME	0.0	43.5	116.0	257.0	502.8	48
		MO	0.0	47.9	127.0	197.0	346.7	48
		GIN	15.9	53.9	122.0	246.0	579.0	55
		OLD	1.0	67.4	131.0	250.0	364.0	20
Filterable reactive phosphorus (µg/L)	20	GW	0.0	11.5	27.0	45.0	92.5	60
		ME	0.0	12.4	31.9	63.7	195.1	48
		MO	2.6	15.7	30.9	67.5	121.8	48
		GIN	6.8	18.7	62.3	145.0	493.7	55
		OLD	17.5	36.2	101.0	413.0	820.1	20

Table D-5: Summary of PERMANOVA (P(perm)) results of water quality and stream metabolism indicators. * represents significant results of p-value <0.05

Water quality indicator	Three-way PERMANOVA (all three zones)			
	ECOSYSTEM	SEASON	YEAR	Interaction terms
Temperature	0.647	***0.001****	***0.001****	***SEASON x YEAR (0.001)***
pH	***0.001****	0.974	***0.001****	***ECOSYSTEM x YEAR (0.001)***
Turbidity	***0.002****	***0.006****	***0.010****	***SEASON x YEAR (0.024)***
Conductivity	***0.001****	***0.039****	***0.001****	***ECOSYSTEM x YEAR (0.001)***
Dissolved oxygen	***0.007****	0.278	***0.001****	***ECOSYSTEM x YEAR (0.001)***
Chlorophyll *a*	0.194	***0.005****	***0.002****	***ECOSYSTEM x SEASON (0.013)***
Dissolved organic carbon	***0.001****	***0.001****	***0.001****	***ECOSYSTEM x SEASON (0.002)***
Total nitrogen	***0.001****	0.106	***0.001****	***ECOSYSTEM x SEASON x YEAR (0.001)***
Total phosphorus	***0.001****	***0.001****	***0.001****	***ECOSYSTEM x YEAR (0.001)***
Nitrate-nitrite	0.731	0.755	0.070	***SEASON x YEAR (0.001)***
Filterable reactive phosphorus	***0.001****	0.936	***0.001****	***ECOSYSTEM x YEAR (0.001)***

Water quality indicator	Three-way PERMANOVA (all three zones)			
	ECOSYSTEM	SEASON	YEAR	Interaction terms
Gross primary production	0.335	0.201	0.173	***ECOSYSTEM x YEAR (0.011)***
Ecosystem respiration	0.138	0.423	0.262	Not Significant
Net primary production	***0.044****	0.267	***0.030****	***ECOSYSTEM x YEAR (0.012)***

Turbidity was highly variable and consistently above the ANZECC guideline range (Table D-4). In particular, the channel ecosystem had high and highly variable turbidity levels associated with hydrological variability (Figure D-5). Reduced turbidity in wetland ecosystems resulted from reduced flow velocity and emergent plants trapping sediments from the water column. A three-way PERMANOVA showed a significant interaction between season and year (Table D-5). In 2016-17, turbidity was significantly lower than all other years ($p<0.5$, Figure D-5), reflecting a dilution effect provided by several flow pulses in this ‘wet year’.

Conductivity values were consistently within the ANZECC guideline trigger values (Table D-4). A three-way PERMANOVA showed a significant interaction between Ecosystem and Year (Table D-5). Three channel zones had relatively a lower average conductivity compared with the wetland zones (Figure D-6).

Dissolved oxygen concentrations had a wider range associated with flow magnitude in previous years, occasionally outside ANZECC guideline trigger values (Table D-4 and Figure D-6). A three-way PERMANOVA analysis showed a significant interaction between Ecosystem and Year (Table D-5), with significantly higher dissolved oxygen in channel environments.

Chlorophyll *a* concentrations were consistently higher than the ANZECC guideline trigger value (Table D-4). A three-way PERMANOVA showed a significant interaction between Ecosystem and Season (Table D-5). For example, in 2017-19 ‘dry years’, chlorophyll *a* concentrations were higher than all other years in both channel and wetland ecosystems (Figure D-6), reflecting the higher chlorophyll *a* in summer months, exacerbated during extended periods of low or no flow.

Nutrient (TN, TP, NOx and FRP) concentrations were consistently higher than the ANZECC guideline trigger values (Table D-4). Three-way PERMANOVA showed a significant interaction between Ecosystem, Year and/or Season (Table D-5). In general, wetland sites had consistently higher DOC, TN, TP and FRP concentrations than channel sites, reinforcing the role of wetlands as a long-term sink for nutrients.

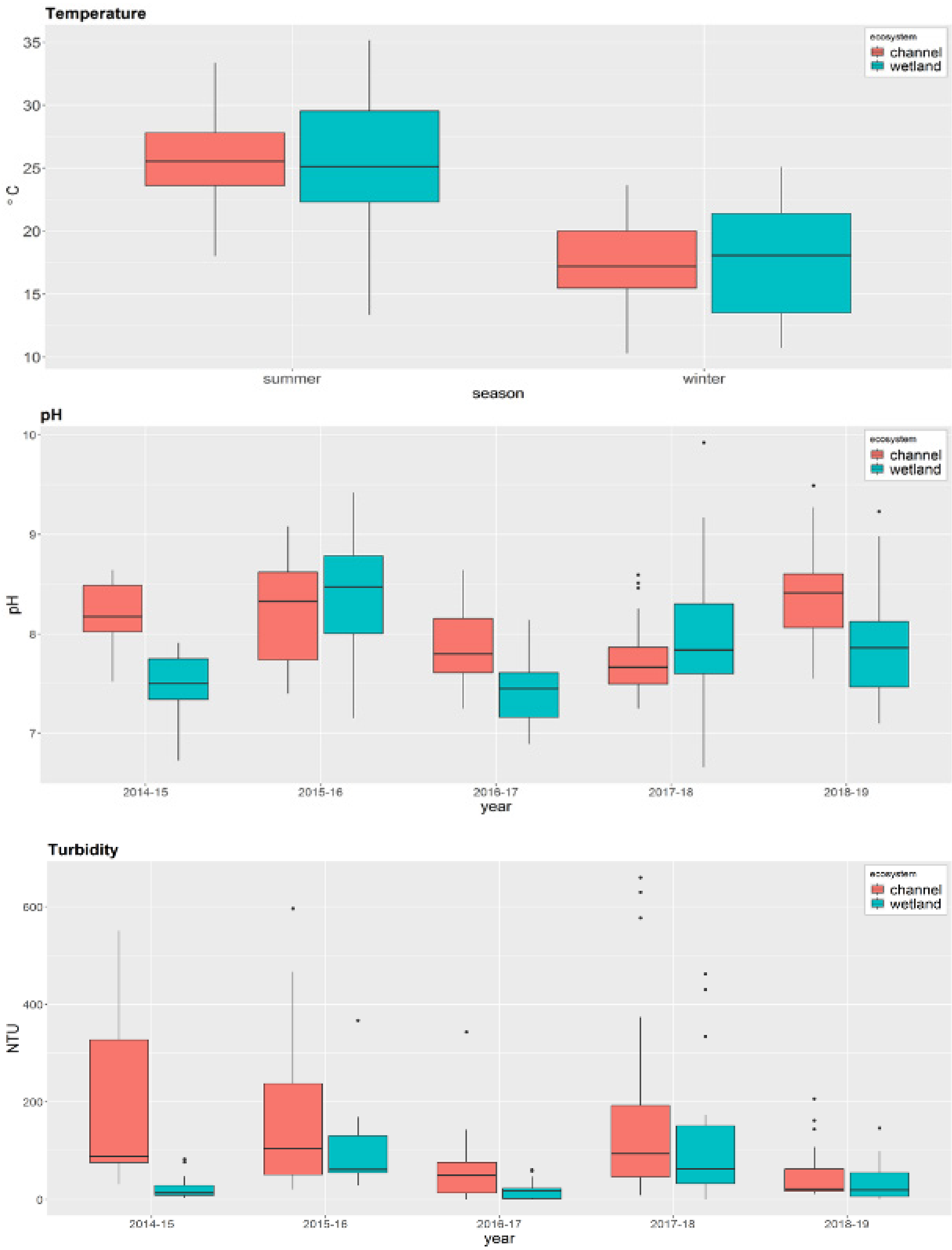

Figure D-5: Boxplots for temperature, pH and turbidity.

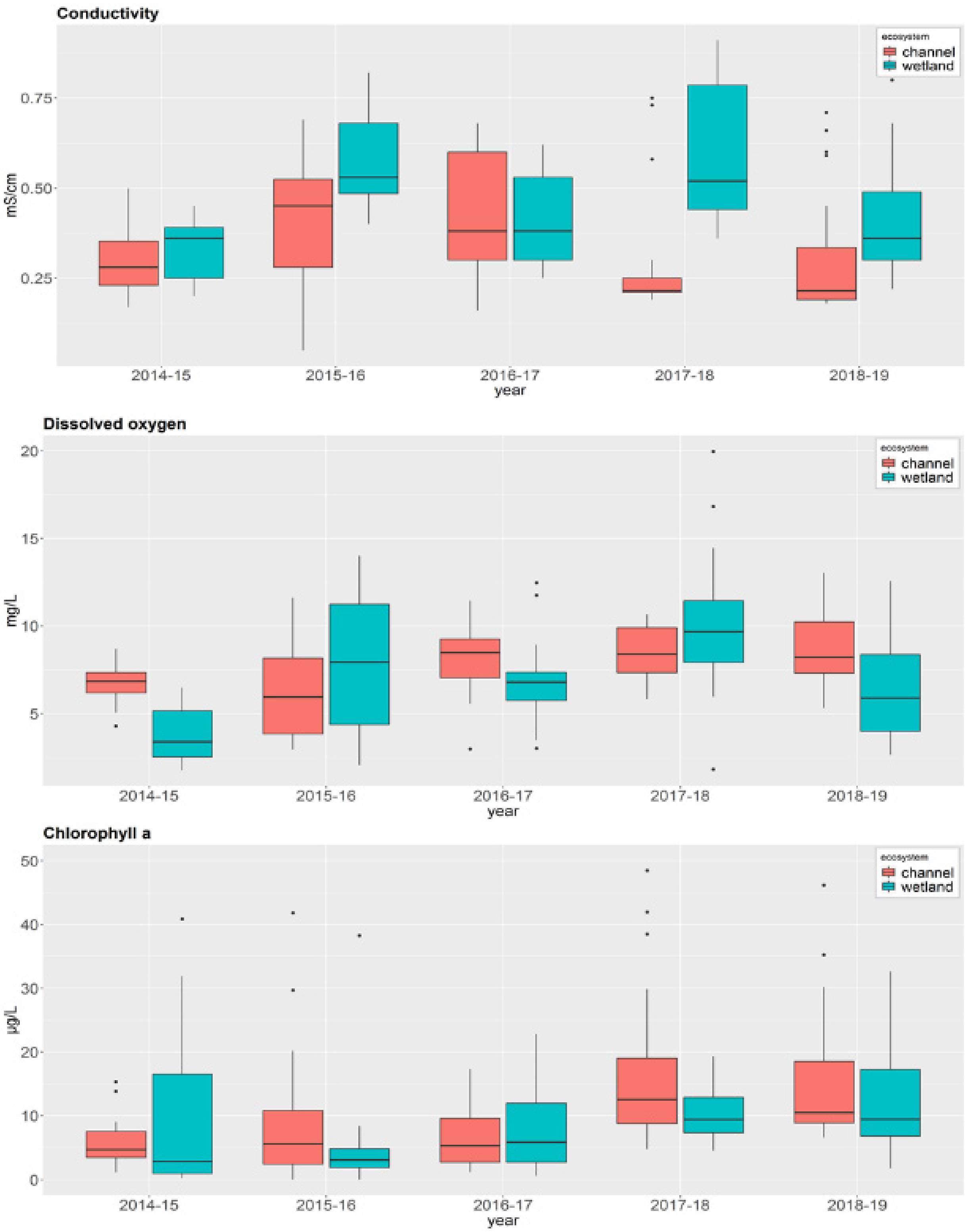

Figure D-6: Boxplots for conductivity, dissolved oxygen and chlorophyll *a* concentrations.

A total of 41 valid stream metabolism samples from the Gwydir River, and the Lower Gwydir River and Gingham Watercourse zones were reported in 2014-19 mainly due to the low percentage of data that met the BASE model output requirements (Table D-6). Three-way PERMANOVA analysis for GPP and NPP showed a significant interaction between ecosystem and year (Table D-5).

The highest average GPP rate was recorded in the wetland ecosystem in 2015-16 in response to high levels of algal production in the water column during the contraction phase in late summer (Figure D-7). ER rates were generally higher than GPP rates, with a higher average ER rate in wetland ecosystem samples, again in the summer periods during contracting water levels (Figure D-7).

Overall, the Gwydir River, and the Lower Gwydir River and Gingham Watercourse zones were a carbon sink. NPP was predominantly net heterotrophic with a few net autotrophic periods recorded in 2015-16 (Figure D-7) during a major inundation event. For example, the Gingham wetland open water habitat (BUNOW and GINOW) shifted to net autotrophy from increased GPP, driven by internal nutrient cycling during a prolonged inundation event in summer with high ambient water temperature. Net heterotrophy in these systems was driven by low GPP rates and high rates of ER (Figure D-7). Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which dead organic matter is colonised by microbes and fungi or consumed by detritivores that are then eaten by higher consumer (Kobayashi *et al.*, 2009).

Table D-6: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each stream metabolism indicators.

Variable	Zone	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
GPP	GW	0.3	0.92	1.79	3.18	6.1	27
	GIN	1.3	2.37	5.89	12.2	36.5	12
	OLD	0.4	0.46	0.51	0.57	0.6	2
ER	GW	0.7	2.09	3.14	6.33	9.7	27
	GIN	2.9	6.59	8.48	10.6	39.5	12
	OLD	4.5	5.72	7.49	9.25	10.4	2
NPP	GW	-8.5	-2.8	-1.4	-0.4	0.7	27
	GIN	-8.2	-3.9	-1.6	-0.2	2.4	12
	OLD	-9.8	-8.7	-7	-5.3	-4.1	2

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

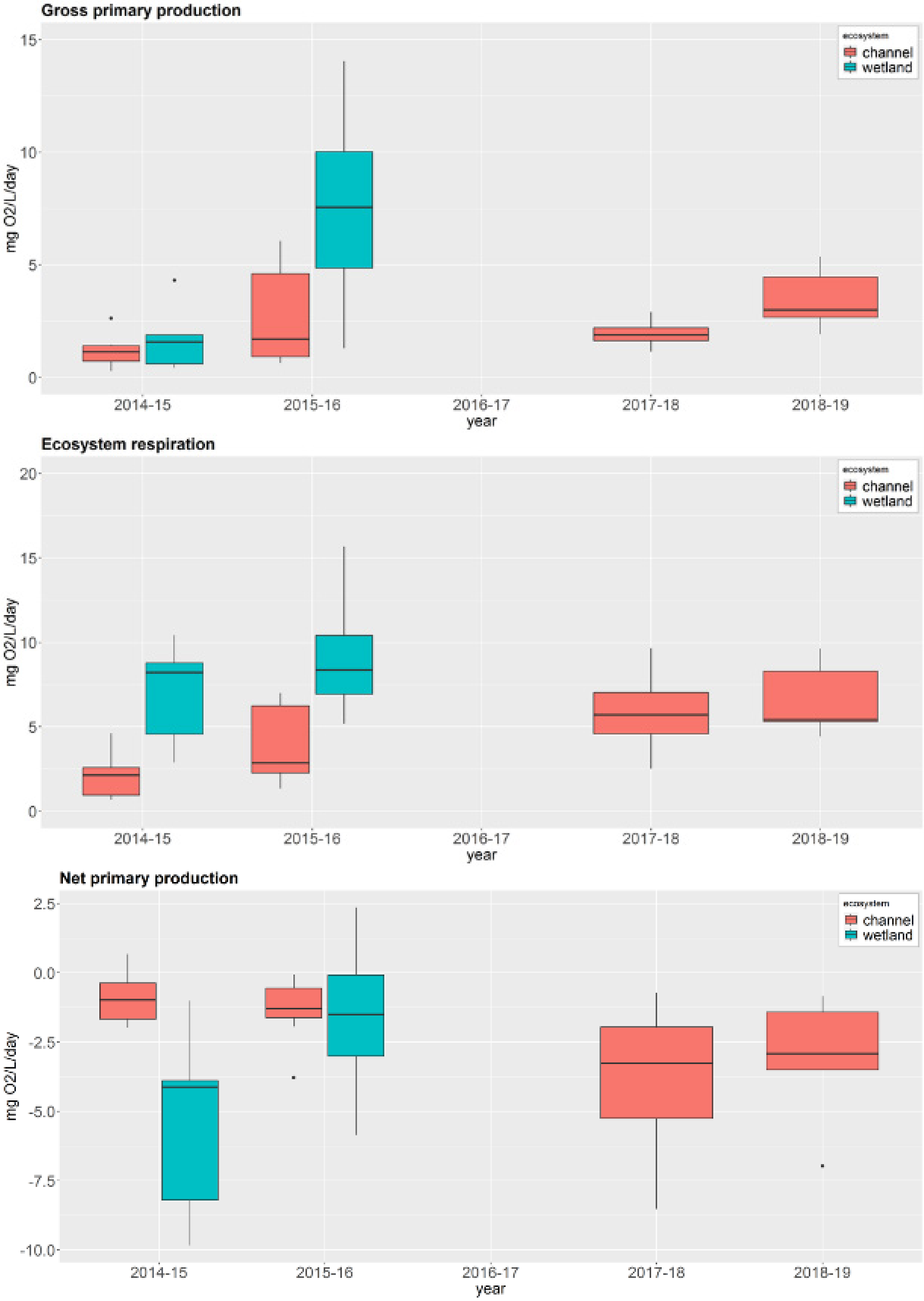

Figure D-7: Boxplot of GPP, ER and NPP rates.

D.3.2 Channel ecosystem

Twenty sampling occasions between 2014 and 2019 captured discharge between 0 ML/d to 1,700 ML/d in the Gwydir River, Mehi River and Moomin Creek. Daily discharge data collated from the WaterNSW gauge stations were used to explore hydrological thresholds and infer patterns in each water quality indicator (Table D-2). In general, all channel zones experienced similar rates of rise and fall in water levels, with the peak in discharge in late 2016 (Figure D-2).

Similar to overall water temperature, the channel ecosystem temperature was higher in summer than in winter months due to seasonal variation (Figure D-8). Environmental water did not contribute an observable change in water temperature.

The pH values were consistently alkaline and had lower values with increasing magnitude in discharge up to 1,500 ML/d (Figure D-8). This pattern was consistently observed: any increase in flow variability and magnitude, augmented by environmental water, improved pH through a dilution effect, provided by the higher discharge. However, there was no strong predictable relationship with discharge and pH (Table D-7).

Turbidity decreased with increasing discharge (Figure D-8) as the majority of flow events were from managed dam releases. The highest turbidity of around 600 NTU was recorded in Moomin Creek, reflecting changes in the channel and streambank vegetation, and broad land use change in the catchment. However, there was no strong predictable relationship with discharge and turbidity (Table D-7).

In the channel ecosystem, conductivity decreased with increasing discharge up to 1,500 ML/d (Figure D-8). This pattern was observed consistently throughout the project with an increase in flow variability and magnitude augmented by environmental water lowering conductivity, matching the trend observed at the Gwydir River continuous monitoring station. However, there was no strong predictable relationship with discharge (Table D-7).

<u>Channel dissolved oxygen regime</u>

Dissolved oxygen levels were highly variable during base flow conditions, reflecting differences when sites were disconnected into pools (Figure D-8). There was no strong predictable relationship with discharge (Table D-7). In 2016-17, lower dissolved oxygen levels were recorded after three months of stable low flow. In contrast, higher dissolved oxygen levels were found in the river channel contraction phase in 2017-18. Dissolved oxygen showed an inconsistent response to flow and environmental water events throughout the LTIM project regulated by antecedent flow conditions associated with time since flow recession, and phytoplankton productivity may be limited by light through interactions among turbidity, depth and turbulence (Hall Jr. *et al.* 2015).

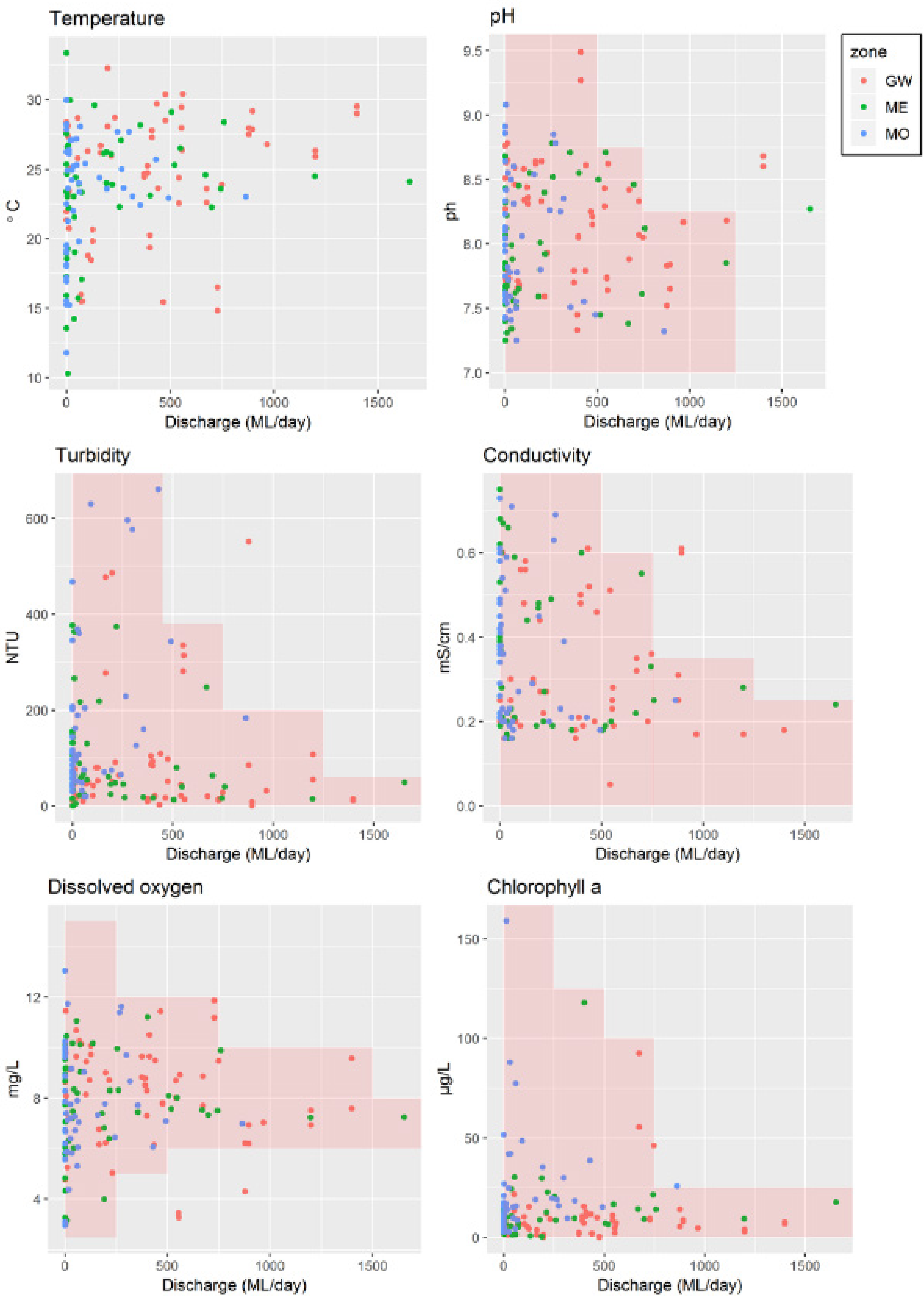

Figure D-8: Regressions between discharge (ML/d) and water quality indicators in three channel zones. Red shading areas show potential water quality thresholds.

Table D-7: Summary of regression results between continuous hydrological factors and water quality and stream metabolism indicators in channel and wetland ecosystems.

Water quality indicator	Channel Ecosystem					Wetland Ecosystem				
	F	df	p-value	R^2	model	F	df	p-value	R^2	model
Temperature (°C)	6.69	2,153	***0.01****	0.08	poly	0.55	2,72	0.58	0.015	poly
pH	0.45	2,153	0.64	0.01	poly	1.32	2,72	0.27	0.035	poly
Turbidity (NTU)	1.29	2,153	0.28	0.02	poly	0.80	2,72	0.45	0.022	poly
Conductivity (mS/cm)	3.85	2,153	0.02	0.05	poly	0.31	2,72	0.74	0.008	poly
Dissolved oxygen (mg/L)	0.52	2,153	0.60	0.01	poly	0.15	2,72	0.86	0.004	poly
Chlorophyll *a* (µg/L)	0.35	2,153	0.71	0.00	poly	1.28	2,72	0.28	0.034	poly
Dissolved organic carbon (mg/L)	0.22	2,153	0.80	0.00	poly	2.29	2,72	0.11	0.060	poly
Total nitrogen (µg/L)	0.92	2,153	0.40	0.01	poly	1.18	2,72	0.31	0.032	poly
Total phosphorus (µg/L)	1.31	2,153	0.27	0.02	poly	2.31	2,72	0.11	0.060	poly
Nitrate-nitrite (µg/L)	0.04	2,153	0.96	0.00	poly	0.33	2,72	0.72	0.009	poly
Filterable reactive phosphorus (µg/L)	1.21	2,153	0.30	0.02	poly	0.14	2,72	0.87	0.004	poly
Gross primary production (mg O2/L/day)	1.68	2,24	0.21	0.12	poly	0.76	2,11	0.49	0.121	poly
Ecosystem respiration (mg O2/L/day)	0.95	2,24	0.40	0.07	poly	1.34	2,11	0.30	0.196	poly
Net primary production (mg O2/L/day)	0.28	2,24	0.76	0.02	poly	0.87	2,11	0.45	0.136	poly

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

'poly' represents quadratic polynomial regression model.

Channel chlorophyll *a* regime

Higher algal production in the three channel zones during low and base flow periods was consistently positively associated with peaks in carbon and nutrient concentrations, reflecting that water quality deterioration in river channel during contraction phases is predominantly controlled by decreased flow and longitudinal disconnection. At discharges above 750 ML/d, chlorophyll *a* dropped to below 25 µg/L, likely due to the dilution effect and increased turbidity provided by higher discharge (Figure D-8). However, there was no strong predictable relationship with discharge and algal production (Table D-7).

Channel nutrient regime

Channel ecosystem nutrient concentrations were consistently higher than ANZECC guideline trigger values (Table D-4 and Figure D-9). In the Gwydir and Mehi Rivers, higher TN concentrations were observed during events that included environmental water and other environmental water, reflecting longitudinal inputs of nutrients from upstream environments (Bayley & Sparks, 1989). All other nutrients (i.e. DOC, NOx, TP and FRP) were higher during contraction phases, suggesting the internal recycling and accumulation of nutrients from the sediment and water column. However, there was no strong predictable relationship with discharge and the measured water nutrient indicators (Table D-7).

Channel stream metabolism regime

ER rates were generally higher than GPP rates (Figure D-10). NPP rates were predominantly net heterotrophic which means the channel ecosystems were a net carbon sink. The major reason for heterotrophy in these systems was low rates of GPP compared with higher rates of ER. The increase in rates of GPP and ER correspond to higher carbon and phosphorus availability in the wet phase during 2016, which are either transported along with the environmental water or released *in situ* from freshly inundated sediments and organic matter. This suggested carbon and phosphorus availability may regulate metabolism in these systems. However, there was no strong predictable relationship with discharge and these stream metabolism indicators (Table D-7).

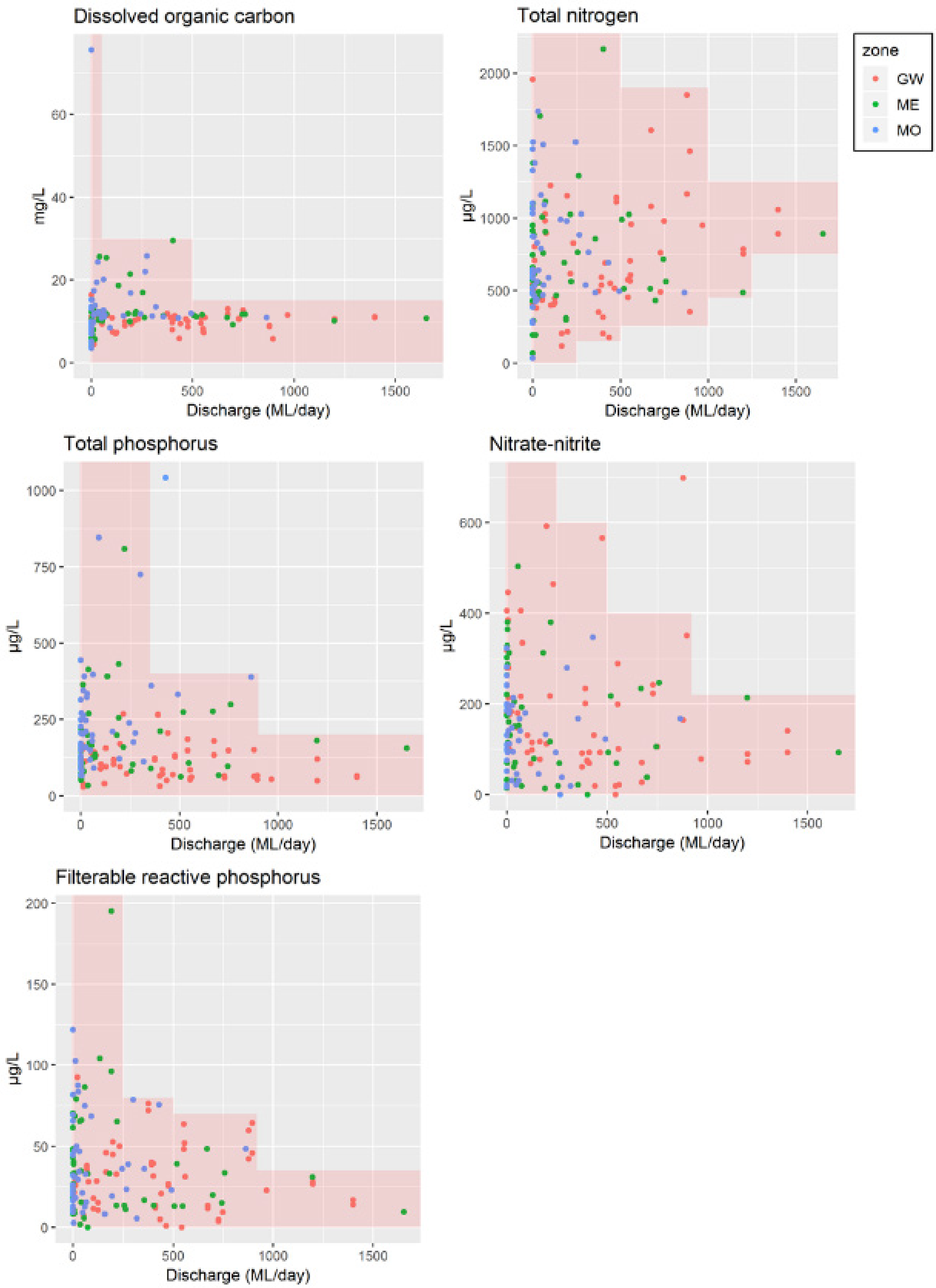

Figure D-9: Regressions between discharge (ML/d) and water quality indicators in three channel zones. Red shading areas show potential water nutrient thresholds.

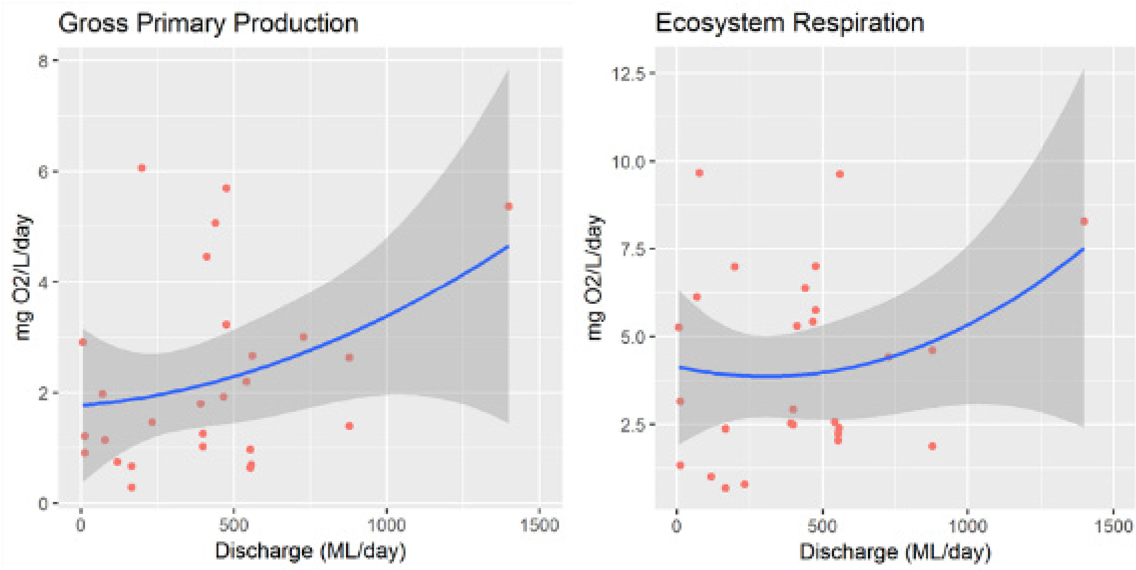

Figure D-10: Regressions between discharge (ML/d) and stream metabolism indicators in the Gwydir River zone.

D.3.3 Wetland ecosystem

Similar to overall water temperature, the two wetland zones recorded higher temperatures in summer, exacerbated by low water levels during the contraction phase (Figure D-11). Environmental water did not contribute to an observable change in water temperature.

The pH values were consistently alkaline and lower in the Lower Gwydir wetland as leachates from rewetted organic matter lowered the pH (Figure D-11). In the Gingham wetland, pH values peaked around 20 days in time since connection, and then were lowered with increasing time since connection. In 2017-18, connection events improved pH due to dilution in the Gingham wetland zone. In the Lower Gwydir wetland, pH levels did not have a strong correlation with time since connection (Table D-7).

Turbidity levels were consistently higher in the Gingham wetland compared with the Lower Gwydir wetland. In the Gingham wetland, turbidity increased with increasing time since connection (Figure D-12). It is likely that in the Gingham wetland, with increasing time since connection, bioturbation by organisms such as fish and benthic macroinvertebrates contributed to these high values in smaller remnant pools (Adámek & Maršálek, 2013). In the Lower Gwydir wetland, turbidity levels did not have a strong correlation with time since connection (Figure D-11).

In the two wetland zones, conductivity increased at different rates with increasing time since connection (Figure D-11). This pattern was observed in the previous years and associated with evapoconcentration during the contraction phase causing conductivity to rise.

Dissolved oxygen levels were highly variable in the two wetland zones (Figure D-11). Dissolved oxygen concentrations below 5 mg/L were recorded from different time since connection periods. In the Gingham wetland, low dissolved oxygen was recorded in the beginning of the event (fewer days since connection). In the Lower Gwydir, lower dissolved oxygen levels were recorded after 25 days of time since connection, with the rewetting of *in situ* organic matter driving rates of heterotrophic metabolism (Baldwin *et al.* 2013). Differences in dissolved oxygen concentrations were likely to be driven by different in geomorphic characteristics and hydrological regimes between two zones.

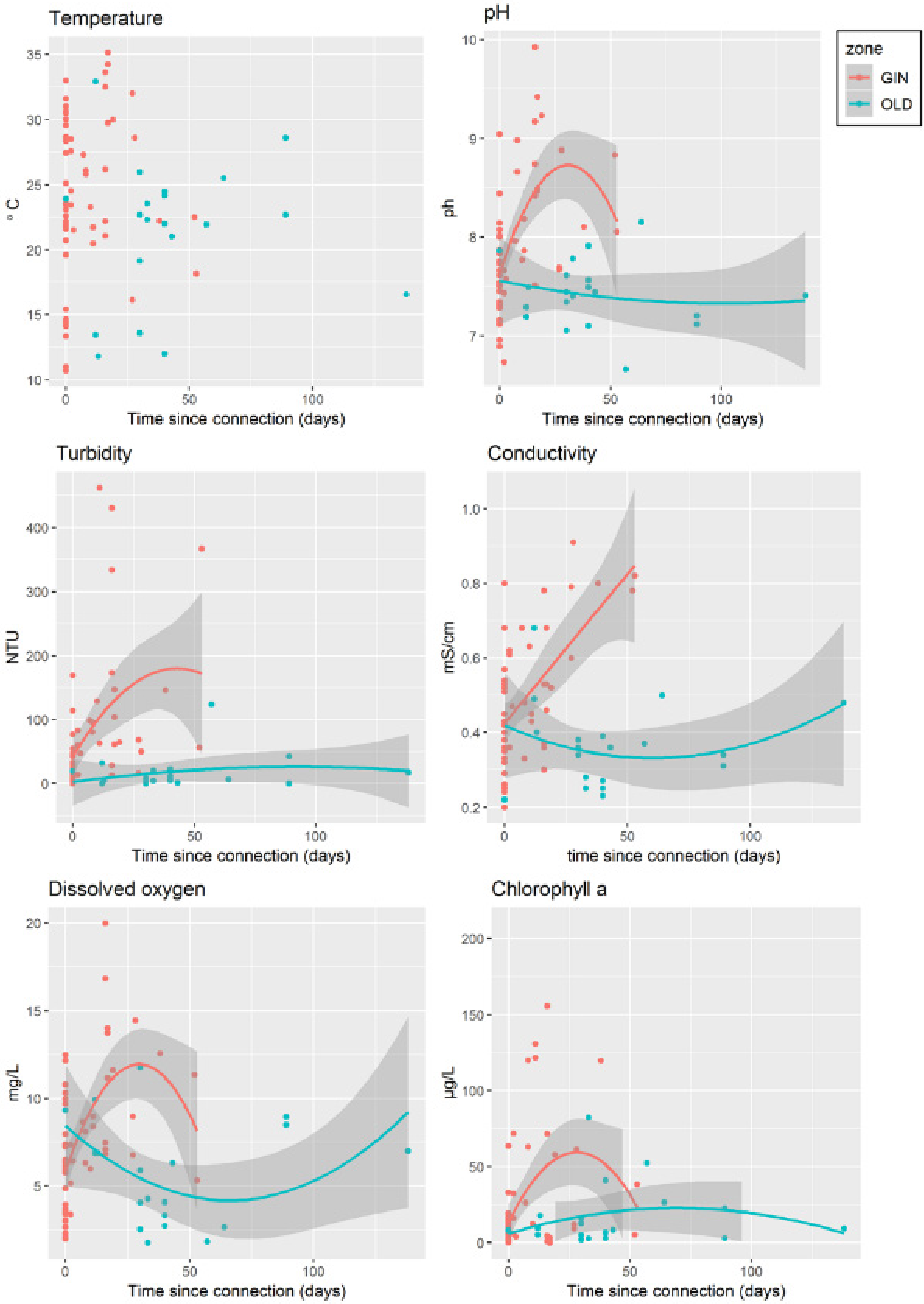

Figure D-11: Regressions between time since connection (days) and water quality (chemistry) indicators within two wetland zones.

There were unimodal relationships between chlorophyll *a* and time since connection in the two wetland zones. In both wetland zones, chlorophyll *a* peaked around 25 days since connection, suggesting a lag in primary production stimulation despite high nutrient concentrations. In 2017-18, the highest concentrations in the Gingham wetland coincided with exceptionally high TN and TP concentrations and the onset of warmer temperatures. This suggests temperature also plays a critical role in moderating the productivity of this system and highlights the potential ecological significance of the timing and seasonality of flow events.

Wetland zone nutrient concentrations were consistently higher than the ANZECC guideline values (Table D-4 and Figure D-12). In the Gingham wetland, dissolved organic carbon concentrations increased with increasing time since connection (Figure D-12). This pattern was consistently found in the contraction period as flows receded, suggesting the internal recycling of nutrients from the sediment and water column.

In the Gingham wetland, TN, TP and NOx had unimodal relationships with time since connection (Figure D-12). TN, TP and NOx were peaked around 25 days since connection, reflecting longitudinal and lateral inputs of nutrients. These nutrients concentrations decreased in the contraction phase up to 50 days since connection (Figure D-12), reflecting nutrients being utilised. However, there was no strong predictable relationship with discharge for nutrient indicators (Table D-4). Extremely high TN in the Gingham wetland prior to environmental water delivery in September 2015 was diluted by environmental water delivery leading to improved water quality.

Nutrient inputs to the Lower Gwydir wetland from the December 2016 environmental water event were reduced compared with those from the natural flow in October 2016. This suggests that environmental water and natural flood water may lead to differing water quality outcomes, and therefore biological responses, with lower productivity resulting from environmental water events that diluted nutrients in the wetland.

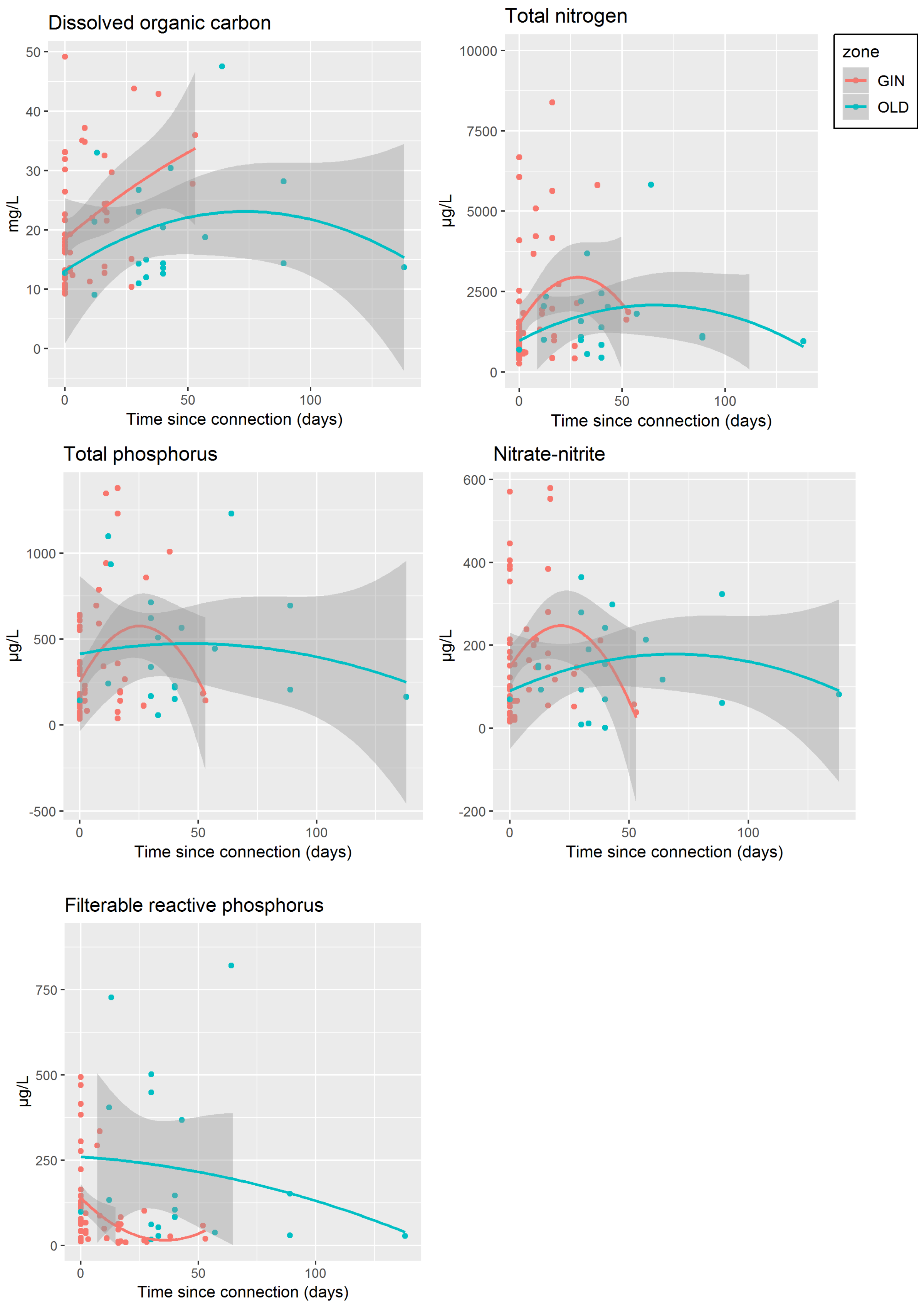

Figure D-12: Regressions between time since connection (days) and water quality (nutrient) indicators within two wetland zones.

ER rates were generally higher than rates of GPP, with both the highest average GPP and ER rates recorded around 20 days since connection (Figure D-13). Highest GPP and ER rates coincided with highest TN, TP and NOx concentrations at around 25 days since connection, reflecting increased rates of metabolism following increased nutrient concentrations. However, rates of GPP and ER did not follow increased nutrients during a winter environmental water event in September 2018, likely due to cooler temperatures limiting primary producer metabolic rates in the wetlands.

NPP rates were predominantly net heterotrophic from low rates of GPP and high rates of ER (Figure D-13). The Gingham wetland shifted to autotrophy with two positive NPP records in April 2016 during a contraction phase following a period of extended inundation. Shallow and no flow environments with long water residence times provide ideal conditions for improved light penetration and regeneration of inorganic nutrients through anoxic sediment processes that stimulate algal productivity. At the wetland scale, highest GPP and ER occurred in the shallow water couch habitats while open water habitat had similar rates of GPP and ER across sampling occasions.

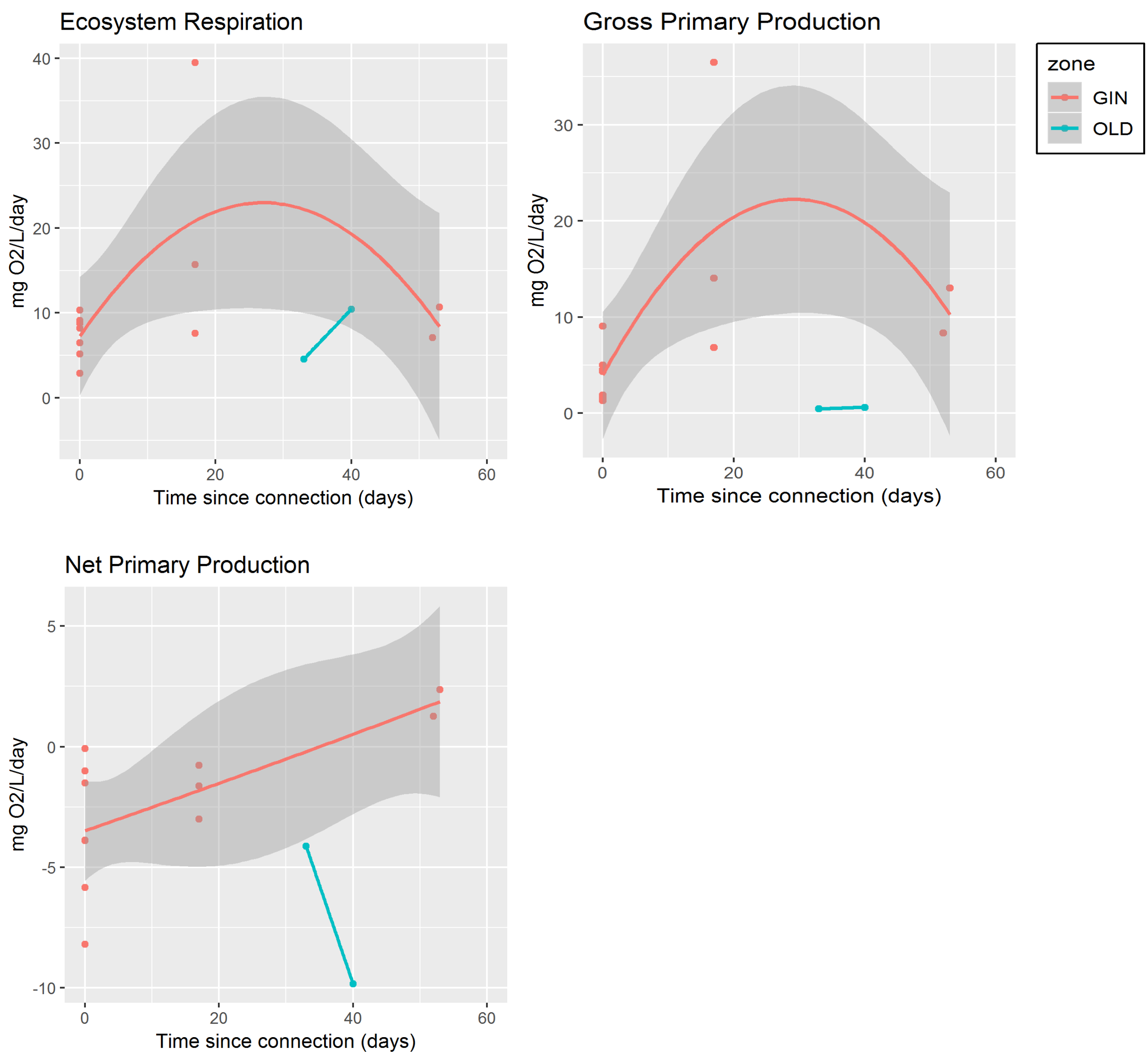

Figure D-13: Regressions between time since connection (days) and stream metabolism indicators within two wetland zones.

D.4 Conclusion

Hydrology is the primary driver of water quality in the channel and wetland environments within the Gwydir Selected Area. Seasonal change exerted a strong influence on water temperature, conductivity and nutrients that responded to receding water levels and evapoconcentration processes. Improved pH values were found in three channel zones with an increase in flow variability and magnitude augmented by environmental water or natural flow events that provided dilution. In the Gingham wetland, pH value peaked around 20 days since connection. This dilution effect in pH was less evident in the Lower Gwydir wetland due to differences in antecedent flow conditions and the magnitude and duration of inundation for each event.

Turbidity was high and highly variable across the Gwydir Selected Area. In the channel areas, increases in flow variability and magnitude augmented by environmental water events or from natural flow reduced turbidity. Increasing turbidity with time since connection in the Gingham was likely due to bioturbation by benthic organisms such as fish and benthic macroinvertebrates. In particular, carp are known to disturb benthic habitats and increase turbidity.

Conductivity was significantly higher in wetland compared to channel environments. In channels, increased flow variability and magnitude augmented by environmental water lowered conductivity reflecting a dilution effect provided by higher discharge in channels. In wetland environments, conductivity increased with increasing time since connection due to evapoconcentration during the contraction phase.

Dissolved oxygen levels were highly variable with no strong relationship with hydrological factors in channel environments. In wetlands, low dissolved oxygen concentrations below 5 mg/L were recorded but no hypoxic events were observed throughout the project. This inconsistent response in dissolved oxygen to discharge and inundation was driven by antecedent flow conditions and time since flow recession or connection, and phytoplankton productivity that may be limited by light, through interactions among turbidity, depth and turbulence. It is also likely that seasonal change in temperature exerted a strong influence on dissolved oxygen, through the moderation of productivity in the system.

Chlorophyll *a* concentrations were consistently high in channels with high levels of algal production in the water column dominating in the contraction phase and was positively associated with peaks in carbon and nutrient concentrations. In wetlands, chlorophyll *a* peaked around 25 days since connection, suggesting there was lag in the stimulation of primary production in response to environmental water actions. Temperature also plays a critical role in moderating productivity in this system and highlights the potential ecological significance of the timing of flow events. Nutrient (DOC, TN, TP, NOx and FRP) concentrations were consistently high in all channel and wetland environments, reflecting land use throughout the catchment and deposition of transported nutrients in wetland systems. The highest nutrient concentrations were recorded during contraction phases in wetlands, suggesting the internal recycling of nutrients from the sediment and water drives productivity. The flow pulses of environmental water provided connection between the Gwydir River and the Lower Gwydir and Gingham wetlands led to increases in nutrient concentrations that peaked around 25 days since connection.

It is commonly accepted that large rivers and terminal wetlands are net heterotrophic (Kobayashi *et al*., 2011) and the lower Gwydir conforms to this model irrespective of water depth or volume, or time of year. This result reflects that dominance of the microbial loop and decomposer pathways either through pelagic decomposition of DOC or benthic decomposition of organic matter deposited from wetland plants. Therefore, environmental water can help to foster these processes through the delivery of DOC as a food resource to wetlands.

Water quality was generally poor and nutrient concentrations generally exceeded ANZECC guideline values, yet no detrimental ecological consequences were recorded for biota. The LTIM project provides the best available long-term dataset that could be tailored into water quality guidelines for more appropriate and realistic management goals. Water quality targets should be updated and adjusted as more low flow and high flow conditions are reported.

D.5 References

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Appendix E Microinvertebrates

E.1 Introduction

The Microinvertebrates indicator aimed to assess the contribution of Commonwealth environmental water to microinvertebrate abundance and diversity within the Gwydir River system Selected Area (Gwydir Selected Area). Several specific questions were addressed through this indicator during the project:

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

E.2 Methods

E.2.1 Field and laboratory methods

Microinvertebrates were sampled in association with Category III Water Quality (Appendix D) and Macroinvertebrate (Appendix F) indicators from twenty sampling occasions between 2014 and 2019. Sampling sites were located in five Sampling Zones within the Gwydir Selected Area: Gwydir River, Mehi River, Moomin Creek, Gingham Watercourse and Lower Gwydir wetlands (Figure E-1).

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

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

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

The volumes of the total samples were recorded, and subsample totals were scaled to each total sample volume and reported as microinvertebrate density (individuals/L). Samples were stored in 70% ethanol with Rose Bengal for auditing purposes. Four microinvertebrate variables were calculated: density, diversity, richness and community abundance (Table E-1).

Table E-1: Category III Microinvertebrate variables.

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

E.2.2 Microinvertebrate Diversity Indices

Shannon Weiner diversity index (H')

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

Taxa richness (S)

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

E.2.3 Explanatory factors

Spatial and temporal factors were used to test if microinvertebrate indicators were spatially or temporally dependent. Seventeen sampling sites were categorised in two ecosystems: channel and wetland (Table E-2). Twenty sampling occasions were categorised into five years and two seasons (i.e. summer from October to April and winter from May to September) (Table E-3).

Hydrological data were used to test the influence of environmental water and other flow events. In all channel sites, daily discharge data was collated from the nearest WaterNSW gauge station to determine any hydrological thresholds for microinvertebrate variables (Table E-2 and Figure E-2).

In wetland sites, time since connection was identified and calculated using data from the nearest WaterNSW gauge (Table E-2 and Figure E-3). For the Gingham Watercourse sites (i.e. BUNOW, BUNTY and BUNWC), connection was identified when Gingham@Tillaloo gauge dropped below 10 ML/d. Time since connection was calculated using days between when Gingham@Tillaloo gauge dropped below 10 ML/d and the first day of the next sampling trip (Figure E-3). At 10 ML/d at Tillaloo it was assumed water would cease to flow into the wetlands. For site GINWH, time since connection was calculated using days between when Gingham@Waterhole water level began to recede and the first day of the next sampling trip (Figure E-3). In the Lower Gwydir sites (i.e. OLDBS, OLDCB, OLDTY and OLDWC), connection was identified when Gwydir@Millewa gauge levels rose above 1.5 m. Time since connection was calculated using days between when Gwydir@Millewa gauge was above 1.5 m and the first day of the next sampling trip (Figure E-3). 1.5 m on the Millewa gauge was considered to be the point at which water flowed into the Lower Gwydir wetlands.

Continuous hydrological factors (i.e. discharge in channel and time since connection in wetland) were further transformed into categorical hydrological factors (discharge groups in channel and time since connection group in wetland) to infer patterns in statistical analyses.

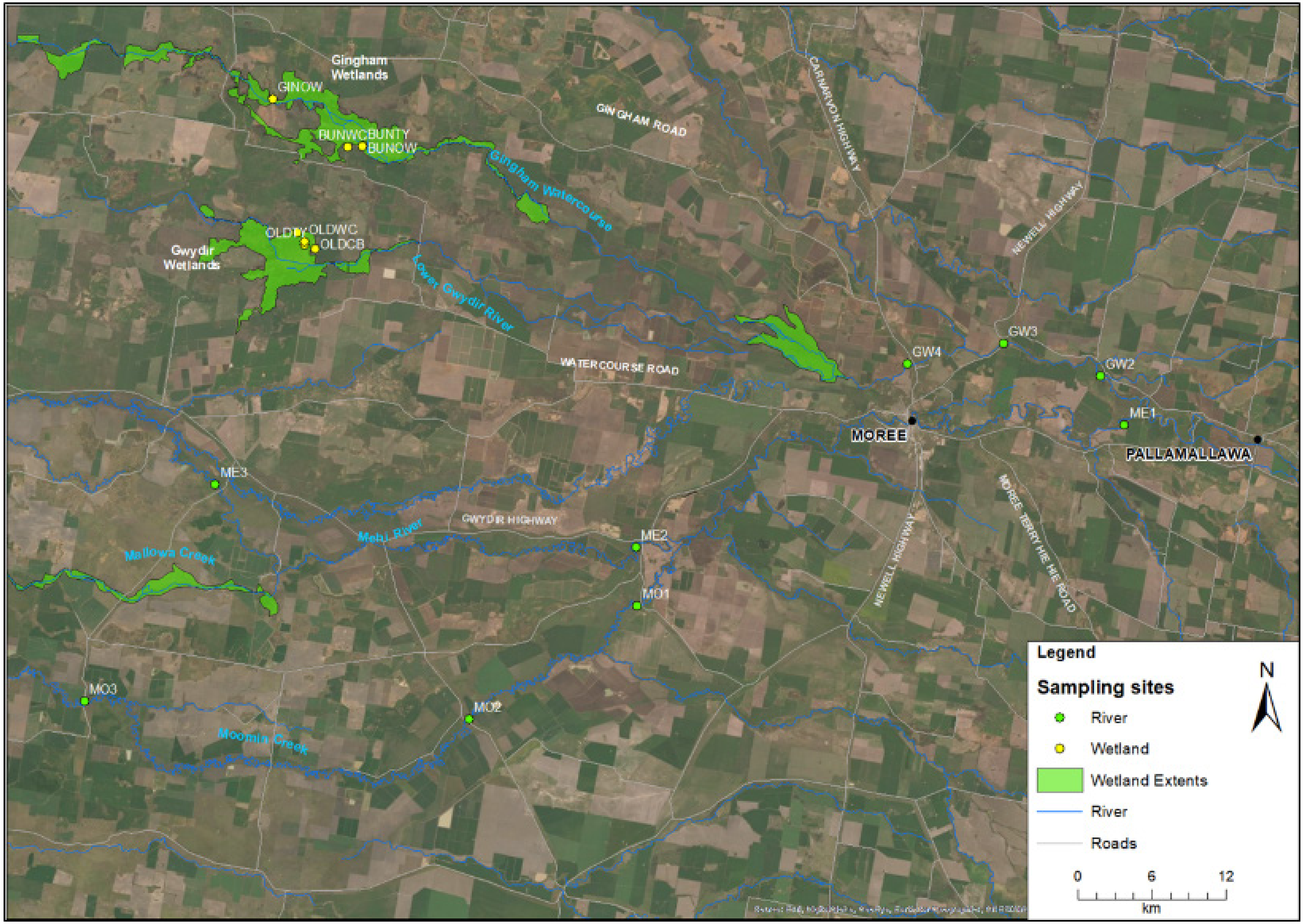

Figure E-1: Location of microinvertebrate sites within the Gwydir Selected Area

E.2.4 Statistical methods

Two data sets by habitats

Benthic and pelagic microinvertebrate samples were analysed as two datasets since different sampling methods were used for each habitat. The minimum, 20th, 50th (median) and 80th percentile and maximum values of each microinvertebrate indicator were calculated.

PERMANOVA

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

PERMANOVA was used to test the overall difference in microinvertebrate indicators between ECOSYSTEM, YEAR and SEASON and their interactions. Within two ecosystems, microinvertebrate patterns were mainly driven by different hydrological events and therefore were analysed separately. In the channel ecosystem, PERMANOVA was used to test the difference in microinvertebrate indicators between discharge categories. In the wetland ecosystem, PERMANOVA was used to test the difference in microinvertebrate indicators between time since connection categories.

Regression

Relationships between microinvertebrate indicators (Table E-1) and continuous hydrological factors were analysed using non-linear polynomial regression. In the channel ecosystem, regression was used to explore the relationships between microinvertebrate indicators and discharge. In the wetland ecosystem, regression was used to explore the relationships between microinvertebrate indicators and time since connection. Regression outputs of F-statistic, degrees of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

BIOENV

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

nMDS and SIMPER

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

Table E-2: Microinvertebrate site locations and the nearest gauge stations. Map projection GDA94 Zone 55. Explanatory (spatial) factors to infer macroinvertebrate patterns in statistical analyses.

Ecosystem	Sampling Zone	Site	Easting	Northing	WaterNSW gauge station	Distance from gauge station (downstream)
Channel	Gwydir River (GW)	Gwydir River Site 2 (GW2)	791299	6740442	418042 (Gwydir D/S Tareelaroi)	6 km
		Gwydir River Site 3 (GW3)	783417	6743136		11 km
		Gwydir River Site 4 (GW4)	775598	6741492	418004 (Gwydir @ Yarraman Br)	0 km
	Mehi River (ME)	Mehi River Site 1 (ME1)	793235	6736492	418044 (Mehi D/S Tareelaroi)	3 km
		Mehi River Site 2 (ME2)	753567	6726597	418037 (Mehi D/S Combadello)	7 km
		Mehi River Site 3 (ME3)	719420	6731644	418085 (Mehi D/S Gundare Reg)	15 km
	Moomin Creek (MO)	Moomin Creek Site 1 (MO1)	753679	6721789	418048 (Moomin@Combadello)	10 km
		Moomin Creek Site 2 (MO2)	740017	6712591	418060 (Moomin@Glendello)	0 km
		Moomin Creek Site 3 (MO3)	708808	6714077	418061 (Moomin@Alma Br)	0 km
Wetland	Gingham wetland (GIN)	Bunnor Open Water (BUNOW)	731409	6759165	418076 Gingham@Tillaloo Br	8 km
		Bunnor Typha (BUNTY)	731394	6759148		
		Bunnor Water Couch (BUNWC)	730157	6759022		
		Gingham Waterhole (GINWH)	724103	6762962	418077 Gingham @ Water Hole	0 km
	Lower Gwydir wetland (OLD)	Old Dromana Bolboschoenus (OLDBS)	726067	6752088	418066 GWYDIR@MILLEWA	3 km
		Old Dromana Coolibah (OLDCB)	727611	6750685		
		Old Dromana Typha (OLDTY)	726680	6751125		
		Old Dromana water Couch (OLDWC)	726664	6751404		

Table E-3: Explanatory (temporal) factors to infer Category III Microinvertebrate patterns in statistical analyses.

Year	Sampling occasion	Month	Season	Number of sites
2014-15	1	2014-12	summer	7
	2	2015-02	summer	7
	3	2015-03	summer	6
	4	2015-04	summer	5
2015-16	5	2015-09	winter	12
	6	2016-02	summer	12
	7	2016-03	summer	12
	8	2016-04	summer	11
2016-17	9	2016-10	summer	15
	10	2016-12	summer	12
	11	2017-02	summer	13
	12	2017-05	winter	13
2017-18	13	2017-09	winter	13
	14	2017-11	summer	13
	15	2018-02	summer	13
	16	2018-04	summer	12
2018-19	17	2018-08	winter	16
	18	2018-12	summer	16
	19	2019-01	summer	12
	20	2019-03	summer	11

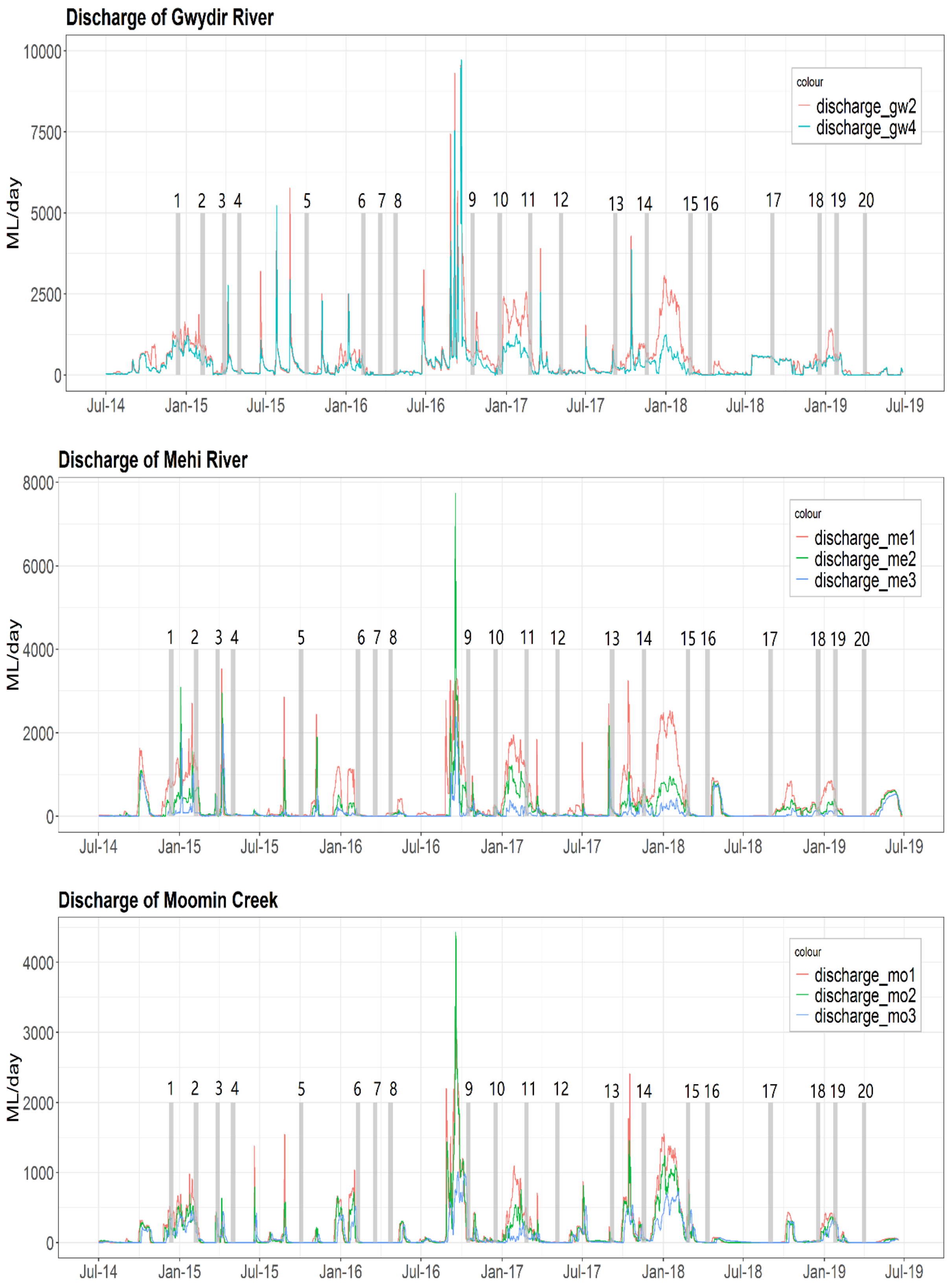

Figure E-2: Mean daily discharge in the Gwydir River and the Mehi River and Moomin Creek with sampling occasions (numbered grey bars). Water gauge stations information in Table D-2Table E-2.

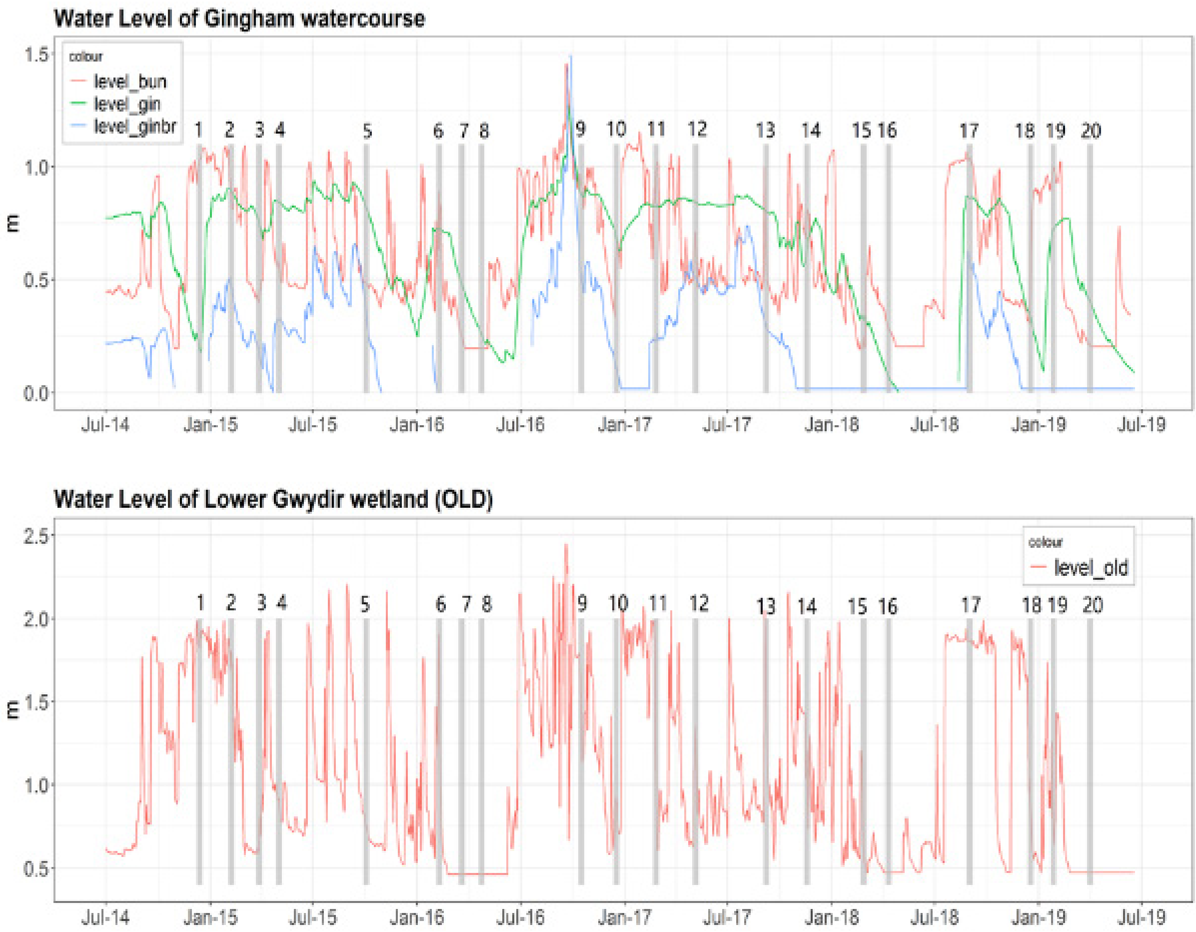

Figure E-3: Mean daily water level in the Gingham and Lower Gwydir wetlands with sampling occasions (numbered grey bars). Water gauge stations information in Table D-2Table E-2.

E.3 Results and Discussion

E.3.1 Overall patterns

Overall microinvertebrate density pattern

Across two habitats, five sampling zones and 20 sampling occasions, microinvertebrate density ranged from 9 to 108,432 individuals/L (Table E-4). The densities of microinvertebrates recorded in this period were similar to those reported in previous studies from the Murray, the Ovens and the Macquarie Marshes floodplain river and wetland within the Murray-Darling Basin (Kobayashi *et al*. 2011; Ning *et al.* 2013).

Within the Gwydir Selected Area, benthic habitats had higher microinvertebrate density than pelagic habitats (Figure E-4). Overall, wetlands had higher microinvertebrate density than channels, reflecting spatial and hydrological differences between these geomorphic habitats and demonstrating the importance of wetland connection supported by management decisions to stimulate microinvertebrate prodution. Three-way PERMANOVA analyses showed significant differences between year in benthic habitat (Pseudo-F=11.572, d.f.=4, p=0.001 Figure E-4) and significant interaction between ecosystem and season in pelagic habitat (Pseudo-F=6.133, d.f.=1, p=0.02; Figure E-4). In winter, primary productivity measured as chlorophyll *a* did not respond to high TN input from environmental water events, suggesting that cooler temperatures earlier in the season may limit water column primary production, and did not support the same rates of secondary production. Similarly, increased DOC concentrations in wetland habitats, increasing with time since inundation, provide a food resource for microbial food webs that fuel pelagic microinvertebrate grazers.

Table E-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of microinvertebrate density were calculated (individuals/m^2).

Habitat	Zone	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
Benthic	GW	98	824	1,764	6,812	45,312	60
	ME	161	752	2,148	7,198	45,120	48
	MO	236	1,331	2,762	6,237	24,000	48
	GIN	232	1,536	5,248	11,928	62,400	51
	OLD	513	1,646	5,760	16,307	108,432	20
Pelagic	GW	9	15	24.5	438	5,020	60
	ME	14	26.8	102	953	18,000	48
	MO	16	62.4	208	1,170	14,320	48
	GIN	22	88	421	2,682	20,880	51
	OLD	9	53.2	907	2,214	17,184	17

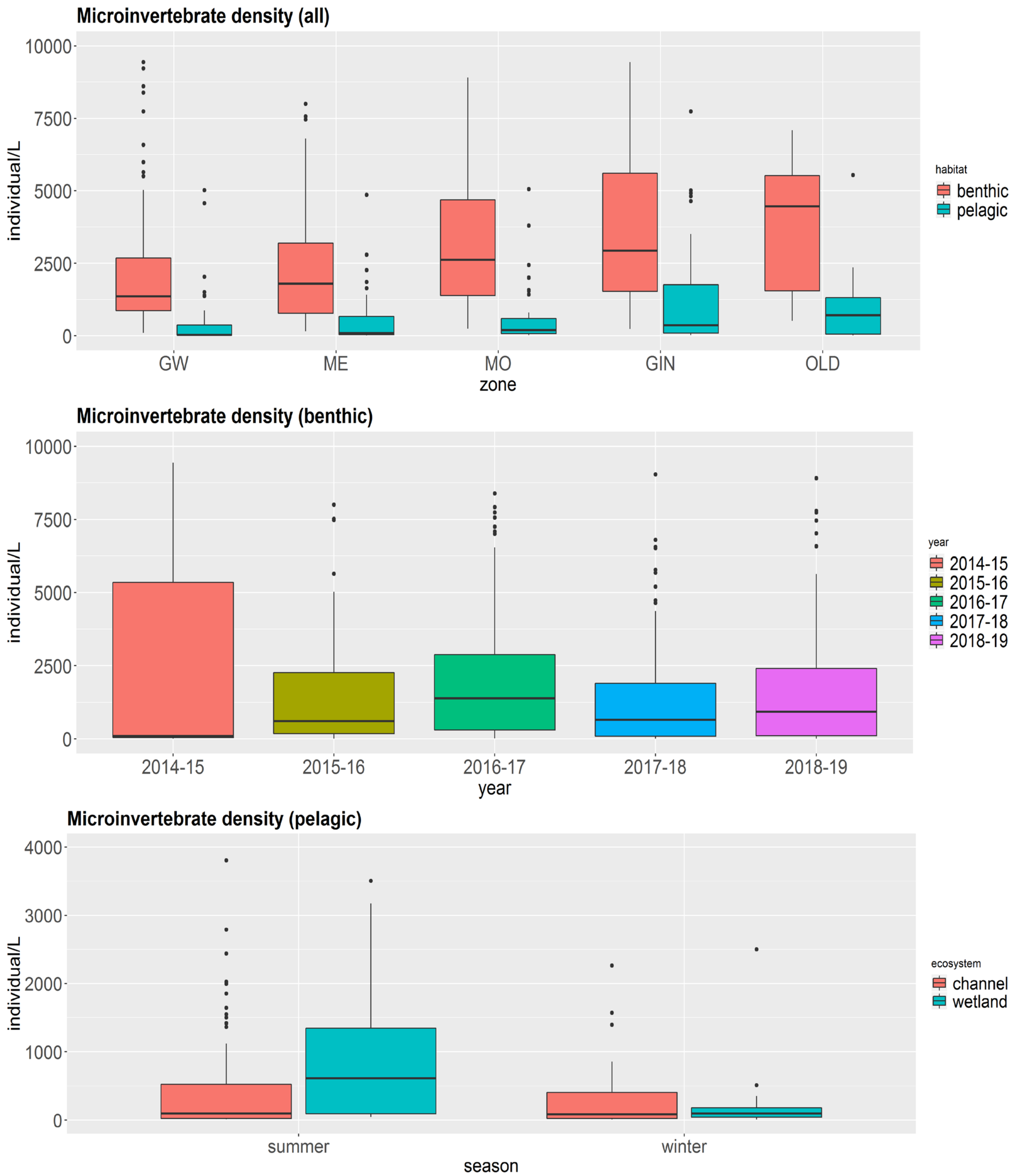

Figure E-4: Boxplots of microinvertebrate density.

Overall microinvertebrate diversity pattern

A total of 42 microinvertebrate taxa were identified from 451 samples (227 samples from benthic habitats and 224 samples from pelagic habitat; Supplement A). Rotifers were the most abundant taxonomic group (50.8%), followed by Copepoda (20.3%) and Cladocera (13.7%). The 17 most abundant taxa (>1% in total abundance) comprised 94% of the total abundance with the most abundant taxa, Copepod nauplii (13% of the total abundance). The other most abundant taxa were Family Brachionidae (12%), Phylum Nematoda (9.5%), Order Bdelloida (9.4%), and Family Lecanidae (5.9%) that occurred in more than 50% of sites and sampling occasions.

Microinvertebrate taxonomic richness ranged from 3 to 22 and Shannon diversity index ranged from 0.60 to 2.93 (Table E-5). There was a distinct spatial and temporal pattern in microinvertebrate diversity and richness. In general, channels had higher richness and diversity than wetlands, regardless of year or season (Figure E-5). Three-way PERMANOVA analyses showed significant interactions between ecosystem, year and season in benthic richness (Pseudo-F=2.718, d.f.=3, p=0.41), between year and season in pelagic richness (Pseudo-F=5.239, d.f.=3, p=0.002), between ecosystem and season in benthic diversity (Pseudo-F=13.105, d.f.=0, p=0.001) and between years in pelagic diversity (Pseudo-F=3.701, d.f.=4, p=0.006) (Figure E-5).

Table E-5: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each microinvertebrate diversity indicators.

Variable	Habitat	Zone	Minimum	Percentile			Maximum	Number of samples
				20th	50th	80th		
Richness	Benthic	GW	5	9	12	15	19	60
		ME	7	11	13	16	22	48
		MO	8	12	14	17	20	48
		GIN	3	9	11	13	17	51
		OLD	5	9	12	15	17	20
	Pelagic	GW	5	9	12	15	17	60
		ME	4	9	13	15	21	48
		MO	7	9	12	14	19	48
		GIN	4	10	11	14	20	51
		OLD	6	9	12	14	17	17
Diversity	Benthic	GW	1.12	1.66	1.85	2.09	2.47	60
		ME	1.12	1.71	1.99	2.24	2.60	48
		MO	1.48	1.79	2.03	2.21	2.47	48
		GIN	0.85	1.28	1.60	1.87	2.19	51
		OLD	0.76	1.61	1.94	2.08	2.20	20
	Pelagic	GW	0.60	1.59	1.97	2.53	2.81	60
		ME	0.67	1.38	1.86	2.36	2.93	48
		MO	1.02	1.41	1.74	2.18	2.63	48
		GIN	0.61	1.29	1.66	2.00	2.45	51
		OLD	0.84	1.32	1.71	1.99	2.21	17

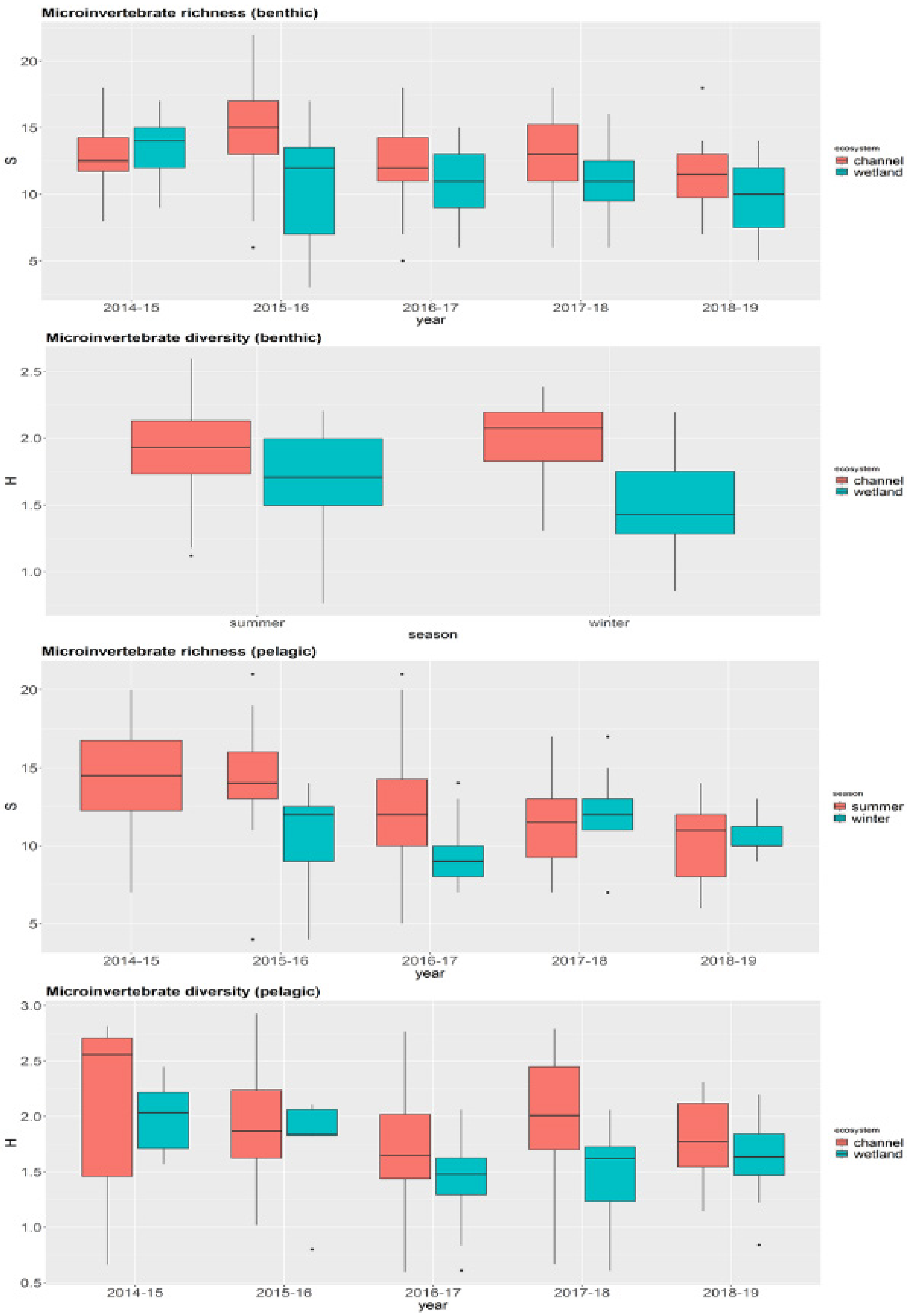

Figure E-5: Boxplots of microinvertebrate diversity and richness.

Overall microinvertebrate community pattern

Microinvertebrate taxonomic composition significantly differed between benthic and pelagic habitats (Pseudo-F=104.14, p=0.001; Figure E-6), driven by the higher average abundance of benthic taxa such as P.Nematoda, O.Bdelloida, Copepod nauplii, F.Brachionidae and F.Notommatidae (Table E-6).

There was a distinct spatial and temporal pattern in community composition (Figure E-6). In the benthic habitat, a three-way PERMANOVA showed a significant interaction between zone, year and season (Pseudo-F=1.824, d.f.=3, p=0.009). In the pelagic habitat, a three-way PERMANOVA analysis also showed multiple significant interactions between zone, year and season (Pseudo-F=2.619, d.f.=4, p=0.001). These patterns reflect temporal, hydrological and geomorphic differences between the three zones exerting a strong influence on community composition in both benthic and pelagic habitats (Figure E-6).

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

Taxa		Average abundance	
		Benthic	Pelagic
Benthic	P.Nematoda	**19.89**	0.8
	O.Bdelloida	**18.37**	2.77
	nauplii	**22.39**	8.57
	F.Brachionidae	**16.35**	9.28
	F.Notommatidae	**15.99**	3.31
	F.Chydoridae	**11.59**	1
	F.Lecanidae	**11.19**	2.45
	O.Cyclopoida	**8.89**	2.5
	sC.Oligochaeta	**6.86**	0.47
	F.Macrothricidae	**5.69**	0.53
	O.Calanoida	**5.99**	1.24
	F.Asplanchnidae	**3.62**	2.77
	O.Harpacticoida	**3.46**	0.44
	P.Tardigrada	**2.92**	0.23
	C.Ostracoda	**3.51**	0.34
	F.Euchlanidae	**3.75**	0.63
	F.Trichotriidae	**1.9**	0.5
Pelagic	F.Synchaetidae	6.2	**6.93**
	F.Filiniidae	6.34	**6.59**
	F.Hexarthridae	2.18	**2.61**

P=Phylum; O=Order; F=Family; sC=sub-Class; C=Class

Bold represents the higher abundance group.

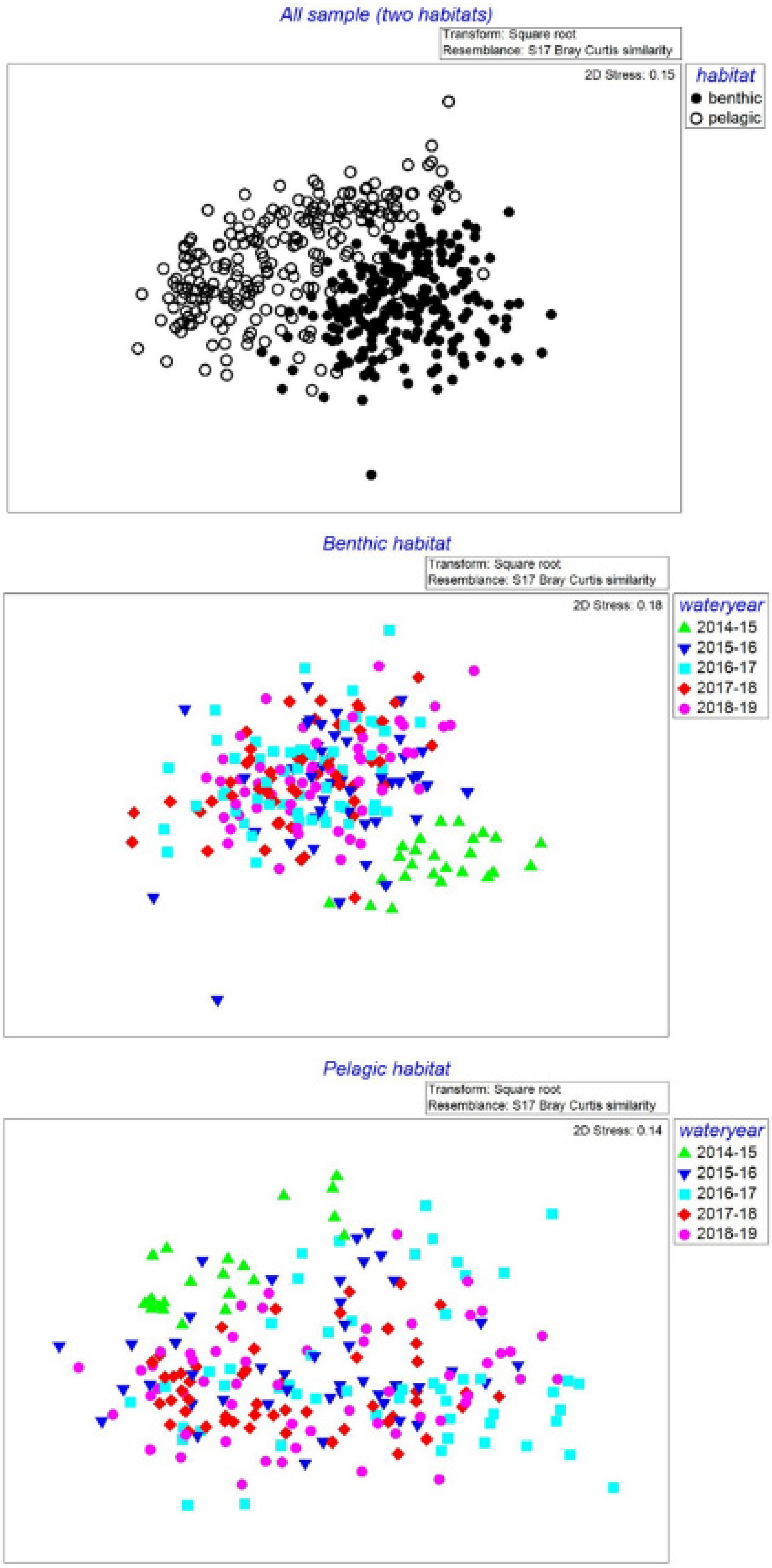

Figure E-6: nMDS ordination of microinvertebrate community composition using the community abundance (square root) dataset.

E.3.2 Channel ecosystem

Channel microinvertebrate density

In channels, density was highly variable during base flow conditions in both habitats (Figure E-7). The highest densities recorded were generally found during base flow conditions with density decreasing with increasing discharge (Figure E-7; Table E-7). The BIOENV result showed that chlorophyll *a* and DOC concentrations were best correlated with microinvertebrate density in both habitats (Table E-8), highlighting these as important basal food resources for microinvertebrates. During contraction periods, an increase in microinvertebrate density was supported by higher carbon and nutrient concentrations and hydrological conditions conducive for their growth and reproduction.

Microinvertebrate densities were reduced in higher discharge periods, suggesting that environmental water and natural flow pulse events acted as hydrological disturbances and initiated taxonomic replacement and dilution through longitudinal displacement. In both benthic and pelagic habitats, microinvertebrate density generally decreased to below 5,000 individuals/L in benthic habitats and 1,000 individuals/L in pelagic habitats with increasing discharge with a threshold around 500 ML/d (Figure E-7).

Table E-7: Summary of regression results between continuous hydrological factors and microinvertebrate indicators.

Habitat	Ecosystem	Microinvertebrate indicator	Regression				
			F	d.f.	p-value	R^2	model
Benthic	Channel	Density	4.2	2,153	***0.017****	0.05	poly
		Diversity (Shannon diversity index)	8.9	2,153	***<0.001****	0.10	poly
		Richness	11.4	2,153	***<0.000****	0.13	poly
	Wetland	Density	1.7	2,65	0.184	0.05	poly
		Diversity (Shannon diversity index)	1.2	2,65	0.303	0.04	poly
		Richness	4.4	2,65	**0.017***	0.12	poly
Pelagic	Channel	Density	3.7	2,153	**0.027***	0.05	poly
		Diversity (Shannon diversity index)	15.7	2,153	**<0.001***	0.17	poly
		Richness	3.2	2,153	**0.043***	0.04	poly
	Wetland	Density	10.9	2,68	***<0.001****	0.24	poly
		Diversity (Shannon diversity index)	5.8	2,68	***0.005****	0.15	poly
		Richness	3.1	2,68	0.051	0.08	poly

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

'poly' represents quadratic polynomial regression model.

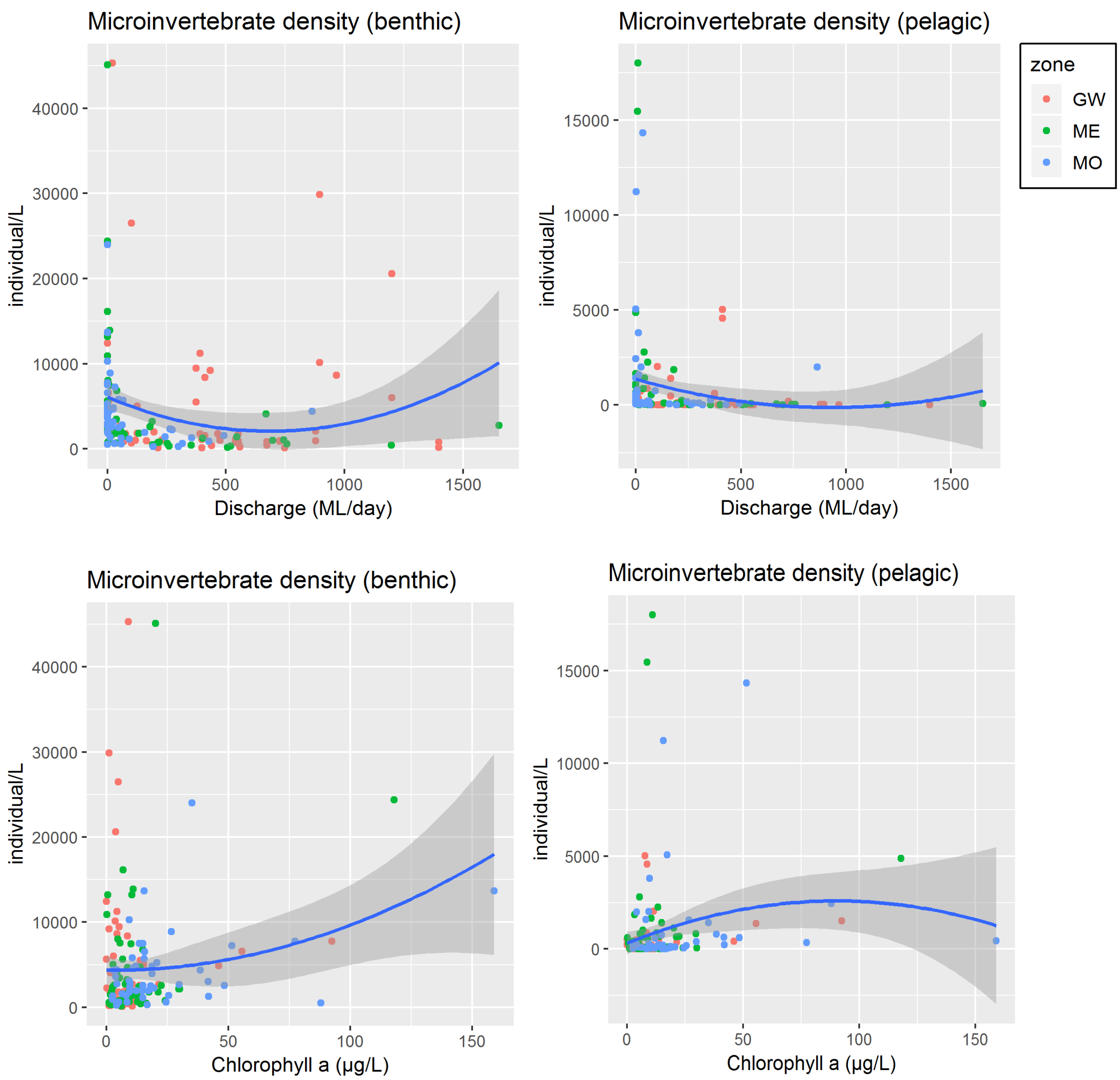

Figure E-7: Regression between microinvertebrate density and discharge and water quality (Cat III) indicators in three channel zones.

Table E-8: Summary of BIOENV results of microinvertebrate indicators within the Gwydir Selected Area in 2014-19. 'v' represents environmental indicators that highly correlated to microinvertebrate indicators.

Habitat	Ecosystem	Microinvertebrate indicator	Rho	p	Water chemistry						Water nutrient					Hydrological indicator
					Temperature	pH	Turbidity	Conductivity	Dissolved oxygen	Chlorophyll *a*	Dissolved organic carbon	Total nitrogen	Total phosphorus	Nitrate-nitrite	Filterable reactive phosphorus	
Benthic	Channel	Density	0.246	**0.001**						v	v					v
		Richness	0.09	0.32					v		v			v		
		Diversity	0.088	**0.02**										v		v
		Community	0.233	**0.01**					v	v						v
	Wetland	Density	0.333	**0.01**						v						v
		Richness	0.158	0.16				v				v			v	
		Diversity	0.141	0.06		v						v				v
		Community	0.284	**0.01**	v			v				v				v
Pelagic	Channel	Density	0.388	**0.01**				v		v	v					
		Richness	0.133	0.08			v	v							v	v
		Diversity	0.199	**0.01**												v
		Community	0.285	**0.01**				v		v						
	Wetland	Density	0.236	0.07			v			v						
		Richness	0.179	0.23					v					v		v
		Diversity	0.166	0.22					v					v		
		Community	0.222	**0.01**												v

Channel microinvertebrate diversity

In channels, microinvertebrate diversity and richness had a weak correlation with discharge in both benthic and pelagic habitats (Table E-7 and Figure E-8). The lowest diversity and richness occurred around discharges of 750 ML/d, suggesting a discharge threshold at which flow may act as a disturbance in channel sites.

Microinvertebrate diversity and richness were highly correlated to multiple water quality and nutrient indicators in both habitats (Table E-8). Among all highly correlated indicators, microinvertebrate diversity declined with increasing dissolved nitrogen concentrations in benthic habitat (Figure E-8) during the low flow periods (Appendix C). This highlights that longitudinal connectivity in channels can improve water quality, in turn supporting a more diverse assemblage of microinvertebrate taxa and feeding opportunities for higher level consumers.

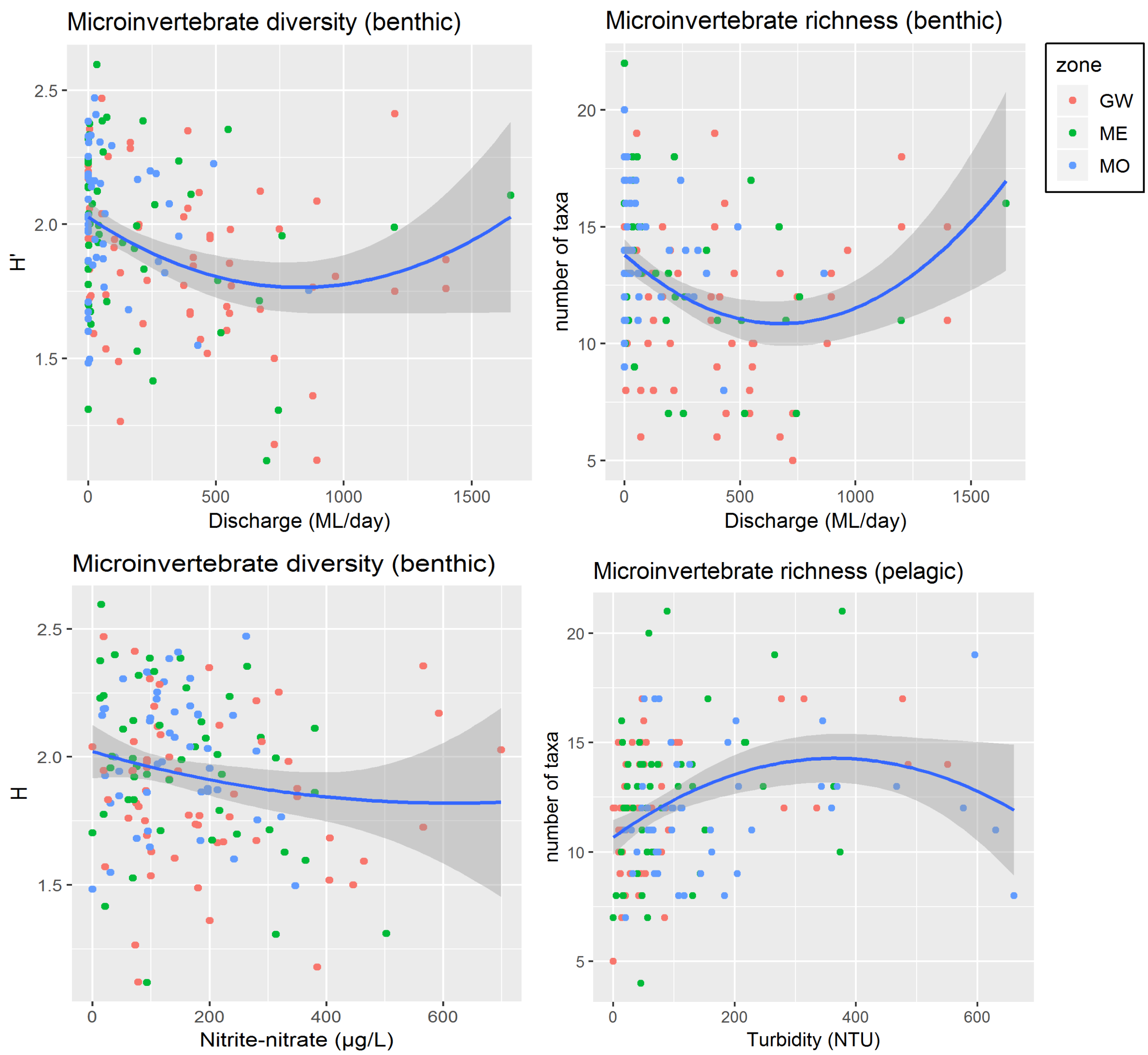

Figure E-8: Regression between discharge at Pallamallawa gauging station (NSW425003) and chlorophyll *a* and microinvertebrate diversity.

Channel microinvertebrate community

Channel community composition was significantly different between discharge groups in benthic (Pseudo-F=5.487, p=0.001) and pelagic habitats (Pseudo-F=8.386, p=0.001; Figure E-9a; Figure E-10a). In the benthic habitat, community composition in the <50 ML/d discharge group was significantly different to all other discharge groups. In the pelagic habitat, the <50 ML/d discharge group, 50-99 ML/d group and 100-499 ML/d group each had a distinctive community composition and were significantly different to all other discharge groups.

Benthic community composition was highly correlated to chlorophyll *a* and dissolved oxygen concentrations, and pelagic community composition was highly correlated to chlorophyll *a* and pH (Table E-8). The nMDS ordinations show higher chlorophyll *a* concentrations associated with the lower discharge group (<50ML/d) in both benthic and pelagic habitats (Figure E-9a; Figure E-10b), suggesting that microinvertebrate community composition was driven by increased primary production and a higher abundance of rotifer Families Brachionidae and Synchaetidae as well as Copepod nauplii (Figure E-9c; Figure E-10c).

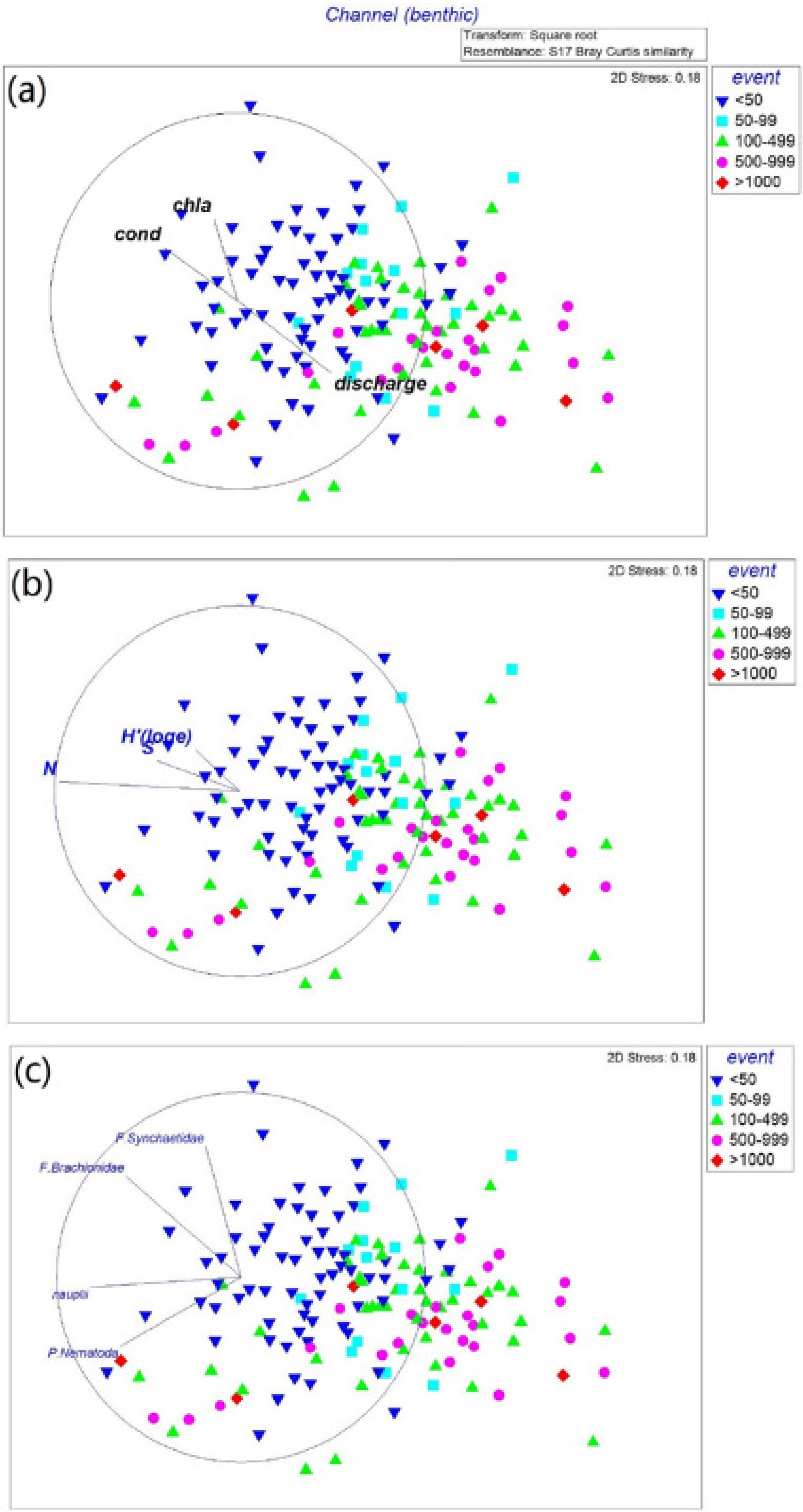

Figure E-9: nMDS ordinations of three channel zones benthic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (a) environmental variables, (b) microinvertebrate univariate indicators and (c) microinvertebrate taxonomic composition data which underlie the community composition pattern.

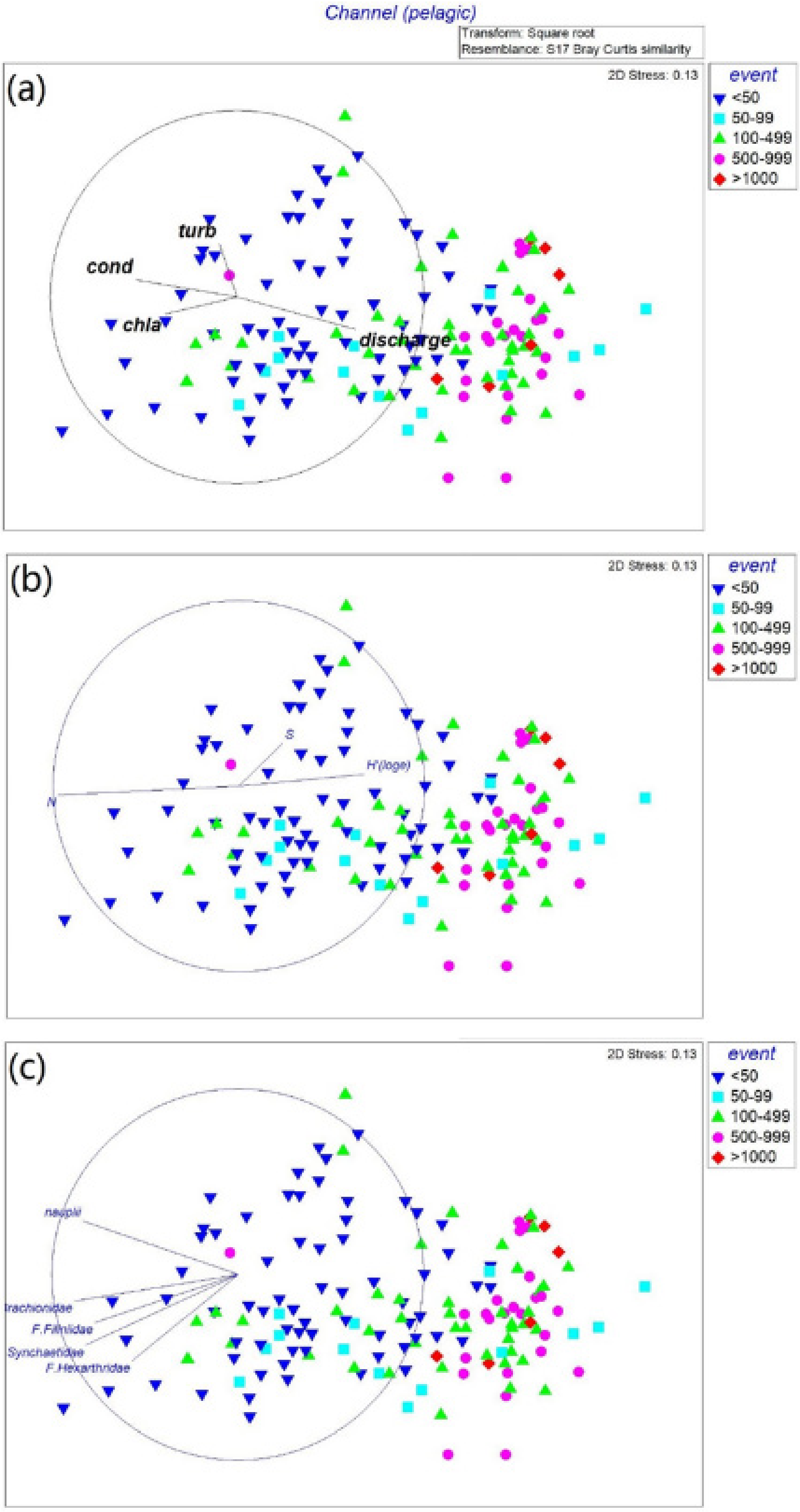

Figure E-10: nMDS ordinations of three channel zones pelagic microinvertebrate community composition using community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (a) environmental variables, (b) microinvertebrate univariate indicators and (c) microinvertebrate taxonomic composition data which underlie the community composition pattern.

E.3.3 Wetland ecosystem

Wetland microinvertebrate density

In wetlands, microinvertebrate density increased with increasing time since connection in both habitats (Figure E-11). Time since connection had a stronger predictable relationship with density in pelagic habitat compared with the benthic habitat (Table E-7). Similar to the channel environment, BIOENV showed that chlorophyll *a* concentrations were best correlated with microinvertebrate density in both habitats (Table E-8). During retention and contraction periods, an increase in microinvertebrate density was supported by higher carbon and nutrient concentrations. The highest microinvertebrate densities were consistently recorded during wetland contraction periods, highlighting the importance of prolonged inundation in wetlands to support secondary productivity and providing the eggbank for the next generation of zooplankton.

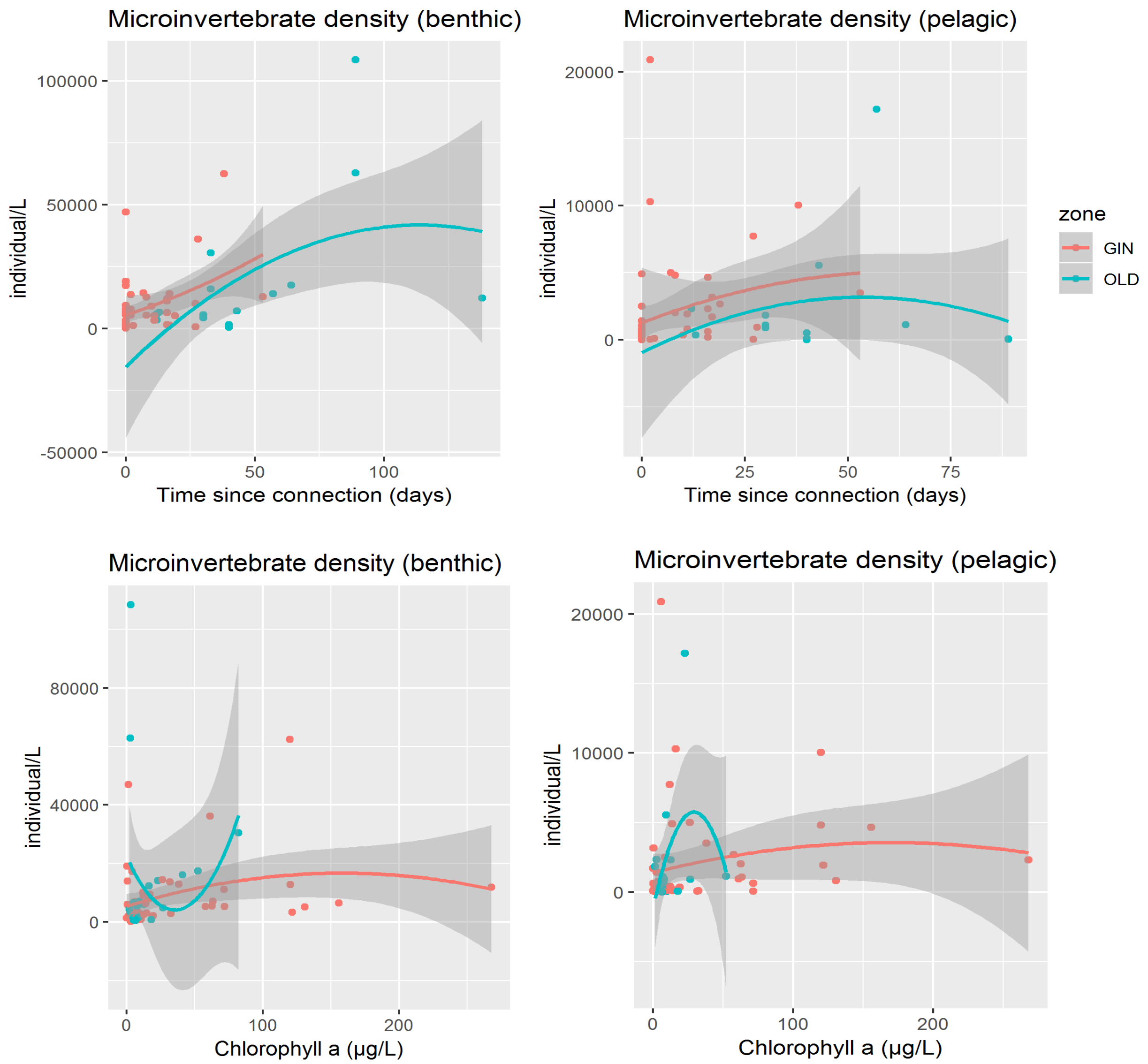

Figure E-11: Regression between microinvertebrate density and time since connection and chlorophyll *a* concentration.

The highest wetland microinvertebrate density was recorded in the Gingham Watercourse in December 2016 during the contraction phase, three months after a prolonged inundation event. At the same time, the Lower Gwydir wetland was predominantly dry (Figure E-12, Table E-9). Different wetland wide microinvertebrate densities were found in six environmental watering events that aimed to maintain and prolong inundation in the Gingham Watercourse and Lower Gwydir wetlands. This suggests that flow conditions that maintain an inundated wetland core may maximise microinvertebrate productivity upon broad scale rewetting.

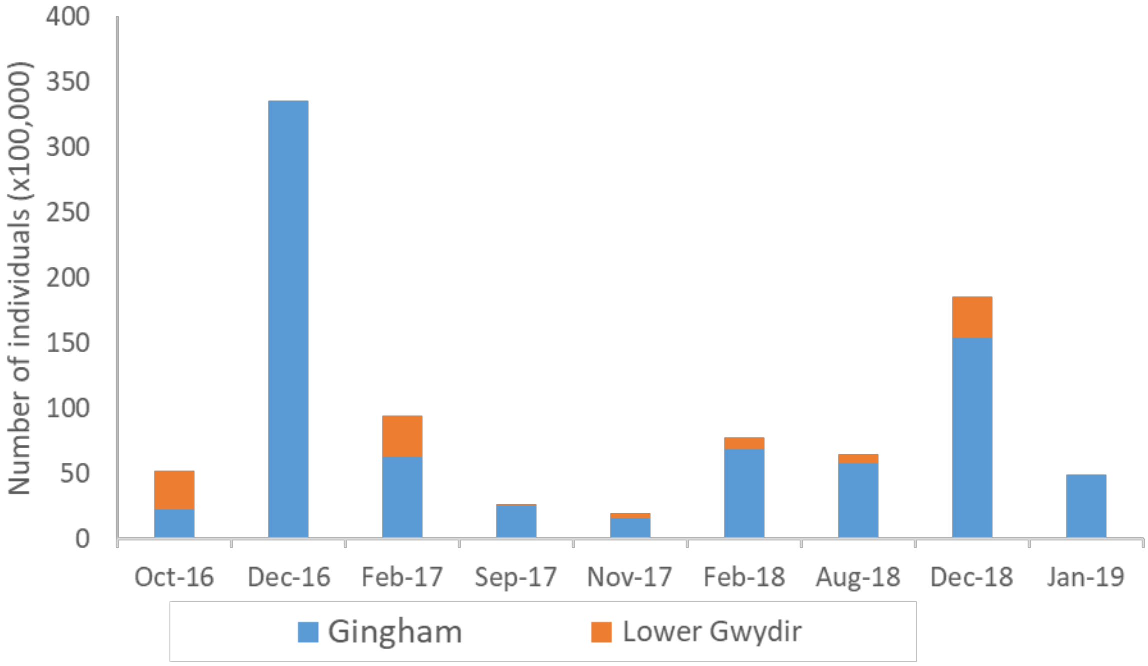

Figure E-12: Whole system scale microinvertebrate density (individuals/m^2) in the Lower Gwydir wetland and Gingham Watercourse.

Table E-9: Whole system scale microinvertebrate density (individuals/m^2) among 7 wetland sites in the Gingham Watercourse and Lower Gwydir wetland. Dominant water source for each sampling occasion described.

Zone	Site	2016-17			2017-18			2018-19		
		Oct-16	Dec-16	Feb-17	Sep-17	Nov-17	Feb-18	Aug-18	Dec-18	Jan-19
		Post natural flood (1 month)	Post natural flood (3 month)	EW delivery	EW: Early Season Stimulus Triggered Flow	EW: Stable Fish Flow	post EW	EW	EW: Lower Gwydir only	EW: Gingham only
Gingham	BUNOW	720,000	17,100,000	940,000	1,502,000	463,000	3,349,000	855,600	8,551,707	1,172,800
	BUNTY	450,000	5,500,000	750,000	931,000	197,000	2,315,000	147,150	2,979,828	455,823
	BUNWC	380,000	-	-	-	-	-	-	-	-
	GINWH	720,000	10,970,000	4,610,000	85,000	941,000	1,180,000	4,761,000	3,859,267	3,238,800
Lower Gwydir	OLDBS	1,250,000	-	3,140,000	86,000	346,000	930,000	308,100	957,691	-
	OLDCB	-	-	-	-	-	-	175,063	317,944	-
	OLDTY	-	-	-	-	-	-	78,300	971,657	-
	OLDWC	1,670,000	-	-	-	-	-	189,682	943,841	-
Gingham Total		2,270,000	33,570,000	6,300,000	2,518,000	1,601,000	6,844,000	5,763,750	15,390,801	4,867,423
Lower Gwydir Total		2,920,000	-	3,140,000	86,000	346,000	930,000	751,145	3,191,134	-
All wetland Total		5,160,000	33,570,000	9,420,000	2,603,000	1,947,000	7,774,000	6,514,895	18,581,935	4,867,423

EW = Environmental Water

Wetland microinvertebrate diversity

In wetlands, diversity and richness increased with increasing time since connection in both pelagic and benthic habitats (Figure E-13). Microinvertebrate diversity and richness were highly correlated to multiple water quality and nutrient indicators in both habitats (Table E-8). Among all highly correlated indicators, microinvertebrate diversity decreased with increasing total nitrogen concentration in benthic habitat and increased pH in the pelagic habitat (Figure E-13), both were linked to poor water quality during the water retention and contraction periods (Appendix D). This means that longer inundation duration in wetlands can support more diverse microinvertebrate communities and offer a wider range of feeding opportunities for higher level consumers.

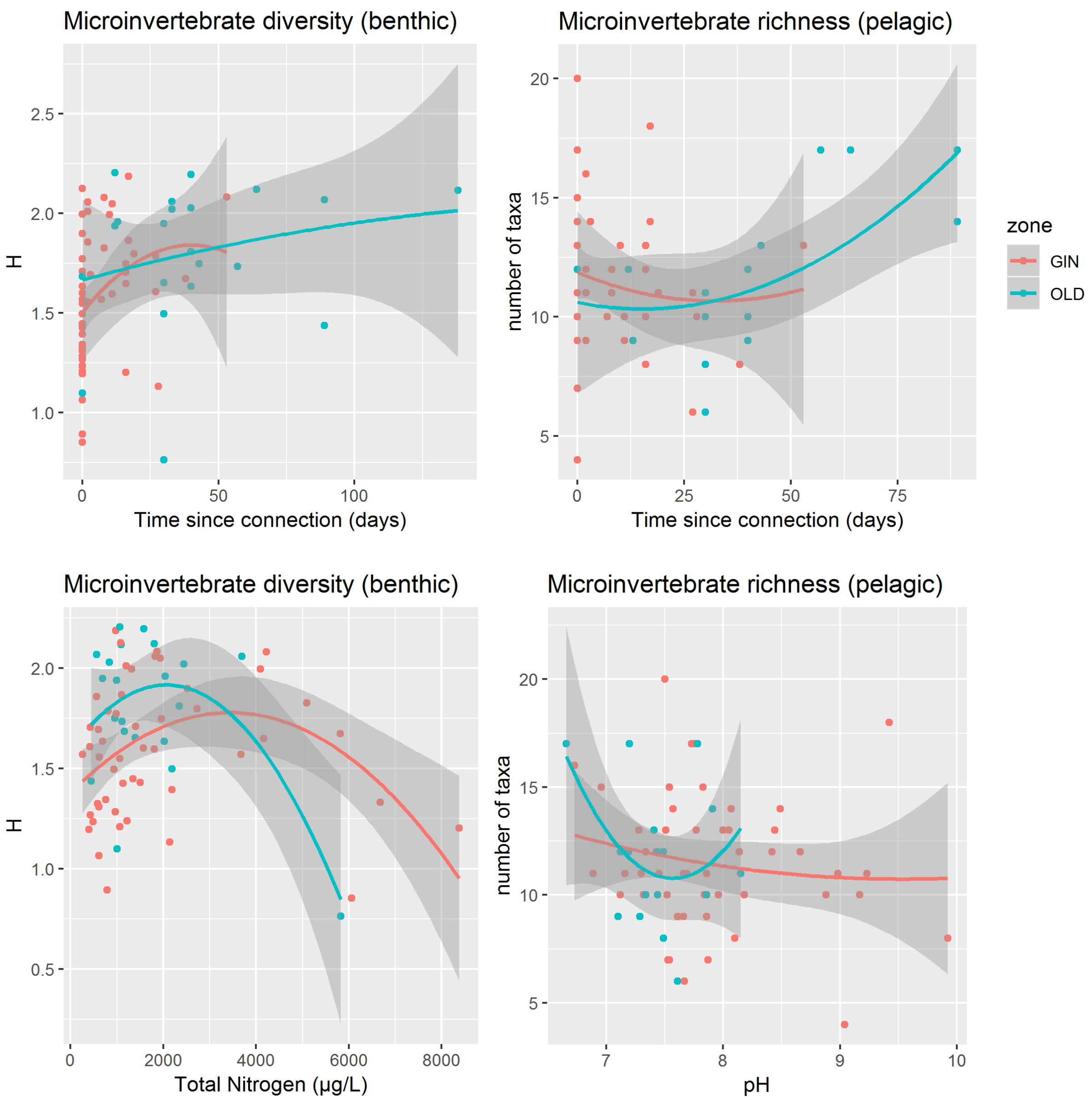

Figure E-13: Regression between microinvertebrate diversity, richness and time since connection and water quality indicators (Cat III) in two wetland zones.

Wetland microinvertebrate community

In benthic and pelagic habitats, one-way PERMANOVA indicated that the community composition was significantly different between time-since groups (Pseudo-F=1.987, p=0.001; Pseudo-F=2.819, p=0.001) with evidence that the 51 to 100 days group was most different from groups that had >50 days since connection (p<0.05; Figure E-14a). Microinvertebrate community composition was highly correlated to multiple water quality and nutrient indicators in benthic habitats (Table E-8). Among all highly correlated indicators, microinvertebrate diversity showed a shift in community composition with increased temperature, total nitrogen and chlorophyll *a* concentrations in the 51 to 100 days since connection group (Figure E-14b), linked to poor water quality during the water retention and contraction periods, especially in the Gingham Watercourse (Appendix D). In pelagic habitats, the <10 days group was most different from 11 to 50 days since connection (p<0.05; Figure E-15a). The BIOENV result showed that community composition was also solely correlated to time since groups (Table E-8).

The temporal shift in community composition with time since inundation was driven by increasing abundance of rotifer Family Brachionidae, Family Synchaetidae and Order Bdelloida, reflecting community succession from smaller to larger body size taxa, and changes in resource availability in the system (Figure E-14c; Figure E-15c). In particular, a rotifer genus Brachionus known to tolerate poor water quality conditions (Shiel, 1983) increased in abundance and dominated community in benthic and pelagic habitats in water retention and contraction phases.

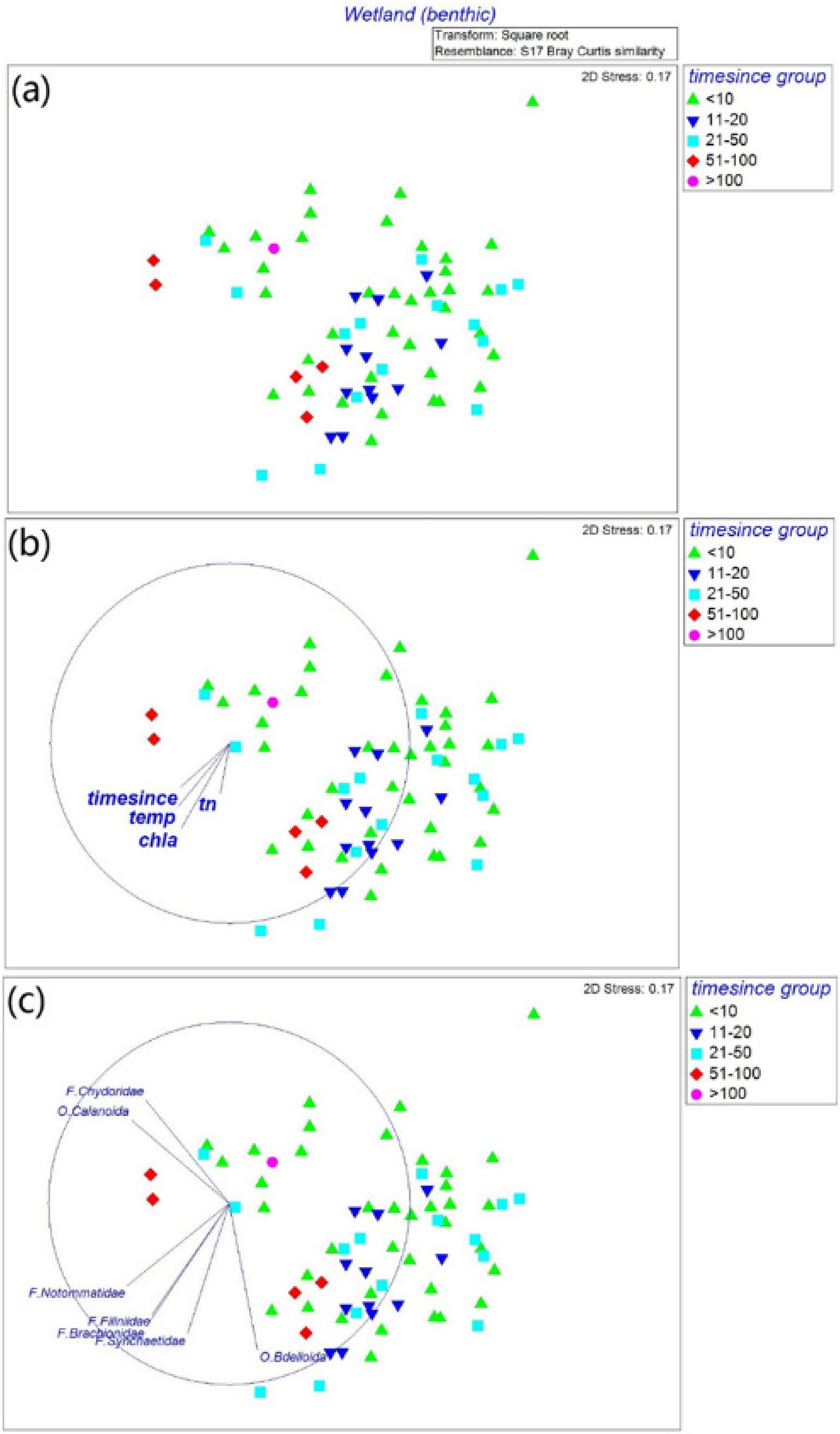

Figure E-14: nMDS ordinations of two wetland zones benthic microinvertebrate community composition using (a) community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables and (c) microinvertebrate taxonomic composition data which underlie the community composition pattern.

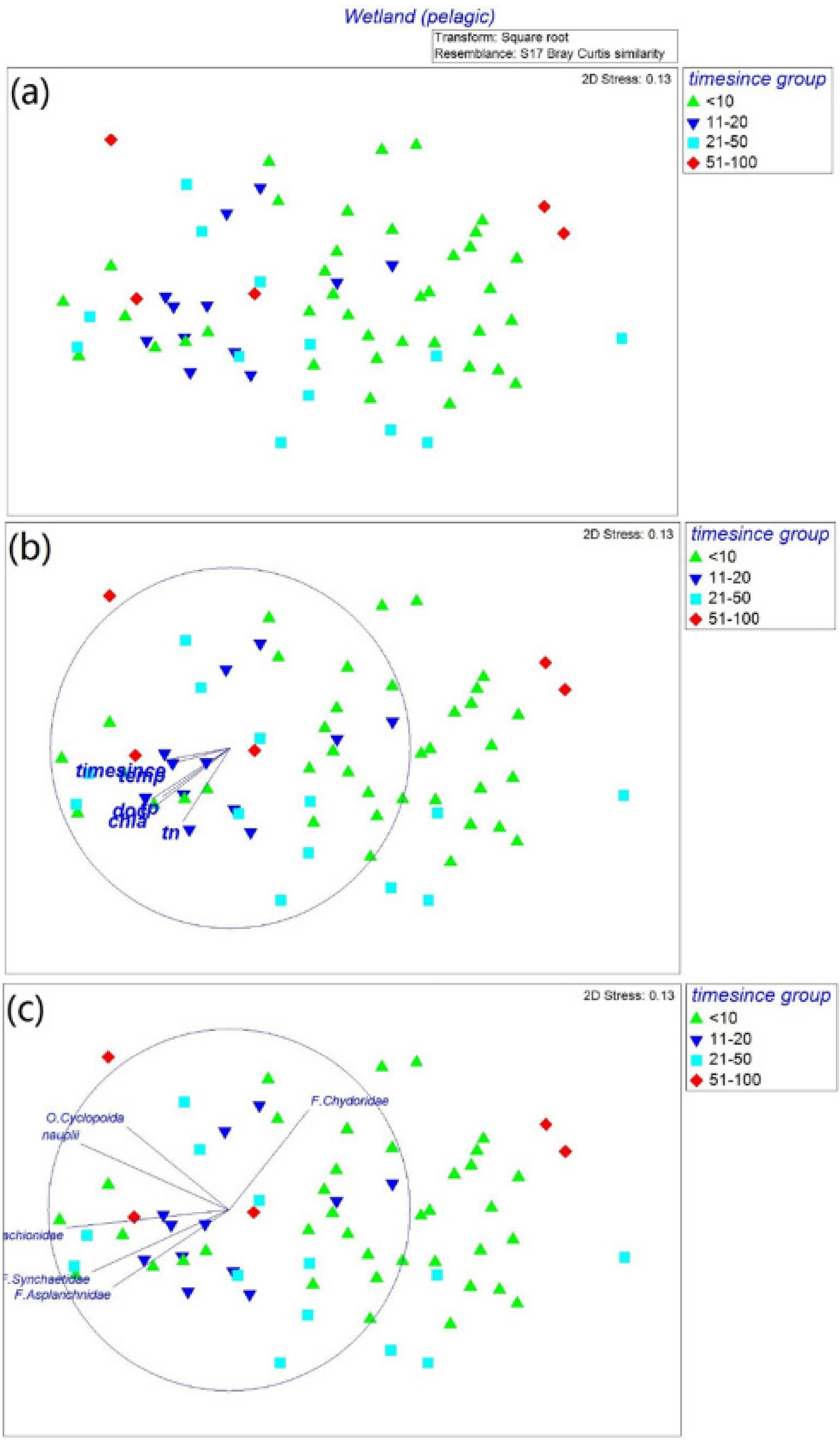

Figure E-15: nMDS ordinations of two wetland zones pelagic microinvertebrate community composition using (a) community abundance (square root) dataset with vectors (normalised data, Spearman correlation) of (b) environmental variables and (c) microinvertebrate taxonomic composition data which underlie the community composition pattern.

E.4 Conclusion

Hydrology is the primary driver of microinvertebrate patterns in channels (Gwydir River, Mehi River and Moomin Creek) and wetlands (Gingham wetland and Lower Gwydir wetland) of the lower Gwydir system. Moreover, broader spatial (zone) microinvertebrate patterns were predominantly driven by water quality. Microinvertebrate density and composition reflected variations in chlorophyll *a* and DOC concentrations, with higher densities stimulated by increases in algal and microbial food resources. During contraction periods, an increase in microinvertebrate secondary productivity was supported by higher nutrient and carbon concentrations delivered to the lower Gwydir system during wet periods that provide inundation conditions conducive for their growth and reproduction. Temperature seems to play a critical role in primary and secondary productivity, highlighting the potential ecological significance of the timing of flow events. This suggests that flows delivered over the warmer months may increase secondary productivity.

In channels, microinvertebrate densities were reduced in discharges over 500 ML/d, suggesting that environmental flows and natural flow events act as hydrological disturbances for microinvertebrates. For example, in 2016-17, the flow peak of 39,500 ML/d was much higher than all other years due to high rainfall in the upstream catchments. Benthic microinvertebrate density in this ‘wet year’ was consistently and significantly lower than all other years.

A total of 42 microinvertebrate taxa were identified over the 5 year period. Rotifers were the most abundant taxonomic group, followed by Copepoda and Cladocera. There was a distinctive temporal pattern in microinvertebrate diversity and richness, and channels consistently had a higher microinvertebrate diversity than wetlands. In channels, environmental watering actions provided steady longitudinal and lateral connection and increased diversity of habitats with improved water quality, in turn, supporting a more diverse range of microinvertebrate taxa. In wetlands, diversity and richness increased with increasing time since connection in both habitats.

Microinvertebrate taxonomic composition over the 5-year period showed significant differences between benthic and pelagic habitats. In channels, community composition was significantly different between discharge groups with evidence that the <50 ML/d group was most different to all other discharge groups. In wetlands, benthic microinvertebrate community composition shifted with time since connection groups, regardless of the event size and antecedent conditions. After connection of >50 days, reduced water quality conditions with higher nutrient concentrations in both habitats led to increases in microinvertebrate taxa with higher tolerances to poor water quality.

The multiple wetting and drying regime experienced in 2016-17 led to the highest microinvertebrate densities found after sediments were inundated for a second time in the Lower Gwydir wetlands. This cycle of multiple wetting and drying events within a water year may stimulate microinvertebrate productivity and wetland food webs. It is proposed that inter-annual hydrological variability and antecedent flow condition play important roles in microinvertebrate communities, highlighting the potential ecological significance of the frequency and magnitude of flow events. The spatial difference between channel and wetland zones highlights the importance of slower flow habitats such as waterholes in the Gingham Watercourse and Lower Gwydir wetland as microinvertebrate refuges that support diverse and abundant microinvertebrate communities and fuel food webs that support fish and waterbird recruitment.

Supplement A: Microinvertebrate taxa collected within the Gwydir Selected Area.

Taxa ID	Class or sub-Class	Order	Family
Class Ostracoda			
C.Ostracoda	Ostracoda	IF	IF
Order Cladocera			
F.Bosminidae	Branchiopoda	Cladocera	Bosminidae
F.Chydoridae	Branchiopoda	Cladocera	Chydoridae
F.Daphniidae	Branchiopoda	Cladocera	Daphniidae
F.Holopediidae	Branchiopoda	Cladocera	Holopediidae
F.Ilyocryptidae	Branchiopoda	Cladocera	Ilyocryptidae
F.Macrothricidae	Branchiopoda	Cladocera	Macrothricidae
F.Moinidae	Branchiopoda	Cladocera	Moinidae
F.Polyphemidae	Branchiopoda	Cladocera	Polyphemidae
F.Sididae	Branchiopoda	Cladocera	Sididae
Class Copepoda			
nauplii	Copepoda	IF	IF
O.Cyclopoida	Copepoda	Cyclopoida	IF
O.Calanoida	Copepoda	Calanoida	IF
O.Harpacticoida	Copepoda	Harpacticoida	IF
Phylum Rotifer			
F.Asplanchnidae	Monogononta	Ploima	Asplanchnidae
F.Atrochidae	Monogononta	Flosculariacea	Atrochidae
F.Brachionidae	Monogononta	Ploima	Brachionidae
F.Collothecidae	Monogononta	Flosculariacea	Collothecidae
F.Colurellidae	Monogononta	Ploima	Colurellidae
F.Conochilidae	Monogononta	Flosculariacea	Conochilidae
F.Dicranophoridae	Monogononta	Ploima	Dicranophoridae
F.Epiphanidae	Monogononta	Ploima	Epiphanidae
F.Euchlanidae	Monogononta	Ploima	Euchlanidae
F.Filiniidae	Monogononta	Flosculariacea	Filiniidae
F.Flosculariidae	Monogononta	Ploima	Flosculariidae
F.Gastropidae	Monogononta	Ploima	Gastropidae
F.Habrotrochidae	Monogononta	Bdelloida	Habrotrochidae
F.Hexarthridae	Monogononta	Flosculariacea	Hexarthridae
F.Lecanidae	Monogononta	Ploima	Lecanidae
F.Mytilinidae	Monogononta	Ploima	Mytilinidae
F.Notommatidae	Monogononta	Ploima	Notommatidae
F.Synchaetidae	Monogononta	Ploima	Synchaetidae
F.Testudinellidae	Monogononta	Ploima	Testudinellidae
F.Trichocercidae	Monogononta	Ploima	Trichocercidae
F.Trichotriidae	Monogononta	Ploima	Trichotriidae
O.Bdelloida	Digonanta	Bdelloida	IF

Taxa ID	Class or sub-Class	Order	Family
Other taxonomic groups			
sC.Collembola	Collembola	Symphypleona	Sminthuridae
C.Arachnida	Arachnida	IF	IF
O.Tricladida	Rhabditophora	Tricladida	IF
P.Nematoda	IF	IF	IF
P.Tardigrada	IF	IF	IF
sC.Oligochaeta	Oligochaeta	IF	IF

E.5 References

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Appendix F Macroinvertebrates

F.1 Introduction

The Macroinvertebrates indicator aimed to assess the contribution of Commonwealth environmental watering to macroinvertebrate abundance and diversity within the Gwydir River system Selected Area (Gwydir Selected Area). Specific questions were addressed through this indicator during 2014-2019:

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

F.2 Methods

F.2.1 Sampling methods

The macroinvertebrates indicator was sampled in association with Category III Water Quality (Appendix D) and Microinvertebrate (Appendix E) indicators on twenty sampling occasions between 2014 and 2019. Sampling sites were located in five Sampling Zones within the Gwydir Selected Area: Gwydir River, Mehi River, Moomin Creek, Gingham Watercourse and Lower Gwydir wetland (Figure F-1).

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

Table F-1: Category III Macroinvertebrate indicators measured in twenty sampling occasion in 2014-19.

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

F.2.2 Macroinvertebrate diversity Indices

Shannon Weiner diversity index (H’)

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

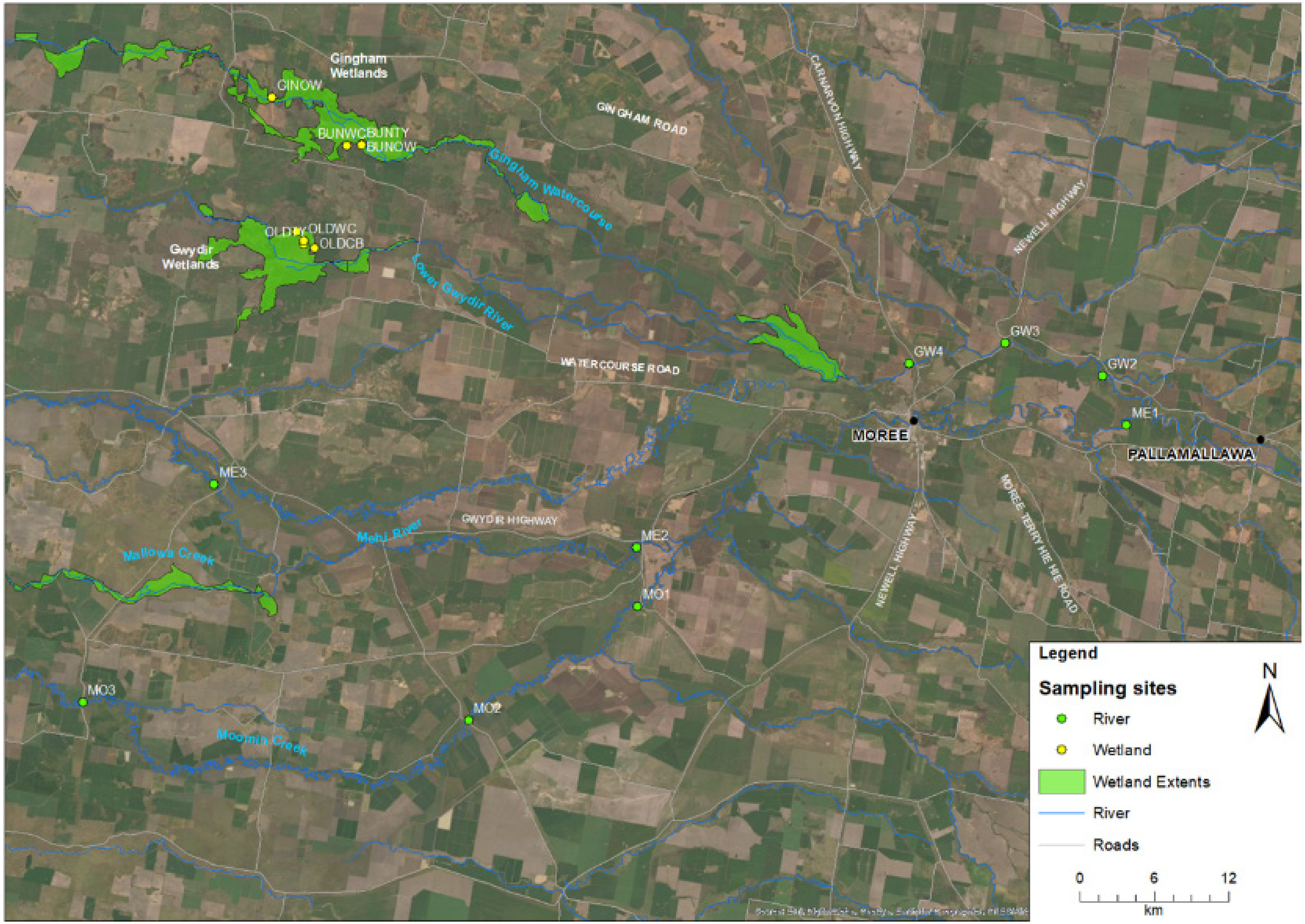

Figure F-1: Location of macroinvertebrate sites within the Gwydir Selected Area between 2014 and 2019.

Taxa richness (S)

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

SIGNAL score

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

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

Salinity index

The macroinvertebrate salinity index in each sample was calculated using edge habitat salinity sensitivity score (Horrigan *et al.* 2005). Macroinvertebrate taxa were assigned a sensitivity score of 1 (very tolerant), 5 (generally tolerant) or 10 (sensitive). The higher salinity index means that the macroinvertebrate community is more sensitive to salinity. The salinity index for each sample was calculated by averaging the sensitivity grades of all of the macroinvertebrate Families collected based on the presence/absence dataset.

F.2.3 Explanatory factors

Spatial and temporal factors were used to test if macroinvertebrate indicators were spatially or temporally dependent. Seventeen sampling sites were categorised in two ecosystems: channel and wetland (Table F-2). Twenty sampling occasions were categorised into five years and two seasons (i.e. summer from October to April and winter from May to September) (Table F-3).

Hydrological data were used to test the influence of environmental water and natural flow events. In all channel sites, daily discharge data was collated from the nearest WaterNSW gauge to determine hydrological thresholds for each macroinvertebrate indicator (Table F-2 and Figure F-2). In all wetland sites, time since connection was identified and calculated using data from the nearest WaterNSW gauge to each site (Table F-2 and Figure F-3).

For the Gingham wetland sites (i.e. BUNOW, BUNTY and BUNWC), connection was identified when the Gingham@Tillaloo gauge dropped below 10 ML/d. Time since connection was calculated using days between when Gingham@Tillaloo gauge dropped below 10 ML/d and the first day of the next sampling trip (Figure F-3). For site GINWH, time since connection was calculated using days between when Gingham@Waterhole water level began to recede and the first day of the next sampling trip (Figure F-3). In the Lower Gwydir sites (i.e. OLDBS, OLDCB, OLDTY and OLDWC), connection was identified when the Gwydir@Millewa gauge level rose above 1.5 m. Time since connection was calculated using days between when the Gwydir@Millewa gauge was above 1.5 m and the first day of the next sampling trip (Figure F-3). Continuous hydrological factors (i.e. discharge in channel and time since connection in wetland) were further transformed into categorical hydrological factors (discharge groups in channel and time since connection group in wetland) to infer patterns in statistical analyses.

F.2.4 Statistical methods

Summary statistics and macroinvertebrate guidelines

The minimum, 20^{th}, 50^{th} (median) and 80^{th} percentile and maximum values of each macroinvertebrate indicator were calculated in five zones within the Gwydir Selected Area.

PERMANOVA

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

PERMANOVA was used to test the overall difference in macroinvertebrate indicators between ECOSYSTEM, YEAR and SEASON and their interactions. Within two ecosystems, macroinvertebrate patterns were mainly driven by different hydrological events and therefore were analysed separately. In channels, PERMANOVA was used to test the difference in macroinvertebrate indicators between discharge categories. In wetlands, PERMANOVA was used to test the difference in macroinvertebrate indicators between time since connection categories.

Regression

Relationships between macroinvertebrate indicators and continuous hydrological factors were analysed using non-linear polynomial regression. In channels, regression was used to explore the relationships between macroinvertebrate indicators and discharge. In wetlands, regression was used to explore the relationships between macroinvertebrate indicators and time since connection (days). Regression outputs of F-statistic, degree of freedom, p-value (levels of significance as $p<0.05$) and R^2 are reported. Regression analyses were performed in R Studio v1.2.1335.

BIOENV

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

nMDS and SIMPER

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

Table F-2: Macroinvertebrate site locations and the nearest gauge stations. Map projection GDA94 Zone 55. Explanatory (spatial) factors to infer macroinvertebrate patterns in statistical analyses.

Ecosystem	Sampling Zone	Site	Easting	Northing	WaterNSW gauge station	Distance from gauge station (downstream)
Channel	Gwydir River (GW)	Gwydir River Site 2 (GW2)	791299	6740442	418042 (Gwydir D/S Tareelaroi)	6 km
		Gwydir River Site 3 (GW3)	783417	6743136		11 km
		Gwydir River Site 4 (GW4)	775598	6741492	418004 (Gwydir @ Yarraman Br)	0 km
	Mehi River (ME)	Mehi River Site 1 (ME1)	793235	6736492	418044 (Mehi D/S Tareelaroi)	3 km
		Mehi River Site 2 (ME2)	753567	6726597	418037 (Mehi D/S Combadello)	7 km
		Mehi River Site 3 (ME3)	719420	6731644	418085 (Mehi D/S Gundare Reg)	15 km
	Moomin Creek (MO)	Moomin Creek Site 1 (MO1)	753679	6721789	418048 (Moomin@Combadello)	10 km
		Moomin Creek Site 2 (MO2)	740017	6712591	418060 (Moomin@Glendello)	0 km
		Moomin Creek Site 3 (MO3)	708808	6714077	418061 (Moomin@Alma Br)	0 km
Wetland	Gingham wetland (GIN)	Bunnor Open Water (BUNOW)	731409	6759165	418076 Gingham@Tillaloo Br	8 km
		Bunnor Typha (BUNTY)	731394	6759148		
		Bunnor Water Couch (BUNWC)	730157	6759022		
		Gingham Waterhole (GINWH)	724103	6762962	418077 Gingham @ Water Hole	0 km
	Lower Gwydir wetland (OLD)	Old Dromana Bolboschoenus (OLDBS)	726067	6752088	418066 GWYDIR@MILLEWA	3 km
		Old Dromana Coolibah (OLDCB)	727611	6750685		
		Old Dromana Typha (OLDTY)	726680	6751125		
		Old Dromana water Couch (OLDWC)	726664	6751404		

Table F-3: Explanatory (temporal) factors to infer macroinvertebrate patterns in statistical analyses.

Year	Sampling occasion	Month	Season	Number of sites
2014-15	1	2014-12	summer	7
	2	2015-02	summer	7
	3	2015-03	summer	6
	4	2015-04	summer	5
2015-16	5	2015-09	winter	12
	6	2016-02	summer	12
	7	2016-03	summer	12
	8	2016-04	summer	11
2016-17	9	2016-10	summer	15
	10	2016-12	summer	12
	11	2017-02	summer	13
	12	2017-05	winter	13
2017-18	13	2017-09	winter	13
	14	2017-11	summer	13
	15	2018-02	summer	13
	16	2018-04	summer	12
2018-19	17	2018-08	winter	16
	18	2018-12	summer	16
	19	2019-01	summer	12
	20	2019-03	summer	11

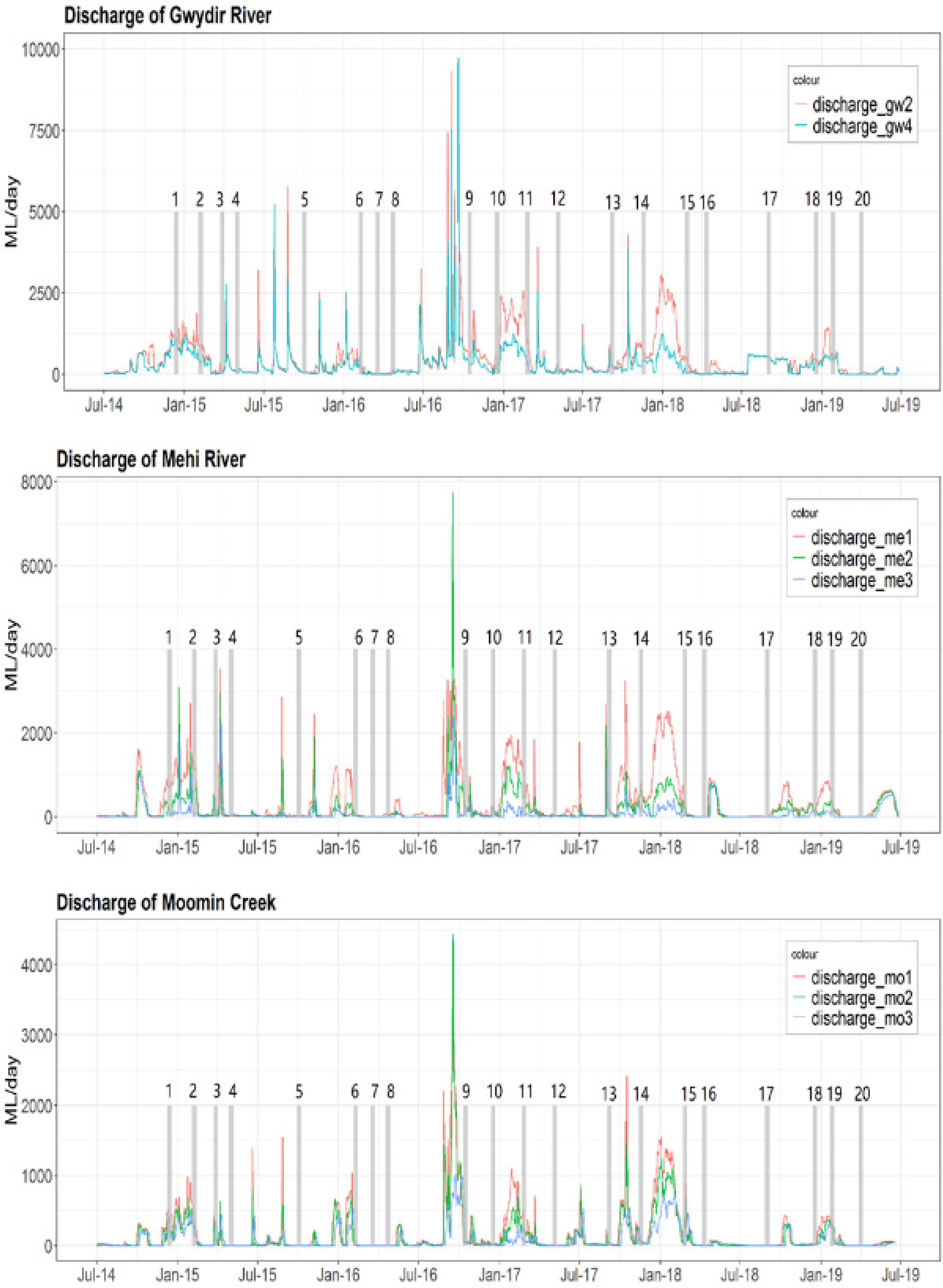

Figure F-2: Mean daily discharge in the Gwydir River, Mehi River and Moomin Creek with sampling occasions (numbered grey bars). Gauge station information in Table F-2.

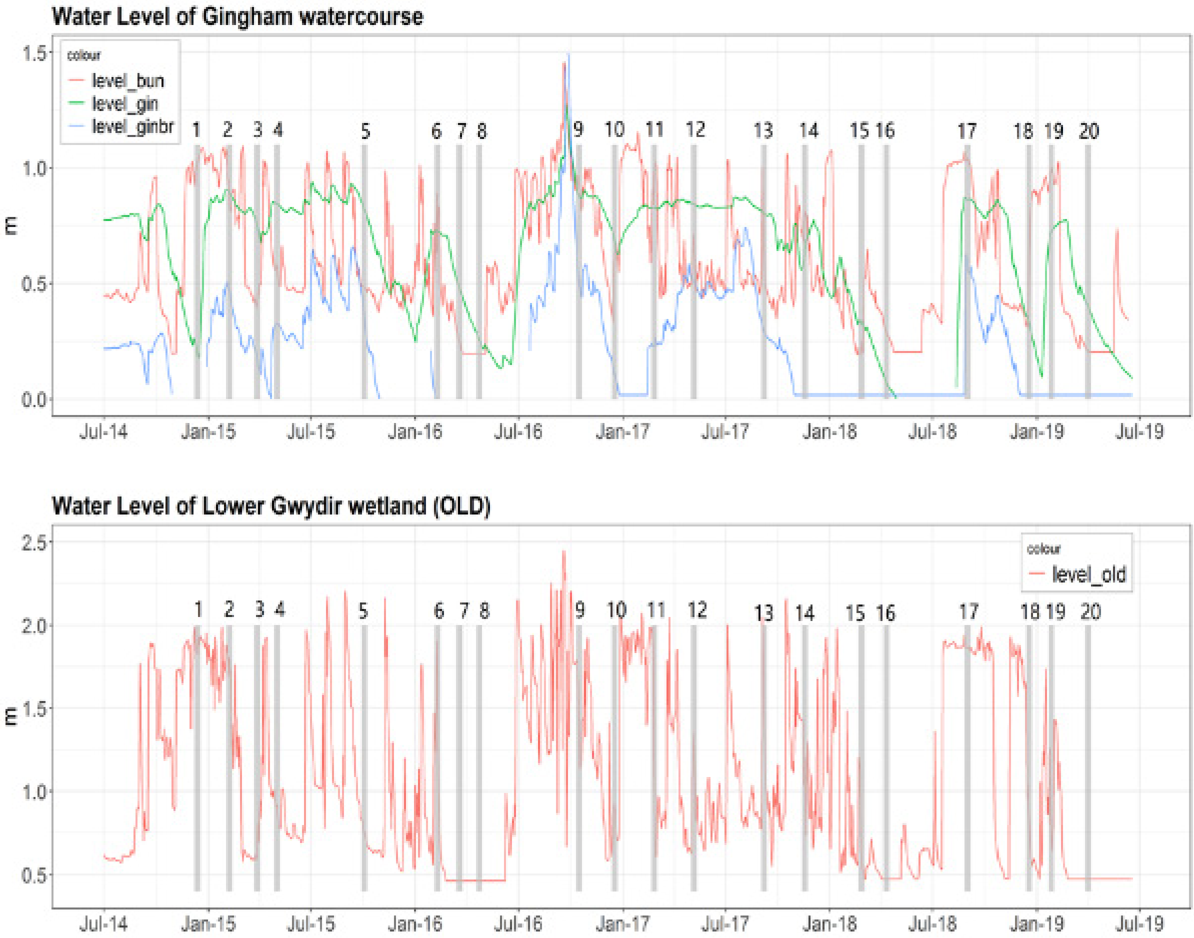

Figure F-3: Mean daily water level in the Lower Gwydir and Gingham wetlands with sampling occasions (numbered grey bars). Gauge station information in Table F-2.

F.3 Results and Discussion

F.3.1 Overall patterns

Macroinvertebrate density ranged from 6 to 2,335 individuals/m^2 (Table F-4). A three-way PERMANOVA analysis did not show any significant difference between Ecosystem, Year or Season. In general, the Lower Gwydir wetland had the highest average macroinvertebrate density, followed by the Gwydir River (Figure F-4). This spatial difference in macroinvertebrate density between zones has been consistent over the five years of monitoring, reflecting geomorphic and hydrological differences between zones exerting influence on macroinvertebrate density.

Table F-4: The minimum, 20th, 50th (median) and 80th percentile and maximum values of macroinvertebrate density (individuals/m^2).

Zone	Minimum	Percentile			Maximum	Number of samples
		20th	50th	80th		
Gwydir	14	7	10	13	911	60
Mehi	27	7.4	10.5	13	640	48
Moomin	9	7	9	12	598	48
Gingham	6	5	9	12	2,335	55
Lower Gwydir	37	8	10.5	17	1,443	20

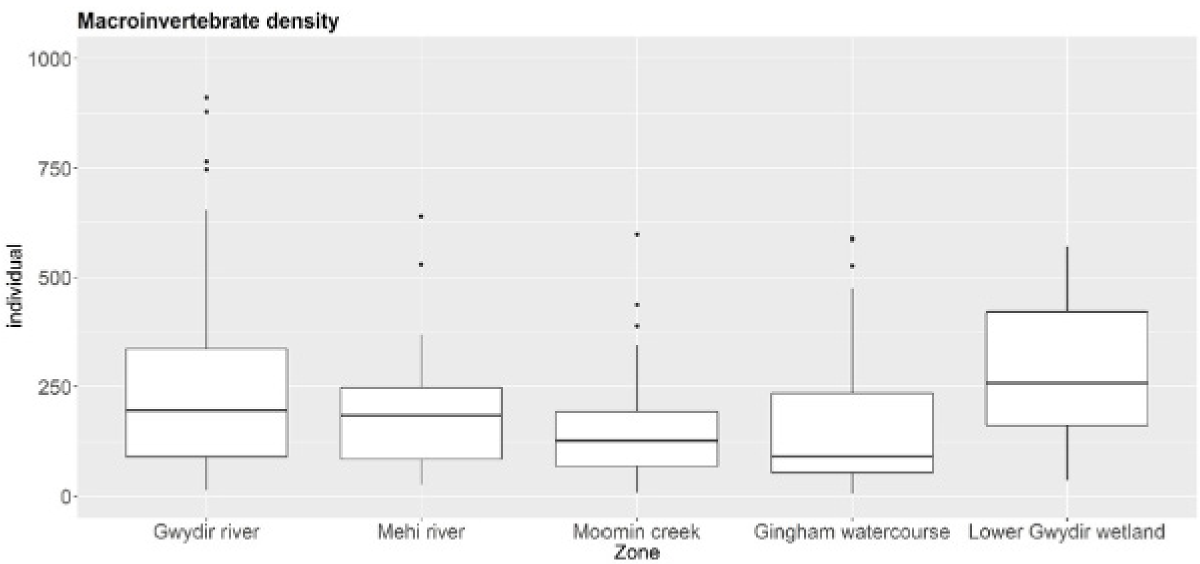

Figure F-4: Boxplot of macroinvertebrate density (individuals/m^2).

A total of 87 macroinvertebrate taxa were identified from 231 samples (Supplement A). The 16 most abundant taxa (>1% in total abundance) comprised 91% of the total abundance, with the most abundant Family being Corixidae (24% of the total abundance). The other most abundant taxa were Atyidae (18%), Chironomidae (13%), Palaemonidae (9%) and Baetidae (8%) that occurred in more than 60% of sites and sampling occasions. Macroinvertebrate taxonomic richness ranged from 3 to 23 and Shannon diversity indice ranged from 0.06 to 2.34 (Table F-5).

Overall, the Lower Gwydir wetland had the highest mean taxonomic richness (Figure F-5), linked to the diversity of vegetation habitats and basal resources that in turn support a more diverse assesmblage of macroinvertebrate taxa. Three-way PERMANOVA analyses showed wetlands had significantly lower macroinvertebrate SIGNAL scores and salinity indices (Pseudo-F=45.539, d.f.=1, p=0.001 and Pseudo-F=21.378, d.f.=1, p=0.001 respectively, Figure F-5), indicating that these taxa are resilient to the variable hydrologic and water quality conditions experienced in these wetland systems. Three-way PERMANOVA analysis showed a significant difference in macroinvertebrate diversity between years (Pseudo-F=3.411, d.f.=4, p=0.011) in which 2018-19 had a significantly less diverse community compared with all other years (p<0.05, Figure F-5).

Table F-5: The minimum, 20th, 50th (median) and 80th percentile and maximum values of each macroinvertebrate diversity indices.

Variable	Zone	Minimum	Percentile			Maximum	Number of samples
			20th	50th	80th		
Richness	Gwydir	4	7	10	13	19	60
	Mehi	3	7.4	10.5	13	16	48
	Moomin	5	7	9	12	18	48
	Gingham	3	5	9	12	17	55
	Lower Gwydir	7	8	10.5	17	23	20
Diversity (H')	Gwydir	0.19	0.97	1.41	1.75	2.12	60
	Mehi	0.06	1.03	1.40	1.78	2.04	48
	Moomin	0.29	1.06	1.37	1.62	2.27	48
	Gingham	0.11	0.83	1.22	1.80	2.34	55
	Lower Gwydir	0.60	1.17	1.70	2.09	2.30	20
SIGNAL score	Gwydir	2.5	3.0	3.5	3.9	5.2	60
	Mehi	2.4	3.0	3.4	3.8	4.3	48
	Moomin	2.3	3.2	3.4	3.8	4.6	48
	Gingham	1.5	2.6	3.0	3.4	4.0	55
	Lower Gwydir	1.6	2.1	2.5	2.8	4.5	20
salinity index	Gwydir	3.4	4.4	5.0	5.7	7.1	60
	Mehi	3.4	4.4	5.0	5.2	6.3	48
	Moomin	3.3	4.3	4.9	5.0	5.8	48
	Gingham	2.6	3.8	4.8	5.2	7.5	55
	Lower Gwydir	1.0	2.3	3.1	3.7	7.5	20

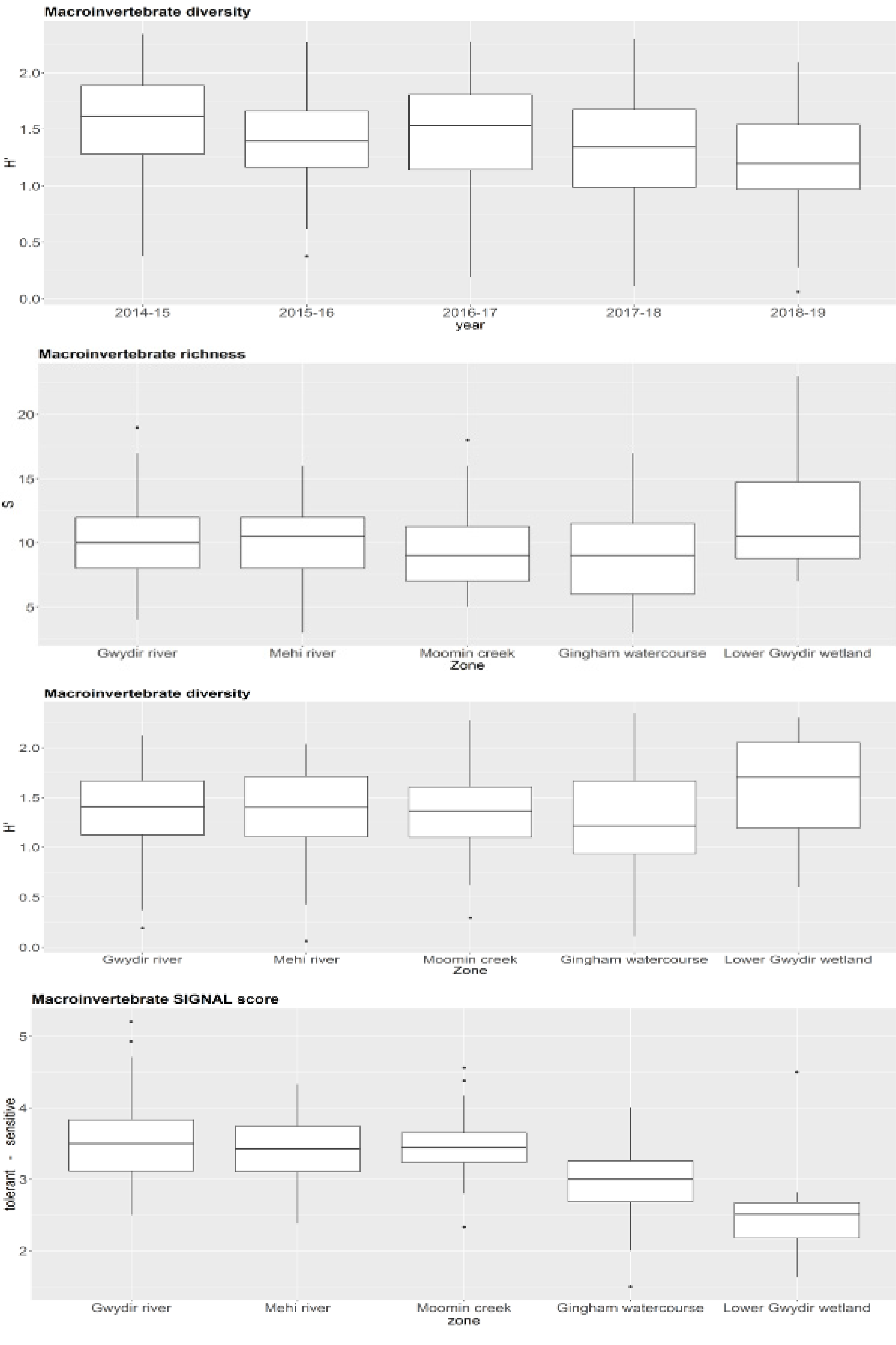

Figure F-5: Boxplot of macroinvertebrate diversity indices.

Macroinvertebrate taxonoimc composition showed strong spatial and seasonal patterns (Table F-6). Three-way PERMANOVA identified significant interactions between Ecosystem, Season and Year, reflecting spatial, temporal and hydrological differences between samples exerting a strong influence on macroinvertebrate community composition (Pseudo-F=1.646, d.f.=3, p=0.015). The spatial differences in macroinvertebrate composition between channel and wetland ecosystems was consistent over the five years of monitoring. The seasonal difference appeared to link to variations in temperature and chlorophyll *a* concentration.

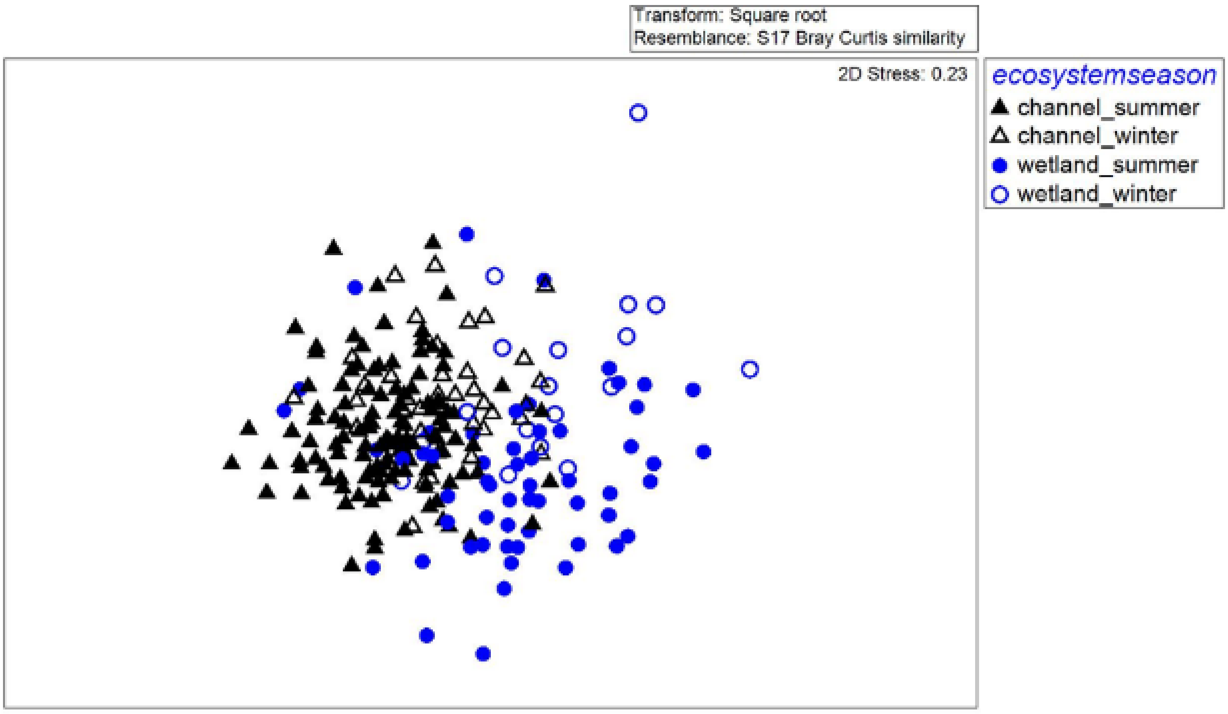

Figure F-6: nMDS ordination of macroinvertebrate community composition using community abundance (square root) dataset

F.3.2 Channel ecosystem

In channels, density was highly variable during base flow conditions, ranging between 30 and 878 individuals/m^2 at zero discharge (Figure F-7). Peak densities in channels were generally during base flow conditions with density decreasing with increasing discharge (Figure F-7). Environmental watering events contributed as disturbances in channel sites, initiating taxonomic replacement through longitudinal displacement that consistently reduced macroinvertebrate densities. However, macroinvertebrate density did not show a significant relationship with discharge between 0 to 1,650 ML/d (Table F-6).

The BIOENV result showed that conductivity and nutrient concentrations were best correlated with macroinvertebrate density (Table F-7). In particular, macroinvertebrate density increased with increasing total and dissolved nitrogen concentrations (Figure F-7). For example, in 2017-18, macroinvertebrate density increased during the post-environmental water period (base flow conditions) with increasing concentrations of nutrients associated with environmental water delivery. Moreover, macroinvertebrate density also increased with increasing microinvertebrate density in the Mehi River and Moomin Creek, suggesting a food web link between microinvertebrates and macroinvertebrates in these channel systems.

Table F-6: Summary of regression results between continuous hydrological factors and macroinvertebrate indicators in channel and wetland ecosystems.

Ecosystem	Macroinvertebrate indicator	Regression				
		F	d.f.	p-value	R^2	model
Channel	Density	0.19	2,153	0.83	0.002	poly
	Diversity (Shannon diversity index)	1.56	2,153	0.21	0.020	poly
	Richness	1.28	2,153	0.28	0.016	poly
	SIGNAL score	0.58	2,153	0.56	0.008	poly
	Salinity sensitivity score	0.06	2,153	0.94	0.001	poly
Wetland	Density	5.67	2,72	***0.01****	0.136	poly
	Diversity (Shannon diversity index)	3.43	2,72	***0.04****	0.087	poly
	Richness	5.89	2,72	***<0.01****	0.141	poly
	SIGNAL score	3.27	2,72	***0.04****	0.083	poly
	Salinity sensitivity score	4.55	2,72	***0.01****	0.112	poly

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

'poly' represents quadratic polynomial regression model.

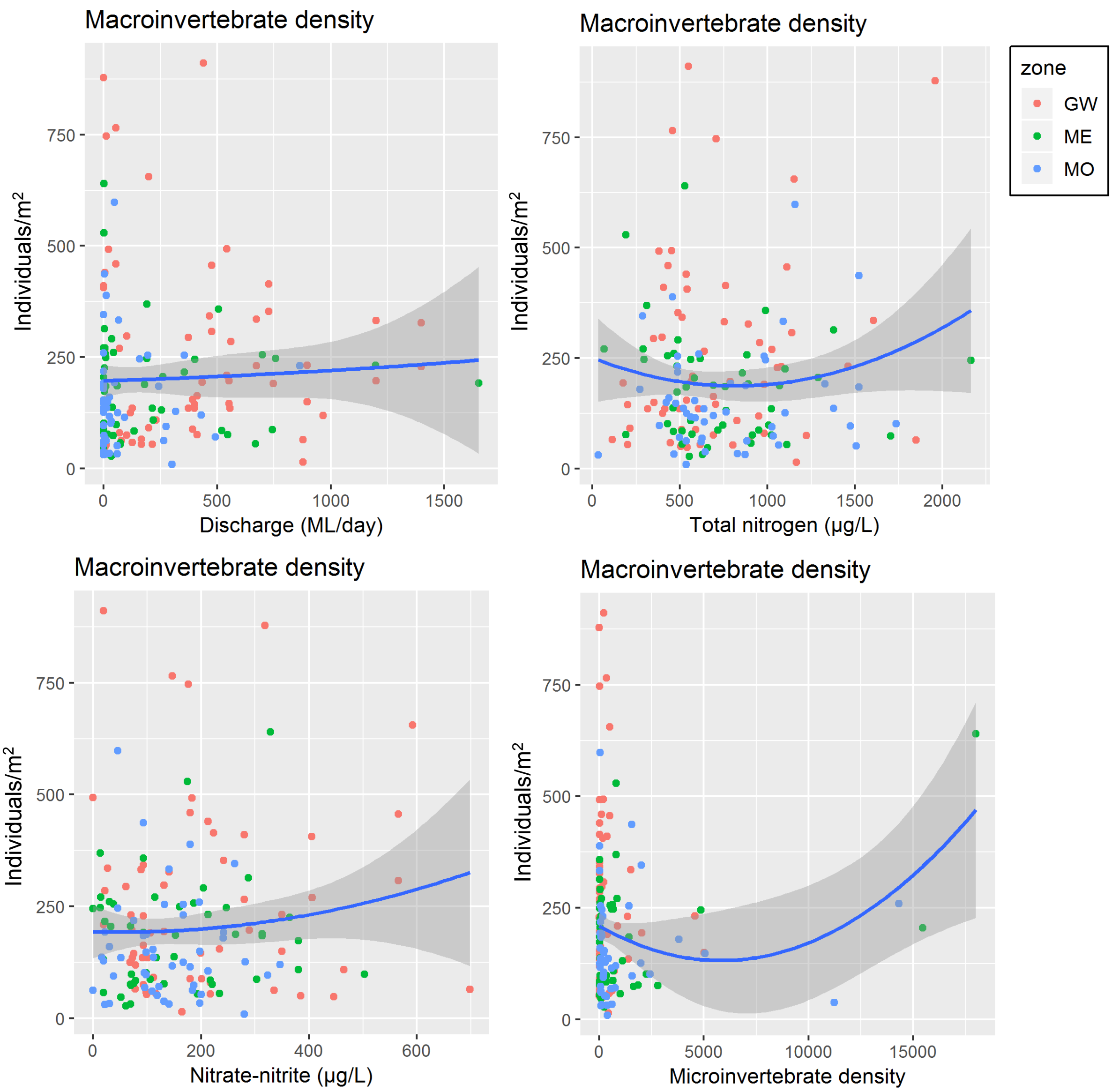

Figure F-7: Regression between macroinvertebrate density and discharge, water quality indicator (Cat III) and microinvertebrate density (individuals/m²) in three channel zones.

Table F-7: Summary of BIOENV results of macroinvertebrate indicators within the Gwydir Selected Area in 2014-19. 'v' represents environmental indicators that highly correlated to macroinvertebrate indicators.

Ecosystem	Macroinvertebrate indicator	Rho	p	Water chemistry						Water nutrient					Hydrological indicator
				Temperature	pH	Turbidity	Conductivity	Dissolved oxygen	Chlorophyll *a*	Dissolved organic carbon	Total nitrogen	Total phosphorus	Nitrate-nitrite	Filterable reactive phosphorus	
Channel	Density	0.104	0.36				v				v		v	v	
	Richness	0.096	0.21	v			v		v	v					
	Diversity	0.051	0.84						v				v	v	v
	SIGNAL score	0.099	0.24				v			v			v		
	Salinity sensitivity score	0.089	0.46										v		
	Community composition	0.227	**0.01**	v						v					
Wetland	Density	0.259	**0.01**			v								v	v
	Richness	0.041	0.93			v			v						
	Diversity	0.145	0.10	v		v			v						
	SIGNAL score	0.137	0.30	v			v					v		v	
	Salinity sensitivity score	0.213	**0.03**	v			v							v	v
	Community composition	0.242	**0.04**												v

Channel macroinvertebrate diversity

In channels, no macroinvertebrate diversity indices had clear relationships with discharge (Figure F-8 and Table F-6). All macroinvertebrate diversity indices were highly variable during base flow conditions and often decreased with increasing discharge (Figure F-8). Similar to the pattern in macroinvertebrate density, environmental watering events were found to act as a disturbance in channel sites that led to decreases both richness and diversity.

The BIOENV result showed that macroinvertebrate diversity indices were highly correlated to multiple water quality and nutrients indicators (Table F-7). In particular, macroinvertebrate richness increased with increasing chlorophyll *a* concentrations and microinvertebrate density, especially in samples with extremely high chlorophyll *a* and microinvertebrate densities (Figure F-8).

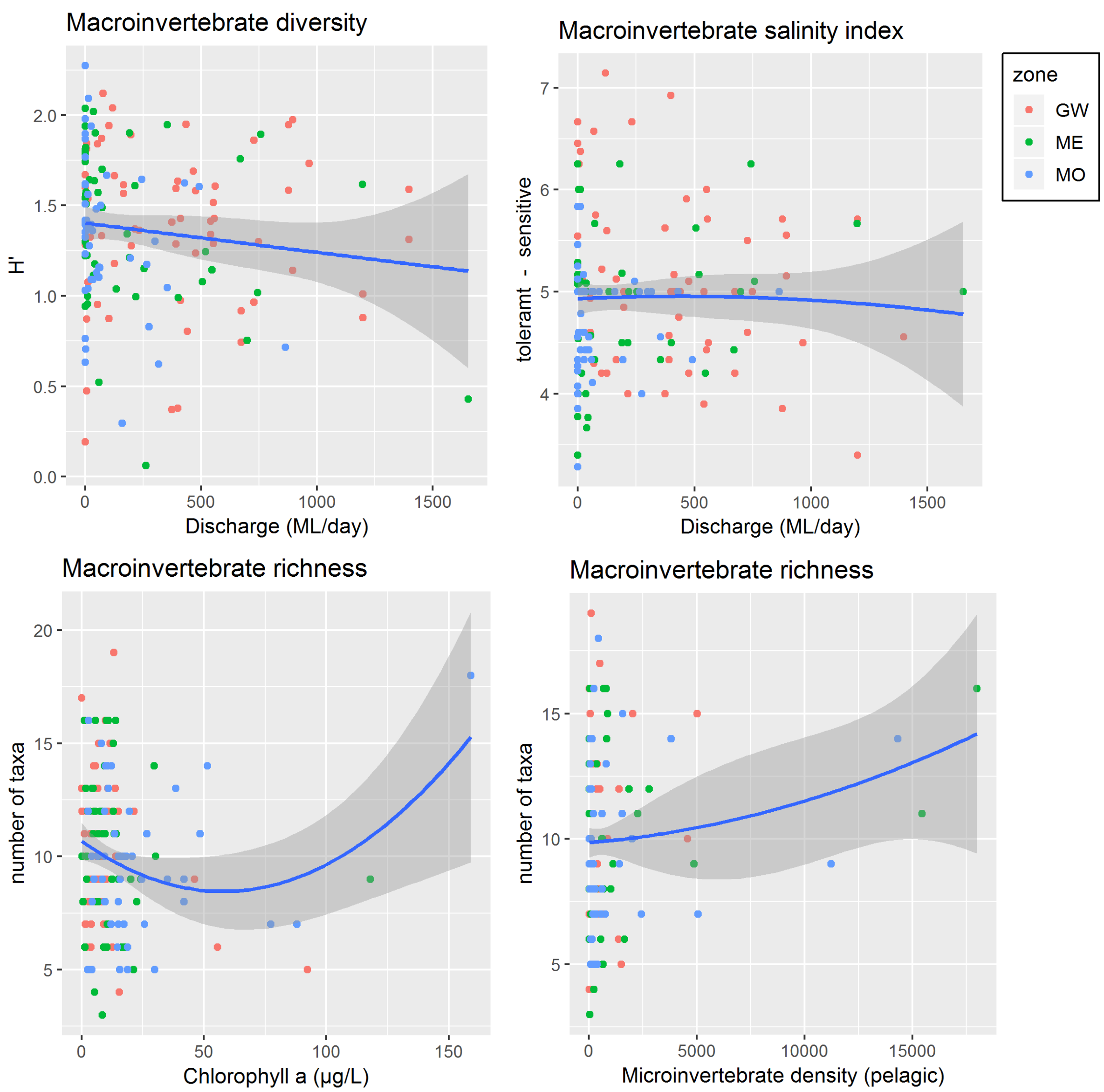

Figure F-8: Regression between macroinvertebrate diversity indices and discharge and water quality indicators (Cat III) in three channel zones.

Channel macroinvertebrate community

Community composition was significantly different between discharge groups (Pseudo-F=2.245, p=0.001) with evidence that the <50 ML/d group was most different from the 100 to 499 ML/d and 500 to 999 ML/d groups (p<0.05; Figure F-9a), highlighting the direct role of hydrology in affecting macroinvertebrate community composition. Temperature and dissolved organic carbon concentrations were also highly correlated to community composition (Table F-7). The nMDS ordination showed higher temperature and dissolved organic carbon concentration in summer, were correlated with higher discharge groups (Figure F-9b).

The nMDS ordination showed higher abundance of pollution tolerant taxa including Corixidae and Chironomiae in the <50 ML/d flow group (Figure F-9c). Higher abundance in tolerant taxa from Diptera (flies) such as sub-Families Chironomiae, Tanypodinae and Family Simuliidae and Ceratopogonidae were also recorded during base flow conditions (Table F-8 and Figure F-9c). These taxa have mobile adult fly stages that are capable of travelling long distances and lay eggs in temporary inland waters (Bilton *et al.* 2001; Robson *et al.* 2011). Moreover, non-biting larval midges (Chironominae) were reported widespread in inland waters because of their drought resistant eggs that hatch upon inundation (Bilton *et al.*, 2001). On the other hand, larger macroinvertebrate such as Atyidae shrimp and Palaemonidae shrimp had higher abundances in the faster flow group (>100 ML/d) (Table F-8 and Figure F-9c).

Table F-8: Macroinvertebrate taxa contributing most of the dissimilarities (SIMPER results) in the channel ecosystem.

Taxa	Group <50	Group 100-499
F.Corixidae	**4.74**	3.09
sF.Chironominae	**4.28**	2.41
sF.Tanypodinae	**0.94**	0.48
F.Simuliidae	**0.64**	0.4
F.Ceratopogonidae	**0.74**	0.38
F.Atyidae	3.93	**6.31**
F.Palaemonidae	3.23	**4.18**
F.Baetidae	3.1	**3.51**

Bold numbers represent the higher group

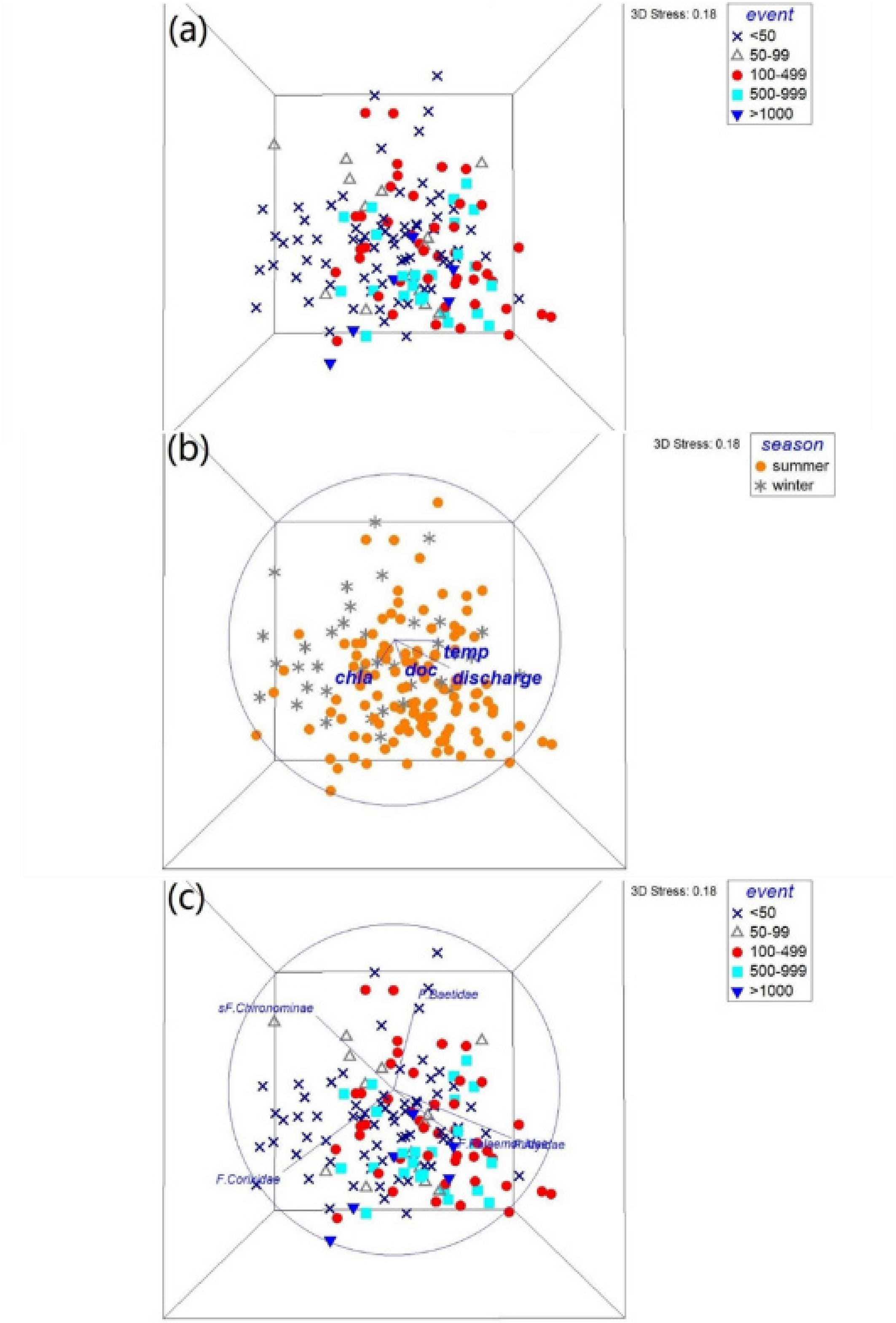

Figure F-9: nMDS ordinations of all channel macroinvertebrate community composition samples using community abundance (square root) dataset (a) by discharge groups, (b) by season with vectors of environmental variables (normalised data, Spearman correlation) and (c) by discharge groups with macroinvertebrate taxa abundance (normalised data, Spearman correlation) which underlie the community composition pattern.

F.3.3 Wetland ecosystem

In the Gingham wetland, macroinvertebrate density increased with increasing time since inundation (Figure F-10). The BIOENV result showed that time since connection, filterable reactive phosphorus concentrations and turbidity were best correlated with macroinvertebrate density (Table F-7). In particular, macroinvertebrate density increased with increasing filterable reactive phosphorus concentrations in the Gingham wetland (Figure F-10). However, there was no strong predictable relationship between macroinvertebrate density and time since connection in the Lower Gwydir wetland (Table F-6).

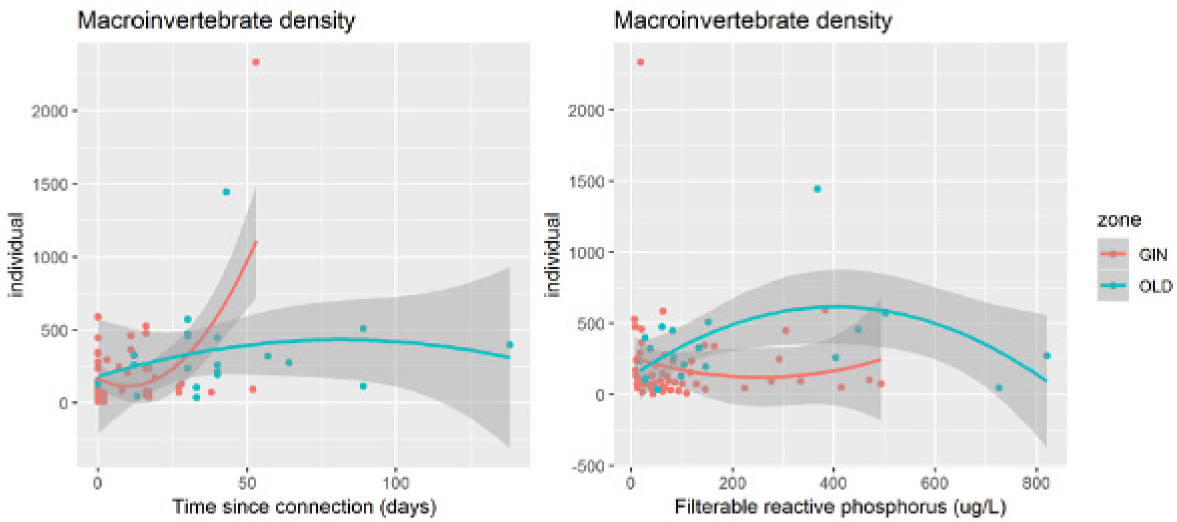

Figure F-10: Regression between macroinvertebrate density (individual/m2) and time since connection and filterable reactive phosphorus in two wetland zones.

Wetland macroinvertebrate diversity

In wetlands, diversity indices showed different patterns with time since inundation (Figure F-11). The BIOENV result showed that macroinvertebrate diversity indices were highly correlated to multiple water quality and nutrient indicators (Table F-7). In particular, macroinvertebrate diversity was positively correlated to temperature and negatively correlated to total phosphorus concentrations (Figure F-11). There was no strong predictable relationship with time since inundation (Table F-6).

In the Gingham wetland, macroinvertebrate density decreased with increasing time since inundation (Figure F-11), accompanied by water quality deterioration recorded during contraction periods from evapoconcentration and internal recycling of nutrients (Appendix C). On the other hand, diversity increased with increasing time since connection in the Lower Gwydir wetland (Figure F-11). This means that longer duration of inundation in the Lower Gwydir wetland can support a more diverse macroinvertebrate community affording a wider range of feeding opportunities for higher level consumers such as frogs, fish, waterbirds and other aquatic vertebrates.

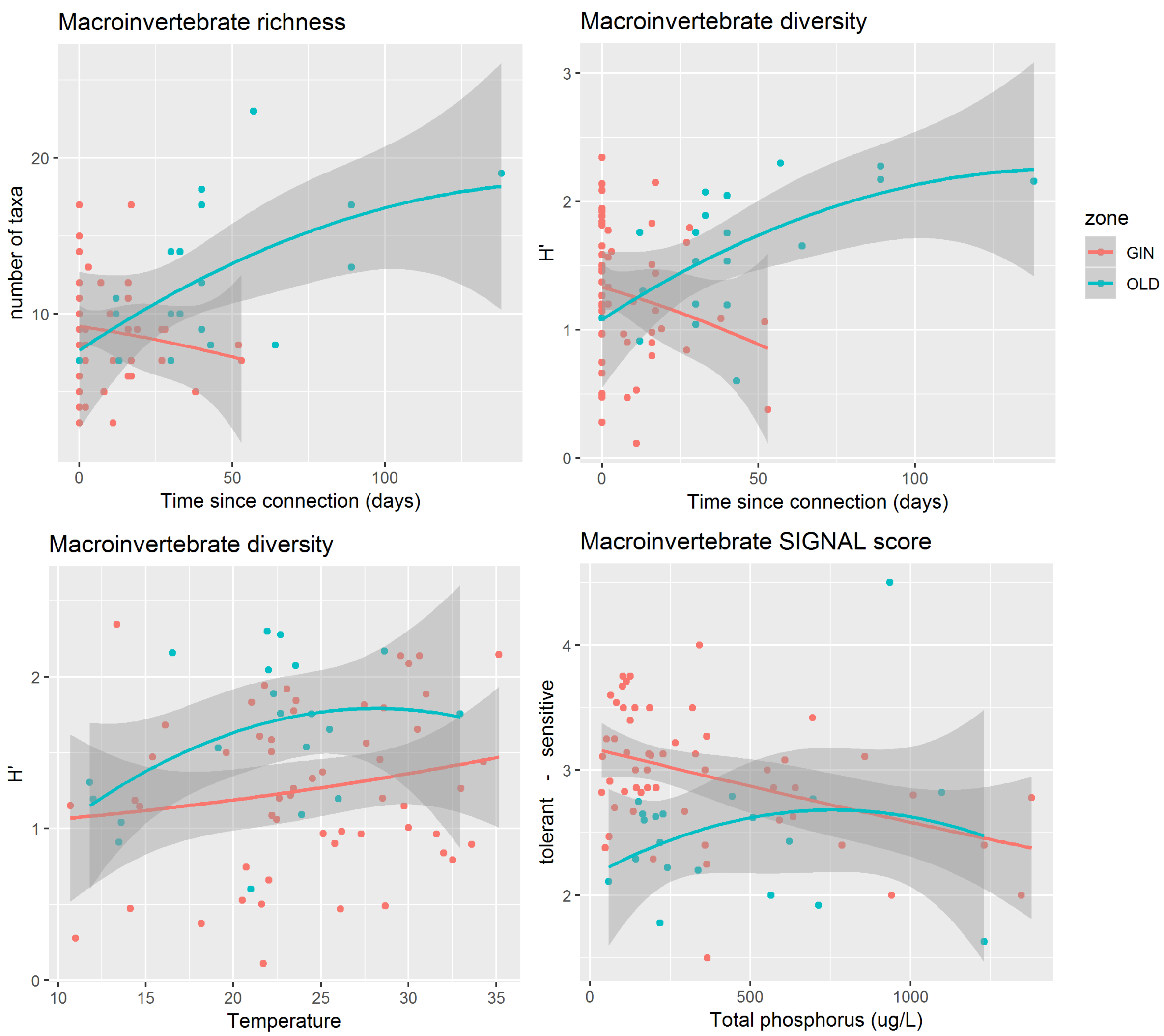

Figure F-11: Regression between macroinvertebrate diversity indices and time since connection and water quality indicators (Cat III) in two wetland zones.

Wetland macroinvertebrate community

Community composition was significantly different between time since inundation groups (Pseudo-F=2.155, p=0.001) with evidence that the <10 days since inundation group was most different from groups >21 days since inundation (p<0.05, Figure F-12a). The nMDS shows macroinvertebrate community composition shifted along the time since inundation groups, regardless of zone and vegetation habitats (Figure F-12a). The BIOENV result showed that community composition was also solely correlated to the time since groups (Table F-7).

Higher abundance of pollution tolerant taxa Chironomiae, Physidae, Notonectidae and Corixidae in 21 to 50 days since inundation and 51 to 100 days since inundation groups were recorded during water retention/ contraction phases (Table F-9). At the same time, a higher abundance of pollution sensitive Family Baetidae was observed (Table F-9). After prolonged retention time (>100 days), the community had a higher abundance of macroinvertebrate predators such as beetle larvae (Hydrophilidae) and bug larvae (Dytiscidae) which shows the capacity for the food web to support higher macroinvertebrate consumers (Table F-9).

There were also differences in community composition between the Lower Gwydir and Gingham wetlands (Figure F-12b), that reinforces the importance of a diversity of watering strategies within the Gwydir Selected Area.

Table F-9: Macroinvertebrate taxa contributing most of the dissimilarities (SIMPER results) among 75 samples in the wetland ecosystem.

Taxa	Group			
	<10	21-50	51-100	>100
F.Baetidae	**1.11**	0.97	0.8	0
sF.Chironominae	4.33	**6.63**	2.35	1.73
F.Physidae	0.66	**4.53**	1.15	0
F.Notonectidae	1.89	**3.05**	2.71	0
F.Corixidae	5.04	2.8	**8.64**	0
F.Hydrophilidae	0.97	3.56	3.3	**15.62**
F.Dytiscidae	0.9	1.75	3.3	**9.38**

Bold numbers represent the highest group contributing most to differences in community composition

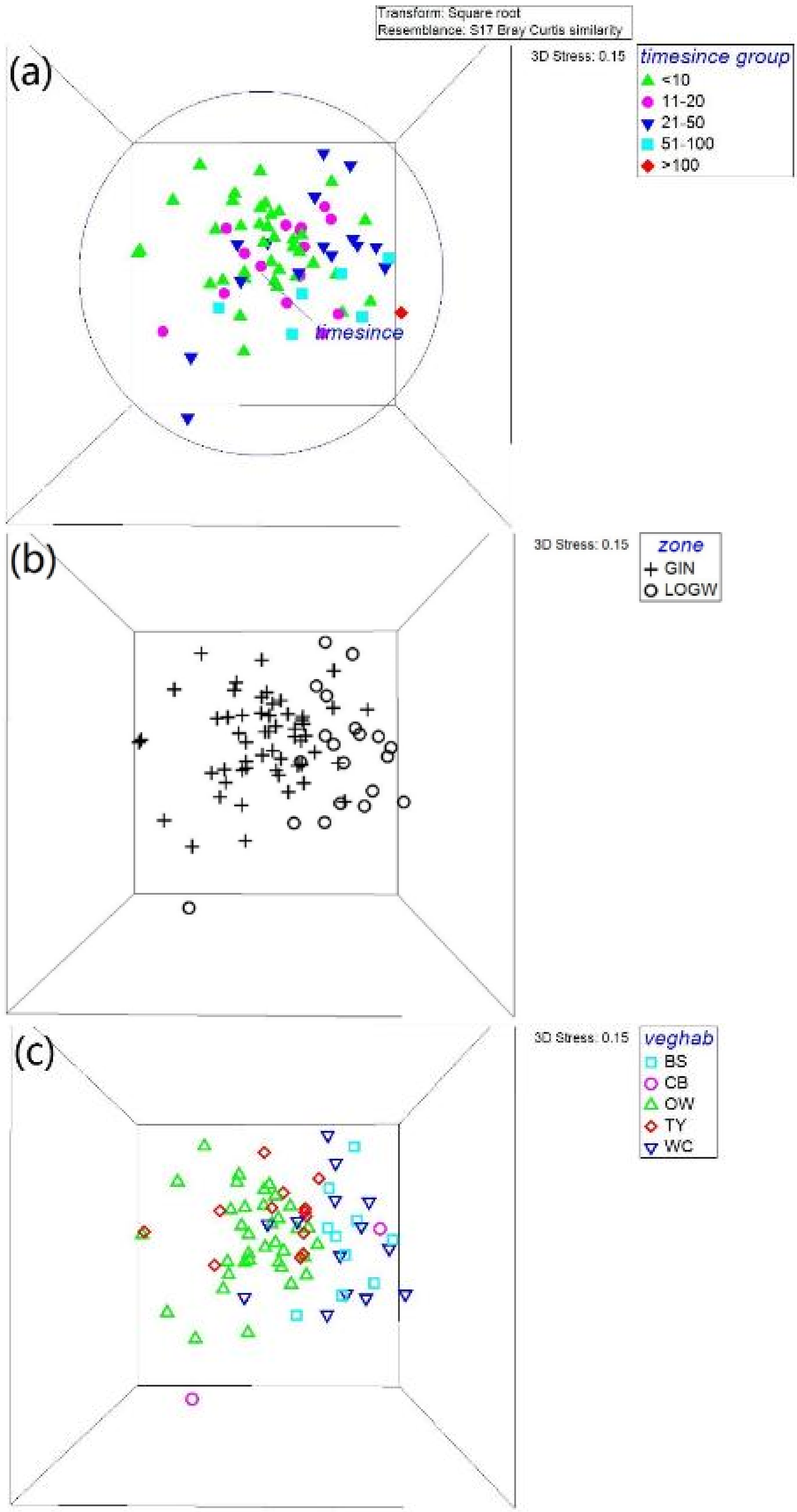

Figure F-12: nMDS ordination of all wetland macroinvertebrate community composition samples using community abundance (square root) dataset (a) by time since groups, (b) by zones and by (c) vegetation habitats which underlie the community composition pattern.

F.4 Conclusion

Hydrology is the primary driver of macroinvertebrate patterns in channels (Gwydir River, Mehi River and Moomin Creek) and wetlands (Lower Gwydir and Gingham wetlands) of the lower Gwydir system. Moreover, broader spatial (zone) patterns in macroinvertebrate indicators were predominantly driven by water quality.

Hydrological connectivity acted to deliver resources to wetland environments that supported a macroinvertebrate cycle. In channels, macroinvertebrate density increased during the post-environmental water period (base flow conditions) following prolonged higher flows. Macroinvertebrate density increased in wetland ecosystems with time since connection and inundation and peaked in the contraction period associated with higher carbon and nutrient concentrations, as well as peak microinvertebrate densities. This highlights the importance of longitudinal and lateral connection by environmental water events to stimulate macroinvertebrate produtivity and provide basal food resources to support wetland foodwebs. However, higher discharge also acted as a disturbance that decreased macroinvertebrate density in channels.

Across all sampling zones, the Lower Gwydir wetlands displayed the highest average density and taxonomic richness for macroinvertebrates. This pattern highlights that longer durations of both longitudinal and lateral connection, supported by environmental water, provided periods of improved water quality and increased inundated habitat diversity, stimulating macroinvertebrate productivity in this wetland environment. The influence of environmental water on macroinvertebrate diversity can persist through time and contribute to high diversity for at least two months following environmental water delivery. For example, the Lower Gwydir wetlands received inflows from several environmental flow events in the 2017-18 water year. These environmental watering actions provided longer inundation and maintained surface water in the Lower Gwydir wetlands until February 2018 and supported higher macroinvertebrate density and taxonomic richness in the Gwydir Selected Area.

Macroinvertebrate taxonoimc composition showed strong links to hydrology. Environmental water that contributed to the cycle of inundation and contraction provided an opportunity for long-term community succession due to changes in local physical and chemical conditions. In channels, community composition was significantly different between discharge groups with evidence that the <50 ML/d group was most different. Since each of the three channel zones had highly variable flow regimes when compared with wetlands, macroinvertebrate taxa with highly mobile traits and body shape more adapted to flow had higher abundances in higher discharges. In wetlands, community composition consistently shifted along the time since inundation regardless of zone and vegetation habitats. In all zones, macroinvertebrate taxa with higher pollution tolerant ability appeared to have higher abundance with increased time since connection/inundation.

In 2017-18, peak macroinvertebrate density did not occur during periods of environmental water delivery in channel sites. Instead, increases in macroinvertebrate density were delayed to when warmer temperatures occurred, coinciding with base flow periods and peak chlorophyll *a* concentrations. This highlights the potential ecological significance of the timing of environmental flow events. Macroinvertebrate community composition was significantly different between zones, suggesting that maintaining macroinvertebrate diversity within the Gwydir Selected Area requires the inundation of both river and wetland areas, as well as different strategies for the Lower Gwydir and Gingham wetlands. Continuing the multi-event watering strategy that has been employed in the Gwydir system will encourage a productive macroinvertebrate community across the system, which will provide benefits for higher order consumers such as fish, frogs and waterbirds.

F.5 Reference

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Appendix G Ecosystem Type

G.1 Introduction

The Ecosystem Type indicator contributes to the broader scale evaluation of Commonwealth environmental water's influence on ecosystem diversity. While primarily designed to inform at larger basin scales, information on the types of ecosystems influenced by Commonwealth environmental water is also useful at the Gwydir River system Selected Area (Gwydir Selected Area) scale. Several specific questions were addressed by measuring ecosystem type within the Gwydir Selected Area during the LTIM project (2014-19):

- 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?

G.1.1 Environmental watering during the LTIM project

A total of 301,172 ML of environmental water was delivered through the Gwydir River system during the LTIM Project, making up 23% of the total water that flowed down the Gwydir River channel during that period (Table G-1). The highest volume occurred during the 2018-19 water year when 62,150 ML of Commonwealth and 52,000 ML of NSW environmental water was used. The lowest volume was in the 2015-16 water year where 13,250 ML of environmental water was delivered.

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system. In-channel flow pulses were delivered down the Mehi River and Carole Creek channels to enhance in-stream ecological function, nutrient cycling, water quality and fish spawning conditions. In addition, flows were delivered to the Lower Gwydir, Gingham Watercourse and Mallowa Creek to provide for wetlands inundation.

During 2015-16, environmental water was delivered to a number of assets within the Gwydir Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for with 964 ML of this water flowing down the Mehi River, and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW water bulk water deliveries. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse in February 2016 to replace flows that were extracted in a supplementary flow event. While not large in volume, these flows made it into the wetlands, inundating up to 161.81 ha (Appendix B). Due to critically low flows experienced in the Lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April 2016. This followed a period of 30 to 40 days of nil flow conditions across the catchment.

A flow event occurred down the Mehi River in September 2016 triggering supplementary water licences owned by the CEWO. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however very little of the moderate flows were diverted into the Mallowa wetlands. In January to March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands. Flows were also delivered into the

Lower Gwydir River and Gingham Watercourse to build upon moderate winter/spring flows. From January to March 2017, 30,000 ML was delivered, aiming to inundate broad areas of semi-permanent wetland vegetation. During 2016-17, no environmental water was delivered to Moomin Creek.

Table G-1: Environmental water use in the Gwydir River system during the LTIM project (2014-19). This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW state governments.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2014-15				
Gwydir River*	56,534	29,895	302,043	29
Gingham Watercourse	15,000	14,868	46,711	64
Lower Gwydir	15,000	15,027	41,171	73
Carole Creek	3,656	-	48,670	8
Mehi River	13,316	-	123,480	11
Mallowa Creek	9,667	-	11,281	86
2014-15 total	***56,534***	***29,895***	***302,043***	***29***
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River<	20,404	5,046 GS	213,134	12
Moomin Creek#	324	175	104,075	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434,462***	***11***
2018-19				
Gwydir River*	63,416	43,941	205,520	53
Gingham Watercourse	20,000	15,000	40,443	87
Lower Gwydir	11,314	16,032	30,254	90
Carole Creek	300	300	16,865	4
Mehi River^	10,430	16,545	82,262	36
Mallowa Creek	16,950	-	17,230	98
2018-19 total	***63,416***	***43,941***	***205,520***	***53***
Grand total	**179,592**	**118,434**	**1,327,700**	**23**

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 14,160 ML delivered as part of the Northern Connectivity Event. The total volume for the NSW component also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system. Also includes 23,051 ML delivered as part of the Northern Fish Flow

+Includes 4,758 ML delivered as part of the Northern Connectivity Event

An early season stimulus flow was triggered by inflows to Copeton Dam in August and September 2017. A total of 10,000 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems as a small fresh during late winter/early spring. Following this, a stable flow release of 10,040 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems in late October to mid-November 2017. These small pulse flows were aimed at providing downstream connectivity and allowing opportunity for movement, breeding and recruitment of fish, particularly freshwater catfish (*Tandanus tandanus*).

A delivery of 8,000 ML including both State and Commonwealth environmental water was made to the Lower Gwydir and Gingham wetlands from mid-December 2017 to late January 2018, to replace supplementary take from a small flow event that occurred in the previous months. This aimed to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands. The last environmental delivery was made in late April/May 2018 as part of the Northern Connectivity Event. This flow aimed to provide longitudinal connectivity and refresh/replenish drought refuge for instream life, particularly native fish in the Barwon-Darling as well as improving conditions to maintain native fish populations within the tributary catchments. During this event, a total of 18,908 ML of both State and Commonwealth water was delivered down the Mehi River, Moomin Creek and Carole Creek. No environmental water deliveries were made to Mallowa Creek in 2017-18.

In 2018-19 environmental water made up 53% of the total flow down the Gwydir River channel (Table G-1). Sixty gigalitres of environmental water was delivered to the Lower Gwydir and Gingham wetlands to support wetland vegetation and channel processes in the Gwydir River. Deliveries to the wetlands began in July 2018 and finished in February 2019. In both systems deliveries were stopped in October and November to allow farmer access during the winter crop harvest. Over the November 2018 to February 2019 period, environmental water was also delivered to the Mallowa wetlands to support wetland vegetation, waterbirds and native fauna. During this event 16,950 ML of Commonwealth environmental water was delivered. A trial delivery of 600 ML was delivered to the Ballin Boora system in January to February 2019 to support wetland and riparian vegetation. Pool replenishment flows were delivered to the Gwydir, Lower Gwydir, Carole and Mehi channels due to low inflows that caused extended no flow periods throughout the water year. In May to June 2019, 23,051 ML was delivered down the Mehi River channel from Copeton Dam, as part of the Northern Fish Flow. This flow reconnected the lower Mehi River, and once in the Barwon River channel, flowed downstream as far as the Culgoa River junction.

G.2 Methods

To assess the extent and diversity of Ecosystem types that were inundated throughout the Gwydir Selected Area during the LTIM project, total wetland inundation extents for each year were intersected with the most recent ANAE GIS layer for the Gingham, Gwydir and Mallowa wetlands (Brooks 2017). For each water year, all analysed Landsat images analysed in Appendix B were combined to give a total inundation area. For ecosystem types outside of the wetland boundaries assessed, the assessment of the influence of environmental water was based on findings presented in the Appendix A.

G.3 Results

A total of 16 mapped ANAE ecosystem types were influenced by environmental water over the duration of the LTIM project. These included six floodplain types, two lacustrine types, five riverine types and three palustrine types (Figure G-1). In the Gingham wetland, Pt2.2.2: Temporary sedge/grass/forb marsh was the most extensively inundated ecosystem type, followed by F1.11: River cooba woodland riparian zone or floodplain and F1.10: Coolibah woodland and forest riparian zone or floodplain. Similarly, in the Lower Gwydir wetland Pt2.2.2: Temporary sedge/grass/forb marsh was the most extensively inundated ecosystem type, followed by Pt2.1.2: Temporary tall emergent marsh and F1.10: Coolibah woodland and forest riparian zone or floodplain. In the Mallowa wetland, F1.10: Coolibah woodland and forest riparian zone or floodplain followed by F2.2: Lignum shrubland riparian zone or floodplain (Table G-2).

The largest areas and diversity of ecosystem types inundated across all three wetlands occurred in 2014-15 as a result of environmental water dominated inundation (Figure G-2 to Figure G-4). During this time, all 13 ANAE ecosystem types were inundated, with 3,333 ha of Pt2.2.2: Temporary sedge/grass/forb marsh, 1,141 ha of F1.10: Coolibah woodland and forest riparian zone or floodplain, and 799 ha of F1.11:

River cooba woodland riparian zone or floodplain (Table G-2). This overall pattern was driven by the Lower Gwydir wetland that showed the greatest annual inundation of ecosystem types during 2014-15 (Table G-2; Figure G-3). During this year a total of 2,147 ha of habitat was inundated, with the majority being Pt2.2.2: Temporary sedge/grass/forb marsh (1,670 ha). In contrast, in the Gingham wetland, maximum inundation of ecosystem types was observed during 2016-17 as a result of a natural flooding event (Appendix A; Figure G-2). Again, Pt2.2.2: Temporary sedge/grass/forb marsh was inundated the most with 1,720 ha, followed by F1.11: River cooba woodland riparian zone or floodplain (963 ha; Table G-2). Maximum inundation of ecosystem types occurred in 2018-19 associated with environmental water deliveries (862 ha; Table G-2; Figure G-4). The vast majority (838 ha) of habitat fell into the F1.10: Coolibah woodland and forest riparian zone or floodplain ecosystem type which was inundated throughout the length of the Mallowa wetlands (Figure G-4).

Outside of the wetlands, three riverine ANAE ecosystem types were inundated, including the Rp1.1: Permanent high energy upland streams type which is found in the mid reaches of the Gwydir River below Copeton Dam, Rp1.3: Permanent low energy upland streams which is found in the Gwydir River zone, and Rt1.3: Temporary low energy upland streams types which was mapped in the upper reaches of the Gingham Watercourse (Figure G-5). Hydrological connectivity was provided through all of these channels at various times throughout the project (Appendix A).

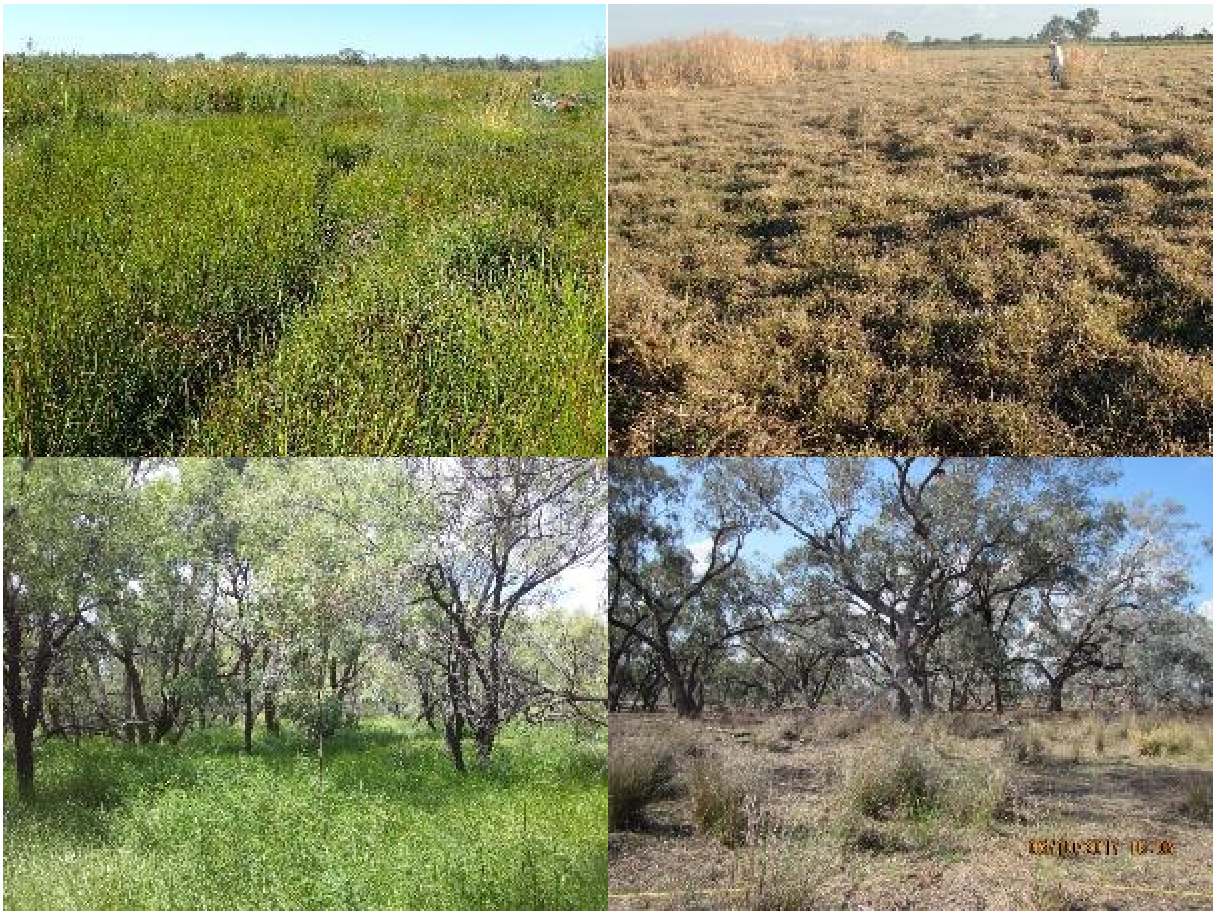


Figure G-1: Wetland ecosystem types found in the Gwydir Selected Area. Pt2.2.2: Temporary sedge/grass/forb marsh (top left and right), F1.11: River cooba woodland riparian zone or floodplain (bottom left), F1.10: Coolibah woodland and forest riparian zone or floodplain (bottom right).

Table G-2: Areas of ANAE types inundated during the 5 years of the LTIM project within the Gingham, Lower Gwydir and Mallowa wetlands.

Wetland	ANAE Type	Area inundated (ha)				
		2014-15	2015-16	2016-17	2017-18	2018-19
Gingham wetland	F1.10: Coolibah woodland and forest riparian zone or floodplain	202	47	325	17	28
	F1.11: River cooba woodland riparian zone or floodplain	693	404	963	24	577
	F1.12: Woodland riparian zone or floodplain	0	0	0	0	0
	F2.4: Shrubland riparian zone or floodplain	1	0	1	0	0
	Lp1.1: Permanent lake	1	10	26	6	1
	Lt1.1: Temporary lake	7	1	7	0	2
	Pt2.1.2: Temporary tall emergent marsh	166	64	23	97	86
	Pt2.2.2: Temporary sedge/grass/forb marsh	1,652	572	1,720	194	670
	Pt3.1.2: Clay pan	42	26	21	17	21
	Rp1.4: Permanent lowland stream	7	7	7	6	7
	Rt1.4: Temporary lowland stream	151	64	66	88	127
	Total	***2,922***	***1,195***	***3,160***	***449***	***1,520***
Lower Gwydir wetlands	F1.10: Coolibah woodland and forest riparian zone or floodplain	166	14	51	3	63
	F1.11: River cooba woodland riparian zone or floodplain	99	78	77	49	99
	F1.2: River red gum forest riparian zone or floodplain	11	6	5	3	8
	Lt1.1: Temporary lake	11	3	9	0	9
	Pt2.1.2: Temporary tall emergent marsh	190	25	50	12	70
	Pt2.2.2: Temporary sedge/grass/forb marsh	1,670	255	825	74	1,262
	Rt1.4: Temporary lowland stream	0	0	0	0	1
	Total	***2,147***	***382***	***1,017***	***141***	***1,511***

Wetland	ANAE Type	Area inundated (ha)				
		2014-15	2015-16	2016-17	2017-18	2018-19
Mallowa wetlands	F1.10: Coolibah woodland and forest riparian zone or floodplain	772	219	935	0.5	839
	F1.11: River cooba woodland riparian zone or floodplain	8	0	10	0	5
	F1.2: River red gum forest riparian zone or floodplain	3	5	10	0	4
	F2.2: Lignum shrubland riparian zone or floodplain	26	4	28	0	6
	Pt2.2.2: Temporary sedge/grass/forb marsh	11	0	7	0	3
	Rp1.4: Permanent lowland stream	5	5	6	0	5
	Rt1.4: Temporary lowland stream	0	1	1	0	0
	Total	***826***	***235***	***996***	***0***	***862***
Grand Total		**5,896**	**1,811**	**5,173**	**591**	**3,893**

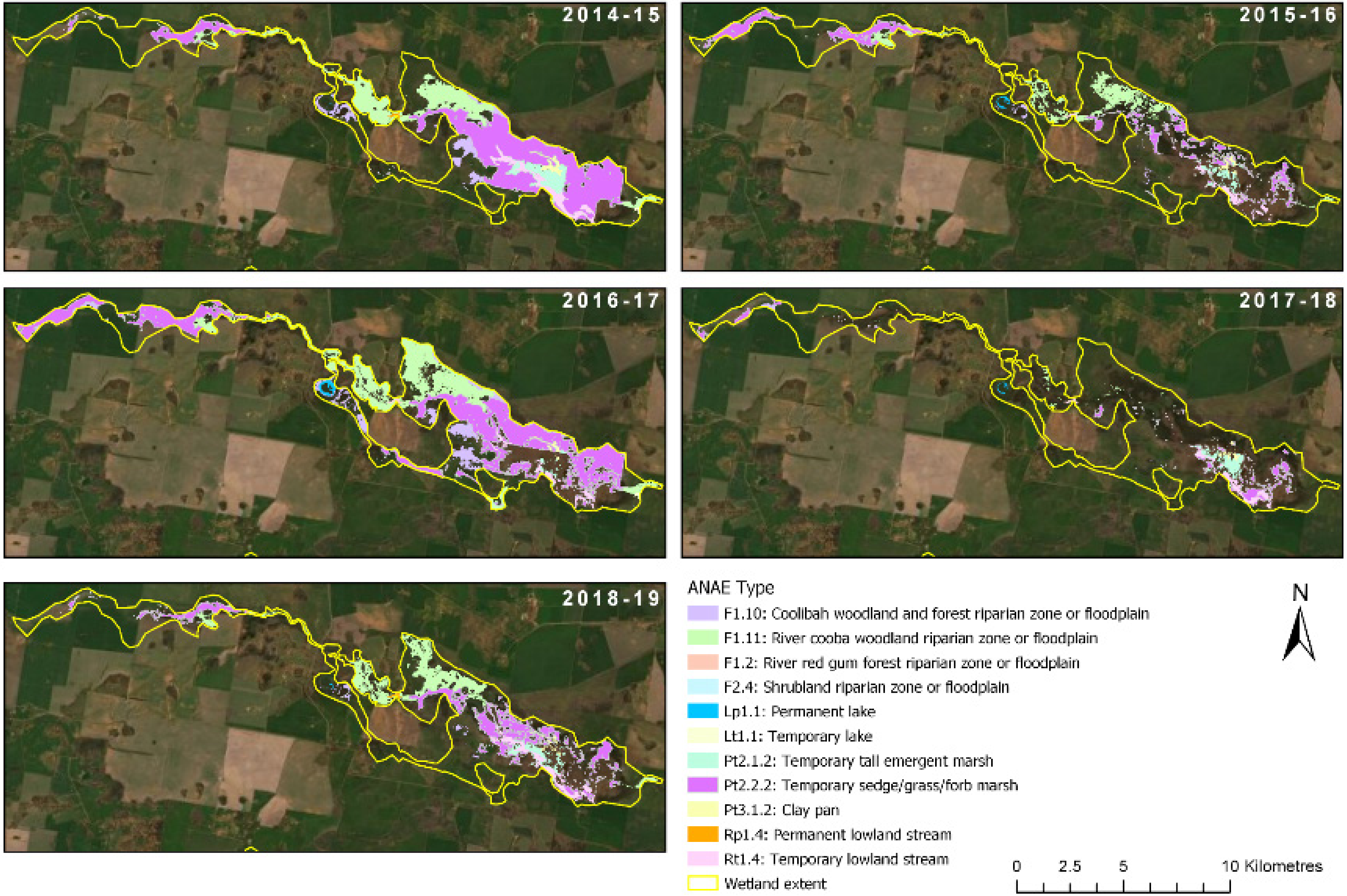


Figure G-2: Inundation of ANAE Types during each year of the LTIM project in the Gingham wetlands

Figure G-3: Inundation of ANAE Types during each year of the LTIM project in the Lower Gwydir wetlands.

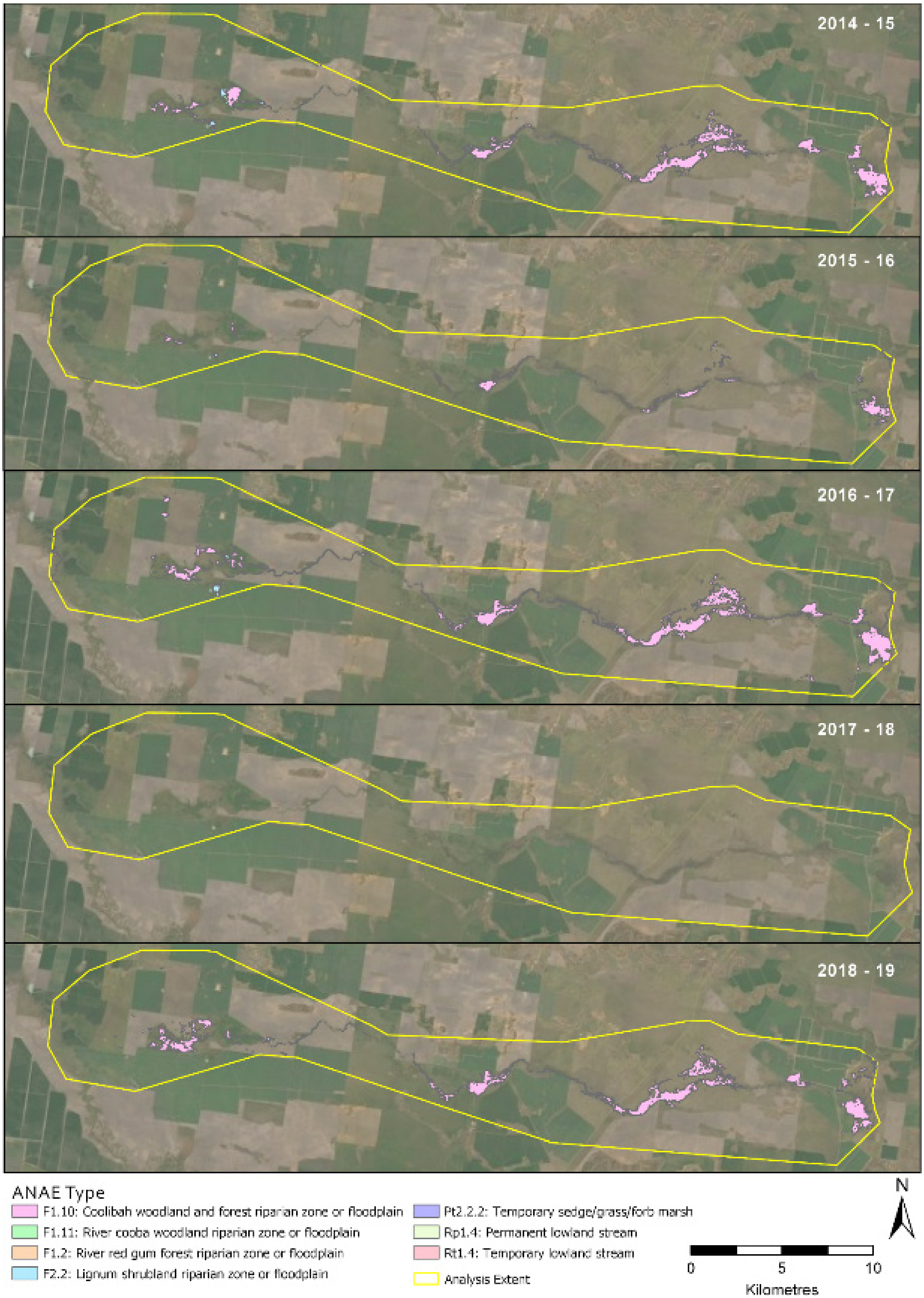


Figure G-4: Inundation of ANAE Types during each year of the LTIM project in the Mallowa wetlands. Note that <1ha of inundation occurred during 2017-18 and was not presented.

Figure G-5: Riverine ecosystem types found in the Gwydir Selected Area. Rt1.4: Temporary lowland stream (top left and right), Lt2.2: Temporary floodplain lake with aquatic beds (bottom left), Rp1.1: Permanent high energy upland streams (bottom right).

Discussion

Environmental water deliveries during the LTIM project maintained a diversity of ecosystem types within the Gwydir Selected Area. Riverine types were connected through water deliveries to the wetlands as well as specific watering events to provide connectivity and stimulate in-channel ecological responses (Appendix A and Appendix B). In the Lower Gwydir and Mallowa wetlands, environmental watering provided the maximum area of inundation throughout the project. This maintained the condition of relatively large areas of marsh and woodland ecosystems that provide habitat for a range of fauna (Appendix K, Appendix E and Appendix F). The large natural flow event in 2016-17 inundated 11 ecosystem types within the Gingham wetlands. The lower Gwydir system supports unique aquatic communities that vary in composition between Gingham, Gwydir and Mallowa wetland systems. Maintaining the diverse ecosystems and their inundation in all wetland systems is likely to be critical for maintaining regional scale ecological diversity.

References

Brooks, SS. (2017). *Classification of aquatic ecosystems in the Murray-Darling Basin: 2017 update*. Report to the Murray-Darling Basin Authority and Commonwealth Environmental Water Office: Canberra, Australia.

Appendix H Vegetation Diversity

H.1 Introduction

The wetlands of the Lower Gwydir River system support a number of water dependent vegetation communities, including flood dependent woodlands (supporting ecological vegetation communities with dominant tree species such as coolabah and black box), floodplain wetland communities (supporting river red gum, coolabah woodlands and river cooba and lignum shrubland species) and semi-permanent wetlands (supporting species such as water couch (*Paspalum distichum*), marsh club-rush (*Bolboschoenus fluviatilis*), spike rush (*Eleocharis)*, tussock rushes (*Juncus aridicola*), sedges and cumbungi (*Typha domingensis*) (Bowen and Simpson 2010). The area occupied by these communities has declined since river regulation due to both restricted flows and clearing for agriculture (Wilson *et al.* 2009; Bowen and Simpson 2010). Maintaining the current extent and then maintaining and improving the health of these communities has become a target for environmental water management in the Gwydir catchment (Commonwealth of Australia 2014a). This chapter addresses the longer-term outcomes of vegetation diversity monitoring over the past 5 years (2014-2019) of the LTIM project within the Gwydir Selected Area. Two specific questions were addressed through this monitoring in the Lower Gwydir, Gingham and Mallowa wetlands:

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

H.1.1 Environmental watering during the LTIM project

A total of 301,172 ML of environmental water was delivered through the Gwydir River system during the LTIM Project, making up 23% of the total water that flowed down the Gwydir River channel during that period (Table H-1). The highest volume occurred during the 2018-19 water year when 62,150 ML of Commonwealth and 52,000 ML of NSW environmental water was used. The lowest volume was in the 2015-16 water year where 13,250 ML of environmental water was delivered.

Through the LTIM project, environmental water deliveries to the wetlands have aimed to inundate core wetland areas, maintaining and promoting the condition of wetland vegetation, in turn maintaining habitat for other wetland species.

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system. In-channel flow pulses were delivered down the Mehi River and Carole Creek channels to enhance in-stream ecological function, nutrient cycling, water quality and fish spawning conditions. In addition, flows were delivered to the Lower Gwydir, Gingham Watercourse and Mallowa Creek to provide wetland inundation, maintaining and promoting vegetation condition.

During 2015-16 environmental water was delivered to a number of assets within the Gwydir river system Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for, with 964 ML of this water flowing down the Mehi River, and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW water bulk water deliveries. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse in February 2016 to replace flows that were extracted in a supplementary flow event. While not large in volume, these flows made it into the wetlands, inundating up to 161.81 ha

(Appendix B). Due to critically low flows experienced in the Lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April 2016. This followed a period of 30 to 40 days of nil flow conditions across the catchment.

Table H-1: Environmental water use in the Gwydir River system during the LTIM project (2014-19). This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW state governments.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2014-15				
Gwydir River*	56,534	29,895	302,043	29
Gingham Watercourse	15,000	14,868	46,711	64
Lower Gwydir	15,000	15,027	41,171	73
Carole Creek	3,656	-	48,670	8
Mehi River	13,316	-	123,480	11
Mallowa Creek	9,667	-	11,281	86
2014-15 total	***56,534***	***29,895***	***302,043***	***29***
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River<	20,404	5,046 GS	213,134	12
Moomin Creek#	324	175	104,075	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434,462***	***11***
2018-19				
Gwydir River*	63,416	43,941	205,520	53
Gingham Watercourse	20,000	15,000	40,443	87
Lower Gwydir	11,314	16,032	30,254	90
Carole Creek	300	300	16,865	4
Mehi River^	10,430	16,545	82,262	33
Mallowa Creek	16,950	-	17,230	98
2018-19 total	***63,416***	***43,941***	***205,520***	***52***
Grand total	**179,592**	**118,434**	**1,327,700**	**22**

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system

During 2016-17, a flow event occurred down the Mehi River in September 2016 and supplementary water licences owned by the CEWO were triggered. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however, very little of the moderate flows were diverted into the Mallowa wetlands. In January to March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands.

Flows were also delivered into the Lower Gwydir River and Gingham Watercourse to build upon moderate winter/spring flows. From January to March 2017, 30,000 ML was delivered, aiming to inundate broad areas of semi-permanent wetland vegetation. During 2016-17, no environmental water was delivered to Moomin Creek.

During 2017-18, an early season stimulus flow was triggered by inflows to Copeton Dam in August/September 2017. A total of 10,000 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems as a small fresh during late winter/early spring. Following this, a stable flow release of 10,040 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems in late October to mid-November 2017. These small pulse flows aimed to provide downstream connectivity and allow opportunity for movement, breeding and recruitment of fish, particularly freshwater catfish (*Tandanus tandanus*).

A delivery of 8,000 ML including both State and Commonwealth environmental water was made to the Lower Gwydir and Gingham wetlands from mid-December 2017 to late January 2018, to replace supplementary take from a small flow event that occurred in the previous months. This aimed to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands.

In 2018-19 environmental water made up 53% of the total flow down the Gwydir River channel (Table H-1). Sixty gigalitres of environmental water was delivered to the Lower Gwydir and Gingham wetlands to support wetland vegetation and channel processes in the Gwydir River. Deliveries to the wetlands began in July 2018 and finished in February 2019. In both systems deliveries were stopped in October and November to allow farmer access during the winter crop harvest. Over the November 2018 to February 2019 period, environmental water was also delivered to the Mallowa wetlands to support wetland vegetation, waterbirds and native fauna. During this event 16,950 ML of Commonwealth environmental water was delivered. A trial delivery of 600 ML was delivered to the Ballin Boora system in January to February 2019 to support wetland and riparian vegetation. Pool replenishment flows were delivered to the Gwydir, Lower Gwydir, Carole and Mehi channels due to low inflows that caused extended no flow periods throughout the water year. In May to June 2019, 23,051 ML was delivered down the Mehi River channel from Copeton Dam, as part of the Northern Fish Flow. This flow reconnected the lower Mehi River, and once in the Barwon River channel, flowed downstream as far as the Culgoa River junction.

H.2 Methods

H.2.1 2015-19 water years

Monitoring throughout the Lower Gwydir, and Gingham wetlands was undertaken biannually during spring and autumn from 2014 to 2019 (Figure H-1, Figure H-2). Surveys of vegetation plots in the Mallowa wetland began in spring 2015 (Figure H-3). Due to restricted access, not all sites were surveyed during every survey event (Table H-2).

Plots were located in four broad wetland vegetation communities and experienced a range of inundation conditions (Table H-3). Vegetation surveys were completed in conjunction with NSW OEH staff, following NSW OEH data collection protocols (Commonwealth of Australia 2014b). In addition to vegetation parameters, a range of environmental variables including the degree of inundation and grazing impact were noted.

Species richness and vegetation cover measures were analysed using a Poisson regression on count data that investigated the influence of inundation, survey time, wetland (Gingham, Lower Gwydir, Mallowa) and vegetation community. Vegetation cover for each plot was calculated by adding together the cover of lower and mid strata types. Therefore, it was possible to get >100% cover. Species Richness measures included lower, mid and overstorey strata types.

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

Survey Event	Date	Plots surveyed	Inundated sites		
			Gingham	Lower Gwydir	Mallowa*
Spring_2014	18 - 21 November 2014	32	0	7	-
Autumn_2015	10 – 13 March 2015	33	18	1	-
Spring_2015	12 – 16 October, 11 December 2015	40	19	0	0
Autumn_2016	13 – 16 March 2016	40	0	0	5
Spring_2016	26 – 30 October 2016	40	19	8	2
Autumn_2017	6 – 9 March 2017	33	8	8	4
Spring_2017	4 – 6 October 2017, 13 November 2017	26	3	1	1
Autumn_2018	12 – 22 March 2018	40	0	0	0
Spring_2018	19 - 21 October 2018, 29 - 30 November 2018, 7 December 2018	32	5	2	0
Autumn_2019	11 -13 March 2019	31	0	0	0

* The Mallowa was an addition to the Monitoring and Evaluation plan in 2015-16 therefore sites in the Mallowa were not monitored during the 2014-15 water year.

To further explain changes in diversity, individual species were grouped into the following four functional groups (Brock & Casanova 1997; Hale *et al.* 2013):

- Amphibious responders (AmR) – plants that change their growth form in response to flooding and drying cycle, including morphologically plastic (ARp) and floating/stranded (ARf) groups;
- Amphibious tolerators (AmT) – plants that tolerate flooding patterns without changing their growth form, including low growing (AtI) and woody growth form (Atw).
- Terrestrial damp plants (Tda) – plants that are terrestrial species but tend to grow close to the water margin on damp soils; and
- Terrestrial dry plants (Tdr) - plants that are terrestrial species which don't normally grow in wetlands but may encroach into the area due to prolonged drying.

Changes in these functional groups were then compared between survey times using a Poisson regression model on count data.

Table H-3: Sites surveyed in the project for vegetation diversity. Map projection GDA94 Zone 55.

Vegetation communities	Sites	Wetland	Northing	Easting
River Cooba - Lignum	Lynworth_1_1	Gingham	6763482	727443
River Cooba - Lignum	Lynworth_1_2	Gingham	6763219	727574
River Cooba - Lignum	Lynworth_1_3	Gingham	6762965	726906
River Cooba - Lignum	Bungunya_1_1	Mallowa	6723793	709823
River Cooba - Lignum	Bungunya_1_2	Mallowa	6723336	710098
River Cooba - Lignum	Coombah_1_1	Mallowa	6722614	723649
River Cooba - Lignum	Coombah_1_2	Mallowa	6722491	723849
River Cooba - Lignum	Valletta_1_1	Mallowa	6723629	716519
River Cooba - Lignum	Valletta_1_2	Mallowa	6723681	716970
River Cooba - Lignum	Valletta_2_1	Mallowa	6725026	716262
Water couch marsh grassland	Bunnor_1_1	Gingham	6760771	728826
Water couch marsh grassland	Bunnor_1_2	Gingham	6760658	728917
Water couch marsh grassland	Bunnor_1_3	Gingham	6760630	728812
Water couch marsh grassland	Goddards _Lease_Ramsar_1_1	Gingham	6760882	731652
Water couch marsh grassland	Goddards _Lease_Ramsar_1_2	Gingham	6760784	731738
Water couch marsh grassland	Goddards _Lease_Ramsar_1_3	Gingham	6760678	731749
Water couch marsh grassland	Lynworth_3_1	Gingham	6762487	728716
Water couch marsh grassland	Lynworth_3_2	Gingham	6762446	728809
Water couch marsh grassland	Lynworth_3_3	Gingham	6762544	728885
Water couch marsh grassland	Mungwonga_1_1	Gingham	6764005	722759
Water couch marsh grassland	Mungwonga_1_2	Gingham	6763930	722771
Water couch marsh grassland	Mungwonga_1_3	Gingham	6764083	722726
Water couch marsh grassland	Westhome_1_1	Gingham	6759094	733487
Water couch marsh grassland	Westhome_1_2	Gingham	6759189	733523
Water couch marsh grassland	Westhome_1_3	Gingham	6759157	733591
Water couch marsh grassland	Old_Dromana_Elders_1_1	Lower Gwydir	6752745	723443
Water couch marsh grassland	Old_Dromana_Elders_1_2	Lower Gwydir	6752603	723435
Water couch marsh grassland	Old_Dromana_Elders_1_3	Lower Gwydir	6752706	723395
Water couch marsh grassland	Old_Dromana_Ramsar_3_1	Lower Gwydir	6751426	726741

Vegetation communities	Sites	Wetland	Northing	Easting
Water couch marsh grassland	Old_Dromana_Ramsar_3_2	Lower Gwydir	6751456	726641
Water couch marsh grassland	Old_Dromana_Ramsar_3_3	Lower Gwydir	6751515	726746
Coolabah Woodland - wet understorey	Lynworth_1_4	Gingham	6763330	728359
Coolabah Woodland - wet understorey	Westholme_Coolibah_1	Gingham	6764083	722726
Coolabah Woodland - wet understorey	Old_Dromana_Elders_1_4	Lower Gwydir	6752918	723552
Coolabah Woodland - wet understorey	Old_Dromana_Nursery_1	Lower Gwydir	6751431	726197
Coolabah Woodland - wet understorey	Old_Dromana_Nursery_2	Lower Gwydir	6751888	724473
Coolabah Woodland - wet understorey	Old_Dromana_Ramsar_2_1	Lower Gwydir	6751800	726701
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_1	Lower Gwydir	6750977	727152
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_2	Lower Gwydir	6750992	727184
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_3	Lower Gwydir	6751075	727098

To further understand the relationship between inundation and vegetation response, the time since each site experienced its last inundation period was calculated using satellite imagery (Appendix B) for each survey time. The inundation data was then used to develop four Inundation categories:

- Inundated – site was inundated at the time of survey (95 instances);
- Recent – 1 – 90 days since site was last inundated (96 instances);
- Frequent – 91 – 324 days since site was last inundated (92 instances) and;
- Infrequent – 325 – 1,131 days since site was last inundated (60 instances).

During the LTIM project, competitive suppression by the native water couch has been observed over the exotic species lippia (*Phyla canescens*) (Commonwealth of Australia 2018). For this reason, temporal trends in the cover of these two species were investigated.

Changes in vegetation community composition over all survey times were investigated using multivariate nMDS plots with differences between inundation, survey time and vegetation community assessed using PERMANOVA in Primer 6. A multivariate dispersion Index (MVDISP) was calculated for each factorial grouping to determine the relative multivariate variability within each group (Clarke & Gorley 2006). SIMPER analysis was then undertaken to determine the main species contributing to the similarity within each factorial group.

Seedling height classes were recorded over the course of the project as per standard methods reported in (Commonwealth of Australia 2014b). Four sites had sufficient tree recruitment data to analyse over the LTIM study period. These sites fell in River Cooba – Lignum and Coolibah Woodland communities. Mean seedling data was compared between sites.

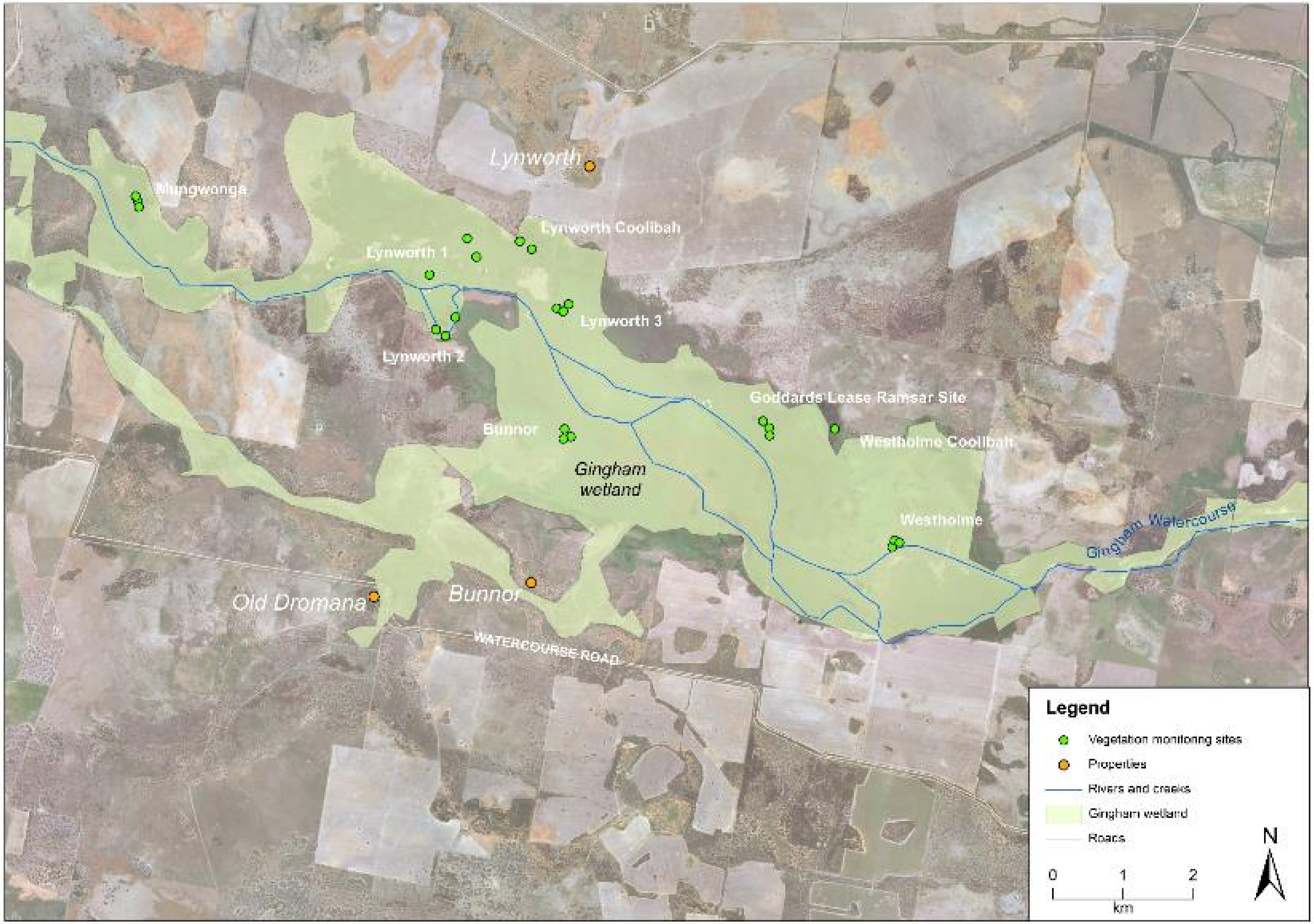


Figure H-1: Location of vegetation monitoring sites within the Gingham wetland.

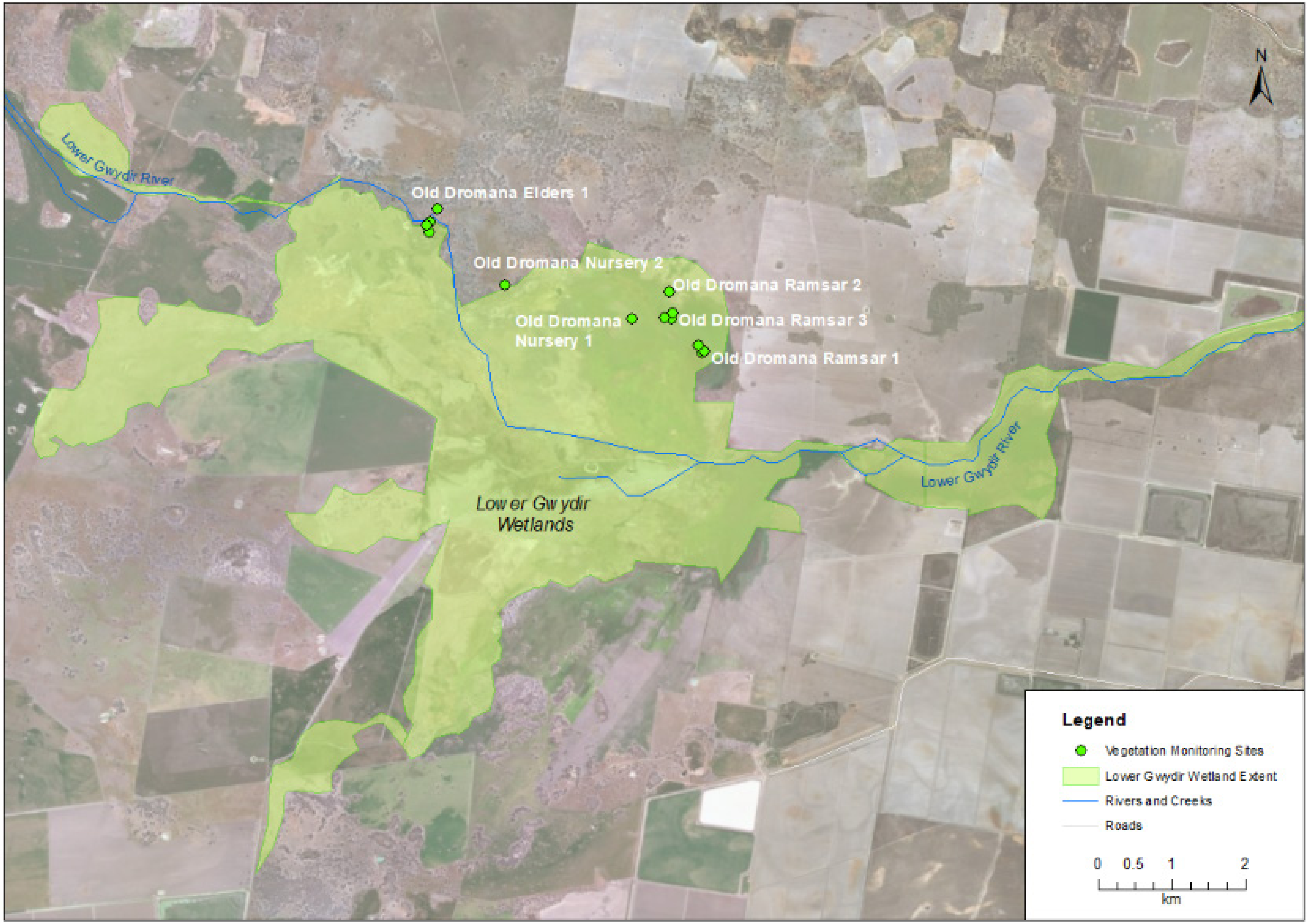


Figure H-2: Location of vegetation monitoring sites within the Lower Gwydir wetlands.

Figure H-3: Location of vegetation monitoring sites within the Mallowa wetlands.

H.3 Results

H.3.1 Species Richness

A total of 303 species from 54 families within four assigned functional groups were recorded within vegetation sites across all monitoring periods (Table H-4).

Table H-4: Species count of the Functional Groups recorded over the course of the project.

Functional Group	Species Count	Common species
Amphibious Responders (AmR)	16	Water couch *(Paspalum distichum),* common nardoo *(Marsilea drummondii),* water hyacinth *(Eichhornia crassipes),* starfruit *(Damasonium minus)*
Amphibious Tolerators (AmT)	37	Lignum *(Duma florulenta),* spike sedge *(Eleocharis* spp), rushes *(Juncus* spp), marsh club-rush *(Bolboschoenus fluviatilis)*
Terrestrial Damp (Tda)	88	Coolabah *(Eucalyptus coolabah),* primrose *(Ludwigia* spp), Warrego grass *(Paspalidium jubiflorum),* lippia *(Phyla canescens)*
Terrestrial Dry (Tdr)	145	Creeping saltbush *(Atriplex semibaccata), Salsola australis,* burr *(Sclerolaena* spp.)

Mean species richness across all wetlands and vegetation communities was highest during spring 2014 (25.72 ± 7.14 species) and lowest during the autumn 2019 (8.32 ± 6.17 species) survey times (Figure H-4), likely a response to the timing of surveys in relation to inundation. Wetlands significantly influenced species richness ($p=<0.05$), with Mallowa sites containing the highest mean species richness (18.05 ± 8.10 species) followed by Lower Gwydir sites (16.26 ± 8.08 species) and then Gingham sites (13.59 ± 7.12 species). Variation was also recorded throughout the project with sites in the Mallowa recorded the highest species richness in spring 2016 (28 ± 5.91 species), whereas sites in the Lower Gwydir and Gingham recorded their highest mean species richness in spring 2014 (27.16 ± 8.08 species; 24.85 ± 6.57 species; Figure H-5). Species richness also varied significantly between vegetation communities ($p=<0.05$), with Coolibah Woodlands recording the highest mean species richness (19.15 ± 9.31 species), followed by River Cooba – Lignum (17.70 ± 7.69 species), Eleocharis tall Sedgelands (14.56 ± 6.45 species) and Water couch Marsh Grasslands (13.21 ± 6.89 species).

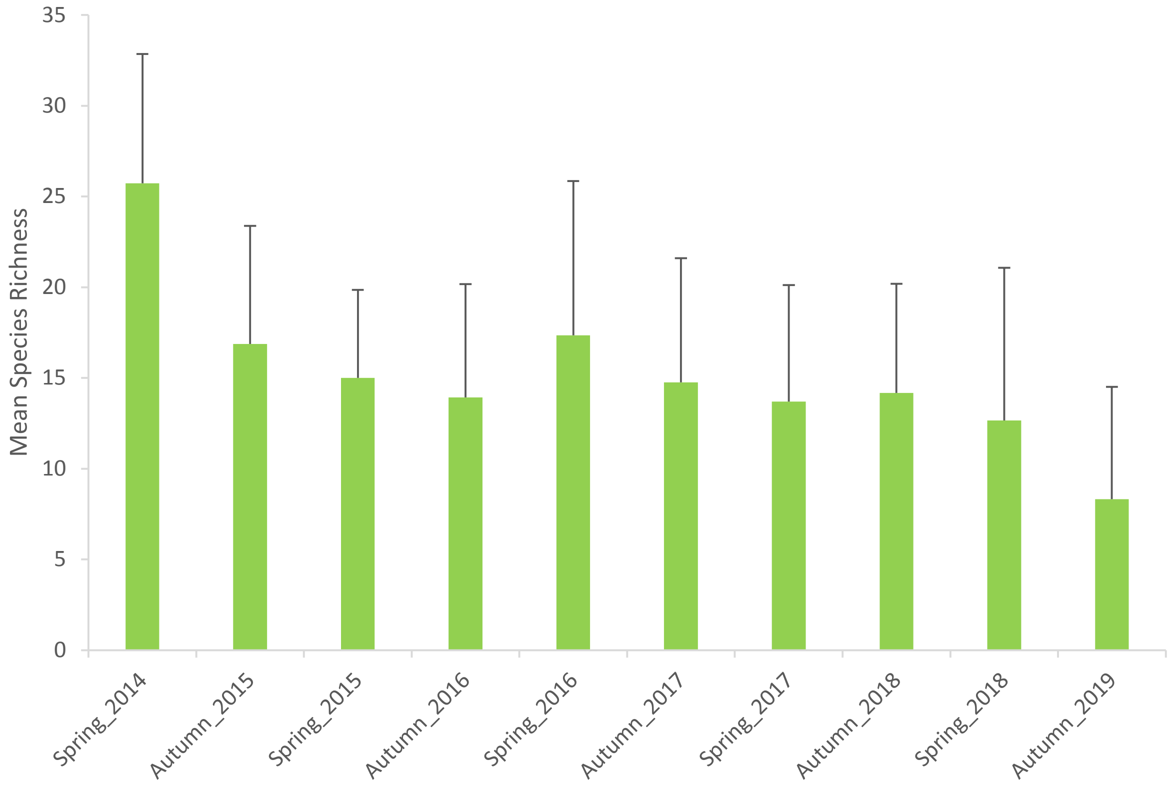


Figure H-4: Mean species richness (± SD) across all survey times, wetlands and vegetation communities.

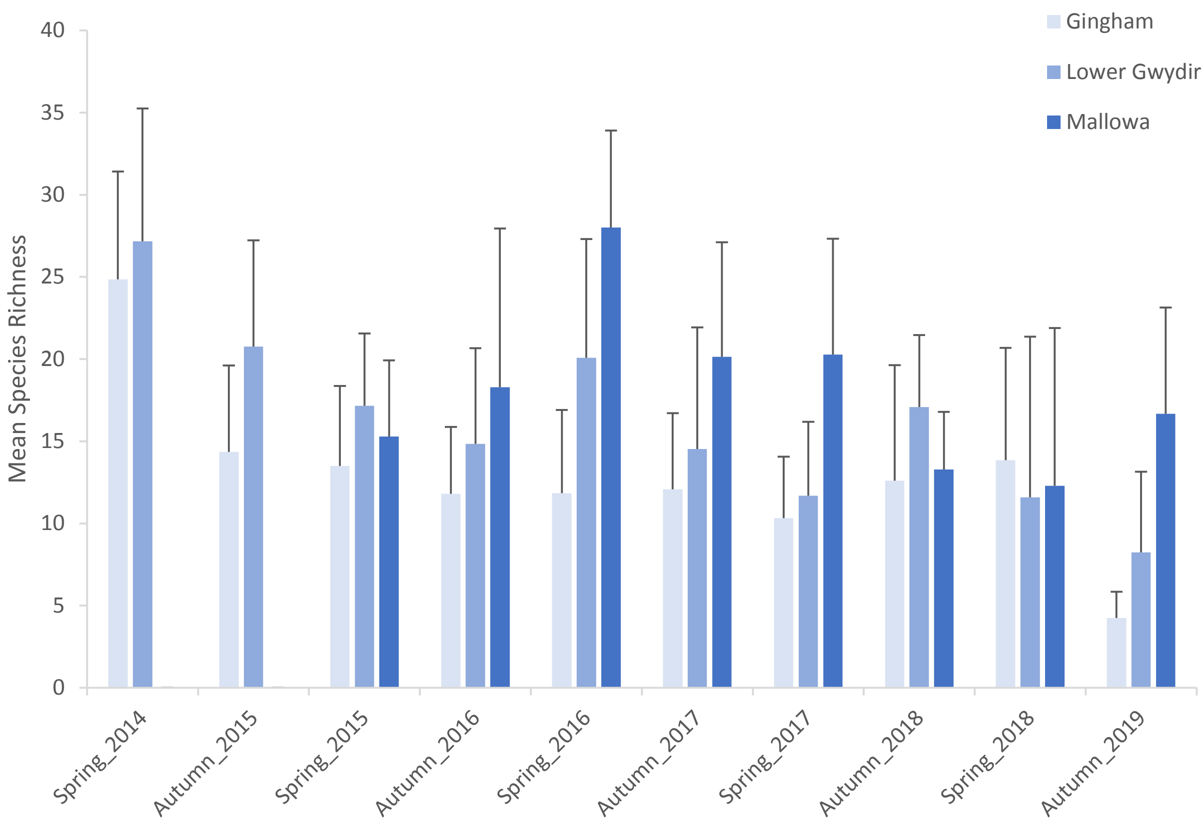


Figure H-5: Mean species richness (± SD) recorded within each wetland, across all survey times.

Significant differences were found between Inundation categories (p=<0.05) with the Infrequent category recording the highest richness (19.03. ± 8.85 species), followed by Frequent (14.70 ± 8.14 species), Recent (14.65. ± 6.19 species) and Inundated (14.03. ± 7.45 species) categories. Functional group species richness exhibited more prominent trends when grouped by inundation category. Mean species richness of the AmR group was significantly higher within inundated sites (2.63 ± 1.81 species), than Infrequently inundated sites (1.32 ± 0.98 species, p=<0.05). The AmT functional group also recorded its highest species richness at inundated sites (4.89 ± 2.18 species) and lowest within the Infrequent category (3.48 ± 1.03 species) which was also significant (p=<0.05). Both the Tda and Tdr functional groups increased in mean species richness throughout the categories, with both group's species richness being significantly higher within the Infrequent connection category (Tda: 7.23 ± 3.91; Tdr: 6.70 ± 0.98 species; p=<0.05 Figure H-6).

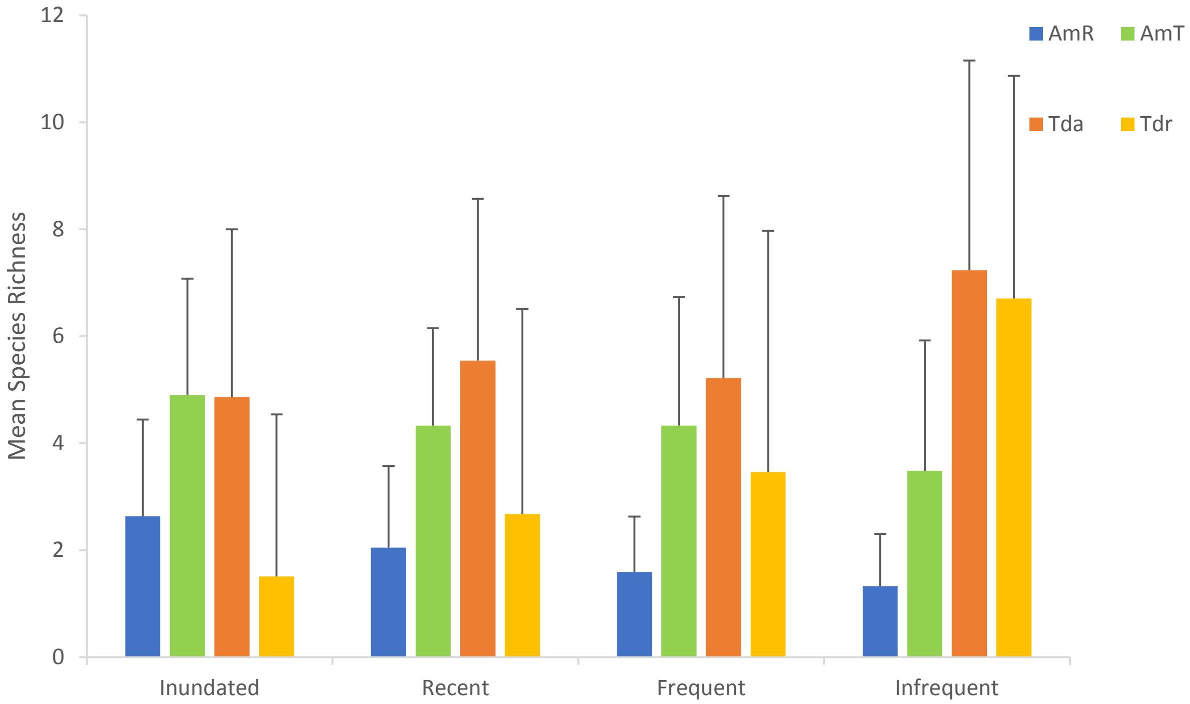


Figure H-6: Mean Species Richness (± SD) of Functional groups when grouped by the Inundation categories.

The response of Functional group species richness to Inundation varied between the four vegetation communities. AmR species richness was highest in the Inundated category in all four vegetation communities, with species richness generally decreasing across inundation categories. Infrequently inundated sites contained the lowest AmT species richness for all communities, with the exception of Eleocharis tall Sedgelands (7 ± 4.24 species), which recorded their highest richness at infrequently inundated sites. Tda species richness increased with drying across Inundation categories within Water couch Marsh Grasslands and River Cooba – Lignum sites, whereas Eleocharis tall Sedgelands and Coolibah Woodlands sites noted a decrease with drying. Tdr species richness increased with drying across inundation categories within all vegetation communities, with Infrequent sites containing the highest species richness (Water couch Marsh Grasslands: 6.39 ± 4.01, Eleocharis tall Sedgelands: 2 ± 1.41, River Cooba – Lignum: 9.78 ± 4.32, Coolibah Woodland: 6.29 ± 3.89 species) within this functional group (Figure H-7).

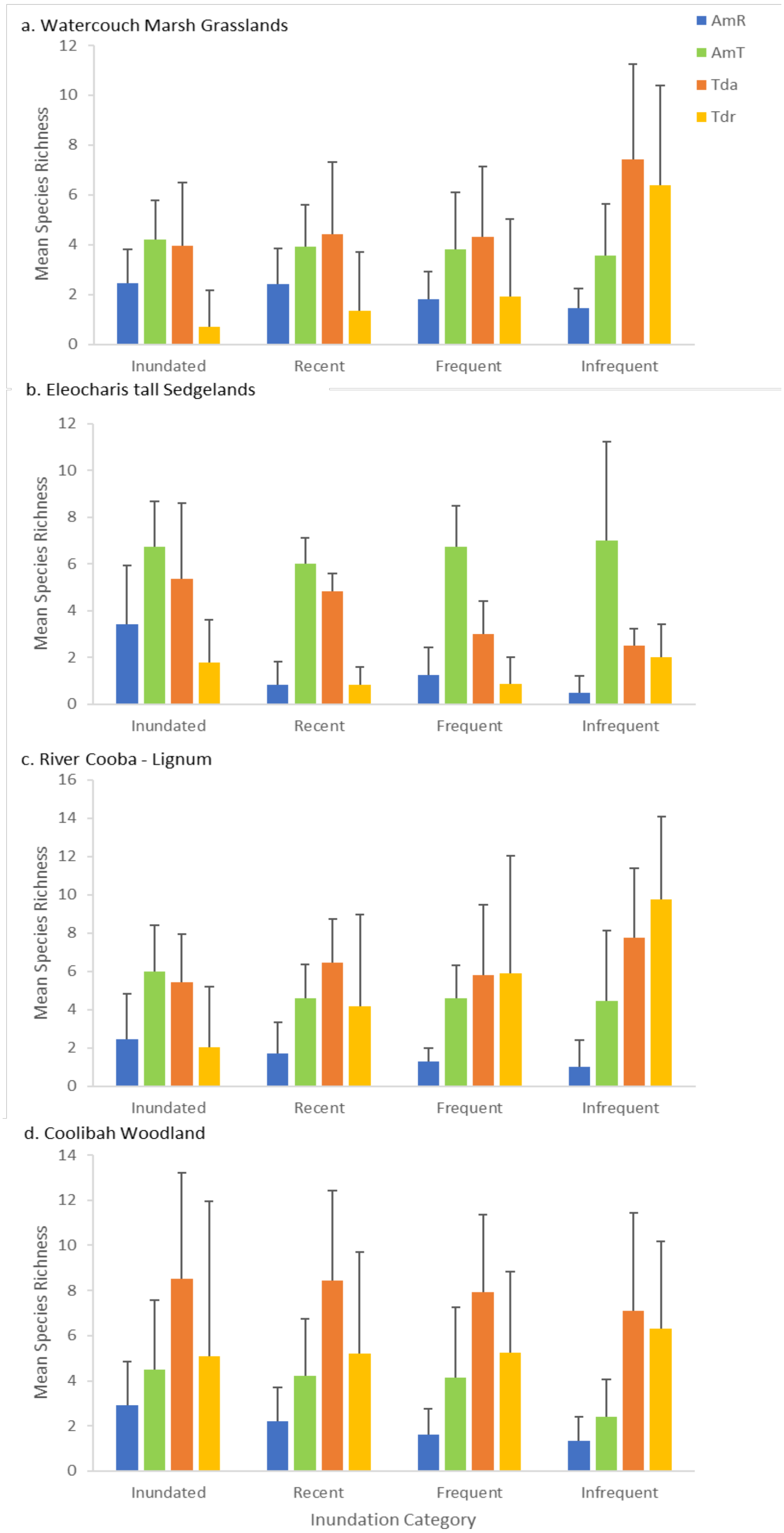


Figure H-7: Functional group species Richness (± SD) of the inundation categories recorded at the four vegetation communities; a. Water couch Marsh Grasslands, b. Eleocharis tall Sedgelands, c. River Cooba - Lignum, d. Coolibah Woodland.

H.3.2 Vegetation Cover

Combining data across wetlands and vegetation communities, the autumn 2015 sample (99.03 ± 20.80%), recorded the highest mean vegetation cover, whilst spring 2018 (56.67 ± 31.28%, Figure H-8) displayed the lowest. The wetland factor significantly influenced vegetation cover (p=<0.05), with Gingham sites containing the highest mean total cover (89.78 ± 24.68%), followed by Lower Gwydir sites (78.12 ± 30.64%) and then Mallowa sites (57.31 ± 33.25%). Temporal variation was also observed with sites within the Gingham and Lower Gwydir systems recording the highest mean cover in autumn 2015 with 110.56 ± 11.67% and 95.61 ± 30.28% cover respectively. Mallowa sites showed highest mean cover in spring 2016 (95.43 ± 22.78%; Figure H-9). Mean total cover varied significantly across vegetation communities (p=<0.05), with Eleocharis tall Sedgeland sites contained the highest mean vegetation cover across all sample times (88.86 ± 24.05%), followed by Water couch Marsh Grasslands (85.55 ± 24.34%), Coolibah Woodlands (72.16 ± 31.83%) and River – Cooba Lignum sites (69.48 ± 34.42%).\

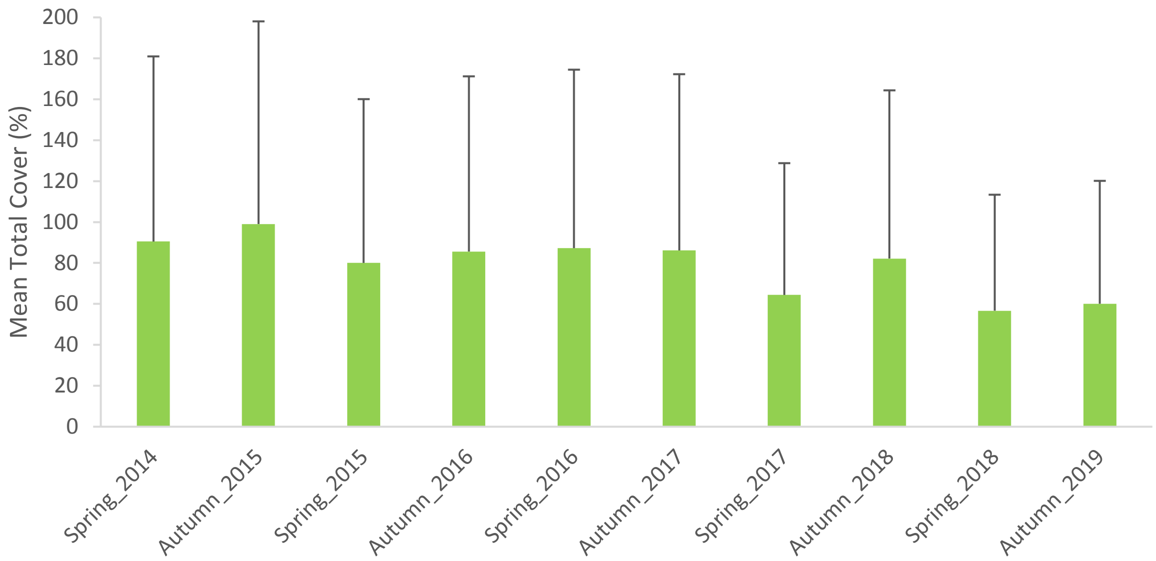


Figure H-8: Mean total cover (± SD) across all sample times, wetlands and vegetation communities.

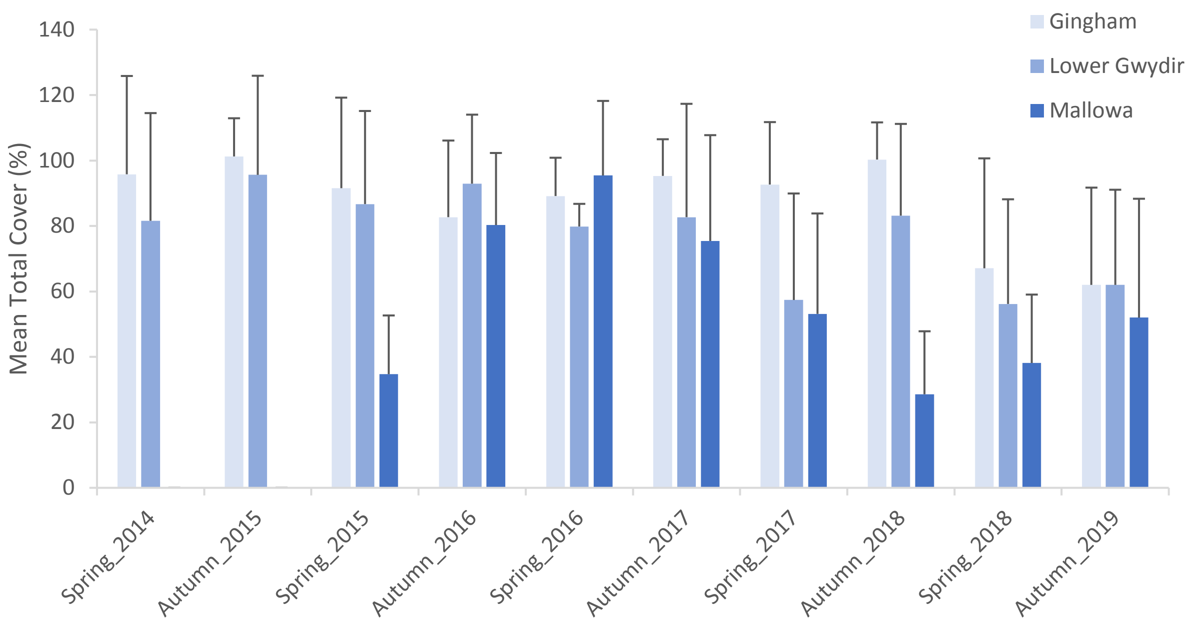


Figure H-9: Mean total cover (± SD) recorded within each wetland, across all sample times.

Significant differences were found between inundation categories (p=<0.05), with Inundated sites displaying the highest cover across all sample times (87.73 ± 26.27%), followed by Recent (78.43 ± 30.10%), Frequent (78.16 ± 31.35%) and Infrequent (72.09 ± 33.87%) inundation categories. Functional group total cover also varied across the Inundation categories, with amphibious groups (AmR, AmT) both recording significantly higher cover at Inundated sites (AmR: 38.62 ± 32.13%; AmT: 36.69 ± 31.53%, p=<0.05) than other inundation categories (with exception to the Inundated – Recent combination within the AmT functional group, p=0.07). Terrestrial species cover significantly increased with drying across inundation categories (p=<0.05, with exception to the Recent – Frequent combination within the Tda functional group, p=0.27), with both Tda and Tdr groups showing their highest mean cover within the Infrequent inundation category (Tda: 23.82 ± 11.40%; Tdr: 8.98 ± 9.38%; Figure H-10).

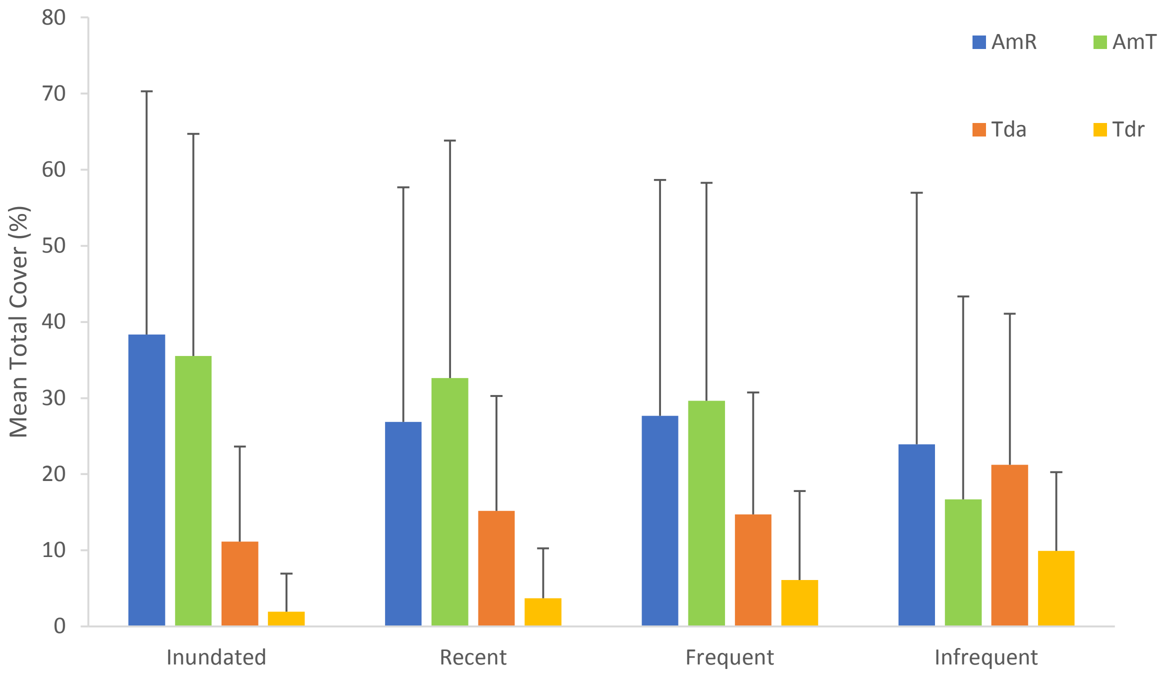


Figure H-10: Mean total cover (± SD) of Functional groups when grouped by the Duration Dry categories.

As with species richness, the response of functional group cover to inundation category varied between the four vegetation communities (Figure H-11). AmR species cover was highest within Water couch Marsh Grassland sites, with Inundated sites recording the highest mean cover (54.55 ± 29.74%). Cover in other communities was also highest within Inundated sites with the exception to Coolibah Woodland sites, in which AmR mean cover was highest within Recently inundated sites (18.44 ± 25.59%). AmR cover generally reduced across inundation categories with Infrequent sites recording the lowest cover within all communities. AmT species cover was highest within Eleocharis tall Sedgeland sites across all inundation categories, with Recently inundated sites recording the highest cover (81.50 ± 15.71%). AmT cover generally reduced with drying across inundation categories with Infrequent sites recording the lowest mean cover within Water couch March Grassland, River Cooba – Lignum and Coolibah Woodland communities. Terrestrial species cover generally increased at all vegetation communities with drying across the inundation categories. An exception to this was Eleocharis tall Sedgeland sites, which recorded their highest terrestrial species cover within Inundated sites (Tda: 6.43 ± 3.87%; Tdr: 1.79 ± 3.87%, Figure H-11).

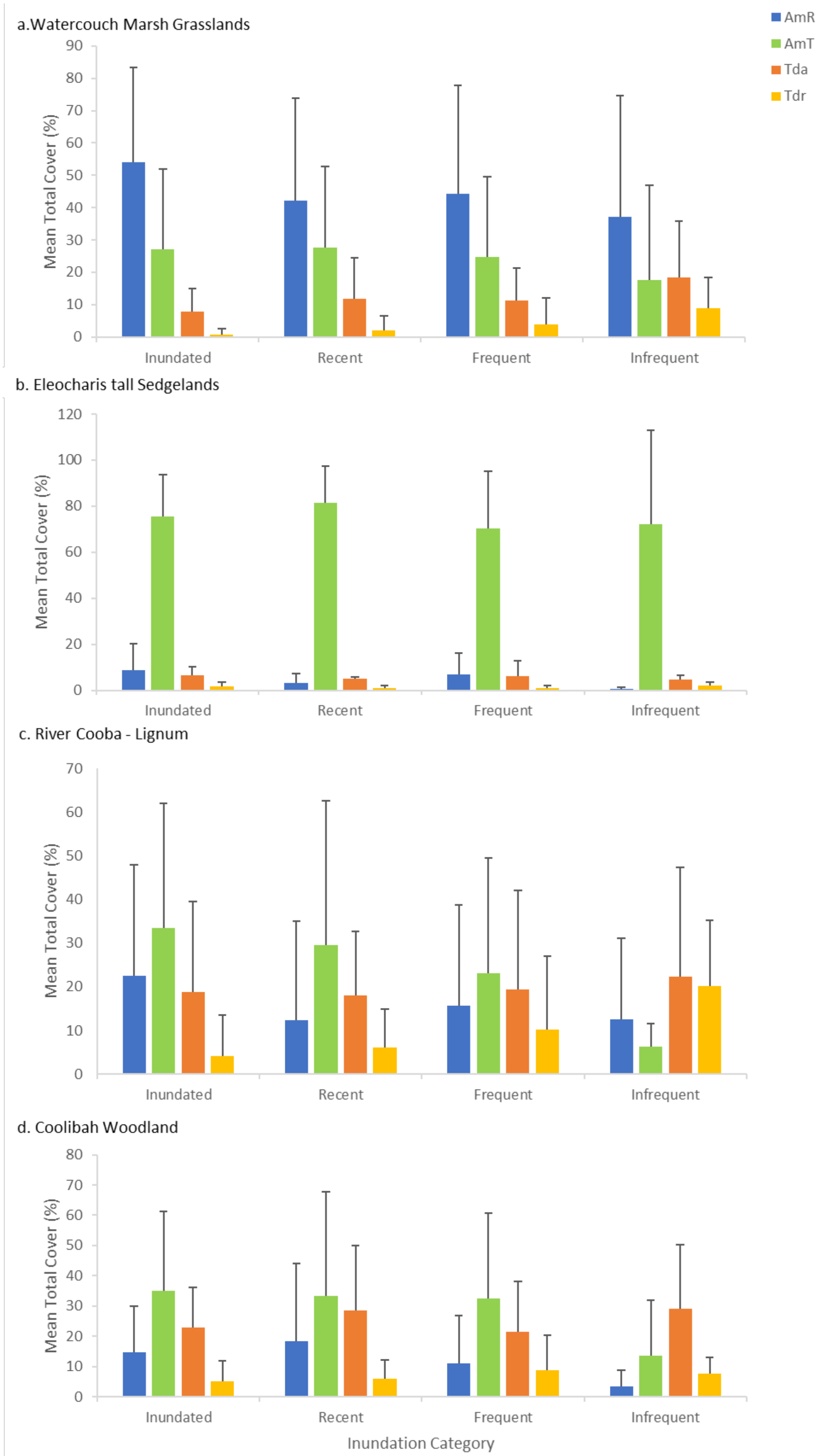


Figure H-11: Mean Functional group species cover (± SD) of the inundation categories recorded at the four vegetation communities; a. Water couch Marsh Grasslands, b. Eleocharis tall Sedgelands, c. River Cooba - Lignum, d. Coolibah Woodland.

Water couch, a native perennial grass of semi-permanent wetlands, recorded its highest mean cover at Inundated sites (43.06 ± 31.30%), maintaining this relatively high cover across the other Inundation categories. However, the wetland weed species lippia, increased in mean cover over the inundation categories with its highest mean cover being recorded at Infrequently inundated sites (18.38 ± 20.32%; Figure H-12). This response was most evident at Mungwonga 1-1, within the 2014-15 water year (Figure H-13). At the time of the spring 2014 survey this site was grouped within the Infrequent inundation category (560 days since inundation). Lippia dominated the site with a total cover of 60% and water couch occupied just 10% of the site at this time. However, an inundation event prior to the following survey time (autumn 2015) influenced relative species cover, with water couch increasing to 81% cover, whilst lippia cover reduced to 3%. Water couch remained a dominant species at this site until spring 2018, where both water couch and lippia cover reduced to below 5% for the remainder of the project (Figure H-13; Figure H-14). The presence of cattle in this area of the Gwydir State Conservation Area prior to this survey time along with the dry conditions experienced within the 2018-19 water year contributed to the high bare ground covers recorded in the spring 2018 (80%). In the autumn 2019 survey, Noogoora burr (*Xanthium occidentale*), another weed species, dominated this site (22% cover; Figure H-14).

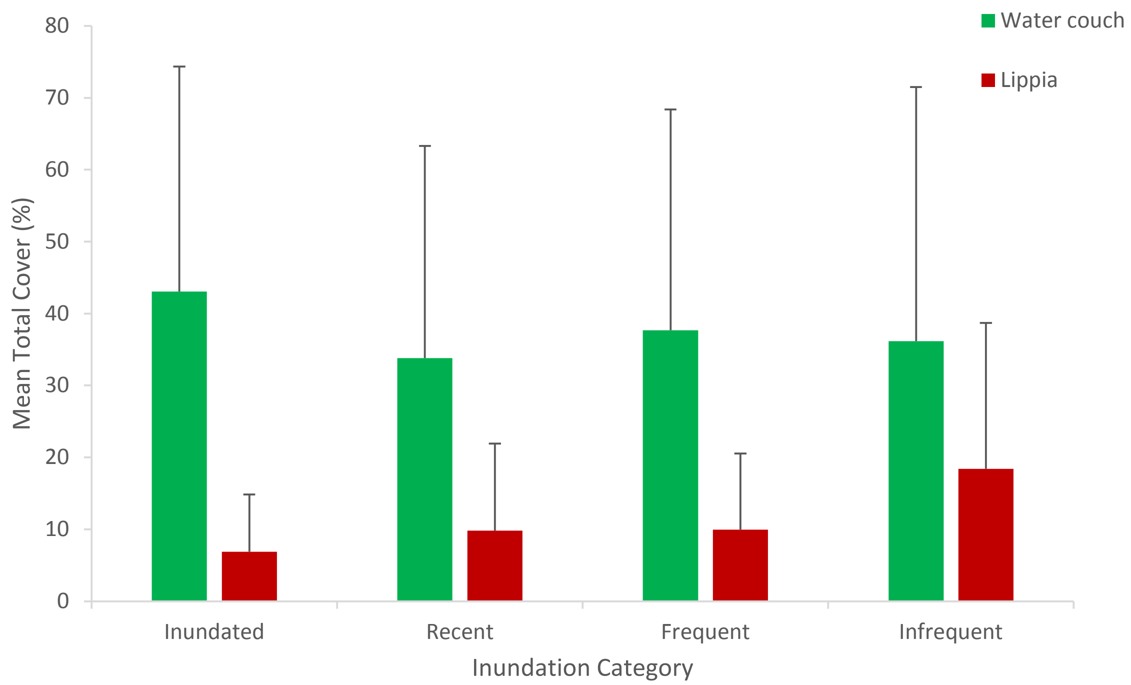
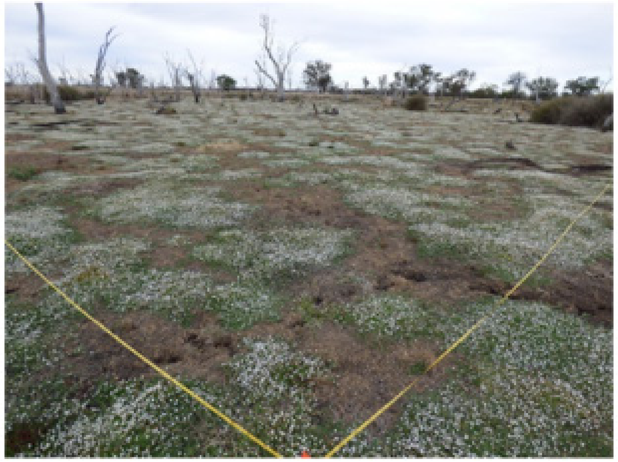


Figure H-12: Mean total cover (± SD) of Lippia and Water Couch when grouped by inundation categories.

Spring 2014 – Water Couch: 10 % / Lippia: 60 %



Autumn 2015 - Water Couch: 81 % / Lippia: 3 %

Spring 2015 - Water Couch: 60 % / Lippia: 3 %

Autumn 2016 - Water Couch: 40 % / Lippia: 32 %

Spring 2016 - Water Couch: 50 % / Lippia: 10 %

Autumn 2017 - Water Couch: 40 % / Lippia: 15 %

Figure H-13: Mungwonga 1-1 site photos (Spring 2014 – Autumn 2017).

Spring 2017 - Water Couch: 35 % / Lippia: 15 %

Autumn 2018 - Water Couch: 80 % / Lippia: 15 %

Spring 2018 - Water Couch: 5 % / Lippia: 0 %

Autumn 2019 - Water Couch: 3 % / Lippia: 1 %

Figure H-14: Munwonga 1-1 site photos (Spring 2017 – Autumn 2019).

H.3.3 Vegetation Community Composition

Vegetation community composition was further assessed using multivariate analyses of species abundance data. PERMANOVA analysis confirmed significant differences between sample times, wetlands, Inundation categories and Functional groups ($p<0.005$). The nMDS plot shows separation between data grouped by survey time with a tendency for sites to group closer together during the first year of the project, and then move further apart within each sample time (Figure H-15). This observation was backed up by the MVDISP, which showed that intergroup variability generally increased through time (Table H-5).

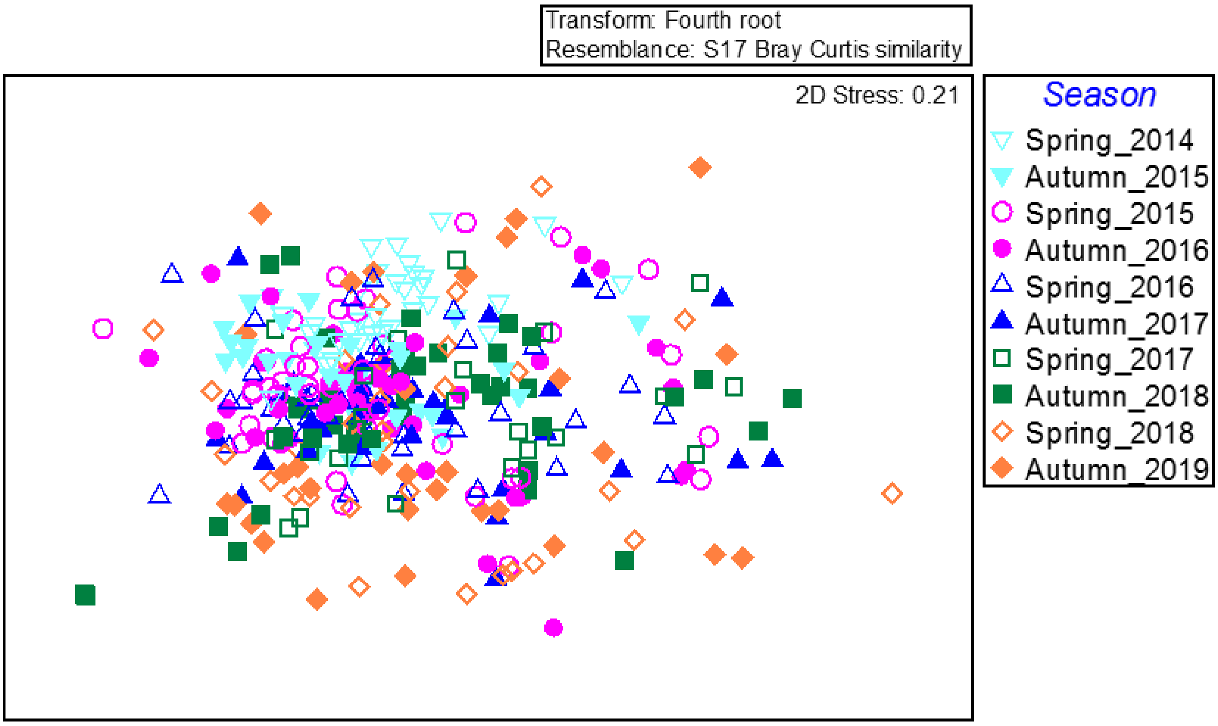


Figure H-15: nMDS plot of species composition data when grouped by survey time.

Table H-5: Dispersion values of survey times

Survey time	Dispersion value
Spring_2014	0.647
Autumn_2015	0.682
Spring_2016	0.918
Autumn_2016	0.999
Spring_2015	1.013
Autumn_2017	1.058
Spring_2017	1.068
Autumn_2018	1.154
Spring_2018	1.194
Autumn_2019	1.276

SIMPER analysis was used to identify dominant wetland species influencing the grouping of each survey time. Variations in water couch cover, contributed most across all survey times (Table H-6). The highest contribution of water couch was in autumn 2015 when mean total cover was 56%, coinciding with significant inundation provided by environmental water in the Gingham and Lower Gwydir wetlands. An unregulated flood event in spring 2016 stimulated the amphibious species, Red Water Fern (*Azolla filliculoides*) to emerge as a dominant species with a contribution percentage of 8.92%. Lippia's highest contribution to within group similarity was recorded in autumn 2018 (19.48%) and autumn 2019 (14.23%), which coincided with the driest survey times of the project (Table H-6).

Table H-6: Contribution and mean cover (%) of the top four lower and mid-story species recorded across sample times.

Survey time	Species (Functional group)	Mean Cover (%)	Contribution (%)
Spring_2014	water couch (AmR)	47.67	15.87
	lippia (Tda)	9.17	7.87
	flat spike-sedge (AmT)	1.93	6.42
	Rorippa eustylis (Tdr)	1	6.05
Autumn_2015	water couch (AmR)	56.39	25.52
	water primrose (AmR)	2.21	9.29
	Budda pea (Tda)	2.12	6.39
	wild aster (Tda)	1.04	6.08
Spring_2015	water couch (AmR)	37.65	17.02
	flat spike-sedge (AmT)	9.03	12.80
	tussock rush (AmT)	2.86	10.08
	swamp buttercup (AmT)	4.4	6.97
Autumn_2016	water couch (AmR)	42.43	19.43
	nardoo (AmR)	1.14	8.97
	lippia (Tda)	11.42	8.95
	flat spike-sedge (AmT)	25.74	8.31
Spring_2016	water couch (AmR)	22.56	14.24
	flat spike-sedge (AmT)	22.07	11.29
	Azolla (AmR)	8.59	8.92
	tussock rush (AmT)	4.39	8.81
Autumn_2017	flat spike-sedge (AmT)	27.5	19.29
	water couch (AmR)	36.95	15.73
	nardoo (AmR)	1.61	8.04
	tussock rush (AmT)	1.95	6.28
Spring_2017	flat spike-sedge (AmT)	11.91	24.32
	tussock rush (AmT)	2.11	11.24
	lippia (Tda)	12.19	10.21
	water couch (AmR)	24.86	9.56

Survey time	Species (Functional group)	Mean Cover (%)	Contribution (%)
Autumn_2018	water couch (AmR)	40.73	14.45
	lippia (Tda)	19.48	10.01
	nardoo (AmR)	1.07	9.90
	narrow-leaved cumbungi (AmT)	30.21	9.07
Spring_2018	flat spike-sedge (AmT)	12.27	13.42
	water couch (AmR)	18.47	11.41
	swamp buttercup (AmT)	3.4	10.28
	lippia (Tda)	10.76	6.70
Autumn_2019	flat spike-sedge (AmT)	15.66	20.06
	lippia (Tda)	14.23	13.68
	narrow-leaved cumbungi (AmT)	24.15	9.37
	water couch (AmR)	45.2	7.98

Species composition variation was observed when grouped by inundation categories (Figure H-16), with Inundated and Recently inundated categories grouping closely together. Frequent and Infrequent categories showed a greater spread in the data, suggesting that vegetation composition during these times was more variable between sites. PERMANOVA analysis showed that inundation categories significantly influenced species composition ($p<0.05$), with significant differences detected between all individual inundation categories ($p<0.05$).

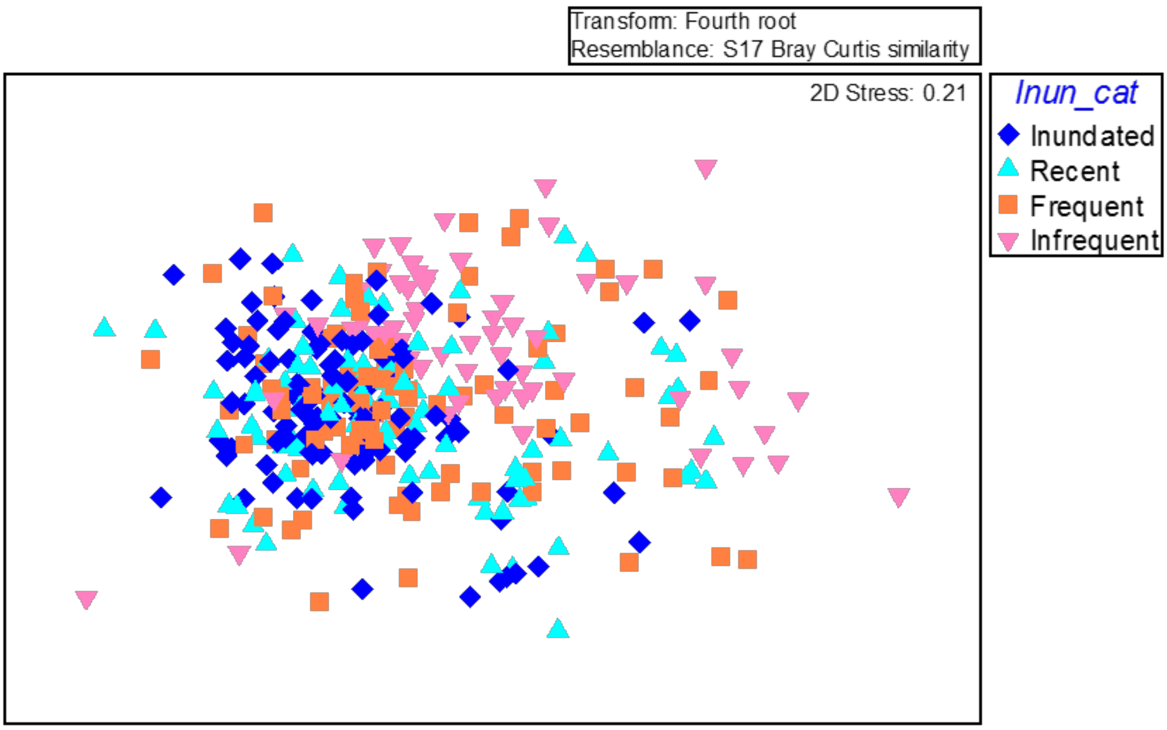


Figure H-16: nMDS plot of species composition data when grouped by Inundation Category.

SIMPER analysis noted variation in species contributions when grouped by inundation category. The contribution of water couch generally reduced across the categories with this species highest mean cover (43%) and contribution percentage (21.48%) occurring within Inundated sites. Flat spike-sedge contributed the most to the Recently inundated grouping (16.42%), then reduced as sites dried. Lippia increased in both contribution percentage and mean cover as inundation categories became drier with Infrequent sites recording the highest contribution (13.90%; Table H-7) and mean cover (18%; Figure H-12).

Table H-7: Contribution and mean cover (%) of the top four lower and mid-story species recorded across each Inundation categories.

Inundation Category	Species (Functional group)	Mean Cover (%)	Contribution (%)
Inundated	water couch (AmR)	43.06	21.48
	flat spike-sedge (AmT)	15.56	10.73
	swamp buttercup (AmT)	3.20	7.54
	tussock rush (AmT)	2.67	7.48
Recent	flat spike-sedge (AmT)	17.54	16.42
	water couch (AmR)	33.81	13.90
	tussock rush (AmT)	2.25	8.14
	lippia (Tda)	10.18	8.01
Frequent	water couch (AmR)	37.68	17.98
	flat spike-sedge (AmT)	17	13.47
	lippia (Tda)	9.97	11.71
	nardoo (AmR)	1.98	6.29
Infrequent	lippia (Tda)	18.38	13.90
	water couch (AmR)	36.15	10.09
	flat spike-sedge (AmT)	8.22	7.79
	wild aster (Tda)	1.2	6.55

H.3.4 Tree Recruitment

Total tree recruitment measured as the abundance of seedlings within River Cooba - Lignum and Coolibah Woodland vegetation plots was recorded for three separate age classes across all survey times (Figure H-17 to Figure H-19). While relatively large recruitment events occurred throughout the project, no clear trends were observed within the recruitment data for the surveyed sites. The Lower Gwydir site, Old Dromana Nursery 2, recorded 42 individuals (0.2 to 0.5 m tall) within autumn 2016, although these did not appear to progress through to the following survey times (Figure H-17). A similar trend was apparent at Old Dromana Ramsar 2-1 in autumn 2017 (9 individuals), with few of these seedlings progressing to the upper age class the following year (4 individuals; Figure H-18). Valetta 1-1, located in the Mallowa wetlands, recorded low recruitment after an initial cohort of 49 individuals were recorded during the spring 2015 survey. No individuals were recorded within the final survey time at this site (Figure H-19).

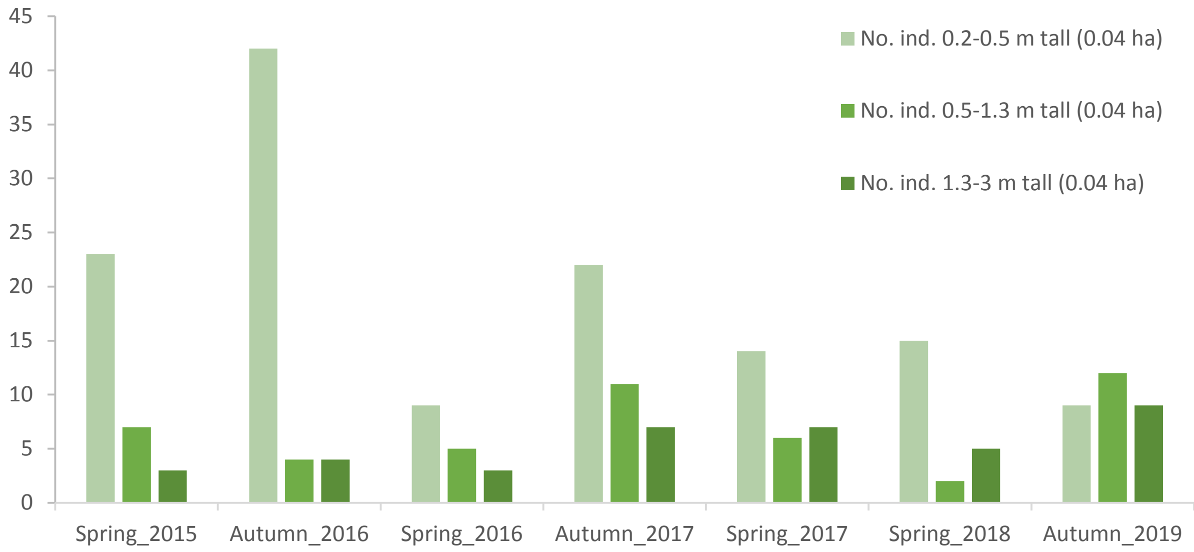


Figure H-17: Number of Coolibah seedlings recorded at Old Dromana Nursery 2 across all sample times

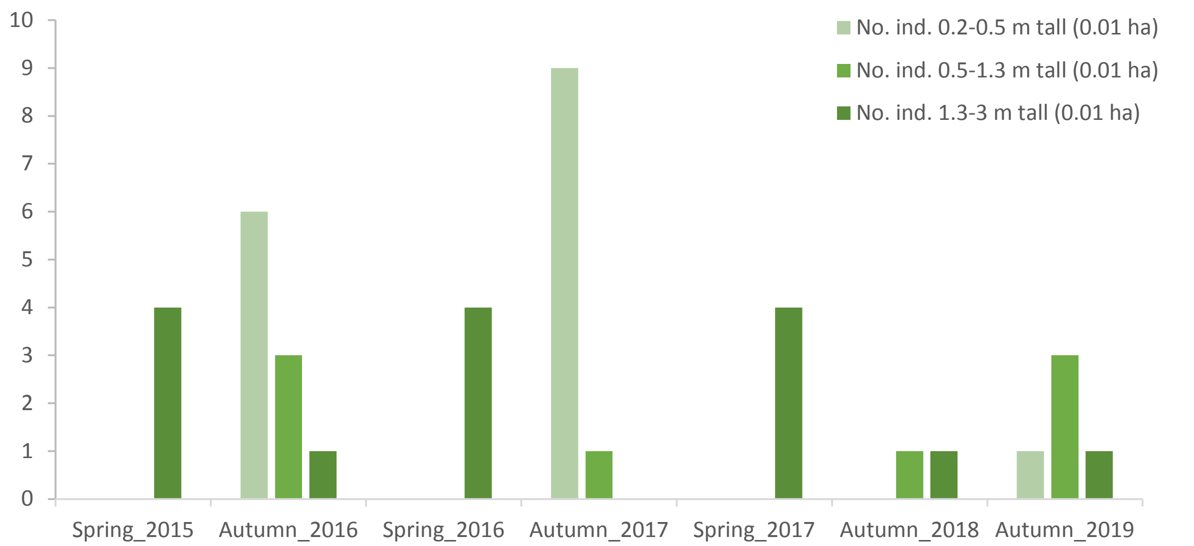


Figure H-18: Number of Coolibah seedlings recorded at Old Dromana Ramsar 2-1 across all sample times

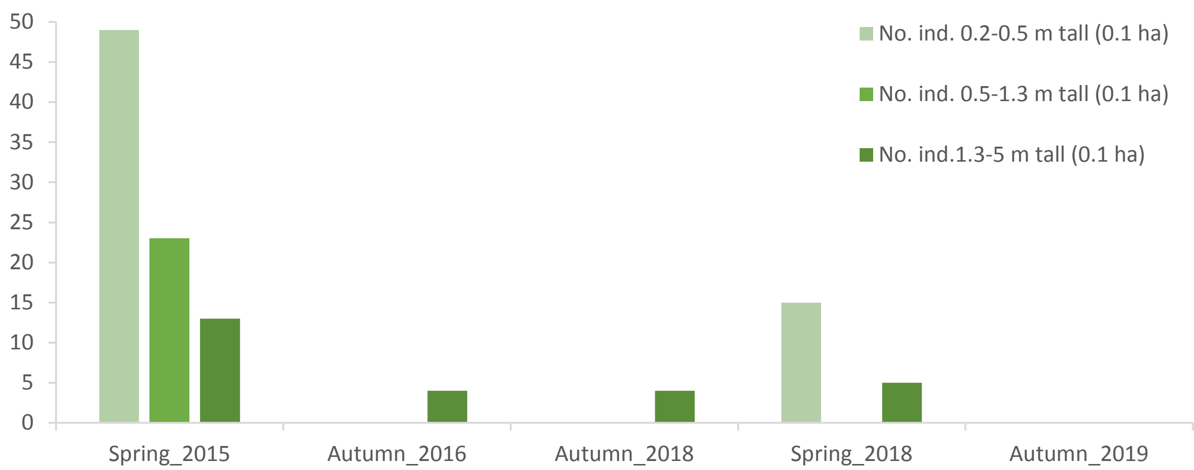


Figure H-19: Number of River Cooba seedlings recorded at Valetta 1-1 across all sample times

H.4 Discussion

Over the duration of the project, vegetation diversity and condition measured as species richness and cover, responded significantly to inundation, with the highest species richness and total cover observed following periods of inundation. Seasonal patterns in vegetation diversity were less evident, with responses being more reflective of the intermittent wetting and drying patterns. Environmental water delivered in early spring 2014 inundated approximately 2,434 ha of the Gingham and 3,908 ha of the Lower Gwydir wetlands. This period of inundation led to the highest species richness within the two wetlands throughout the project (Figure H-5). The greatest vegetation cover was then recorded at the following survey as waters contracted (Gingham 101.25%, Lower Gwydir: 95.61%;Figure H-9), and species took advantage of the increased soil moisture to grow. The vegetative response to environmental watering was not as marked during the 2018-19 water year. Although a similar volume of water was delivered to the Gingham and Gwydir systems (60 GL in total across both channels) the extent of inundation was less than in 2014-15 (Appendix B), a result of the prevailing dry conditions. Vegetation cover was at its lowest during the spring 2018 survey time, and only modest overall increases in cover were noted in the autumn 2019 survey time. Given the extremely dry conditions that were experienced throughout the northern Murray-Darling Basin during 2018-19, even a modest increase in vegetation cover like that observed in the final survey is a positive outcome for the ongoing maintenance of wetland vegetation communities in the Gwydir Selected Area.

Similar responses to inundation were observed in the Mallowa system, with the wetland recording its highest species richness and total cover after an unregulated flow inundated the wetland in spring 2016. Environmental water was delivered at the beginning of February 2017, which helped maintain the elevated species diversity and cover through to spring 2017. Following this, both species richness and cover reduced across the Mallowa sites to their lowest levels of the project. This coincided with an extended dry period in this system with limited inundation during the 2017-18 water year. Environmental water deliveries down the Mallowa system over the 2018-19 summer elicited a positive vegetative response with increases in both cover and species richness. This is positive for the Mallowa wetlands given the extremely dry conditions that have persisted for much of the past year.

Plant functional groups exhibited predictable patterns across the project, with amphibious species responding positively to inundation, and terrestrial plants taking advantage of drier periods. Vegetation communities were found to uniquely influence these groups. Water couch Marsh Grasslands and Eleocharis tall Sedgelands exhibited little response across Inundation categories, with minor decreases being recorded in amphibious species as time since connection increased. Within River Cooba – Lignum and Coolibah sites inundation initiated rapid growth of amphibious species, followed by a steady increase in terrestrial species diversity and cover as sites dried (Figure H-10; Figure H-11). It is believed that the position of these communities in the landscape plays a large role in determining the influence of inundation on vegetation diversity. The four communities can be grouped into two separate wetland categories, that are temporally and spatially dependant on inundation. The Amphibious wetlands (Water Couch Marsh Grasslands and Eleocharis tall Sedgelands) that occur on heavy clay soils in channels and depressions are communities that depend on frequent flooding (at least once per annum), to maintain structural integrity and condition (Bowen, 2010), and therefore host more optimal conditions for amphibious plant species. Whereas the Flood dependent communities (Coolibah Woodlands, River Cooba - Lignum) are communities that depend on flooding for the dominant overstory species to complete their lifestyle (Bowen, 2010). They occur in a wide range of floodplain areas that experience different frequencies and durations of inundation, which consequently determine plant functional group composition.

Throughout the project, inundation patterns were found to influence the cover of lippia, an environmental weed prevalent in the Lower Gwydir system. The species increased in total cover as sites dried out, with mean total cover doubling between sites that were frequently inundated and those that were infrequently inundated (Figure H-12). A separate study by Murray *et al.*, (2012) on the groundcover management of lippia also concluded that “over long timescales inundation frequency may be influencing the coverage of lippia, with significantly more lippia being present in drier areas of the floodplain, than in wetter areas”. In contrast, water couch, a native semi-aquatic grass, recorded its highest mean cover within inundated sites (Figure H-12). Water depth has also been found to determine the rate at which water couch grows, with the most favourable conditions being shallow water (15 - 40 cm). Likewise, depth has been found to influence competition, with waters deeper than 30 cm, resulting in water couch outcompeting lippia (Roberts and Marston, 2011). From these findings, it is suggested that to help maintain low lippia cover, wetland sites should be inundated at least annually.

Sporadic coolibah and river cooba recruitment was recorded over the course of the project. No obvious correlation between inundation and tree recruitment was noted, other than the very low levels of recruitment observed during autumn 2019 that coincided with the driest period of the project. According to Casanova (2015), floods are more common than Coolabah recruitment, so other factors are likely to play a role in stimulus of germination or success of establishment. It is likely that wet soils, or shallow flooding in late summer are required for germination (Foster 2015). It is also possible that grazing by both native and domestic animals may be influencing patterns of tree recruitment in the Lower Gwydir, especially during dry times, when the cover of other forage species is reduced.

H.5 Conclusion

Vegetation community condition and plant diversity of the Gwydir wetlands is driven by patterns of inundation, which Commonwealth environmental water has contributed to over the course of the LTIM project. The highest species richness and cover recorded in the Gingham and Lower Gwydir wetlands was recorded in the 2014-15 water year, following a large release of environmental water in early spring 2014. Environmental water delivered to the Mallowa wetlands in the 2018-19 summer period also elicited a positive vegetation response, which is extremely encouraging given the prevailing dry conditions seen throughout the northern Murray-Darling Basin in recent times. Inundation is also a practical management technique for widespread lippia control, with inundation benefitting native wetland species such as water couch, helping them to outcompete lippia, reducing its cover. Annual flooding appears to be key for supporting this native/exotic species competition. Tree recruitment was sporadic with no clear links to inundation. This highlights the importance of other key factors, such as grazing pressure that are likely to play a role within the lifecycle of wetland species of the Gwydir wetlands.

H.6 References

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Appendix I Fish Category III (River)

I.1 Introduction

The fish assemblages of the Gwydir Basin are generally considered to be in a degraded condition (Murray-Darling Basin Authority 2012). The Sustainable River Audit (SRA) No. 2 Report stated that the fish in the upper sections (above 400 mASL) of the Valley were in “Very Poor” condition, the Slopes (201 to 400 mASL) were in “Moderate” condition, whilst in the Lowland (31 to 200 mASL) regions they were classified as “Poor” (Murray-Darling Basin Authority 2012). Overall, the fish community across the valley as a whole was classified as “Poor”. The SRA found that native fish in the Gwydir in general were reduced in overall abundance and in total numbers of species, and that recruitment was variable and generally low on a site by site basis. Furthermore, there were exotic species sampled at most sites including high abundances of common carp (*Cyprinus carpio*), eastern mosquitofish (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and redfin perch (*Perca fluviatilis*).

The aim of this section of the CEWH Gwydir LTIM monitoring project was to benchmark and describe any changes in the fish community abundance, biomass and health across four hydrological zones in the lower Gwydir system in relation to environmental water releases. 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?

I.1.1 Environmental watering during the LTIM project

A total of 301,172 ML of environmental water was delivered through the Gwydir River system during the LTIM Project, making up 23% of the total water that flowed down the Gwydir River channel during that period (Table I-1). The highest volume occurred during the 2018-19 water year when 62,150 ML of Commonwealth and 52,000 ML of NSW environmental water was used. The lowest volume was in the 2015-16 water year where 13,250 ML of environmental water was delivered.

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system. In-channel flow pulses were delivered down the Mehi River and Carole Creek channels to enhance in-stream ecological function, nutrient cycling, water quality and fish spawning conditions. In addition, flows were delivered to the Lower Gwydir, Gingham Watercourse and Mallowa Creek to provide for wetlands inundation.

During 2015-16 environmental water was delivered to a number of assets within the Gwydir river system Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for with 964 ML of this water flowing down the Mehi River, and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW bulk water deliveries. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse in February 2016 to replace flows that were abstracted in a supplementary flow event. While not large in volume, these flows made it into the wetlands, inundating up to 161.81 ha (Appendix B). Due to critically low flows experienced in the lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April. This followed a period of 30 to 40 days of nil flow conditions across the catchment.

Table I-1: Environmental water use in the Gwydir River system during the LTIM project (2014-19). This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW State governments.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2014-15				
Gwydir River*	56,534	29,895	302,043	29
Gingham Watercourse	15,000	14,868	46,711	64
Lower Gwydir	15,000	15,027	41,171	73
Carole Creek	3,656	-	48,670	8
Mehi River	13,316	-	123,480	11
Mallowa Creek	9,667	-	11,281	86
2014-15 total	***56,534***	***29,895***	***302,043***	***29***
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River<	20,404	5,046 GS	213,134	12
Moomin Creek#	324	175	104,075	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434,462***	***11***
2018-19				
Gwydir River*	63,416	43,941	205,520	53
Gingham Watercourse	20,000	15,000	40,443	87
Lower Gwydir	11,314	16,032	30,254	90
Carole Creek	300	300	16,865	4
Mehi River^	10,430	16,545	82,262	33
Mallowa Creek	16,950	-	17,230	98
2018-19 total	***63,416***	***43,941***	***205,520***	***52***
Grand total	**179,592**	**118,434**	**1,327,700**	**22**

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 14,160 ML delivered as part of the Northern Connectivity Event. The total volume for the NSW component also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system. Also includes 23,051 ML delivered as part of the Northern Fish Flow

+Includes 4,758 ML delivered as part of the Northern Connectivity Event

During 2016-17, a flow event occurred down the Mehi River in September 2016 and supplementary water licences owned by the CEWO were triggered. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however, very little of the moderate flows were diverted into the Mallowa wetlands. In January to March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse to build upon moderate winter/spring flows. From January to March 2017, 30,000 ML was delivered, aiming to inundate broad areas of semi-permanent wetland vegetation. During 2016-17, no environmental water was delivered to the Moomin Creek.

During 2017-18, an early season stimulus flow was triggered by inflows to Copeton Dam in August/September 2017. A total of 10,000 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems as a small fresh during late winter/early spring. Following this, a stable flow release of 10,040 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems in late October to mid-November 2017. These small pulse flows were aimed at providing downstream connectivity and allowing opportunity for movement, breeding and recruitment of fish, particularly freshwater catfish (*Tandanus tandanus*).

A delivery of 8,000 ML including both State and Commonwealth environmental water was made to the Lower Gwydir and Gingham wetlands from mid-December 2017 to late January 2018, to replace supplementary take from a small flow event that occurred in the previous months. This aimed to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands. The last environmental delivery was made in late April/May 2018 as part of the Northern Connectivity Event. This flow aimed to provide longitudinal connectivity and refresh/replenish drought refuge for instream life, particularly native fish in the Barwon-Darling as well as improving conditions to maintain native fish populations within the tributary catchments. During this event, a total of 18,908 ML of both State and Commonwealth water was delivered down the Mehi River, Moomin Creek and Carole Creek. No environmental water deliveries were made to Mallowa Creek in 2017-18.

In 2018-19 environmental water made up 53% of the total flow down the Gwydir River channel (Table I-1). Sixty gigalitres of environmental water was delivered to the Lower Gwydir and Gingham wetlands to support wetland vegetation and channel processes in the Gwydir River. Deliveries to the wetlands began in July 2018 and finished in February 2019. In both systems deliveries were stopped in October and November to allow farmer access during the winter crop harvest. Over the November 2018 to February 2019 period, environmental water was also delivered to the Mallowa wetlands to support wetland vegetation, waterbirds and native fauna. During this event 16,950 ML of Commonwealth environmental water was delivered. A trial delivery of 600 ML was delivered to the Ballin Boora system in January to February 2019 to support wetland and riparian vegetation. Pool replenishment flows were delivered to the Gwydir, Lower Gwydir, Carole and Mehi channels due to low inflows that caused extended no flow periods throughout the water year. In May to June 2019, 23,051 ML was delivered down the Mehi River channel from Copeton Dam, as part of the Northern Fish Flow. This flow reconnected the lower Mehi River, and once in the Barwon River channel, flowed downstream as far as the Culgoa River junction.

I.2 Methods

I.2.1 Sampling sites

Data was collected from 23 sites in each year from 2014 to 2019 within four sub-catchments or hydrological zones across the lower Gwydir system for *Cat III Fish River* analyses; the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek (Figure I-1; Table I-2). Sampling commenced in late February and was completed by mid-May in each year. In all years, seventeen sites were sampled solely as part of the *Gwydir LTIM Cat III* project; six each in the Mehi and Moomin sub-catchments and five in the Gingham. A sub-set of the data from six (randomly chosen in Year 1) of the 10 *LTIM Cat I Fish River* sites sampled from across the Lower Gwydir River was also used in the analyses. For these sites, the first 1,080 sec of boat or 1,200 sec of backpack electrofishing (or where applicable combinations of both) was used as the sampling effort.

Sampling sites in all four sub-catchments were typical of the meandering waterways found throughout the lowland reaches of much of the Murray-Darling Basin. The water at all sites was turbid and relatively shallow and there were distinct pool/run/riffle zones present within many of the sites (Figure I-2 and Figure I-3). In the Gwydir River upstream of Tyreel Weir and in the Mehi River, the river channel was wider, deeper and more permanent in nature, averaging ~30 m in width and ~1.5 m in depth. In the Lower Gwydir, Gingham and Moomin, the majority of sites were narrower (~8 to 16 m) and shallower (~0.5 m). Flows varied markedly between years. On several occasions, individual sites were not sampled at all due to being near or completely 'dry'. For example, all sites were sampled in 2015 with water flowing in all rivers in all zones, whilst in 2019 six of the sites were 'dry' and could not be sampled at all. The dry conditions in 2019 particularly affected sampling in the Gingham and Gwydir zones, with only three of the six sites in the Gwydir and three of the five in the Gingham, sampled (Table I-2).

In-stream habitat across all four sub-catchments was dominated by submerged timber (Figure I-3) and undercut banks. The substratum at sites was typically mud; however, gravel, sand and silt substrates were also present in some areas. In general, all four river systems were highly disturbed as a result of anthropogenic influences, with the majority of sites adjacent to irrigated and/or dryland cropping areas, all had highly altered flow regimes, and all were affected by terrestrial and aquatic introduced species. Most sites were fringed by a narrow riparian zone, dominated by native trees and exotic shrubs (Figure I-2). Notable terrestrial weeds included African boxthorn (*Lycium ferocissimum*), Noogoora burr (*Xanthium pungens*) and lippia (*Phyla canescens*).

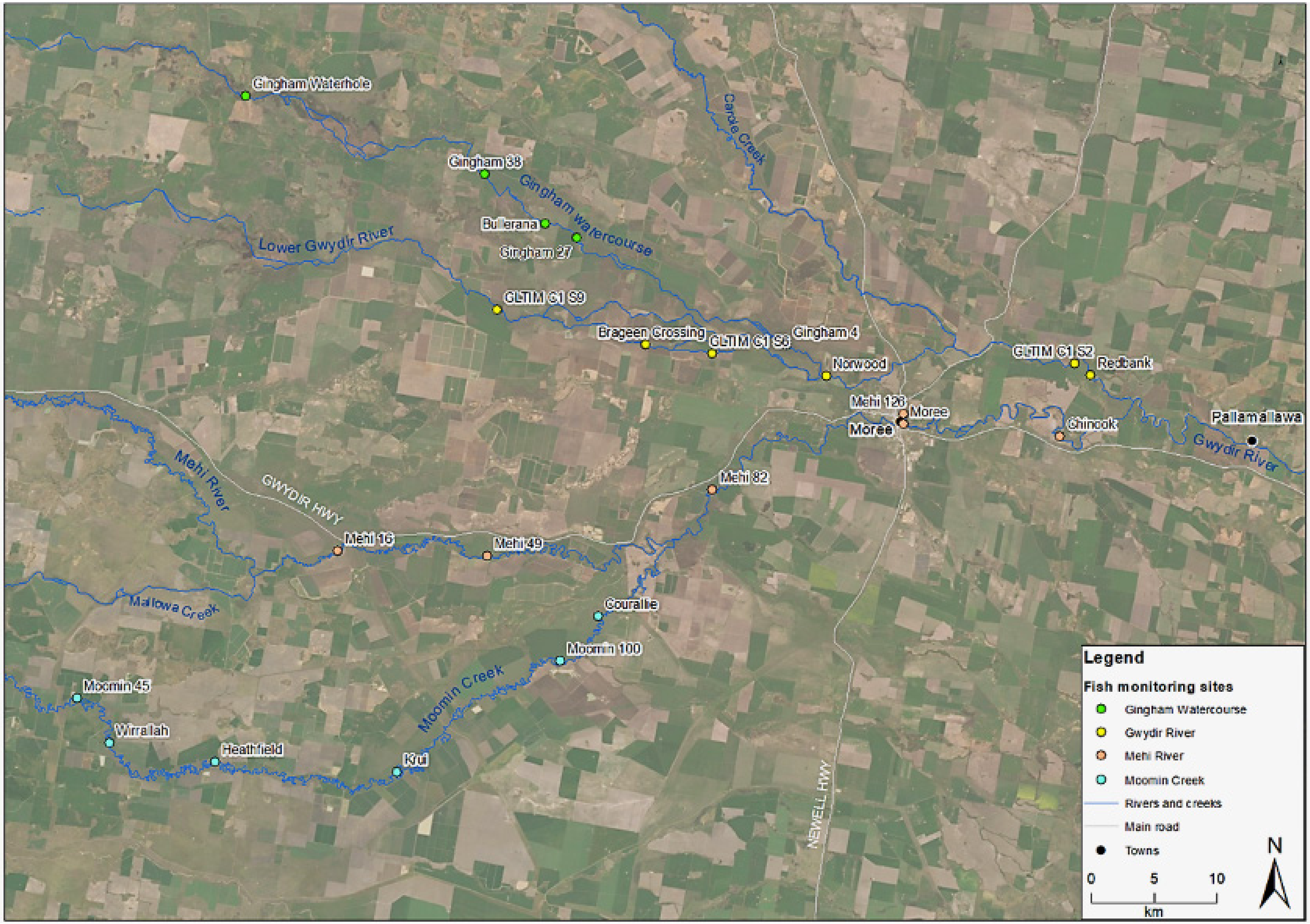

Figure I-1: Location of sampling sites in the Gwydir, Lower Gwydir, Mehi, Moomin and Gingham channels used in Fish (River) analyses.

Table I-2: Sampling sites used in the analysis of Fish (River) assessment (2014-19). 'Years Sampled' column indicates the years by which the respective site was sampled. A missing sampling event is indicative that the site was dry.

Site Name	River	Source	Latitude	Longitude	Altitude (mASL)	Zone	Years Sampled
Gingham 27	Gingham Watercourse	LTIM CAT III	-29.34100	149.57700	168	Lowland	15,16,17,18
Gingham 38	Gingham Watercourse	LTIM CAT III	-29.29600	149.50000	168	Lowland	15,16,17,18
Gingham Waterhole	Gingham Watercourse	LTIM CAT III	-29.24342	149.30227	173	Lowland	15,16,17,18,19
Bullerana	Gingham Watercourse	LTIM CAT III	-29.33100	149.55100	175	Lowland	15,16,17,18,19
Gingham 4	Gingham Watercourse	LTIM CAT III	-29.41400	149.75100	208	Slopes (L)	15,16,17,18,19
Brageen Crossing	Gwydir River	LTIM CAT I	-29.41679	149.63554	185	Lowland	15,17,18
GLTIM C1 S9	Gwydir River	LTIM CAT I	-29.39400	149.51300	187	Lowland	15,17,18
GLTIM C1 S6	Gwydir River	LTIM CAT I	-29.42200	149.69000	198	Lowland	15,17,18
Norwood	Gwydir River	LTIM CAT I	-29.43597	149.78444	201	Slopes (L)	15,16,17,18,19
Redbank	Gwydir River	LTIM CAT I	-29.43086	150.00138	201	Slopes (L)	15,16,17,18,19
GLTIM C1 S2	Gwydir River	LTIM CAT I	-29.42300	149.98800	219	Slopes (L)	15,16,17,18,19
Mehi 16	Mehi River	LTIM CAT III	-29.57000	149.38600	165	Lowland	15,17,18,19
Mehi 49	Mehi River	LTIM CAT III	-29.57100	149.50900	185	Lowland	15,16,17,18,19
Mehi 82	Mehi River	LTIM CAT III	-29.52010	149.69300	184	Lowland	15,16,17,18,19
Moree	Mehi River	LTIM CAT III	-29.46958	149.89977	201	Slopes (L)	15,16,17,18,19
Mehi 126	Mehi River	LTIM CAT III	-29.46200	149.84900	206	Slopes (L)	15,16,17,18,19
Chinook	Mehi River	LTIM CAT III	-29.47556	149.97713	217	Slopes (L)	15,16,17,18,19
Moomin 45	Moomin Creek	LTIM CAT III	-29.68000	149.17400	155	Lowland	15,16,17,18,19
Wirrallah	Moomin Creek	LTIM CAT III	-29.71172	149.20145	160	Lowland	15,17,18,19
Heathfield	Moomin Creek	MDBP	-29.72413	149.28851	163	Lowland	15,16,17,18
Krui	Moomin Creek	LTIM CAT III	-29.72811	149.43867	178	Lowland	15,16,17,18,19
Courallie	Moomin Creek	LTIM CAT III	-29.61283	149.60136	178	Lowland	15,16,17,18,19
Moomin 100	Moomin Creek	LTIM CAT III	-29.64600	149.57100	184	Lowland	15,17,18,19

Figure I-2: Wirrallah survey site on Moomin Creek sampled as part of Fish (River) assessment.

Figure I-3: Mehi 16 survey site on the Mehi River, sampled as part of Fish (River) assessment.

I.2.2 Sampling protocols

Sampling effort at each site was a combination of electrofishing and bait trapping (Commonwealth of Australia 2014). Electrofishing included small and medium boats (2.5 kW or 5 kW Smith-Root electrofisher units respectively), backpack (Smith Root model LR20) or a combination of boat and backpack (Figure I-4). Boat electrofishing consisted of 12 x 90 sec power-on operations per site, while backpack electrofishing consisted of 8 x 150 sec operations. At sites where both boat and backpack sampling were required, the number of operations of each method used was proportional to the area of navigable versus wadable habitat. Boat electrofishing involved a series of ~10 sec power-on and power-off operations, with successive operations undertaken on alternate banks while 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 were undertaken by a minimum of two operators, with three operators used at medium boat sites. Ten unbaited traps were deployed for a minimum of two hours at each site and undertaken at the same times as electrofishing. Traps were set haphazardly throughout the site in water depths of 0.5 m to 1 m.

All fish captured were identified to species level and measured to the nearest mm. Length measurements were taken as fork length for species with forked tails and total length for all other species. Species that had the potential to grow beyond 100 mm were also weighed to the nearest 0.1 g. When an individual or individuals could not be positively identified in the field, a voucher specimen was retained for laboratory identification. Only a sub-sample of individuals were measured and weighed for each gear type when large catches of an individual species occurred. The sub-sampling procedure consisted of firstly measuring the length of all individuals in each operation until at least 50 individuals of each species had been measured in total. The remainder of individuals in that operation were also measured, but any individuals of each species from subsequent operations of that gear type were only counted. Fish that escaped capture but could be positively identified were also counted and recorded as “observed”.

Figure I-4: Backpack electrofishing in the Gingham Watercourse.

I.2.3 Data Analysis

Fish community

Electrofishing and bait trapping data from each site were combined for all statistical analyses. Non-parametric multivariate analysis of variance (PERMANOVA) was used to determine if there were differences between the fish assemblages in each of the four hydrological zones within and between years (PRIMER 6 & PERMANOVA; Anderson *et al.* 2008). Prior to analyses, the data were fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $p<0.05$. *P*-values were adjusted to account for increasing experiment-wise error rates associated with multiple comparisons (Ogle 2016). 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 both within and between years. Only zones and years where >20 individuals were sampled were included in the analyses. *P*-values were adjusted to account for increasing experiment-wise error rates associated with multiple comparisons (Ogle 2016). Species included were: large bodied, consisting of Murray cod (*Maccullochella peelii)*, common carp and bony herring (*Nematolosa erebi*); and small-bodied, consisting of Murray-Darling rainbowfish (*Melanotaenia fluviatilis*), carp-gudgeon (*Hypseleotris* sp.) and Australian smelt (*Retropinna semoni)*.

Health Metrics

Reference Condition

The predicted pre-European fish community of the lower Gwydir system 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 I-3 and Table I-4). The RC-F process involves using 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 prior to 1770 using the standard sampling protocol (Davies *et al.* 2008). Rare species were allocated a RC-F probability of capture of 0.1 (collected at 0 < 0.2 of samples), occasional species (collected at 0.21 < 0.7 of samples) an RC-F of 0.45 and common species (collected at 0.71 < 1.0 samples) an RC-F of 0.85 (RC-F scores being the median capture probability within each category) (Table I-3).

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 based on expert opinion where no published data was available (Table I-4).

Table I-3: Native freshwater fish species predicted to occur across the lower Gwydir system 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 fish condition metrics.

Species	Common name	Occurrence
Ambassis agassizii	olive perchlet[E]	Rare
Bidyanus bidyanus	silver perch[V, C.End]	Occasional
Craterocephalus amniculus	Darling River hardyhead	Rare
Craterocephalus stercusmuscarum fulvus	unspecked hardyhead	Occasional
Hypseleotris sp.	carp-gudgeon	Common
Leiopotherapon unicolor	spangled perch	Common
Melanotaenia fluviatilis	Murray-Darling rainbowfish	Common
Mogurnda adspersa	southern purple-spotted gudgeon	Rare
Nematolosa erebi	bony herring	Common
Maccullochella peelii	Murray cod[Vul]	Occasional
Macquaria ambigua	golden perch	Common
Retropinna semoni	Australian smelt	Occasional
Tandanus tandanus	freshwater catfish[E]	Common

E = Listed as an endangered population under the Fisheries Management Act 1994
V = Listed as vulnerable under the Fisheries Management Act 1994
C.End= listed as critically endangered under the Environment Protection and Biodiversity Conservation Act 1999
Vul = listed as vulnerable under the Environment Protection and Biodiversity Conservation Act 1999

Table I-4: Lengths used to distinguish new recruits for species likely to be sampled across the lower Gwydir system. Values represent the length at one year-of-age for longer-lived species or the age at sexual maturity for species that reach maturity before one year. The final two columns refer to whether or not a juvenile and/or and adult of the species was collected during all sampling years (2014-19).

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)	Sampled during study	
		Non-juvenile	Juvenile
Native species			
olive perchlet	26 mm (Pusey *et al.* 2004)	✓	×
silver perch	75 mm (Mallen-Cooper 1996)	✓	×
Darling River hardyhead	40 mm (expert opinion)	×	×
unspecked hardyhead	38 mm (Pusey *et al.* 2004)	✓	✓
carp gudgeon	35 mm (Pusey *et al.* 2004)	✓	✓
spangled perch	68 mm (Leggett and Merrick 1987)	✓	✓
Murray-Darling rainbowfish	45 mm (Pusey *et al.* 2004: for *M. duboulayi*)	✓	✓
southern purple-spotted gudgeon	40 mm (Pusey et al. 2004)	×	×
bony herring	67 mm (Cadwallader 1977)	✓	✓

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)	Sampled during study	
		Non-juvenile	Juvenile
Murray cod	222 mm (Gavin Butler *unpublished data*)	✓	✓
golden perch	75 mm (Mallen-Cooper 1996)	✓	✗
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)	✓	✓
redfin perch	130 mm (Thorpe 1977)	✗	✗

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 (*Expectedness*, *Nativeness*, *Recruitment*) 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 MatLab Fuzzy Logic toolbox (The Mathworks Inc. USA) using the rule sets by Davies *et al.* (2010).

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

The *Recruitment Indicator* ($SR\text{-}Fi_r$) represents the recent reproductive activity of the native fish community within each altitude zone. The *Recruitment Indicator* is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (RC-F corrected) and the average proportion of total abundance of each species that are new recruits (Robinson 2012). 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 $SR\text{-}FI_e > SR\text{-}FI_r > SR\text{-}FI_n$. The output generated by the Expert Rules analysis is scaled between 0 and 100, with higher values representing a 'healthier' fish community. The index was then partitioned into five equal bands to rate the condition of the fish community; "Good" (81-100), "Moderate" (61-80), "Poor" (41-60), "Very Poor" (21-40), or "Extremely Poor" (0-20).

I.3 Results

I.3.1 Abundance

In total, 12,930 fish were captured (n = 9,603) or observed (n = 3,327) across the lower Gwydir system for all five years (2014-2019) and for all sites and sampling gear types combined. 2017 had the highest total catch (n = 2,204) and 2015 the lowest (n = 1,346). The average ± S.E. total catch per year was 1920.6 ± 231.8.

There was a significant difference in the overall abundances among the fish assemblage between years across the lower Gwydir system ($Pseudo\text{-}F_{4,95}$ = 2.45, P < 0.01). Pair-wise comparisons revealed the dissimilarity was due to significant differences between: 2015 compared with 2016, 2017, 2018 and 2019; 2016 compared with 2017 and 2018; and, 2017 compared with 2019 (Table I-5).

Table I-5: Results of pairwise comparisons to determine differences in abundance among the fish assemblages between years across the lower Gwydir system (2014-2019).

Sampling Years	*t*	*P*
2015 vs 2016	2.02	**0.002**
2015 vs 2017	1.96	**0.009**
2015 vs 2018	1.61	**0.042**
2015 vs 2019	1.86	**0.005**
2016 vs 2017	1.67	**0.022**
2016 vs 2018	1.55	**0.039**
2016 vs 2019	0.76	0.700
2017 vs 2018	1.10	0.308
2017 vs 2019	1.58	**0.035**
2018 vs 2019	1.29	0.142

Bold indicates significant difference of ***p<0.05***.

SIMPER analysis suggested differences between 2015 and 2016 were a result of a greater number of bony herring (contribution to group dissimilarity = 16.09%), carp-gudgeon (contribution = 10.8%) and eastern mosquitofish (contribution = 9.29%) in 2016 and greater numbers of Australian smelt (contribution = 9.55%) in 2015. Bony herring (contribution = 15.54%), Murray-Darling rainbowfish (contribution = 11.19%) and goldfish (contribution = 11.12%) were the main contributors to differences between 2015 and 2017, with the greater numbers collected in 2017. Differences between 2016 and 2017 were a result of higher numbers of bony herring (contribution = 13.1%) and carp-gudgeon (contribution = 11.12%) in 2016, and greater numbers of Murray-Darling rainbowfish (contribution = 12.14%) and goldfish (contribution = 10.96%) in 2017. Bony herring (contribution = 13.93%), carp-gudgeon (contribution = 10.72%), eastern mosquitofish (contribution = 10.22%) and Murray-Darling rainbowfish (contribution = 9.86%) were in higher abundance in 2018 compared to 2015.

Differences between 2016 and 2018 were as a result of higher abundances of bony herring (contribution = 14.79%) in 2016 and higher abundances of carp-gudgeon (contribution = 12.09%), eastern mosquitofish (contribution = 11.2%) and Murray-Darling rainbowfish (contribution = 10.28%) in 2018. Differences between 2015 and 2019 were as a result of greater numbers of bony herring (contribution = 12.52%) and carp-gudgeon (contribution = 11.51%) and fewer common carp (contribution = 10.81%) and Australian smelt (contribution = 9.76%) in 2019. Bony herring (contribution = 13.29%), Murray-Darling rainbowfish (contribution = 12.19%) and goldfish (contribution = 11.2%) were all in higher abundance in 2017 compared to 2019. However, abundances of carp-gudgeon (contribution = 11.55%) were greater in 2019.

Community composition across all years combined comprised 14 species in total; 11 native species and three exotic species. Of the six threatened species that were thought to occur across the lower Gwydir system, four were captured; Murray cod (Vulnerable; EPBC Act) (n = 302), silver perch (Vulnerable; EPBC Act) (n = 1), olive perchlet (Endangered; EPBC Act) (n = 1) and freshwater catfish (Endangered; EPBC Act) (n = 5). No southern purple-spotted gudgeon or Darling-River hardyhead were caught in any year.

Captures within zones varied considerably and included: 2,797 fish among 14 species from the five sites sampled in the Gingham Watercourse; 2,477 among 12 species from the six sites sampled in the Gwydir; 2,455 among 12 species from the six sites sampled in the Mehi (Figure I-5), and 1,874 among 10 species from the six sites sampled in Moomin Creek (Figure I-5).

Bony herring (n = 3,407) were the most abundant native large-bodied species (those that grow to >100 mm) sampled in most years but was also variable among years. In 2015 through to 2018, bony herring made up >40% of the total catch of all native species and zones combined; however, in 2019 the number fell to ~22%. Among the small-bodied species (those that do not grow >100 mm), carp-gudgeon was the most abundant species sampled (n = 1,878), followed by Murray-Darling rainbowfish (n = 789) and Australian smelt (n = 376) (Figure I-5). As with the large bodied species, abundances among the small-bodied species also fluctuated markedly between years. For example, carp-gudgeon made up 91% and 88% of the catch among the native small-bodied species in 2016 and 2019 respectively, whilst in 2017 they only contributed 22% of the catch.

There were significant differences in abundance among the fish assemblages of the four hydrological zones sampled ($Pseudo\text{-}F_{3,95}$ = 7.19, P < 0.01). Pair-wise comparisons revealed the dissimilarity was due to differences between: Gingham and Gwydir, Gingham and Mehi, Moomin and Gwydir and Moomin and Mehi (Table I-6).

Table I-6: Results of pairwise tests to determine differences in abundances among the fish assemblages between the four zones (Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek) sampled across the lower Gwydir system (2014-2019). Bold indicates significant difference of *p<0.05*.

Zones	*t*	*P*
Gingham vs Gwydir	2.52	***<0.001***
Gingham vs Mehi	2.57	***<0.001***
Gingham vs Moomin	1.48	0.058
Gwydir vs Mehi	1.34	0.107
Gwydir vs Moomin	3.54	***<0.001***
Mehi vs Moomin	3.76	***<0.001***

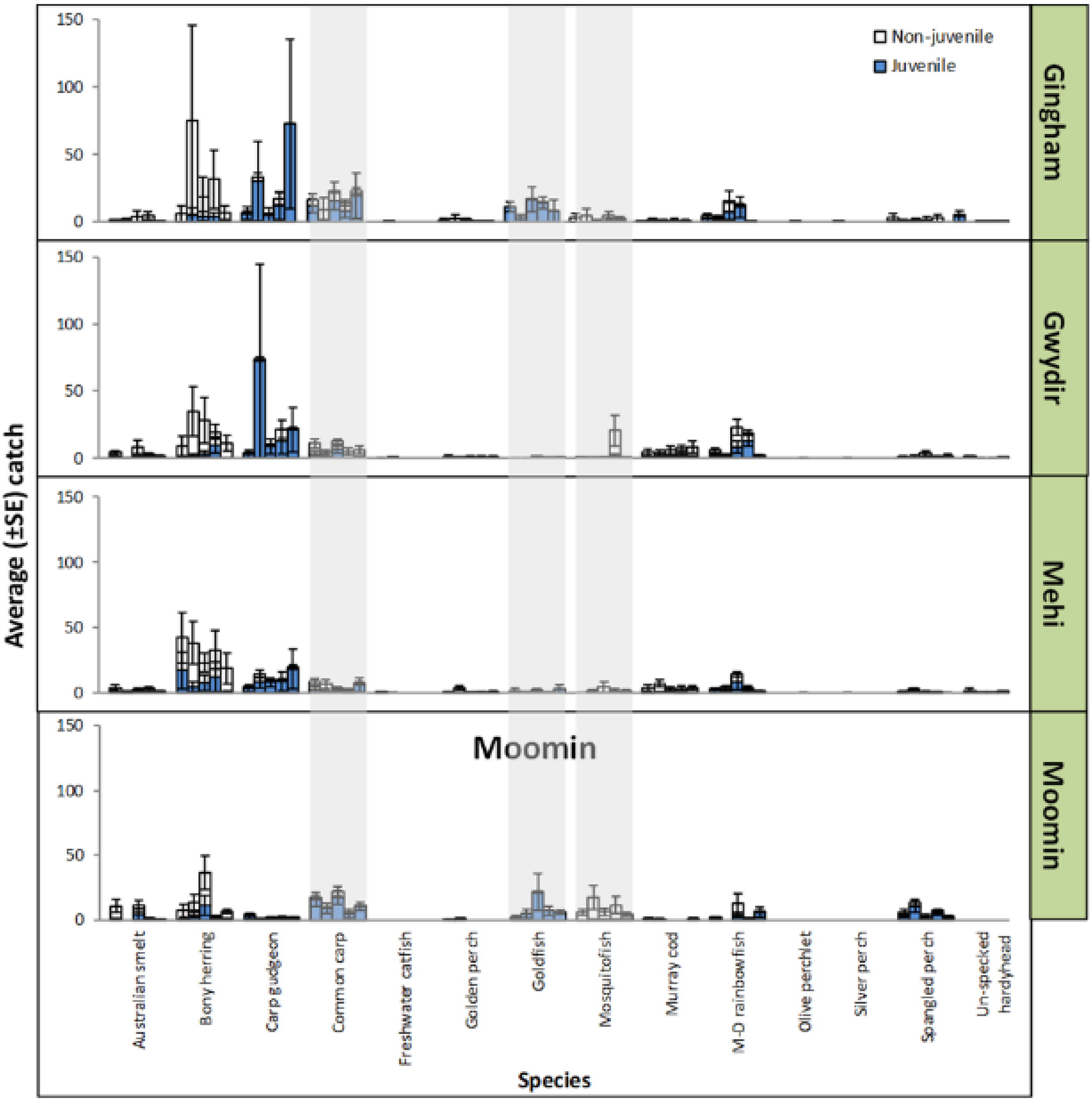

Figure I-5: Average number of individuals (catch) ± S.E. per site per year (sequential) for the 14 fish species sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek. NB*Juveniles and non-juveniles based on the length at one year-of-age for longer-lived species or the length at sexual maturity for species that reach maturity before one year (Table I-4). Dark shading indicates exotic species.

I.3.2 Biomass

Based on estimated and measured weights, a total 1,578.29 kg of fish were sampled for all sites and methods and for all years combined. Common carp had the highest overall biomass (*n* = 723.40 kg) among the 14 species sampled. Common carp accounted for 68.55% of the overall biomass (of all species combined) in the Gingham, 52.93% in the Moomin, 40.01% in the Gwydir and 37.67% in the Mehi (Figure I-6). Murray cod had the second highest biomass (*n* = 463.37 kg) making up 38.96%, 33.81%, 11.66% and 7.89% of the overall biomass in the Gwydir, Mehi, Moomin and Gingham, respectively. Bony herring were third highest totalling 284.86 kg. Among the small-bodied species, Murray-Darling rainbowfish (*n* = 921.23 g), carp-gudgeon (*n* = 635.94 g), and Australian smelt (*n* = 339.82 g) had the first, second and third highest biomasses, respectively (Figure I-8).

There was a significant difference in the overall biomass of species between the four hydrological zones sampled ($Pseudo\text{-}F_{3,95}$ = 6.12, P = <0.001). Pair-wise comparisons revealed the dissimilarity was due to differences between: Gingham and Gwydir, Gingham and Mehi, Gingham and Moomin, Gwydir and Moomin and Mehi and Moomin (Table I-7).

Table I-7: Results of pairwise tests to calculate for differences in the biomass between the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek, across the lower Gwydir system (2014-2019). Bold indicates significant difference of *p<0.05*.

Zones	*t*	*P*
Gingham vs Gwydir	2.30	***0.001***
Gingham vs Mehi	2.30	***0.001***
Gingham vs Moomin	1.96	***0.003***
Gwydir vs Mehi	0.97	0.40
Gwydir vs Moomin	3.16	***<0.001***
Mehi vs Moomin	3.43	***<0.001***

SIMPER analysis suggested the differences between the Gingham and Gwydir were driven by the greater biomass of common carp (contribution = 22.01%) in the Gingham and higher biomass of Murray cod (contribution = 17.87%) and bony herring (contribution = 15.96%) in the Gwydir. Differences between the Gingham and Mehi were as a result of higher biomass of common carp (contribution = 20.09%) in the Gingham and a higher biomass of Murray cod (contribution = 18.55%) and bony herring (contribution = 16.54%) in the Mehi. A higher biomass of common carp (contribution = 26.55%), bony herring (contribution = 16.01%) and goldfish (contribution = 12.77%) in the Gingham resulted in the dissimilarities with the Moomin. Differences between the Gwydir and the Moomin were due to a higher biomass of common carp (contribution = 21.05%), Murray cod (contribution = 18.93%) and bony herring (contribution = 16.53%) in the Gwydir. A higher biomass of common carp (contribution = 19.78%), Murray cod (contribution = 19.49%) and bony herring (contribution = 16.34%) in the Mehi drove differences with the Moomin.

There was a significant difference in the overall biomass among the fish assemblage among years across the lower Gwydir system as a whole ($Pseudo\text{-}F_{4,95}$ = 2.04, P < 0.01). Pair-wise comparisons revealed differences between: 2015 versus 2016, 2015 and 2017; 2016 and 2017; and, 2017 and 2019 (Table I-8).

Table I-8: Results of pairwise tests to determine the differences in the biomass between years (2014-2019) across the lower Gwydir system. Bold indicates significant difference of *p<0.05*.

Sampling Years	*t*	*P*
2015 vs 2016	1.69	***0.031***
2015 vs 2017	1.65	***0.035***
2015 vs 2018	0.94	0.455
2015 vs 2019	1.56	0.050
2016 vs 2017	1.79	**0.014**
2016 vs 2018	1.40	0.097
2016 vs 2019	0.63	0.826
2017 vs 2018	0.95	0.452
2017 vs 2019	1.91	**0.007**
2018 vs 2019	1.26	0.168

SIMPER analysis showed the differences between 2015 and 2016 were due to a higher biomass of common carp (contribution = 23.21%) and Murray cod (contribution = 15.84%) in 2015 and a higher biomass of bony herring (contribution = 17.69%) in 2016. Differences between 2015 and 2017 were due to a higher biomass of common carp (contribution = 18.63%), bony herring (contribution = 18.41%) and Murray cod (contribution = 16.94%) in 2017. A higher biomass of common carp (contribution = 22.43%) and Murray cod (contribution = 15.94%) in 2017 compared to 2016 and a greater biomass of bony herring (contribution = 15.95%) in 2016 resulted in the difference between these years. Differences between 2017 and 2019 were driven by a higher biomass of common carp (contribution = 22.85%) and bony herring (contribution = 16.45%) in 2017 and by a greater biomass of Murray cod (contribution = 16.95%) in 2019.

Figure I-6: Juvenile common carp (*Cyprinus carpio*) captured at the Mehi 49 site on the Mehi River in 2019.

Figure I-7: Juvenile golden perch (*Macquaria ambigua*) (Total Length = 168 mm) captured at Chinook on the Mehi River in 2019.

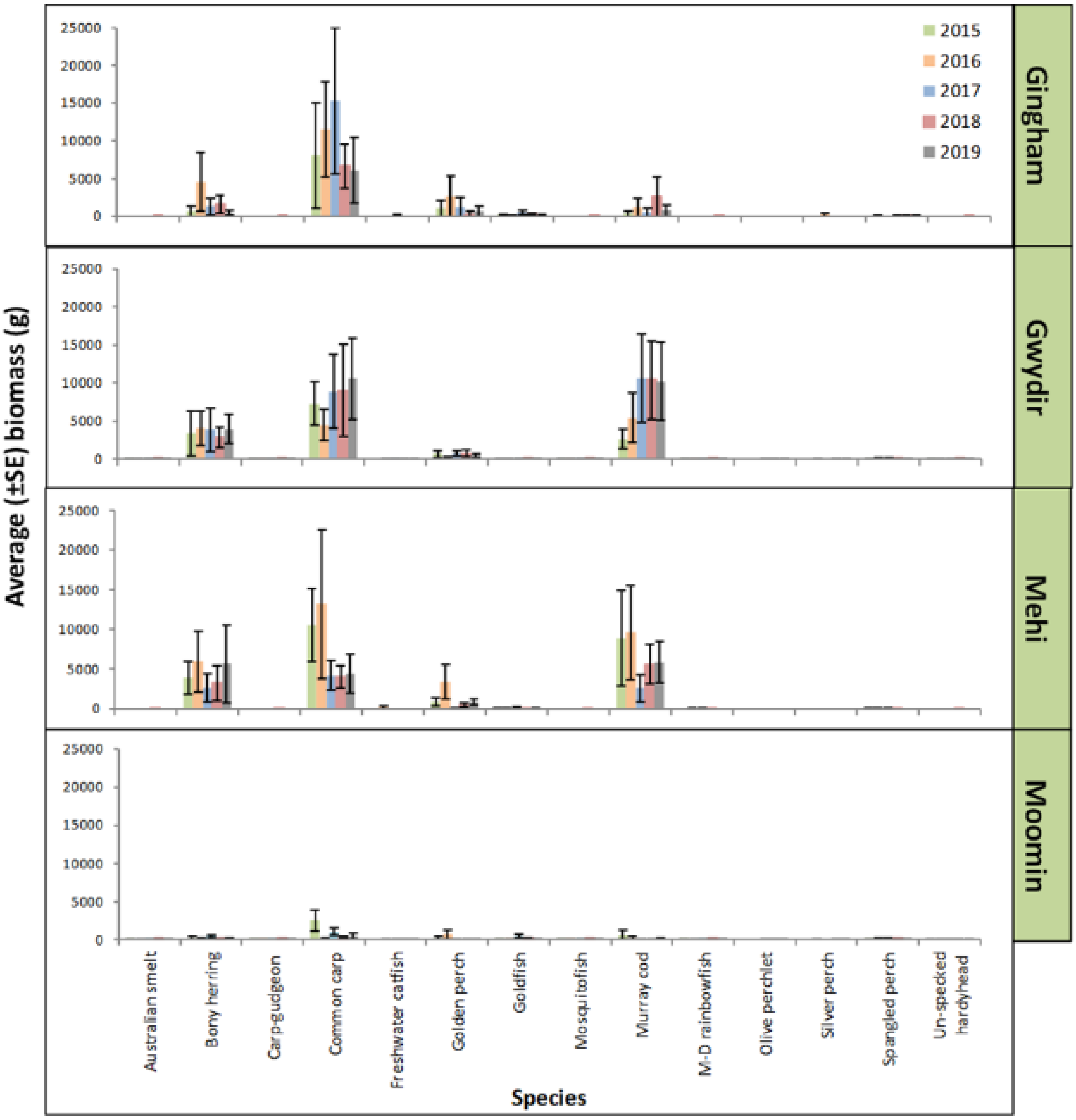

Figure I-8: Average biomass ± S.E. for 14 fish species sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek during the *Gwydir Long Term Intervention Monitoring project* 2014-19: 2014-15 (-----), 2015-16 (-----), 2016-17 (-----), 2017-18 (-----) and 2018-19 (-----).

I.3.3 Length frequency

In general, there were significant differences between years in the length-frequency distribution among the majority of the six more abundant large- and small-bodied species collected (Table I-9). Excluding Murray cod and bony herring, there were significant differences among all other species between 2015 and 2017, 2015 and 2016, 2016 and 2017, 2016 and 2019, 2017 and 2018, 2017 and 2019 and 2018 and 2019 (Table I-9). Among all six species, bony herring populations varied the most between years, with significant differences between all combinations of years. Contrastingly, there were no significant differences in the Murray cod population between any years (Table I-9).

Overall, the population structure of the most abundant small-bodied species varied little for some species, whilst for others it varied year-by-year, both within and in some cases, across hydrological zones (Figure I-9). An example of comparative uniformity is evident among Murray-Darling rainbowfish populations across the majority of zones, with the ratio of recruits and adults relatively consistent across all years sampled (Figure I-9). Unlike Murray-Darling rainbowfish and to a lesser degree Australian smelt, the structure of carp gudgeon populations in most zones (Gingham, Gwydir and Mehi) tended to shift on a year by year basis. This was particularly apparent in the Gingham and Gwydir, where the overall abundance of the population increased through time as did the number of adults in the population (Figure I-9). Of the three species, Australian smelt were the most sporadic in occurrence and also had the most erratic population structures, with very few adults or juveniles sampled consistently in any zone in any of the five years sampled (Figure I-9).

Among the three more abundant large-bodied species (bony herring, Murray cod and common carp), the structure of populations was consistent within some hydrological zones across years, whilst in others there was less consistency, alternating from a population dominated by juveniles, to one made up largely of adults (Figure I-10). Among zones, both the Gingham and Moomin bony herring populations were relatively consistent in structure and were dominated by individuals <150 mm, whilst in the Gwydir and Mehi there were greater numbers of larger adults in most years and less uniformity among years (Figure I-10). In contrast, Murray cod populations in the Gwydir and Mehi were generally structurally consistent between the two zones as well as across years (Figure I-10). Both populations were dominated by small numbers of young-of-year, with the greatest numbers between 250 and 500 mm, and only a small number of individuals >600 mm. Few Murray cod were collected from the Moomin and Gingham compared to the two other zones, however, small numbers of recruits were present in some years suggesting some localised breeding or migration from nearby zones, or possibly even restocking of hatchery reared juveniles. Of the three more abundant larger-bodied species sampled, common carp populations varied the most, both within the majority of zones but also across years (Figure I-10). Of the four hydrological zones, the Moomin and Gingham, (excluding 2015-16, in the Gingham), consistently produced common carp recruits in all years, whilst the other two zones (Gwydir and Mehi) had the most recruits in 2015 and 2017 (Figure I-9). In general, common carp populations in the Moomin and Gingham zones were dominated by juveniles in most years, whilst larger common carp (>500 mm) were sampled more frequently in the Mehi and Gwydir compared to the other two zones (Figure I-10).

Table I-9: Kolmogorov-Smirnov test results for length frequency comparisons of fish between years for all hydrological zones combined (Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek). Bold indicates significant difference of *p<0.05*.

Length Frequency Comparisons	Year (p-value)									
	1 vs 2	1 vs 3	1 vs 4	1 vs 5	2 vs 3	2 vs 4	2 vs 5	3 vs 4	3 vs 5	4 vs 5
Common carp	**<0.001**	**0.011**	**<0.001**	**<0.001**	**<0.001**	0.251	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Murray cod	0.999	0.999	0.999	0.936	0.999	0.999	0.999	0.999	0.999	0.999
Bony herring	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Carp gudgeon	**0.003**	0.793	**0.012**	**<0.001**	**0.004**	**<0.001**	0.368	**0.004**	**<0.001**	**<0.001**
Rainbowfish	0.567	**0.019**	0.119	**0.002**	**0.012**	0.516	**0.029**	**<0.001**	**<0.001**	**0.025**
Australian smelt	**0.004**	**0.005**	0.308	0.308	**0.004**	**0.037**	0.228	0.221	0.168	0.308

Year 1 = 2015; Year 2 = 2016; Year 3 = 2017; Year 4 = 2018; and, Year 5 = 2019

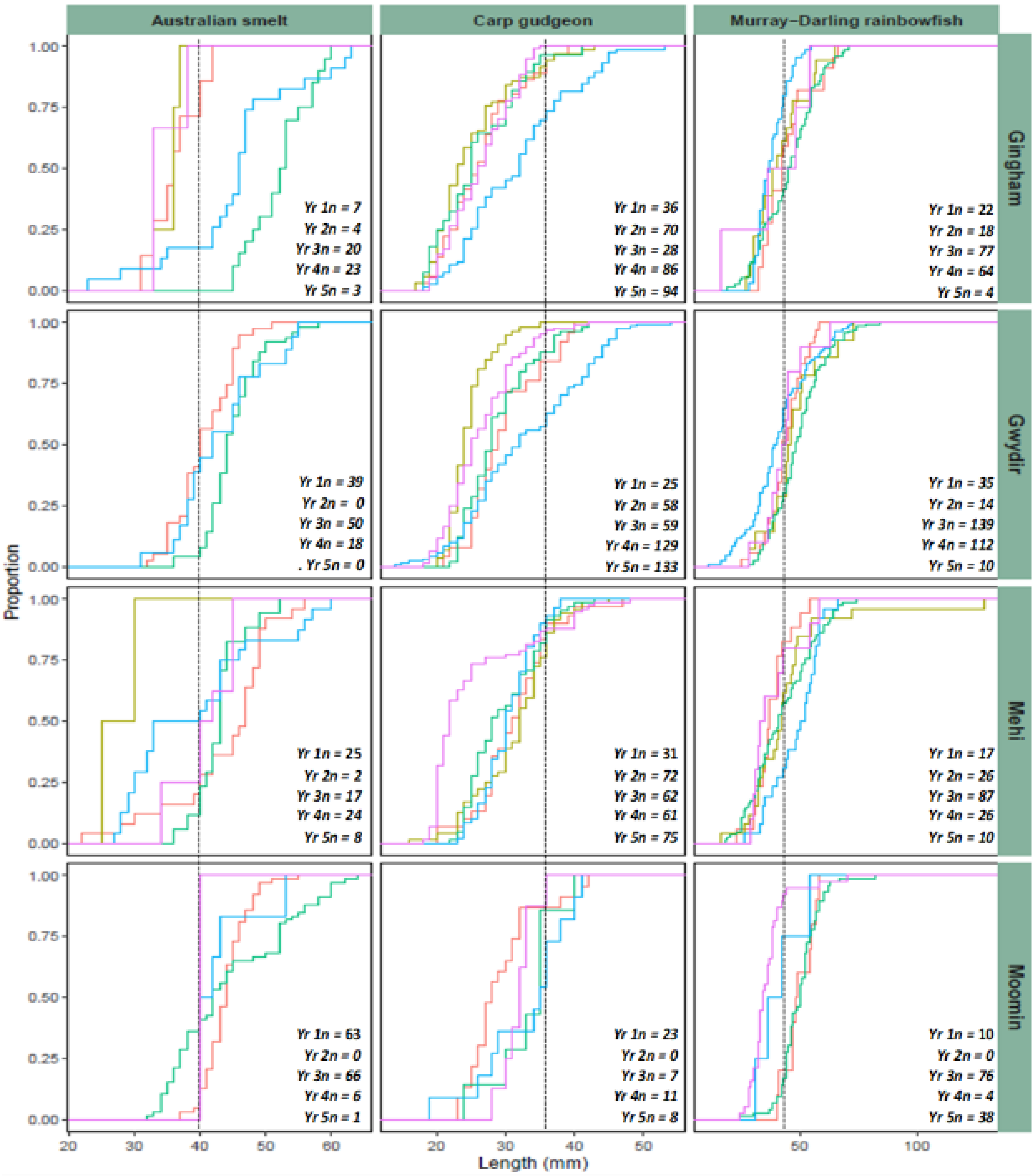

Figure I-9: Length frequency distribution (proportion (%)) of small-bodied species, Australian smelt (*Retropinna semoni*), carp gudgeon (*Hypseleotris* sp.) and Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek.
2014-15 (Yr 1 ▬), 2015-16 (Yr 2 ▬), 2016-17 (Yr 3 ▬), 2017-18 (Yr 4 ▬) and 2018-19 (Yr 5 ▬).
NB* Dashed line represents the approximate length at sexual maturity.

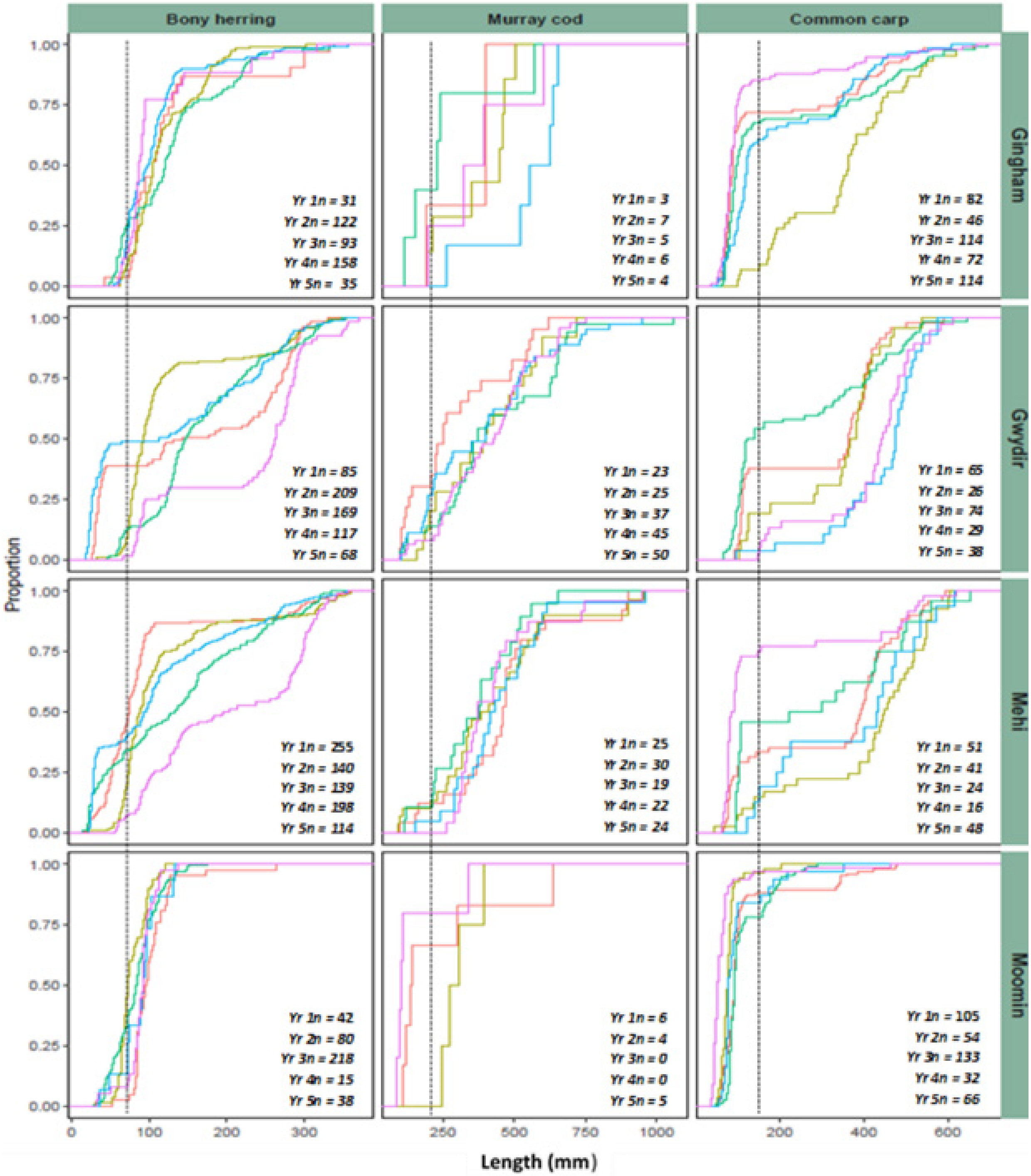

Figure I-10: Length frequency distribution (proportion (%)) of large-bodied species, bony herring (*Nematolosa erebi*), Murray cod (*Maccullochella peelii*) and common carp (*Cyprinus carpio*) sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek.
2014-15 (Yr 1 ▬), 2015-16 (Yr 2 ▬), 2016-17 (Yr 3 ▬), 2017-18 (Yr 4 ▬) and 2018-19 (Yr 5 ▬).
NB* Dashed line is approximate length of one-year-old individual.

I.3.4 Health Indicators

Expectedness

Of the 13 native fish species that potentially could have been sampled across the lower Gwydir system (Table I-3), 11 were caught at a minimum of one site during this study. The two species not caught were southern purple-spotted gudgeon and Darling River hardyhead. Both species are considered to have been naturally 'rare' in the Gwydir system prior to European settlement and, as such would only be expected to be collected at <20% of sites sampled (Table I-3).

By zone, *Expectedness* was the most stable in the Gingham and varied the most in the Gwydir (Figure I-11). Of the four zones, the Moomin consistently had the lowest average *Expectedness* values in all years, reaching a maximum in 2015 (56.7 ± 10.18), before slipping to a rating of "Very Poor" in 2016 (25.9 ± 9.96) and not recovering there after (Figure I-11).

Overall, average ± S.E. *Expectedness* across all sites and zones collectively was highest in 2015 (69.8 ± 3.94) ("Moderate") and lowest in 2019 (45.6 ± 6.18) (rating: "Poor"). The average *Expectedness* across all sites, zones and years collectively was 58.2 ± 2.59 resulting in an overall rating of "Poor" for the Lower Gwydir. Within each zone, the average *Expectedness* for all years combined was lowest in the Moomin 38.8 ± 3.96 ("Very Poor"), whilst the Gingham (64.1 ± 5.1) and Gwydir (64.1 ± 5.85) both rated as "Moderate", and the Mehi was slightly higher at 66.7 ± 3.95 but also rated as "Moderate".

Nativeness

Three exotic species were sampled over the five years (2015-19) of the current study; common carp, goldfish and eastern mosquitofish. Common carp were collected in all zones in all years. Similar to common carp, eastern mosquitofish were present in all zones in all years except for in the Mehi in 2015. Goldish were absent in the Gwydir during 2015 and 2016, however, were collected in all other years within all zones. Of the three exotic species, common carp was the most abundant (*n* = 1,212) followed by goldfish (*n* = 622) and eastern mosquitofish (*n* = 472).

The abundance of individual exotic species varied among years. For common carp, abundance was highest in 2017 (*n* = 345) and lowest in 2018 (*n* = 149). Similarly, goldfish numbers were also highest in 2017 (*n* = 276) but were lowest in 2016 (*n* = 48). The highest overall numbers of eastern mosquitofish were collected in 2018 (*n* = 165) and the least in 2019 (*n* = 49).

Nativeness scores for most zones varied markedly among years (Figure I-11). In contrast, the Moomin was relatively stable with the only notable change, a small decrease in 2019 (Figure I-11). *Nativeness* on average ± S.E. across all sites and zones combined was highest in 2018 (64.1 ± 6.45; "Moderate") and lowest in 2019 (47.9 ± 7.78; "Poor"). Overall the average ± S.E. *Nativeness* across all sites, zones and years was 56.1 ± 2.66 ("Poor").

Within zones (all years combined), the average *Nativeness* was lowest in the Gingham 40.36 ± 6.36 (rating: "Very Poor"), was 44.04 ± 6.04 ("Poor") in the Moomin, 62.6 ± 6.36 ("Moderate") in the Gwydir and highest at 74.7 ± 4.33 ("Moderate") in the Mehi.

Recruitment

The *Recruitment* scores in 2019 were the lowest of all five sampling years in three of the four zones; Moomin, Mehi and Gwydir (Figure I-11). In the Gingham, 2017 and 2018 were relatively stable with only a slight improvement in 2019. An increase in the *Recruitment Indices* occurred simultaneously in the Moomin and Gwydir during 2016, 2017 and 2018 before both zones declined in 2019 (Figure I-11).

Among years (all zones combined), the highest average ± S.E. *Recruitment* score was 60.2 ± 1.26 (“Poor”) in 2015, whilst the lowest was 30.4 ± 1.26 (“Very Poor”) in 2016. Annually, the *Recruitment* scores in the Gingham were close to the score for the Mehi, whilst scores in the Gwydir were similar to that in the Moomin (Figure I-10). Recruits made up 42%, 54%, 35%, 47% and 71% of the total catch of all the native fish caught in 2015, 2016, 2017, 2018 and 2019 respectively. Recruits were caught amongst all the small-bodied species sampled and generally in all four hydrological zones in all years sampled. The exception was Australian smelt, with no recruits detected in the Gwydir in 2019.

No golden perch recruits were caught in any year or zone within the Gwydir LTIM Selected Areas. However, a small number of golden perch recruits were collected during Basin Plan Monitoring fish surveys just outside this study area in Culgoa Creek in 2018 (NSW Fisheries *unpublished data*). No freshwater catfish recruits were recorded during Cat III sampling, but a small number were caught as part of Cat I sampling within the Gwydir hydrological zone. Low numbers of recruits were caught amongst the three remaining large-bodied native species in all years (Murray cod, bony herring and spangled perch). For Murray cod, numbers of recruits were 15, 11, 11, 16 and 10 in 2015, 2016 2017, 2018 and 2019 respectively, representing <25% of the catch of Murray cod in 2016, 2017, 2018 and 2019 respectively, and 88.23% of the catch in 2015. Catches of bony herring recruits varied markedly among years. For example, numbers decreased substantially between 2018 and 2019 from 152 to 14 (or 31% to 5.51%) of the total catch. Spangled perch recruits were caught consistently throughout the study but never in high abundance, with only 9 individuals in 2019, 29 in 2018 and 57 individuals in 2017.

Whilst not considered in the calculation of the *Recruitment* Indices, there was consistent recruitment among all three exotic species (common carp, goldfish and eastern mosquitofish) sampled (common carp: Figure I-10). Common carp recruits were relatively abundant in all years, both in number (2015 = 188; 2016 = 67; 2017 = 233; 2018 = 75; 2019 = 200) and by overall ratio between adults and recruits (2015 = 66%; 2016 = 40%; 2017 = 67%; 2018 = 50%; 2019 = 75.47%). In most years, Moomin Creek and the Gingham Watercourse were the “hotspots” for common carp and goldfish recruitment. Adult eastern mosquitofish dominated the catch in all years, generally making up >95% of the catch of the species.

Overall score

The *Overall Fish Condition* (*ndx-FS*) in the Mehi and Moomin followed a similar trend throughout the duration of the study, with both zones at their highest and lowest in 2015 and 2019, respectively Figure I-11). In the Gingham, the lowest *Overall Fish Condition* score was in 2018, whilst the highest was in 2019. In the Gwydir, the *Overall Fish Condition* fluctuated more compared to the other zones (Figure I-11). During 2015, 2017 and 2018, the scores were similar as were 2016 and 2019. During all years and across all sites and zones, the lowest *Overall Fish Condition* was 19.5 ± 8.13 (“Extremely Poor”) in the Moomin in 2019 and the highest at 75.9 ± 5.85 (“Moderate”) was in the Mehi in 2015 (Figure I-10).

Over the five years and across the four zones (Gingham, Gwydir, Mehi and Moomin), the numbers of ratings for *Overall Fish Condition* were: “Extremely Poor” n = 1, “Very Poor” n = 7, “Poor” n = 7, “Moderate” n = 5. No zones scored an *Overall Fish Condition* rating of “Good” in any year.

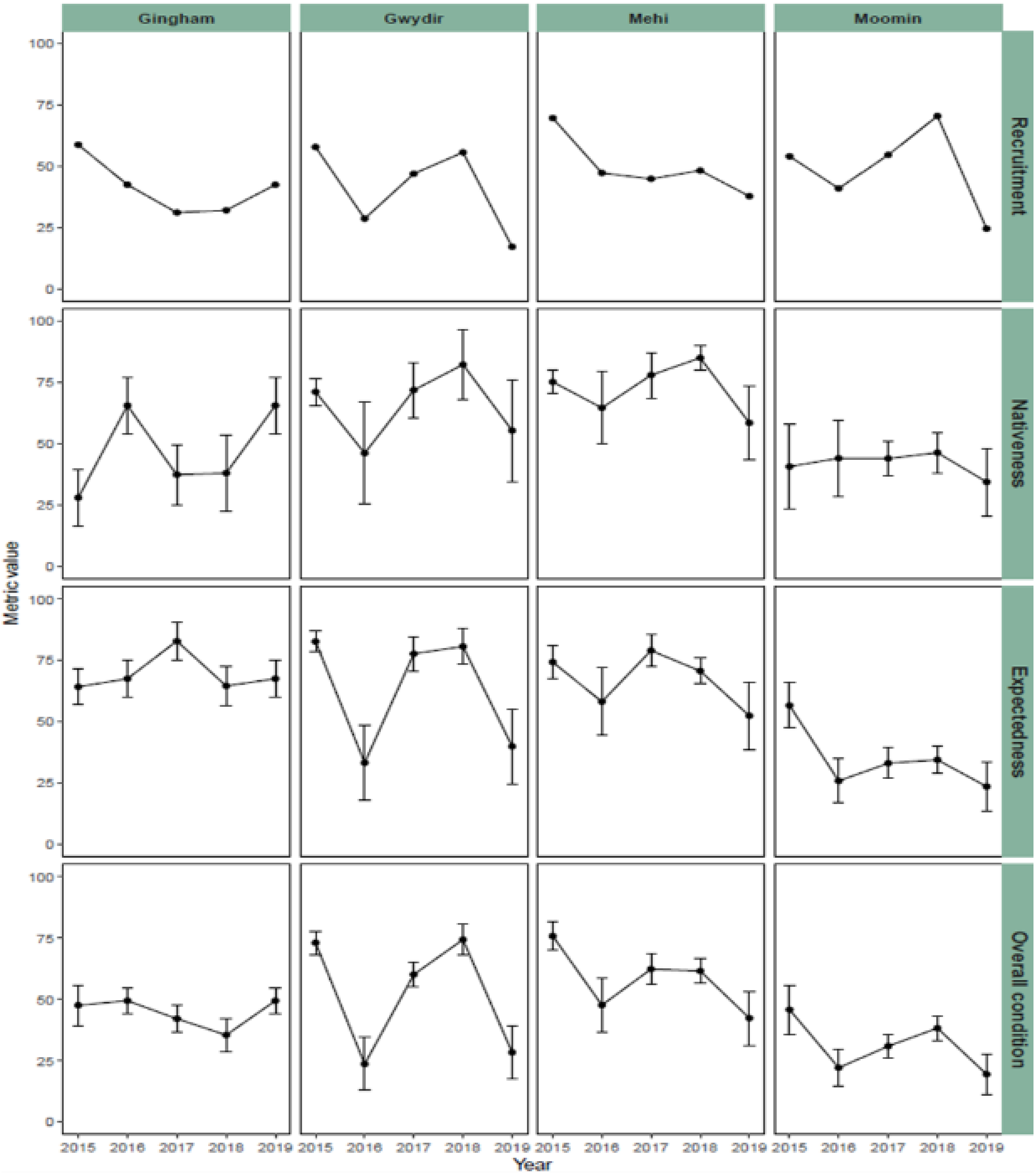

Figure I-11: ***Recruitment, Nativeness, Expectedness*** **and Overall Condition (*****ndxFS)*** **Indicator values for Cat III fish in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek.**

I.4 Discussion

As suggested in previous reporting, it appears that the native fish community across the lower Gwydir system is in a constant state of flux, ranging from periods of extreme stress, resulting in low or no recruitment and localised extirpations, through to periods of relative stability when recruitment and mortality are at or near equilibrium. Over the five years of the current study, relatively small numbers of native fish and large numbers of exotic species were caught in the initial sample in 2015, followed by a shift in the fish community to one dominated by greater numbers of native fish and less or stable numbers of exotics in 2016 and 2017, before a gradual decline back to one similar to the 2015 fish community in 2018 and 2019. This pattern is typical of an ephemeral river, where fish communities and particularly flow dependent species experience a “boom and bust” cycle in good and bad times respectively, which can generally be linked to the quantities of water in the system at the time (Balcombe *et al.* 2006; Bond *et al.* 2008). However, while this pattern is now considered as somewhat normal for the lower Gwydir, historically the system functioned differently, with native fish in relatively high abundances and fewer periods of “bust” and more periods of stable and higher flows in comparison to what the system now experiences (Copeland *et al.* 2003).

Whilst there was a general increase in native fish numbers in 2016 and 2017, it still could not be said that the lower Gwydir system during this time was in effect ‘booming’. The concept of carrying capacity is one that is poorly understood and too often is not well considered when rehabilitating rivers (Cairns *et al.* 1994). Whilst the extent or scale of carrying capacity may not be well understood, the consensus is that as a system degrades so does its ability to sustain fish populations at the same level as pre-disturbance (Huntington *et al.* 1996; Hudon *et al.* 2012). In highly regulated and degraded rivers like the Gwydir and its tributaries, the expectation of what a fish community should be like may therefore be orders of magnitudes away from what can be realistically achieved in the short-term. What we saw during the “boom” period of 2016 and 2017 may be as good as can be expected, in that the system in its current state is at or near it’s carrying capacity and as such native fish numbers will most likely stay low and will take longer to recover each time a ‘bust” event occurs. In respect to managing water for the environment in the lower Gwydir, the approach must be to maintain system connectivity as much as possible so as to facilitate access to refuge pools as the system dries but also minimise as much as possible the complete dry down of the system so as to avoid catastrophic “bust” events that now appear to be more common across the entire lower Gwydir system.

In contrast to the relative low abundance of most native species, 11 of the 13 native species that were expected to occur where sampled at least once during the study. These included the threatened species Murray cod, silver perch, olive perchlet and freshwater catfish. However, the total absence of southern purple-spotted gudgeon and Darling River hardyhead does question the current status of these species within the lower Gwydir system. Both species have undergone a dramatic decline across the entire Murray-Darling Basin system and are now considered at best to be patchily distributed and rare in the northern Murray-Darling Basin (Lintermans 2007). Recently, Hammer *et al.* (2015) reported finding southern purple-spotted gudgeon in a section of the lower Murray River from where they were thought to be locally extinct for ~30 years. However, unlike the current study, Hammer *et al.* (2015) specifically targeted the species using “species specific” sampling equipment and techniques in habitats where it had previously been caught, rather than employing a more generalised fish population survey methodology as was the approach in the current study. Similarly, Knight *et al.* (2007) developed a specific method to sample the endangered Oxleyan pygmy perch (*Nannoperca oxleyana*), a small-bodied native species found in coastal habitat in mid-eastern Australia. A similar targeted approach may be needed to ascertain the relative abundance and extent to which populations of rare species such as southern purple-spotted gudgeon and Darling River hardyhead remain across the Gwydir system. Understanding these populations will allow future use of water for the environment to potentially better target regions where remnant populations of threatened and rare species persist.

In contrast to the somewhat sporadic recruitment among the native fish present, there was generally consistent recruitment in most years among all three exotic species sampled. This was best exemplified by common carp, with recruits relatively abundant in all zones and years, particularly in the Moomin and Gingham systems where there is ready access to wetland environments. As with the majority of successful exotic species introductions worldwide, common carp exhibit a range of dissimilar ecological characteristics when compared to naturally occurring species, which effectively gives them a competitive advantage in highly modified systems like the lower Gwydir (Harris & Gehrke 1997; Koehn 2004; Koehn *et al.* 2000; Brown *et al.* 2004; Driver *et al.* 2005; Stuart & Jones 2006). Similarly, the biology of goldfish also makes the lower Gwydir an ideal environment for the species to thrive (Lintermans 2007). The third exotic species sampled, eastern mosquitofish, was also captured in all zones in every year. Like common carp and goldfish, eastern mosquitofish can tolerate a wide range of environmental conditions, but prefers warm, slow flowing or still waters (Harris 2013). The generally dry conditions experienced throughout much of the current study therefore suited the species, allowing it to reproduce and grow in low flowing wetland type systems like those in the Gingham Watercourse. This highlights another challenge for water managers going forward, in that not only do they need to provide water to stimulate and facilitate breeding of native fish species, but they must also endeavour to minimise the opportunities for exotic species to prosper at the same time.

I.5 Conclusion

This chapter summarises five years of sampling to determine the benefits of environmental water for the native fish community across the lower Gwydir system. Much of the study encompassed a period of extreme and unprecedented low rainfall and drought, which in effect limited the opportunities for native fish to move, reproduce and grow. However, while the conditions were not always positive for native fish, without environmental flows there is no doubt it would have been much worse. The data collected has provided a further insight into the volatile and fragile nature of the lower Gwydir system and provided direction for future water management activities. One of the biggest challenges going forward, is that as the climate continues to warm and become even drier as is predicted under current climate change modelling, populations of native fish will likely come under even greater stress leading to an increased risk of localised extirpations. This means that the very survival of some species in the lower Gwydir system is at genuine risk. In some ways, this may already be happening for species like silver perch, freshwater catfish, golden perch, olive perchlet, Darling -River hardyhead and the southern purple-spotted gudgeon, with few or none captured over the five years of the current study. It could be said that the lower Gwydir system has always experienced extreme cycles of flooding and drought even before the construction of Copeton Dam and that despite the unpredictable nature of the environment, native fish have survived and to some degree prospered. However, the changing climate coupled with continued over exploitation of water in what is best described as a semi-arid environment, means that what is occurring across the system now is unprecedented. To ensure the long-term future of the native fish populations within the lower Gwydir, well-informed management decisions based on defendable science drawing on long-term monitoring programs are required. Only then can we hope to build greater resilience, increase survival, build-up abundance and ultimately start to return species to the lower Gwydir going forward.

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Appendix J Fish (Movement)

J.1 Introduction

For many freshwater fish species, river flow is a strong behavioral cue for movement and also facilitates movement via increased connectivity (Butler *et al.* 2009; Koehn 2004; Reinfelds *et al.* 2013; Reynolds 1983; Simpson & Mapleston 2002; Young *et al.* 2010). Movement allows individual fish to find habitats most suitable for survival and growth, and at a broader scale, allows migration between different habitats used by different life-history stages, access to refugia from disturbances, gene flow and colonization or recolonization of unoccupied areas (Albanese *et al.* 2004). Variation in river flow and hydraulic conditions is a key determinant of the nature, timing and extent of fish movement, for both fine scale movements (Carpenter-Bundhoo *et al.* 2019; Cocherell *et al.* 2011; Korman & Campana 2009) and long range movements (Koehn 2004; Marshall *et al.* 2016; Reinfelds *et al.* 2013; Simpson & Mapleston 2002).

Flow alteration is possibly the largest threat to riverine ecosystems caused by humans (Bunn & Arthington 2002). However, the infrastructure responsible for flow alteration is often necessary to sustain urban, industrial and agricultural activities (Poff *et al.* 1997), and as such a more impartial and efficient approach to management of water is required to ensure the health of riverine ecosystems. Environmental flows are released in regulated rivers with the intention of benefiting native flora and fauna. However, the outcomes for biodiversity and the mechanisms that underpin changes due to these manipulations are poorly understood (Murchie *et al.* 2008). Although the effectiveness of environmental flows in enhancing spawning and recruitment of fish has been demonstrated (King *et al.* 2010; Zampatti & Leigh 2013), most assessments have been carried out separately from any measurement of fish movement.

Bio-telemetry is used extensively by fisheries scientists across the globe to answer a range of questions, including many related to fish movements and their response to changes in river flows. There are currently a number of active acoustic bio-telemetry programs throughout the Murray-Darling Basin, answering among other questions, those relating to environmental flows and fish movement. Unlike these existing programs, the Gwydir LTIM project offers a unique opportunity to utilise bio-telemetry to answer a range of Selected Area questions specific to the northern Murray-Darling Basin. Here we report the findings of long-term broad-scale movements of Murray cod (*Maccullochella peelii*) and freshwater catfish (*Tandanus tandanus*) across the Gwydir River system Selected Area (Gwydir Selected Area). We evaluate how fish movement characteristics varied between two broad-scale arrays in response to changing environmental conditions and how this varied between fish morphology. Due to the dwindling numbers of freshwater catfish in the Murray-Darling Basin, most fish included in the study were sourced and translocated from Copeton Dam, ~200 km upstream.

We previously described the differences in behaviours between resident and translocated freshwater catfish, as well as the fine-scale movements and habitat use of Murray cod and freshwater catfish in years 3 and 4 Gwydir LTIM project reporting (Commonwealth of Australia 2017, 2018), and in Carpenter-Bundhoo *et al.* (2019). In relation to this reporting period, several short-term (one-year) specific questions were posed in relation to the Fish Movement indicator:

- What did Commonwealth environmental water contribute to native fish dispersal?
- Did environmental water stimulate target species to exhibit movement consistent with breeding behaviour?
- Did environmental water facilitate target species to move/return to refuge habitat?

One Long-term (five-year) specific question was addressed in relation to the Fish Movement indicator:

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

J.1.1 Environmental watering in 2016-18

A total of 298,026 ML of environmental water was delivered through the Gwydir River system during the LTIM project, making up 22% of the total water that flowed down the Gwydir River channel during that time (Table I-1). The highest use was during the 2018-19 water year with a 63,416 ML of Commonwealth and 43,941 ML of NSW environmental water used. The lowest use was in 2015-16 where 13,250 ML of environmental water was delivered.

As the Fish (Movement) indicator was only examined from 24 May 2016 to 20 May 2018, our environmental flow descriptions focus on water years 2015-16 to 2017-18. During 2015-16 environmental water was delivered to a number of assets within the Gwydir river system Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for with 964 ML of this water flowing down the Mehi River, and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW bulk water deliveries. Due to critically low flows experienced in the lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April. This followed a period of 30-40 days of nil flow conditions across the catchment.

During 2016-17, a flow event occurred down the Mehi River in September 2016 and supplementary water licences owned by the CEWO were triggered. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however, very little of the moderate flows were diverted into the Mallowa wetlands. In January-March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands. During 2016-17, no environmental water was delivered to the Moomin Creek.

During 2017-18, an early season stimulus flow was triggered by inflows to Copeton Dam in August/September 2017. A total of 10,000 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems as a small fresh during late winter/early spring. Following this, a stable flow release of 10,040 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems in late October to mid-November 2017. These small pulse flows were aimed at providing downstream connectivity and allowing opportunity for movement, breeding and recruitment of fish, particularly freshwater catfish (*Tandanus tandanus*).

An environmental flow delivery was made in late April/May 2018 as part of the Northern Connectivity Event. This flow aimed to provide longitudinal connectivity and refresh/replenish drought refuge for instream life, particularly native fish in the Barwon-Darling as well as improving conditions to maintain native fish populations within the tributary catchments. During this event, a total of 18,908 ML of both State and Commonwealth water was delivered down the Mehi River, Moomin Creek and Carole Creek. No environmental water deliveries were made to Mallowa Creek in 2017-18.

Table J-1: Environmental water use in the Gwydir River system during 2015-18. This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW State. As Fish (Movement) was only examined from 24 May 2016 to 20 May 2018, environmental flow descriptions focus on water years 2015-16 to 2017-18.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River<	20,404	5,046 GS	213,134	12
Moomin Creek	324	175	104,075[#]	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434***	***11***

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system

J.2 Methods

J.2.1 Study area

The study was located in the Mehi and Gwydir River channels within the Gwydir Selected Area (Figure J-1). In the Mehi River, the study reach extended from Tareelaroi Weir, where the Mehi diverges from the Gwydir, downstream to the township of Moree. In the Gwydir, the study reach extended from 6 km upstream of Tareelaroi Weir, downstream to immediately below the junction of the Gwydir and Gingham Watercourse. Each study reach covered approximately 45 km of their respective river. The Gwydir and Mehi typically do no exceed 25 m in width and 3 m in depth. Both river systems are highly regulated, and the surrounding catchment is used for intensive agricultural including large areas under irrigated crops. The system receives environmental flows from the main upstream impoundment, Copeton Dam. The instream environment of both systems includes a variety of mesohabitats, such as woody debris, gravel beds, undercut banks, reed beds, overhanging riparian vegetation and small amounts of aquatic macrophytes. The rivers support a host of native fish species, including populations of the endangered freshwater catfish and the threatened Murray cod.

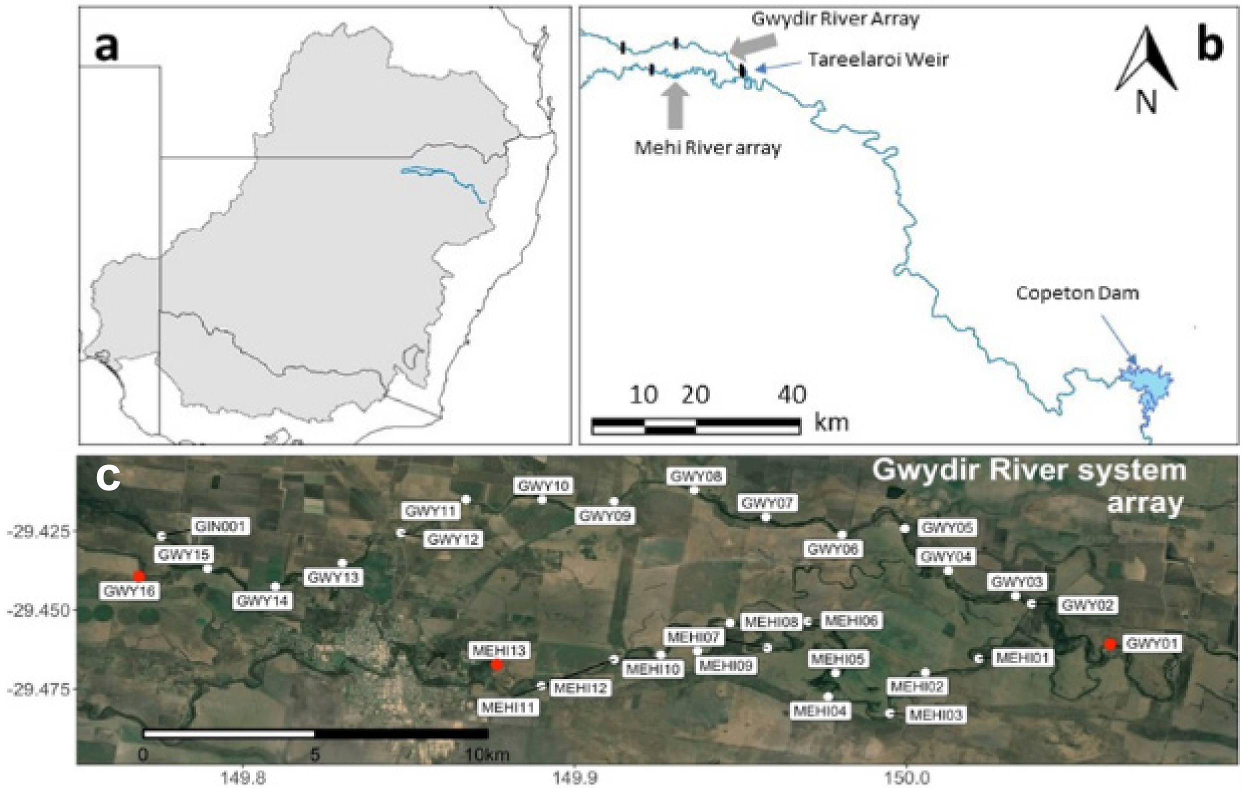

Figure J-1: (a) Location of Gwydir River system (blue lines) in the Murray-Darling Basin (grey area), with State borders. (b) Study area and upper catchment of the Gwydir River system, showing Copeton Dam (upstream), weirs within the study reach (vertical black bars) and fine-scale acoustic array locations (grey arrows). (c) White dots denote receiver locations, while red dots denote terminal receivers of the arrays.

J.2.2 Broad-scale acoustic array

Large scale fish movements were monitored between 24 May 2016 and 20 May 2018 using an extensive linear array of 30 (15 in each system) Vemco VR2W 69 KHz receivers (Figure J-2), deployed at intervals of ~3 km along the Gwydir and Mehi rivers (Figure J-1c). This broad-scale array recorded binary presence/absence data when a tagged fish entered the reception range of a given receiver. The array was deployed prior to the release of tagged fish between 9 and 13 May 2016. Temperature loggers (OneTemp, Sydney) were also deployed at the upper and lower extremes of both arrays on the same dates.

Figure J-2: Acoustic receiver deployed in the Gwydir River.

J.2.3 Fish collection

The original project design proposed to tag five 'resident' freshwater catfish and five "resident" Murray cod in each river, and to also translocate 10 catfish from Copeton Dam and release five in each system as well. However, despite exhaustive efforts, riverine catfish were in such low abundance that numbers had to be supplemented with a greater number of translocated individuals (Table J-2). All resident fish were caught within the confines of the fine-scale array to eliminate possible movement away from the array as a result of homing behaviour.

Table J-2: Source and numbers of freshwater catfish and Murray cod tagged and released in the Gwydir and Mehi rivers, May 2016.

Species and Source	Gwydir fine-scale	Gwydir broad-scale	Mehi fine-scale	Mehi broad-scale
Resident freshwater catfish	3	0	0	1
Translocated freshwater catfish	7	10	10	9
Resident Murray cod	5	5	5	5

All fish were collected by electrofishing, gill netting (mesh size 100 mm) or angling from 23 May to 1 June 2016. The exact capture location of riverine "resident" fish was recorded, and all fish were released within 50 m of their capture site. Freshwater catfish from Copeton Dam were transported to the study sites in aerated 220 L containers, with a maximum of five fish per container. Fish from Copeton Dam were kept in a floating cage (mesh size 50 mm) until tag implantation.

J.2.4 Acoustic tag implantation

Fish were anaesthetised in ambient water containing 50 mg L^{-1} benzocaine (ethyl-*p*-aminobenzoate) (Sigma Aldrich, Shanghai) and weighed (g) and measured (mm). Fish were then transferred to an operating cradle (Figure J-3), with water containing an equivalent level of anaesthetic (50 mg L^{-1}) continually pumped over the gills to maintain anaesthesia. To access the peritoneal cavity, an incision was made through the body wall of the fish, adjacent to the linea alba and anterior of the anal vent. The gonads of the fish were examined through the incision to determine sex before the insertion of the tag. Either a Vemco V9 or V13 69 KHz acoustic telemetry transmitter tag (delay 90 to 160 secs, approximate battery life of >2 years) was used, with tag size dictated by the recommended maximum of 2.25% of body weight (Jepsen *et al.* 2002; Butler *et al.* 2009; Wagner *et al.* 2011). Passive integrated transponder (PIT) tags were also inserted in the cavity to allow the long-term identification of tagged fish. Incisions were closed with two or three sutures using 0.3 mm pseudo-monofilament, absorbable thread (Vetafil Bengen; WdT, Garbsen, Germany). After suturing, the fish were given an intramuscular injection of oxytetracycline hydrochloride (0.25 mL kg^{-1}; CCD Animal Health and Nutrition, Toowoomba) and then returned to a floating cage to recover.

Figure J-3: Murray cod (*Maccullochella peelii*) being implanted with acoustic tag.

J.2.5 Statistical analyses (broad-scale)

For statistical analyses, each study reach was initially digitized to create a spatial object using satellite imagery in ArcGIS 10.4 (ESRI, Redlands, CA, USA). We then calculated the distance of each given receiver from the downstream-most receiver in its respective river array. These data were then converted into a distance matrix in the V-Track package (Campbell *et al.* 2012) in R (R Development Core Team; www.r-project.org). A database of fish movements was then created by pairing individual fish detections with the distance matrix. Distance between subsequent detections was then calculated for each individual. Total daily movement was calculated for each fish ID by summing absolute movement distance values. The database was then matched with daily total river discharge, spawning period, environmental flow period and average daily river temperature and fish morphology data. Spawning period was assigned as a binary variable, falling within or outside of the fishes' respective known spawning period. For freshwater catfish, spawning period was recorded as beginning when average daily water temperatures reached 24°C and ended 70 days later (Carpenter-Bundhoo *et al.* 2019a; Davis 1977). The same was done for Murray cod beginning at 15°C and also extending 70 days (Humphries 2005; Koehn & Harrington 2006).

The first 24 hours for each fish were removed from data analysis to discount any abnormal behaviour due to the tagging process, as per Carpenter-Bundhoo *et al.* (2019b). Fish movements were visually inspected by plotting fish position within study reaches and cumulative distance moved over time. Fish range and site fidelity were also visually examined by calculating and plotting proportion of detections at each receiver for the total study period.

Broad-scale fish movement responses to the environmental variations were investigated using hurdle linear mixed models in the *lme4* package (Bates *et al.* 2015). As the response variable data was of a continuous nature and contained a large number of zeros, we created a model that specified a generalized logistic regression (GLMM) for the binary indicator that the response is zero or not, and then a standard linear mixed model (LMM) for the non-zero responses. In this model, daily total movement was the response variable and river discharge, spawning period, environmental flow period, river temperature, moon phase and fish length were considered as the independent variables. Population source was also included as an independent variable for freshwater catfish. Fish identity (ID) was included as a random effect in the model. All possible models and interactions were checked, and the best model was selected with backwards stepwise model selection, using the LMERConvenienceFuntions package (Tremblay & Ransijn 2013) for the binary component, and the LMERTest package (Kuznetsova et al. 2017) for the non-zero component. Following the protocol of Zuur *et al.* (2010), we checked for statistical outliers and collinearity among predictor variables using variance inflation factors (VIF) in R. Model residuals were checked for normality and model fit was assessed by comparing model residuals and fitted values.

J.3 Results

J.3.1 General findings

All 20 tagged Murray cod were detected within their respective array post-release at some time during the study period. Those tagged in the Gwydir River array were detected for far fewer days than those in the Mehi River array (average ± S.E days; Gwydir 56.21 ± 14.54, Mehi 177.7 ± 66.03). Translocated freshwater catfish in the Gwydir and Mehi Rivers were detected for 100.05 ± 32.24 and 49.06 ± 10.09 days respectively, and resident freshwater catfish for 14 ± 7 and 52 days respectively. One resident (ID 53543) and two translocated (ID 53551 and 53552) freshwater catfish were not detected at all throughout the study. Fish ID 53543 was confirmed as alive by the fine-scale array deployed early during the study

(Commonwealth of Australia 2018), but solely inhabited an area between the detection range of two receivers.

Figure J-4: Days detected within either Mehi or Gwydir linear arrays for Murray cod and freshwater catfish. Each symbol denotes a minimum of one detection on a given day. Red points denote detection at a terminal receiver.

Linear distance metrics (Figure J-5) revealed that fish in the Gwydir River were unable to traverse weirs in the upstream direction; however, a small number were able to traverse downstream across all barriers. Three Murray cod were recorded moving from the Mehi array into the Gwydir array via the Mehi regulator (ID 53588, 53597 and 53601; Figure 4). No fish moved from the Gwydir into the Mehi River.

Fish in the Mehi River, of both species, showed larger linear ranges, while within a river, both species showed similar ranges. Murray cod and freshwater catfish from the Mehi River inhabited 16.46 ± 4.84 and 18.44 ± 3.67 km of river, respectively, whereas Murray cod and freshwater catfish from the Gwydir River inhabited 6.71 ± 1.82 and 7.98 ± 1.56 km of river, respectively. Murray cod displayed the highest cumulative movement, averaging 48.22 ± 12 km. Comparing resident and translocated freshwater catfish revealed that none of the highest moving individuals were resident. However, overall there was little difference in the cumulative distance moved between population sources. Translocated fish moved 38.34 ± 10.23 km, whilst resident fish moved 37.11 ± 8.77 km (mean ± S.E.).

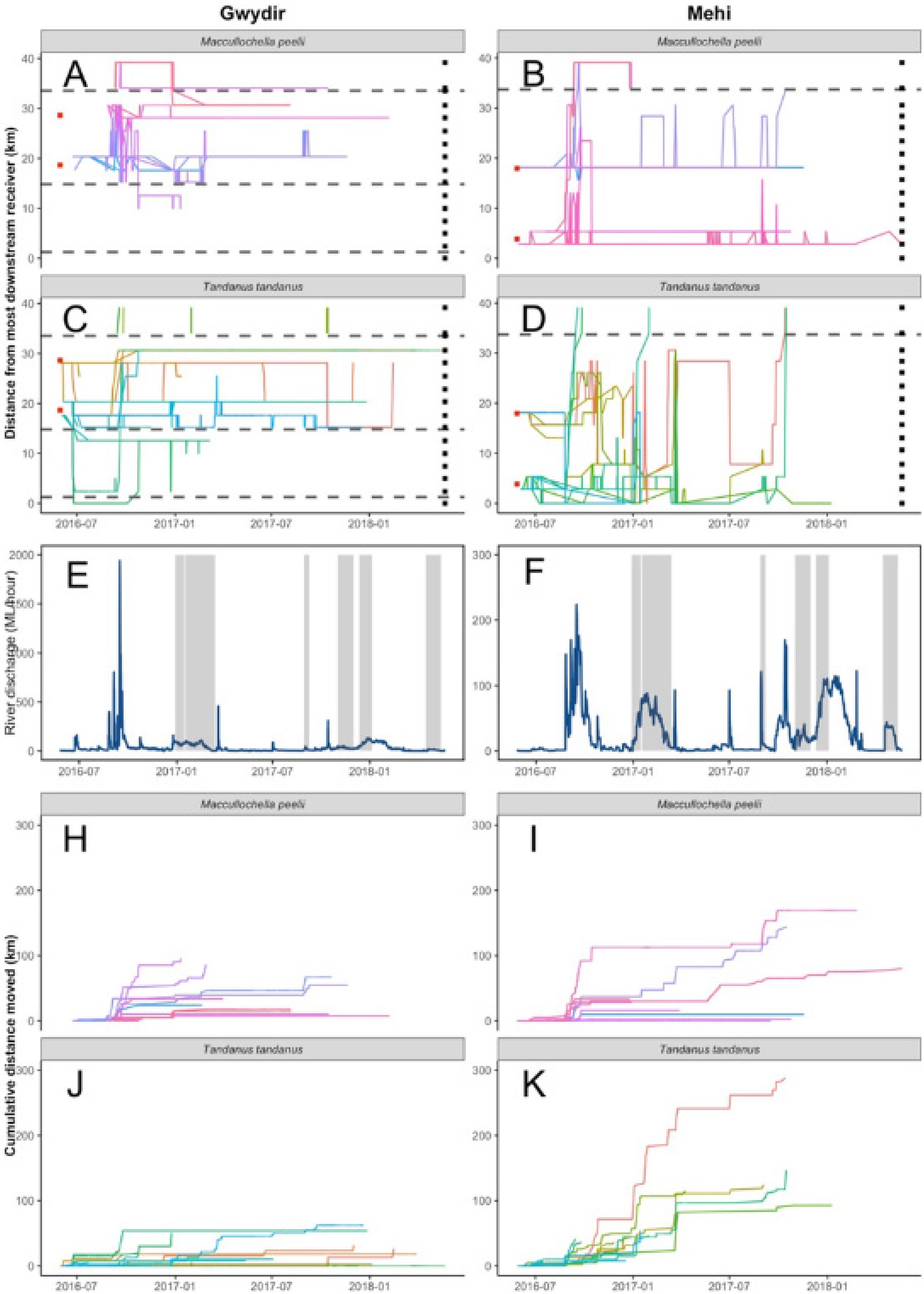

Figure J-5: Linear distance travelled and orientation over time for Murray cod in the (A) Gwydir and (B) Mehi River arrays, and freshwater catfish in the (C) Gwydir and (D) Mehi River arrays. Red points on left denote release sites in respective array, black points on right denotes receiver locations along the array and dashed lines denote weir or regulator position. (E) Hydrograph for the Gwydir and (F) Mehi Rivers, with grey shaded area denoting timing on environmental flows. Cumulative distance travelled by individual Murray cod in the (H) Gwydir and (I) Mehi River arrays, and freshwater catfish in the (J) Gwydir and (K) Mehi River arrays. Each coloured line represents a different individual.

Several Murray cod showed pronounced increases in cumulative movement in the September/October period (breeding season). In a small number of cases some of these breeding related movements were one-way, with these individuals not returning to their previous ranges throughout the study period.

J.3.2 Model results

Based on statistical modelling, overall the tagged population of freshwater catfish moved larger distances outside the periods of environmental flow releases during the study. However, when considering the two systems separately, those tagged in the Mehi moved further during environmental flow releases. Freshwater catfish were also more likely to move during environmental flows when releases occurred during the species breeding season but, were less likely to move on environmental flows during periods of higher water temperatures, particularly over summer. Although daily discharge was not a primary contributor to either the probability of movement or an increase in the distance moved, the likelihood of both did increase during the species breeding season when river discharge increased. Overall, freshwater catfish in the Mehi River had a higher probability of movement in relation to increasing river discharge of all types compared to those in the Gwydir. Increasing water temperature also had a positive effect on the probability of movement. This was stronger among the larger fish, particularly those from within the Mehi River, but appeared to have a lesser effect on males compared to females. Population source was not found to be a meaningful predictor of probability of movement, but riverine freshwater catfish did move larger distances compared to their translocated conspecifics (Table J-3).

Murray cod were more likely to move during an environmental flow event, but like freshwater catfish, were less likely to move on environmental flows during periods of higher water temperature. Overall, Murray cod were more likely to move, and would move further, at higher river discharges be it natural, or environmental and/or irrigation releases. As with freshwater catfish, the probability of Murray cod moving was higher during increases in river discharge in the Mehi. However, on average Murray cod was more likely to move in the Gwydir compared to the Mehi. Murray cod were more likely to move during the breeding period; however, the probability of this occurring was lower for males compared to females (Table J-3). Overall, Murray cod males were more likely to move than females. Regardless of discharge levels, Murray cod were more likely to move as river temperatures increased.

Table J-3: Parameter estimates (± S.E.) and significance levels (p) from hurdle G/LMM relating to environmental variables, spawning season and morphology, and fish movements across two species. Also shown are attributes of the random effects from each G/LMM, including number of fish IDs in each model, among fish ID standard deviation and number of observations. ROM equals Range of Movement. Bold values are significant at the 0.05 level.

Effects		Freshwater catfish (*Tandanus tandanus*)				Murray cod (*Maccullochella peelii*)			
		Binomial		Non-zero (*log* ROM)		Binomial		Non-zero (*log* ROM)	
		Estimate	*P*	Estimate	*P*	Estimate	*P*	Estimate	*P*
Fixed effects	Environmental flow	0.072 ± 0.334	0.829	-0.32 ± 0.141	**0.024**	1.067 ± 0.257	**<0.001**	-	-
	River discharge	0.543 ± 0.288	0.06	-0.003 ± 0.016	0.846	0.503 ± 0.102	**<0.001**	0.054 ± 0.018	**0.002**
	Spawning	0.103 ± 0.333	0.756	-0.098 ± 0.081	0.228	2.264 ± 0.327	**<0.001**	-	-
	River temperature	0.795 ± 0.247	**0.001**	0.028 ± 0.058	0.628	0.495 ± 0.212	**0.02**	-0.031 ± 0.049	0.533
	River - Mehi	2.029 ± 0.619	**0.001**	0.091 ± 0.073	0.221	-1.33 ± 0.397	**0.001**	0.028 ± 0.08	0.732
	Population source - Riverine	-	-	0.262 ± 0.126	**0.041**	-	-	-	-
	Length	1.932 ± 0.595	**0.001**	-	-	0.253 ± 0.303	0.404	-0.085 ± 0.047	0.093
	Sex - male	0.513 ± 0.76	0.499	-	-	3.064 ± 0.683	**<0.001**	-	-
	Environmental flow: Spawning	1.902 ± 0.545	**<0.001**	-	-	-	-	-	-
	Environmental flow: River temperature	-1.249 ± 0.332	**<0.001**	-	-	-0.996 ± 0.273	**<0.001**	-	-
	Environmental flow: River - Mehi	-	-	0.411 ± 0.164	**0.013**	-	-	-	-
	River discharge: Spawning	0.991 ± 0.458	**0.03**	0.557 ± 0.136	**<0.001**	-	-	-	-
	River discharge: River - Mehi	1.534 ± 0.339	**<0.001**	-	-	1.128 ± 0.172	**<0.001**	-	-
	River discharge: Length	1.323 ± 0.288	**<0.001**	-	-	-0.365 ± 0.082	**<0.001**	-	-
	River discharge: Sex - male	-1.386 ± 0.31	**<0.001**	-	-	-0.686 ± 0.163	**<0.001**	-	-
	River temperature: River - Mehi	0.526 ± 0.23	**0.022**	0.214 ± 0.066	**0.001**	-0.908 ± 0.237	**<0.001**	0.204 ± 0.068	**0.003**
	River temperature: Length	0.446 ± 0.161	**0.006**	-	-	-0.226 ± 0.096	**0.018**	-0.064 ± 0.029	**0.028**
	River temperature: Sex - male	-1.01 ± 0.217	**<0.001**	-	-	-	-	-	-
	Length: Sex - male	-1.823 ± 0.852	**0.032**	-	-	-	-	-	-
	Spawning: Sex - male	-	-	-	-	-1.92 ± 0.395	**<0.001**	-	-
Random effect (fish ID)	Fish IDs (number)	38		31		20		17	
	Standard Deviation	1.638		0.0503		1.186		0.1489	
	Observations (number)	3,293		284		2,546		226	

J.4 Discussion

J.4.1 Freshwater catfish

The results of the current study suggest that population source, being either resident or translocated, had no effect on probability of freshwater catfish movements. While we did not find river discharge to be a main driver of freshwater catfish movements, discharge did increase both the probability and the distance of movements under select conditions, including during the breeding season. For many riverine fish species, flow is a behavioural cue that stimulates breeding-related movement (Amtstaetter *et al.* 2016; Reinfelds *et al.* 2013; Walsh *et al.* 2013). However, the recognised life history strategies of freshwater catfish does not include a breeding migration that is stimulated by flow, but rather they are considered sedentary nesters (Davis 1977; Lake 1967; Merrick & Midgley 1981), which have even been known to reproduce in ponds (Lake 1967). However, while other environmental factors such as water temperature are thought to cue and dictate reproductive success (Davis 1977), river discharge may also play a primary role by facilitating movement to better nesting areas or to areas of lower competition. Freshwater catfish require access to areas of shallow, cobble beds to build nests (Davis 1977; Lake 1967; Merrick & Midgley 1981) and elevated river discharge increases inundation of and connectivity between such habitat patches in an intermittent river like those across the Lower Gwydir Basin.

The results of the current study also suggest that male freshwater catfish were less likely to move than females during the species breeding season even during periods of increased flow. As previously reported, this is consistent with freshwater catfish breeding behaviour, where once a nest site is selected, the males remain on or near the nest for the duration of the breeding season (Lake 1967). The increased probability of movement during higher river discharges was also found to be stronger in the Mehi compared to the Gwydir. Whilst there could be a number of factors that may have contributed to this phenomenon, it may simply be due to the difference in the overall size of the two rivers. The Mehi is far smaller in both depth and width, and therefore an equal quantity of water in both systems would result in proportionally higher connectivity and increased inundation of benches. As such future release of water for the environment should not only consider the amounts and timing of flows but also should consider the relative size of the system receiving the water.

J.4.2 Murray cod

There was a marked increase in activity during the known breeding season of Murray cod in both years of the current study. While individuals have previously been reported to make large movements during the breeding season (Koehn *et al.* 2009; Thiem *et al.* 2018), some have also been recorded as having restricted ranges during this same period (Koehn *et al.* 2009). In many species of fish, including freshwater catfish (Davis 1977), reproductive condition is cued to a large degree by increasing water temperature. Given Murray cod have been observed reproducing without movement (G Butler *pers. comm.*), it is likely that some individuals in intermittent rivers only opportunistically move to breed, facilitated by increased connectivity which directly links to increases in discharge. Similar to freshwater catfish, male Murray cod were found to be less likely to move than females during the spawning period. This again is best explained by the nesting behaviour of the species, where males remain sedentary on a nest site for up to four weeks after the initial selection process (Rowland 1998). In comparison to freshwater catfish, Murray cod movements were significantly less in the Mehi River in comparison to the Gwydir. Murray cod make extensive use of submerged wood debris (Koehn 2009), something that the Mehi River possess in greater abundance compared to the Gwydir River. As such, while the Mehi River may have poorer quality habitat overall for freshwater catfish which resulted in more frequent movements between habitat patches, it appears Murray cod did not have to move as frequently or as far to find suitable habitat.

J.5 Conclusion

Given the ambiguous nature of the timing and volumes of environmental water deliveries to the Lower Gwydir system, our results can only at best be used to comment on the overall timing and on the effect of the total combined river discharge during these periods, rather than specifically regarding environmental water on its own. We suspect a number of factors contribute to the effectiveness of environmental flows across the channels of the Lower Gwydir system, however, based on our findings, river discharge, river type, and target species life history are the main factors to be considered when managing environmental flow releases.

One factor that was made apparent in the current study was that environmental flow deliveries need to be tailored to specific species needs in order to ensure the most effective outcomes for fish movement. However, this is difficult given the multitude of objectives around environmental water releases, particularly when considering priorities across a diversity of taxa that include not only fish but waterbirds, vegetation, invertebrates and amphibians. Given this complexity and based on the findings of the current study, we suggest that not all species of fish require targeted flow releases to stimulate breeding events in all years, but generally only require a supplemented baseflow to provide better connectivity during critical periods of the species life history. Our data and other literature suggest that increased connectivity via environmental water releases during the spawning season (October to December for catfish, August to October for Murray cod) may enhance spawning in terms of availability and quality of nesting habitat, but that it may not be required every year for the species' long-term existence. Rather, larger pulses may be better allocated to align with the spawning schedules of species that use flow as a cue such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*).

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Appendix K Waterbird Diversity

K.1 Introduction

Waterbirds can be highly responsive to changing patterns of resource distribution and therefore, their occurrence in wetland systems can be a useful indicator of system health (Kingsford *et al.* 2010). The Gwydir wetlands located to the west of Moree are recognised as an important area for waterbirds and support some of the largest breeding colonies in Australia (DECCW 2011). The breeding cycles rely heavily on extended periods of large-scale wetland flooding, which is being augmented through strategic environmental watering (NSW OEH 2015). LTIM monitoring in previous water years indicates that waterbird abundance, species richness and periods of breeding are driven by inundation patterns and that the delivery of environmental water is supporting local and regional waterbird populations. For the purposes of this report, raptors, reed-inhabiting passerines along with traditionally known waterbirds have been included under the definition of 'waterbirds' as outlined in the LTIM standard method (Hale *et al.* 2014). Waterbird monitoring conducted during the 2018-19 season represents the final seasonal monitoring for the 2014-19 LTIM project. As such, this report summarises the results of the 5-year LTIM project.

The monitoring of waterbird diversity in the Gingham, Lower Gwydir, Mallowa and Mehi wetlands sought to address the following questions:

- What did Commonwealth environmental water contribute to waterbird populations?
- What did Commonwealth environmental water contribute to waterbird species diversity?
- What did Commonwealth environmental water contribute to waterbird survival?

K.1.1 Environmental watering during the LTIM project (waterbird survey periods)

A total of 298,026 ML of environmental water was delivered through the Gwydir River system during the LTIM project, making up 23% of the total water that flowed down the Gwydir River channel during that time (Table K-1). Highest use occurred during the 2018-19 water year when 63,416 ML of Commonwealth and 43,941 ML of NSW environmental water was used. Lowest use was in 2015-16 where 13,250 ML of environmental water was delivered.

During 2014-15 environmental water was delivered to several assets within the Gwydir River system. In-channel flow pulses were delivered down the Mehi River and Carole Creek enhancing aquatic ecological function, nutrient cycling, water quality and fish spawning conditions. Moreover, flows were delivered to the Lower Gwydir, Gingham Watercourse and Mallowa Creek to provide for wetland inundation.

During 2015-16 environmental water was delivered to several assets within the Gwydir Selected Area. In November 2015, a flow event occurred down the Mehi River and supplementary water licences owned by the CEWO were triggered. A total of 1,300 ML was accounted for with 964 ML of this water flowing down the Mehi River, and 336 ML directed down Mallowa Creek. Through January 2016, flows were delivered into the Mallowa Creek system to inundate fringing wetlands in association with WaterNSW water bulk water deliveries. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse in February 2016 to replace flows that were extracted in a supplementary flow event. While not large in volume, these flows made it into the wetlands, inundating up to 161.81 ha (Appendix B). Due to critically low flows experienced in the Lower Gwydir system in March and April 2016, water was delivered to the Lower Gwydir, Gingham, Mehi and Carole channels as part of a dry river flow action in early April 2016. This followed a period of 30 to 40 days of nil flow conditions across the catchment.

Table K-1: Environmental water use in the Gwydir River system during the LTIM project (2014-19). This includes high security, general security (GS) and supplementary (sup) water managed by both the Commonwealth and NSW state governments.

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
2014-15				
Gwydir River*	56,534	30,000	302,043	29
Gingham Watercourse	15,000	14,868	46,711	64
Lower Gwydir	15,000	15,027	41,171	73
Carole Creek	3,656	-	48,670	8
Mehi River	13,316	-	123,480	11
Mallowa Creek	9,667	-	11,281	86
2014-15 total	***56,534***	***30,000***	***302,043***	***29***
2015-16				
Gwydir River*	8,400	4,850	184,759	7
Gingham Watercourse	675	2,375	29,043	11
Lower Gwydir	675	2,375	20,273	15
Carole Creek	409	-	25,318	2
Mehi River	3,155 (incl 964 ML sup)	100 (Whittaker Lagoon)	64,505	5
Mallowa Creek	3486 (incl 336 ML sup)	-	4,463	86
2015-16 total	***8,400 (incl 1,300 ML sup)***	***4,850***	***184,759***	***7***
2016-17				
Gwydir River*	22,847 (incl 6,351 sup)	21,800 (incl 800 sup)	614,484	7
Gingham Watercourse	4,259	13,741 (incl 3,000 GS)	102,667	18
Lower Gwydir	4,741	7,259	52,745	23
Carole Creek	1,351 (sup)	-	112,485	1
Mehi River	5,000 (sup)	-	205,349	2
Mallowa Creek	7,496	800 (sup)	8,668	96
2016-17 total	***22,847 (incl 6,351 sup)***	***21,800 (incl 800 sup)***	***614,484***	***7***
2017-18				
Gwydir River*	28,290	18,748 (including 15,748 GS)	434,462	11

Channel	Commonwealth Environmental Water (CEW) delivered (ML)	NSW ECA/General Security/ Supplementary environmental Water delivered (ML)	Annual total flow (ML)	Environmental Water (% of total flow)
Gingham Watercourse	2,000	5,534 (including 4,520 GS)	20,894	36
Lower Gwydir	2,000	5,706 (including 4,520 GS)	19,850	39
Carole Creek	3,886	2,462 (including 1,662 GS)	95,341	7
Mehi River<	20,404	5,046 GS	213,134	12
Moomin Creek#	324	175	104,075	0
Mallowa Creek	-	-	121	0
2017-18 total	***28,290***	***18,748 (incl 15,748 GS)***	***434,462***	***11***
2018-19				
Gwydir River*	63,416	43,941	205,520	53
Gingham Watercourse	20,000	15,000	40,443	87
Lower Gwydir	11,314	16,032	30,254	90
Carole Creek	300	300	16,865	4
Mehi River^	10,430	16,545	82,262	33
Mallowa Creek	16,950	-	17,230	98
2018-19 total	***63,416***	***43,941***	***205,520***	***52***
Grand total	**179,592**	**118,434**	**1,327,700**	**22**

* All environmental water delivery to the Gwydir system flows through the Gwydir River. Therefore, volumes for this channel represent total volumes delivered downstream and as such are used to represent the total flow.

< Includes 499 ML that flowed down Moomin Creek but returned to the Mehi downstream. Also includes 14,160 ML delivered as part of the Northern Connectivity Event. The total volume for the NSW component also includes 90 ML NSW General Security water for delivery to Whittaker's Lagoon.

^ Includes 600 ML delivered to Ballin Boora system. Also includes 23,051 ML delivered as part of the Northern Fish Flow

+Includes 4,758 ML delivered as part of the Northern Connectivity Event

During 2016-17, a flow event occurred down the Mehi River in September 2016 and supplementary water licences owned by the CEWO were triggered. A total of 5,000 ML was accounted for in the Mehi River. Supplementary flows were triggered in the Mallowa in September 2016, however very little of the moderate flows were diverted into the Mallowa wetlands. In January - March 2017, planned deliveries of 5,000 ML were increased to 7,496 ML to the Mallowa Creek system to inundate fringing wetlands. Flows were also delivered into the Lower Gwydir River and Gingham Watercourse to build upon moderate winter/spring flows. From January - March 2017, 30,000 ML was delivered, aiming to inundate broad areas of semi-permanent wetland vegetation. During 2016-17, no environmental water was delivered to Moomin Creek.

During 2017-18, an early season stimulus flow was triggered by inflows to Copeton Dam in August/September 2017. A total of 10,000 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems as a small fresh during late winter/early spring. Following this, a stable flow release of 10,040 ML was delivered into the main Gwydir River, Mehi and Carole Creek systems in late October to mid-November 2017. These small pulse flows were aimed at providing downstream connectivity and allowing opportunity for movement, breeding and recruitment of fish, particularly freshwater catfish (*Tandanus tandanus*).

A delivery of 8,000 ML including both State and Commonwealth environmental water was made to the Lower Gwydir and Gingham wetlands from mid-December 2017 to late January 2018, to replace supplementary take from a small flow event that occurred in the previous months. This aimed to maintain wetland habitat quality and support the survival and resilience of flora and fauna in the wetlands. The last environmental delivery was made in late April/May 2018 as part of the Northern Connectivity Event. This flow aimed to provide longitudinal connectivity and refresh/replenish drought refuge for instream life, particularly native fish in the Barwon-Darling as well as improving conditions to maintain native fish populations within the tributary catchments. During this event, a total of 18,908 ML of both State and Commonwealth water was delivered down the Mehi River, Moomin Creek and Carole Creek. No environmental water deliveries were made to Mallowa Creek in 2017-18.

In 2018-19 environmental water made up 53% of the total flow down the Gwydir River channel (Table K-1). Sixty gigalitres of environmental water was delivered to the Lower Gwydir and Gingham wetlands to support wetland vegetation and channel processes in the Gwydir River. Deliveries to the wetlands began in July 2018 and finished in February 2019. In both systems deliveries were stopped in October and November to allow farmer access during the winter crop harvest. Over the November 2018 to February 2019 period, environmental water was also delivered to the Mallowa wetlands to support wetland vegetation, waterbirds and native fauna. During this event 16,950 ML of Commonwealth environmental water was delivered. A trial delivery of 600 ML was delivered to the Ballin Boora system in January to February 2019 to support wetland and riparian vegetation. Pool replenishment flows were delivered to the Gwydir, Lower Gwydir, Carole and Mehi channels due to low inflows that caused extended no flow periods throughout the water year. In May to June 2019, 23,051 ML was delivered down the Mehi River channel from Copeton Dam, as part of the Northern Fish Flow. This flow reconnected the lower Mehi River, and once in the Barwon River channel, flowed downstream as far as the Culgoa River junction.

K.2 Methods

K.2.1 Survey area and timing

A total of 29 monitoring sites were surveyed across the 2014-19 Gwydir LTIM project, encompassing channel, floodplain wetland and waterhole sites within the Lower Gwydir River and Gingham Watercourse, and the Mehi River and Moomin Creek monitoring zones (Figure K-1; Figure K-2; Table K-2). A review by OEH staff in 2016 resulted in some sites from the 2014-15 year being combined to ensure statistical independence. 2014-15 data were retrospectively updated to match new site parameters and to include sites in the Mehi River and Moomin Creek monitoring zone that were added to the LTIM project in 2015-16. The new sites and parameters remain equivalent for the subsequent surveys. Multi-year comparisons were conducted on the updated data.

Monitoring was undertaken biannually during both autumn and spring, comprising 10 separate survey periods from spring 2014, through to autumn 2019. Twenty-two sites were monitored during all 10 survey periods, with two sites each monitored during six, eight and nine survey periods respectively, whilst one site was monitored during four survey periods.

K.2.2 Survey approach

Monitoring for waterbirds was done in conjunction with staff from NSW OEH, NPWS and North West LLS. Surveys were undertaken for a minimum of 20 minutes but no more than one hour in each survey site, resulting in a representative count of birds. At larger sites, transect surveys were conducted along a pre-defined transect with fixed starting and finishing points. Any species recorded *en route* to a site were recorded as incidental and, where spatially appropriate, these observations were included in the data for the nearest site. Replicate surveys were undertaken in the morning and evening of a different day at each site, with several sites receiving three visits to capture a representative measure of waterbird species richness. Fifteen of these sites were located on private property and we acknowledge the landholders for allowing us access to sample these sites (Table K-2).

All species observed along with the maximum count of each species in any one replicate survey were used in the analysis. Site information including percent inundated area, vegetation type and cover and weather conditions were recorded for each replicate survey. Inundation was determined based on the percent inundated area with sites classified into the following categories:

- Dry – 0% inundation
- Very Low – 1-9% inundation
- Moderate – 10-49% inundation
- High – 50-74% inundation
- Very High – 75-94% inundation
- Full – 94-100% inundation.

A total of 270 surveys were undertaken across all sites during the LTIM period, the majority of which were undertaken during Dry (76) and Moderate (82) inundation conditions (Table K-2).

K.2.3 Statistical analysis

Waterbird abundance data was converted into density (abundance per hectare) for each site. Diversity was calculated as a Simpson's Diversity Index using the statistical software R and the statistical package PRIMER (Version 6). Poisson regression modelling was conducted in R to determine statistical differences in species richness, abundance and Simpson's Diversity based on inundation (wet, dry), system (Gingham, Lower Gwydir, Mallowa, Mehi) and site type (creek, floodplain, waterhole). Density data was fourth-root transformed and converted into a resemblance matrix in PRIMER to analyse patterns in waterbird community composition using non-metric multi-dimensional scaling (nMDS), permutational multivariate analysis of variance (PERMANOVA) and similarity percentages (SIMPER). Pairwise PERMANOVA tests were also conducted in PRIMER to describe interactions in more detail. For nMDS analyses that had large numbers of data points, the 'distance among centroids' function was used to group the data by the appropriate factor to aid interpretation of the nMDS plots. This was done for all multi-year nMDS comparisons. Sites that had a density of 0 were omitted prior to PRIMER analysis.

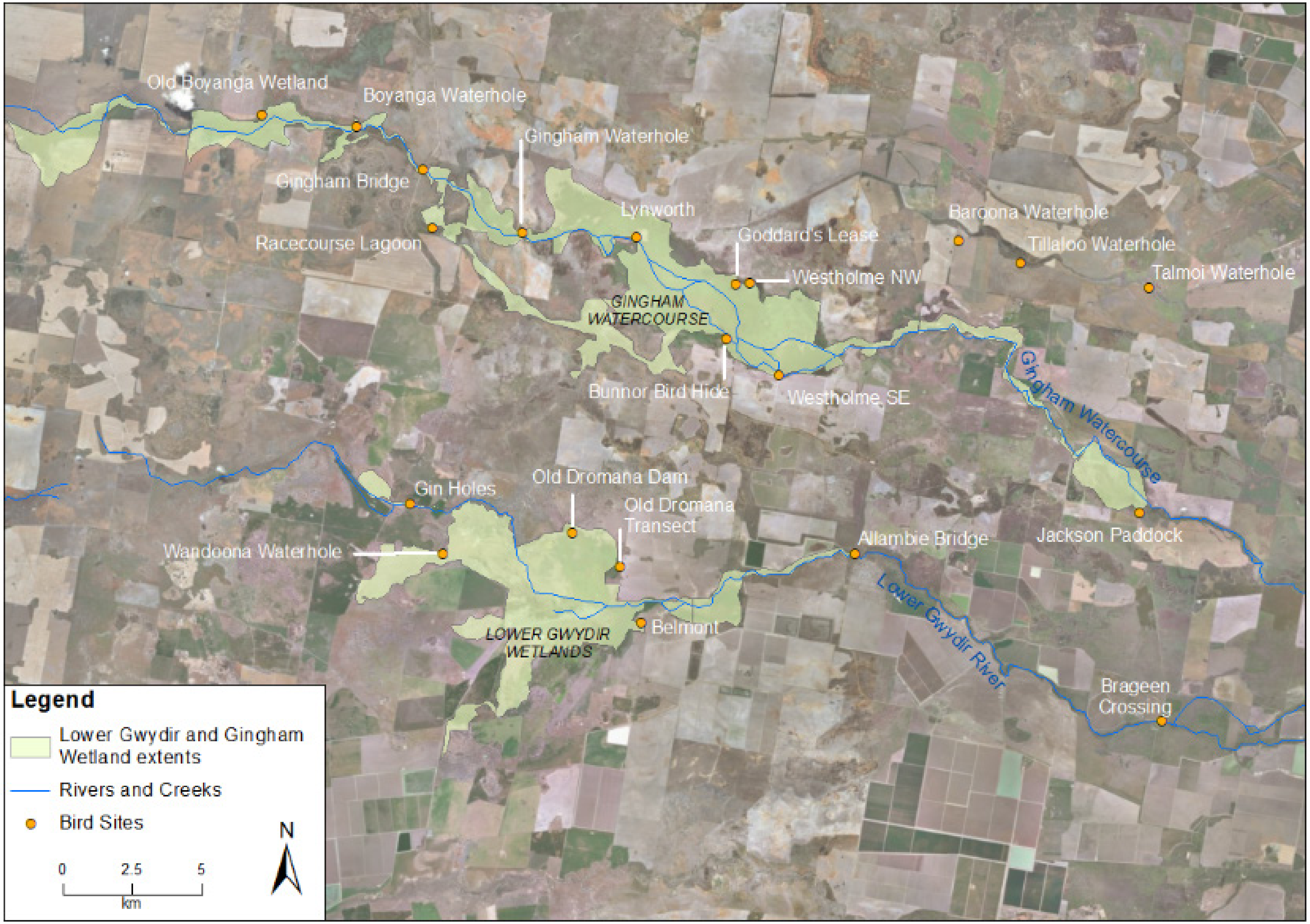


Figure K-1: Waterbird diversity monitoring sites within the Lower Gwydir and Gingham Watercourse monitoring zone.

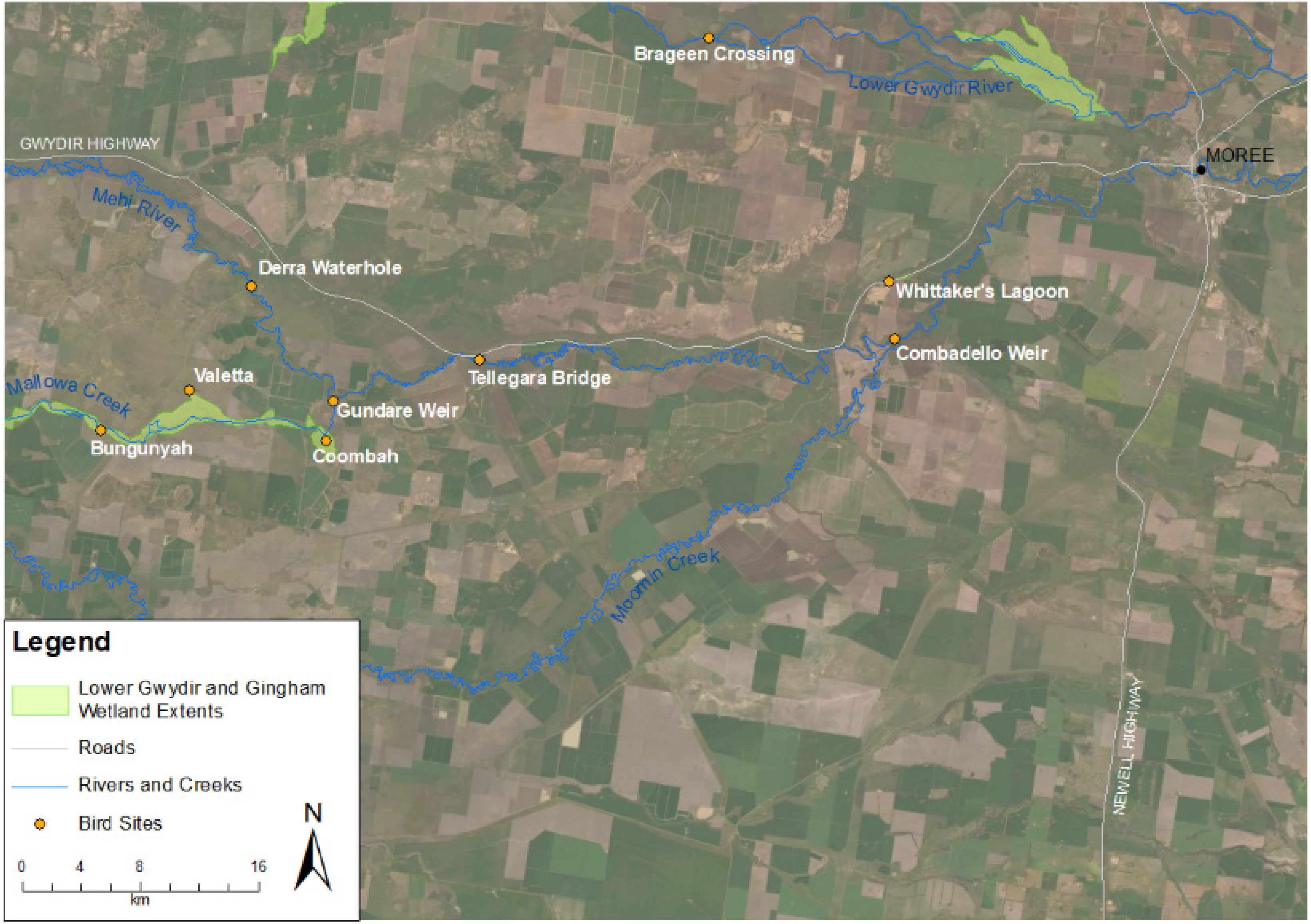


Figure K-2: Waterbird diversity monitoring sites within the Mehi River and Mallowa Creek monitoring zone.

Table K-2: Inundation status of waterbird survey sites within the Gwydir River system Selected Area across all survey periods during the LTIM project.

Monitoring Zone	System	Site Name	Site Type	Dry (0%)	Very Low (1-9%)	Moderate (10-49%)	High (50-74%)	Very High (75-94%)	Full (94-100%)	**Total**
Lower Gwydir River and Gingham Watercourse	Gingham	Baroona Waterhole*	Waterhole	6		1	1	2		**10**
		Boyanga Waterhole*	Waterhole	2	2	3	1	2		**10**
		Bunnor Bird Hide	Floodplain wetland				3	7		**10**
		Old Boyanga Wetland*	Floodplain wetland	6	1	1		1		**9**
		Gingham Bridge	Creek	2	3	3				**8**
		Gingham Waterhole	Waterhole			3	4	2	1	**10**
		Goddard's Lease	Floodplain wetland	1	2	1	1		1	**6**
		Jackson Paddock*	Floodplain wetland		6	2	2			**10**
		Lynworth*	Floodplain wetland	2	2	2	2	1	1	**10**
		Racecourse Lagoon*	Waterhole	5	2	1	1	1		**10**
		Talmoi Waterhole*	Waterhole	6	2	1		1		**10**
		Tillaloo Waterhole*	Waterhole	7		2	1			**10**
		Westholme NW	Floodplain wetland	3			2	1		**6**
		Westholme SE	Floodplain wetland	1	1	1	2	2	3	**10**
	Lower Gwydir	Allambie Bridge	Creek	2	1	5	1	1		**10**
		Brageen Crossing	Creek	3	1	6				**10**
		Belmont*	Floodplain wetland		3	1				**4**
		Gin Holes*	Waterhole	2		5	1			**8**
		Old Dromana Dam	Waterhole		1	4	4	1		**10**

Monitoring Zone	System	Site Name	Site Type	Dry (0%)	Very Low (1-9%)	Moderate (10-49%)	High (50-74%)	Very High (75-94%)	Full (94-100%)	**Total**
		Old Dromana Transect	Floodplain wetland	2	2		4		2	**10**
		Wandoona Waterhole*	Waterhole	3		2	1	4		**10**
Mehi River and Moomin Creek	Mallowa	Bungunya*	Floodplain wetland	6	1	3				**10**
		Coombah*	Floodplain wetland	5	1	2		1		**9**
		Gundare Weir	Creek			9	1			**10**
		Valetta*	Floodplain wetland	3	3		1	2	1	**10**
	Mehi	Combadello Weir	Creek			7	3			**10**
		Derra Waterhole	Waterhole	1	2	7				**10**
		Tellegara Bridge	Creek	2	1	7				**10**
		Whittaker's Lagoon	Waterhole	6	1	3				**10**
			Total	**76**	**38**	**82**	**36**	**29**	**9**	**270**

* Sites located on private land

K.3 Results

K.3.1 Waterbird species richness, density and diversity

A total of 29,784 individual waterbirds from 94 species were recorded across all sites during the LTIM project (Table K-3). Across all years the Plumed whistling-duck (*Dendrocygna eytoni*) was the most abundant waterbird species with 4,596 individuals recorded, followed by Pacific black duck (*Anas superciliosa*) (3,484 individuals), grey teal (*Anas gracilis*) (3,107 individuals) and glossy ibis (*Plegadis falcinellus*) (3,484 individuals). Pacific black duck was the only species recorded across all 29 sites, whilst white-faced heron was recorded at all bar one site (Table K-3).

Nine species listed under China-Australia Migratory Bird Agreement (CAMBA), Japan-Australia Migratory Bird Agreement (JAMBA) and Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA) international migratory bird agreements have been recorded during the survey period (Table K-3). Eight of these species, along with the glossy ibis, are also listed as migratory species under the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act). Additionally, eight species listed as vulnerable under the NSW *Biodiversity Conservation Act 2016* (BC Act) were also recorded, along with Australasian bittern (*Botaurus poiciloptilus*) and black-necked stork (*Ephippiorhynchus asiaticus*) listed as Endangered and red goshawk (*Erythrotriorchis radiatus*) listed as Critically Endangered under the NSW BC Act (Table K-3). Red goshawk is considered extremely rare in NSW, with only three published records since 2000 (NSW OEH, 2019). In the absence of supporting photographs, this record at Valetta in spring 2018, is considered unconfirmed due to the rarity of the species and its similarity to other more commonly recorded raptors.

Bunnor Bird Hide had the highest average species richness (26.6 ± 8.1 species), followed by Goddard's Lease (20 ± 5.7 species) and Gingham Waterhole (18.9 ± 5.7 species). All three of these sites are located within the Gingham Watercourse system that had the highest average species richness (11.73 ± 10.52 species), followed by the Lower Gwydir (10.02 ± 7.84 species), Mallowa (6.62 ± 7.26 species) and Mehi (4.70 ± 4.15 species; Figure K-4a). Floodplain sites recorded the highest average species richness (13.28 ± 10.29 species) as well as the highest standard deviation, reflecting the response of waterbirds to periodic inundation of these sites. Waterhole sites recorded moderate average species richness (9.44 ± 8.67 species), whilst creek sites recorded relatively low (3.38 ± 2.75 species; Figure K-4b). Average species richness was positive correlated with increased inundation with full sites (19.67 ± 7.48 species) recording the highest species richness whilst dry sites recorded by far, the lowest species richness sites (2.29 ± 3.78 species; Figure K-5).

Highest average species richness across all seasons was recorded during spring 2018 (14.35 ± 10.48 species; Figure K-6). This coincided with the highest environmental water delivery across the LTIM project occurring in the 2018/19 water year, in which 70,462 ML of Commonwealth and 30,241 ML of NSW environmental water was delivered (Table K-1). Environmental water comprised 53% of total water flow in the Gwydir River system for the 2018/19 water year, demonstrating the important contribution of environmental water to waterbird species richness. The second and third highest average species richness across all seasons were recorded during autumn 2017 (12.89 ± 8.89 species) and spring 2016 (12.76 ± 9.09 species; Figure K-6) during the 2016/17 water year. This coincided with the highest annual flow for the Gwydir River system recorded during the LTIM project (614,484 ML; Table K-1). Environmental water contributed only 7% of total water flow during the 2016/17 water year, therefore demonstrating the importance that natural inflows also have on waterbird species richness (Table K-1).

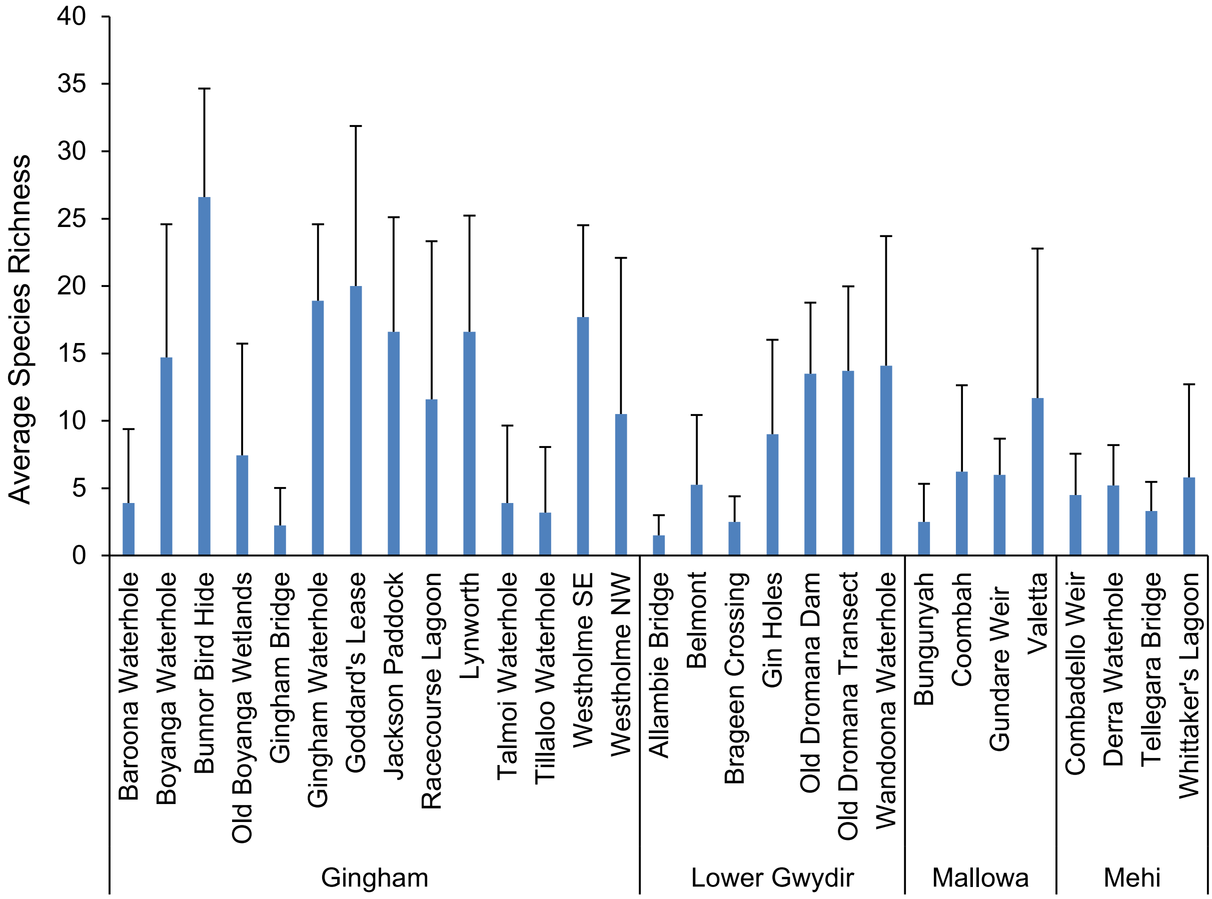
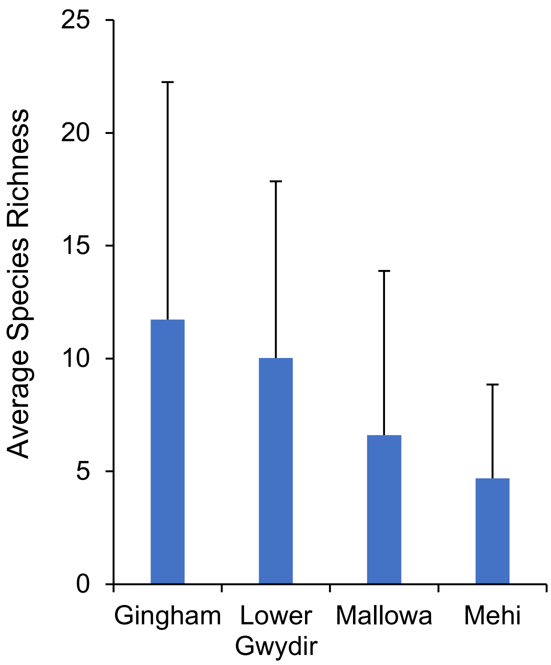


Figure K-3: Average species richness counts (± SD) for each site.

a)



b)

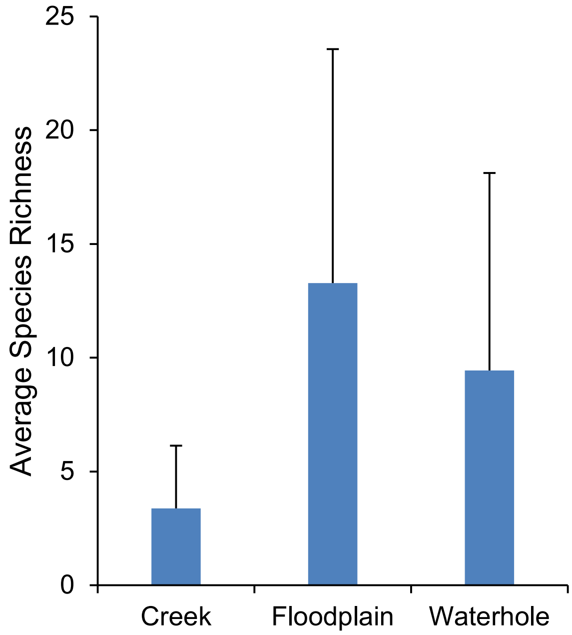


Figure K-4: a) Average species richness (± SD) for each wetland system and; b) for each site type

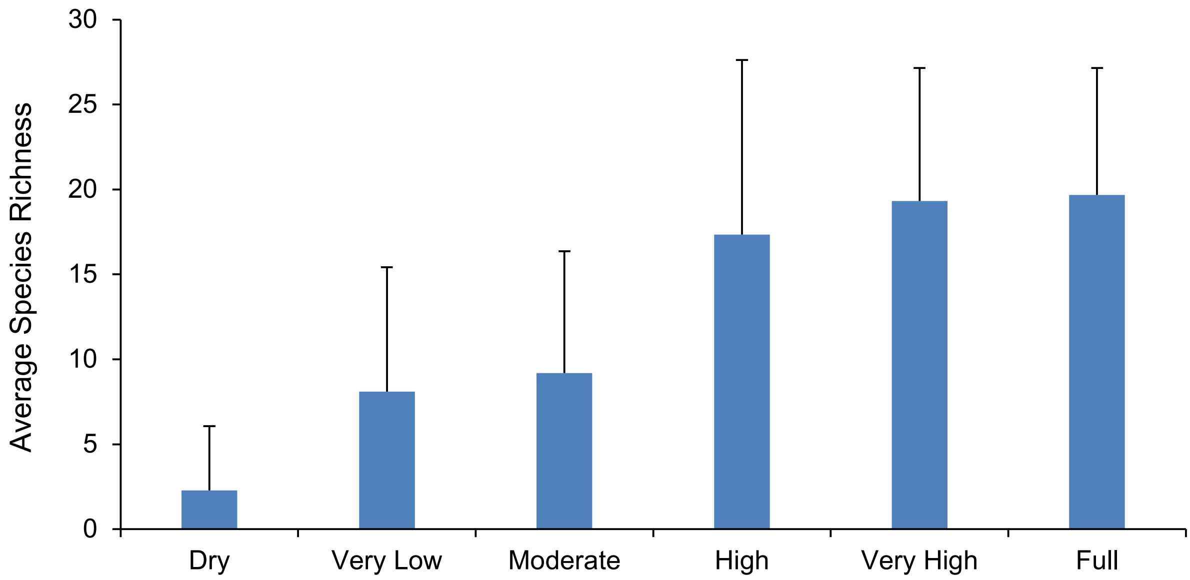


Figure K-5: Average species richness (± SD) for each inundation status.

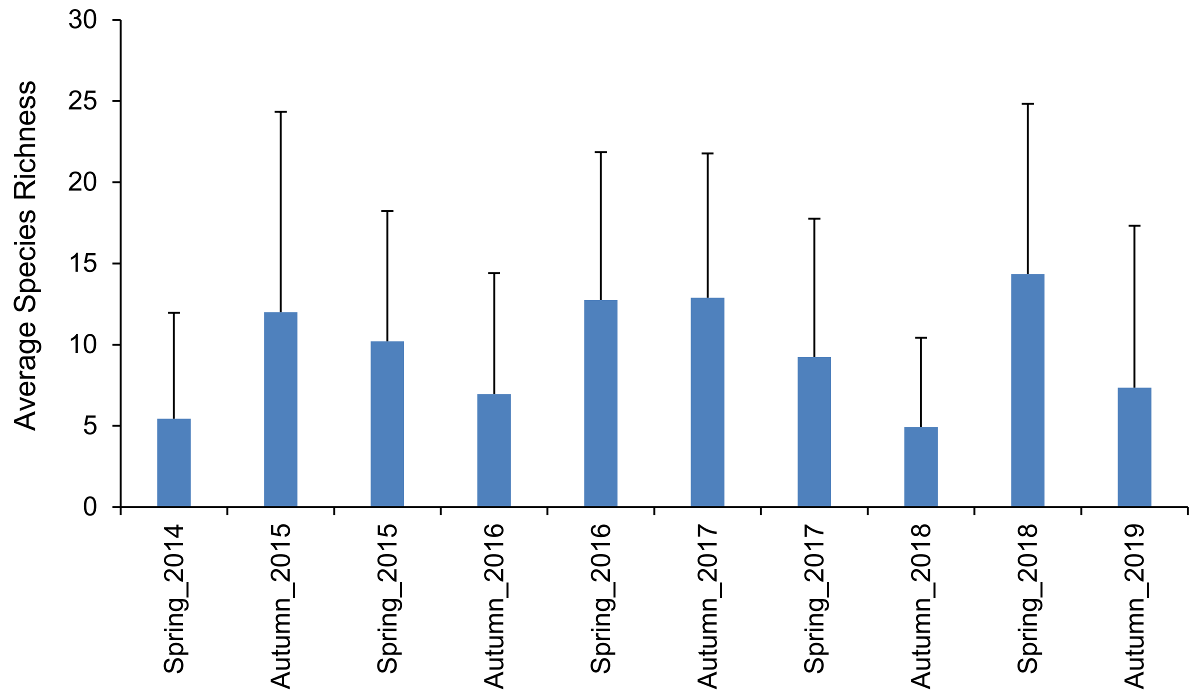


Figure K-6: Average species richness (± SD) for each survey period.

Bunnor Bird Hide stands out as the site with by far the highest maximum waterbird density (Figure K-7). These scores were recorded as a result of large flocks of Pacific black ducks and plumed whistling ducks (autumn 2015) and little pied cormorants and magpie geese (spring 2017) present during surveys, combined with the relatively small area (3.6 ha) of the site. Bunnor Bird Hide is located within the Gingham Watercourse system that recorded the highest average density (22.06 ± 56.48 birds/ha), along with the Lower Gwydir (20.82 ± 32.91 birds/ha) wetland system. The Mallowa (8.51 ± 13.72 birds/ha) and Mehi (3.04 ± 3.67 birds/ha) wetland systems in contrast, recorded much lower waterbird density scores (Figure K-8a).

The Mehi wetland system contains two Creek sites (11.59 ± 19.78 birds/ha) and two waterhole sites (15.02 ± 27.27 birds/ha) that recorded lower average waterbird density compared to floodplain sites (22.19 ± 63.19 birds/ha; Figure K-8b).

Sites surveyed during high inundation (33.05 ± 45.92 birds/ha) and very high inundation (19.31 ± 7.84 birds/ha) recorded the highest average density, whilst the lowest average density was recorded at sites during Dry (0.79 ± 2.68 birds/ha) and Very Low (5.88 ± 9.32 birds/ha) inundation (Figure K-9). High waterbird densities recorded during high inundation conditions are mostly the result of large flocks from multiple species congregating at sites within the Gingham wetland system, in particular at Bunnor Bird Hide and Gingham Waterhole. The data demonstrates a decline in waterbird density at full inundation sites (along with an associated fall in waterbird abundance), which is likely the result of widespread inundation in the system, dispersing waterbirds over a wider area.

Highest average waterbird density across all seasons was recorded during spring 2018 (32.73 ± 53.96 birds/ha; Figure K-10). This coincided with the highest environmental water delivery across the LTIM project occurring in the 2018/19 water year, in which environmental water comprised 53% of total water flow in the Gwydir River system (Table K-1). This demonstrates the important contribution of environmental water to waterbird density in the Gwydir Selected Area. The second highest average waterbird density across all seasons was recorded during autumn 2017 (27.92 ± 38.52 birds/ha; Figure K-10), which coincided with high natural inflows to the Gwydir River system (Table K-1), therefore demonstrating the importance that these natural inflows also have on waterbird density.

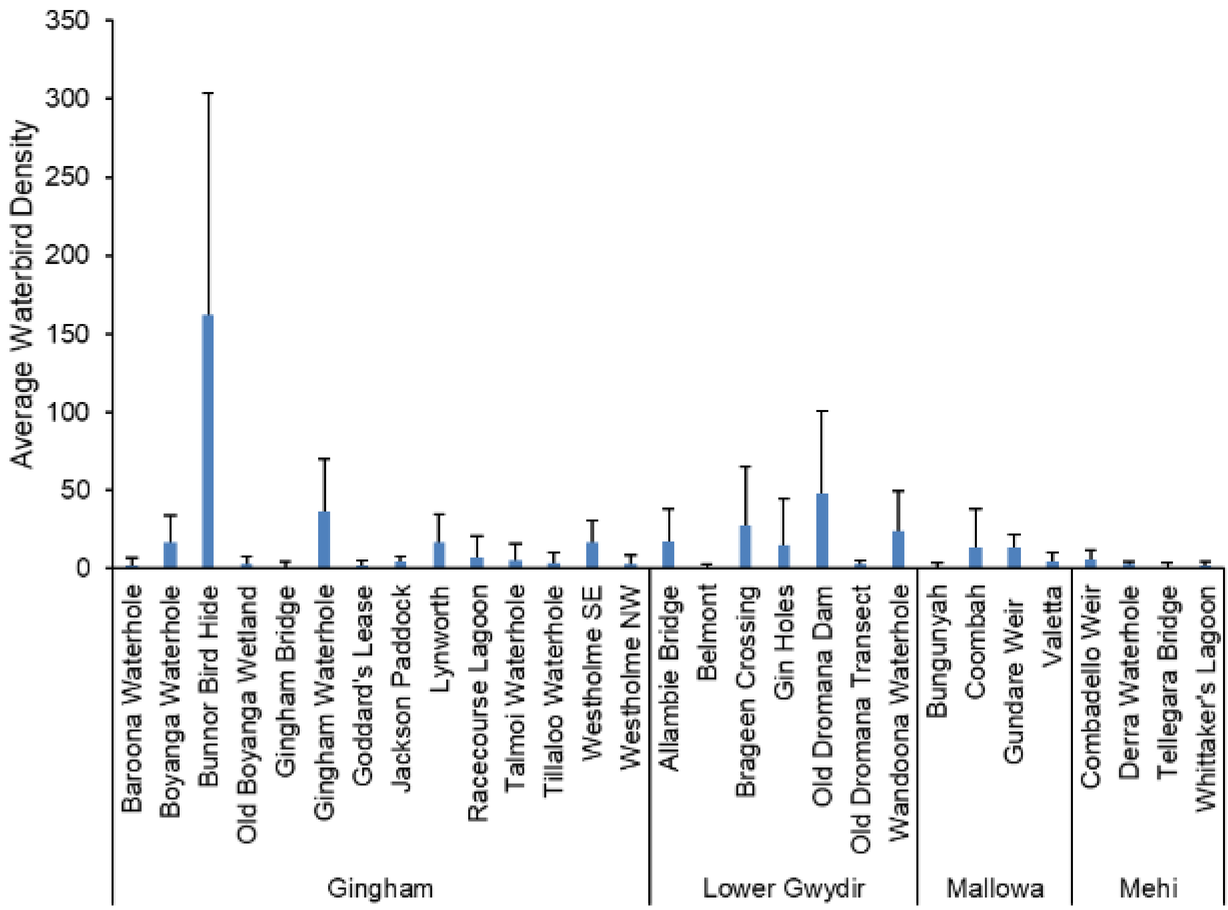


Figure K-7: Average waterbird density (waterbirds/ha) (± SD) for each site across the LTIM project

a) b)

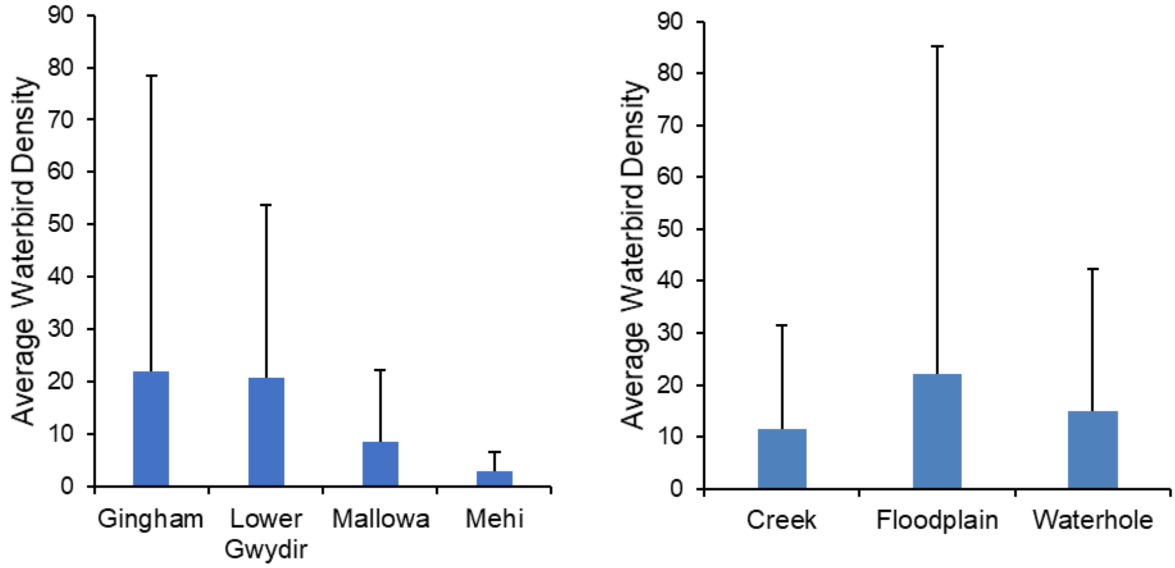


Figure K-8: a) Average waterbird density (waterbirds/ha) (± SD) for each wetland system and; b) for each site type

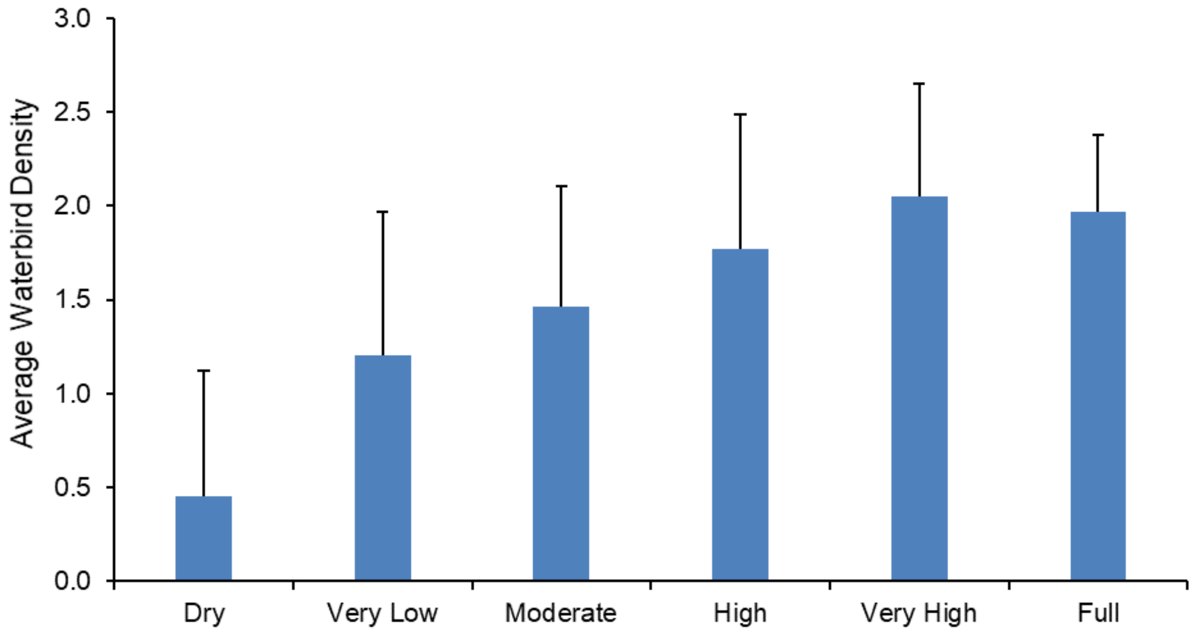


Figure K-9: Average waterbird density (waterbirds/ha) (± SD) for each inundation status

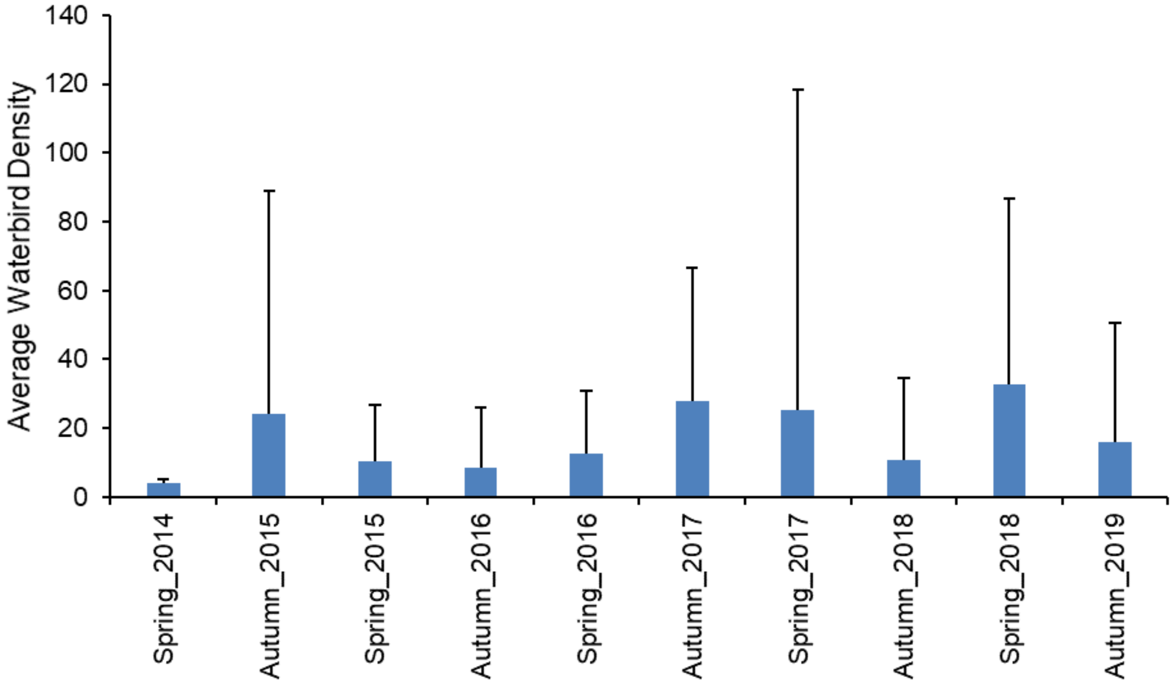


Figure K-10: Average waterbird density (waterbirds/ha) (± SD) for each survey period

Boyanga Waterhole (2.00 ± 0.88) and Bunnor Bird Hide (2.00 ± 0.53; Figure K-11) recorded the highest average Shannon Diversity across all sites. Both sites are located within the Gingham wetland that also recorded the highest average diversity results (1.35 ± 0.92), followed by Lower Gwydir (1.29 ± 0.83), Mallowa (1.10 ± 0.84) and Mehi (1.09 ± 0.72; Figure K-12a) wetland systems. Floodplain sites recorded the highest average Shannon Diversity (1.49 ± 0.82 species), followed by Waterhole sites (1.25 ± 0.94 species) and Creek sites (0.87 ± 0.66; Figure K-12b). High Shannon Diversity scores were associated with high inundation with sites surveyed during very high (2.05 ± 0.60) and full (1.97 ± 0.41 species) inundation status recording the highest average Shannon Diversity scores. In contrast, dry sites recorded by far the lowest species richness (2.29 ± 3.78 species), followed by very low sites (2.29 ± 3.78 species; Figure K-13).

Highest average Shannon Diversity results across all seasons were recorded during spring 2018 (1.7 ± 0.7) and spring 2016 (1.7 ± 0.7), whilst the second highest average results were recorded during spring 2015 (1.5 ± 0.9) and autumn 2017 (1.5 ± 0.6; Figure K-14). High results recorded during spring 2018 coincided with the largest environmental water delivery across the LTIM project occurring in the 2018/19 water year, in which environmental water comprised 53% of total water flow in the Gwydir River system (Table K-1). Additionally, high diversity recorded during spring 2016 and autumn 2017 coincided with the highest natural inflows to the Gwydir River system (Table K-1) recorded during the LTIM project. These results demonstrate the important contribution of both environmental water and natural inflows to waterbird diversity in the Gwydir River system.

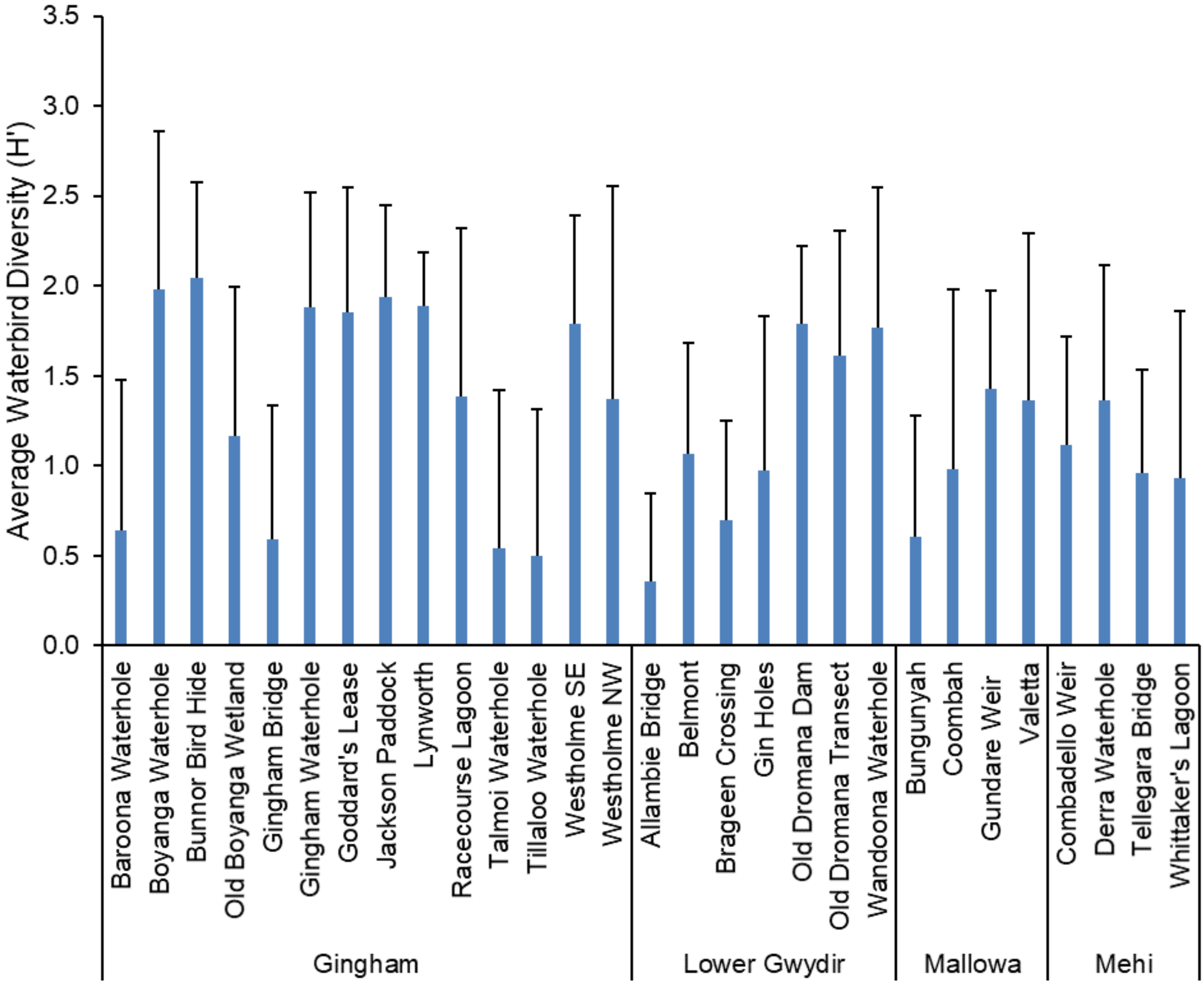


Figure K-11: Average waterbird diversity (H') (± SD) for each site across the LTIM project

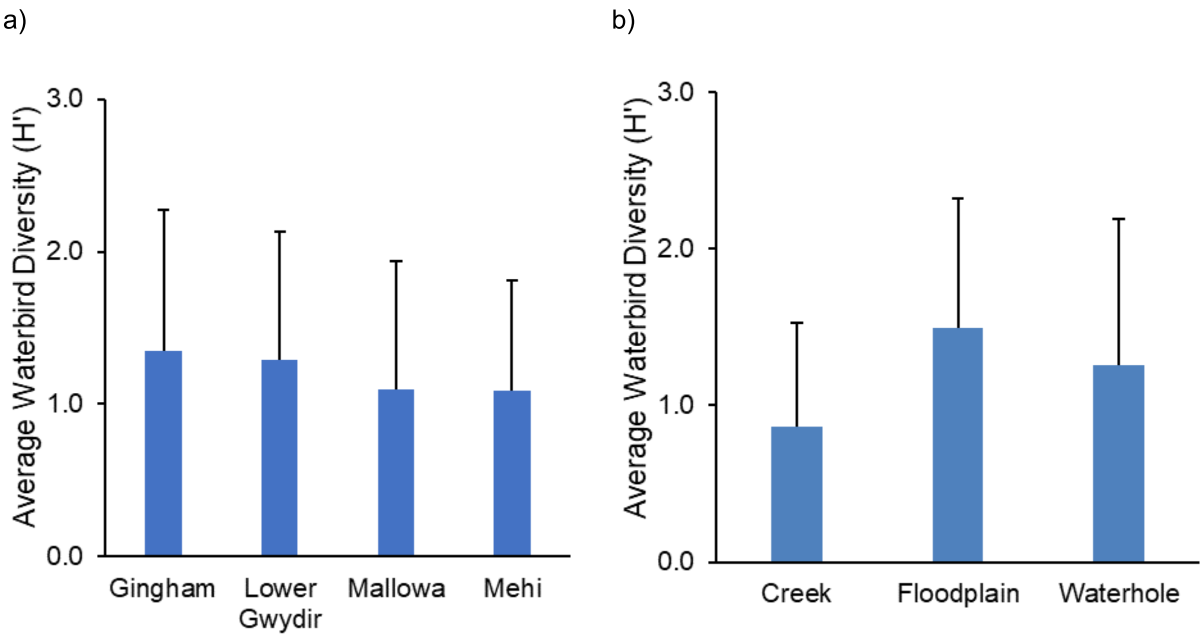


Figure K-12: a) Average waterbird diversity (H') (± SD) for each wetland system and; b) for each site type

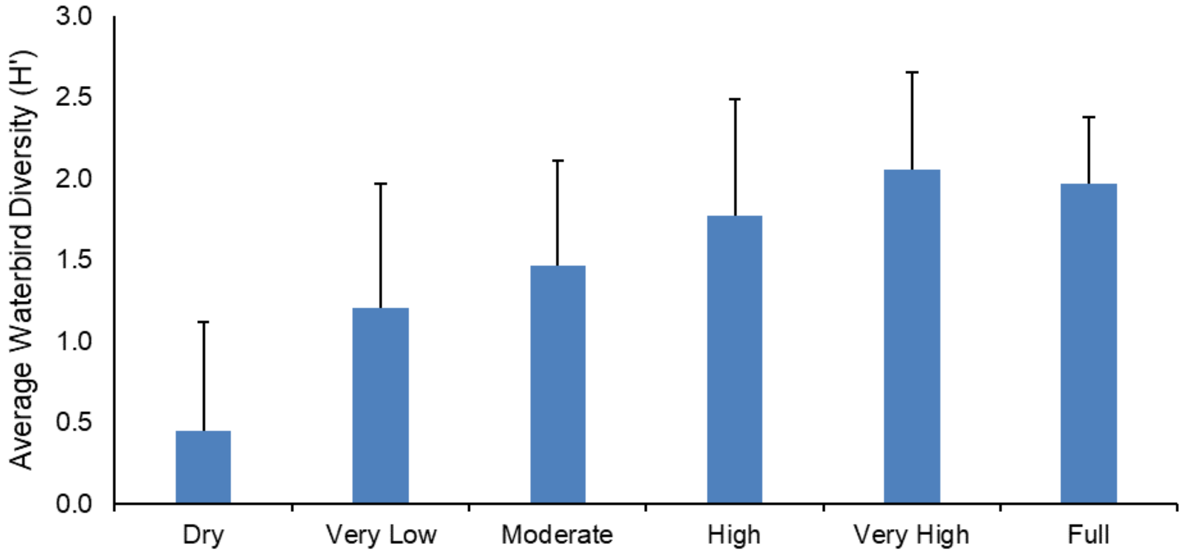


Figure K-13: Average waterbird diversity (H’) (± SD) for each inundation status

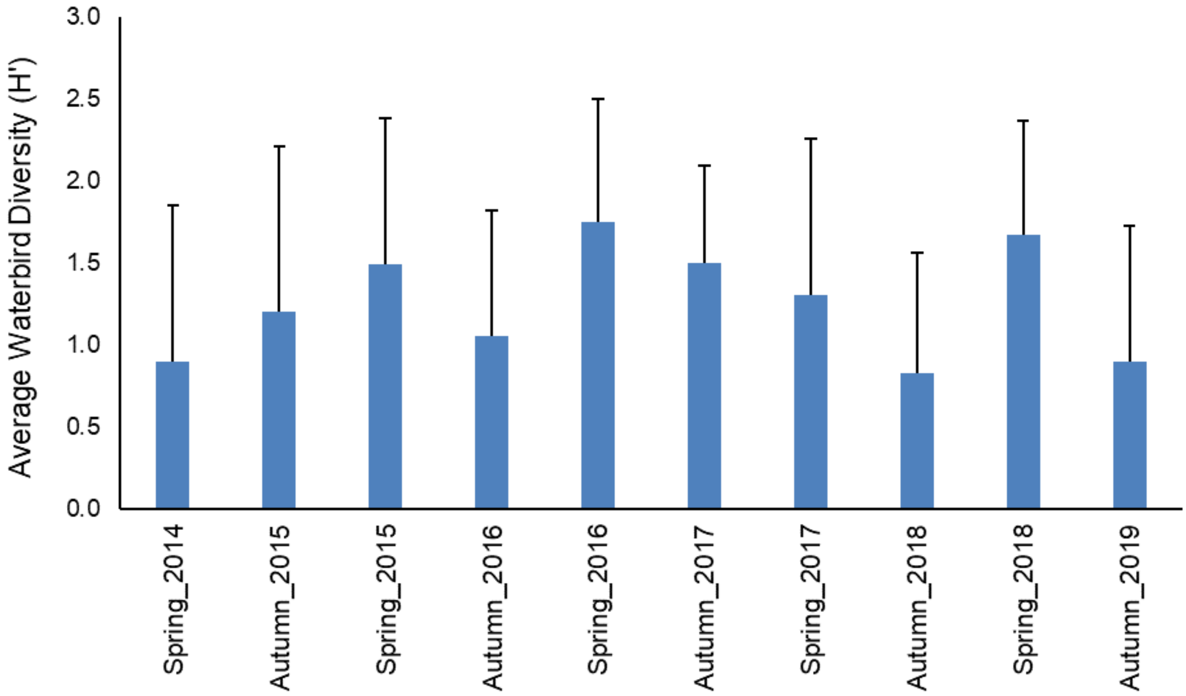


Figure K-14: Average waterbird diversity (H’) (± SD) for each survey period

Table K-3: Maximum count for all waterbird species recorded within Gingham Watercourse and Lower Gwydir River sites during the LTIM project

Monitoring Zone		Gingham Watercourse and Lower Gwydir River wetlands																				
System		Gingham														Lower Gwydir						
Functional Guild	Common Name	Baroona Waterhole	Boyanga Waterhole	Bunnor Bird Hide	Old Boyanga Wetlands	Gingham Bridge	Gingham Waterhole	Goddard's Lease	Jackson Paddock	Lynworth	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme N-W	Westholme S-E	Allambie Bridge	Belmont	Brageen Crossing	Gin Holes	Old Dromana Dam	Old Dromana Transect	Wandoona Waterhole
Australian-breeding Charadriiform shorebirds	Australian Painted Snipe[V]																		2		1	
	Australian Pratincole					1									1							
	Banded Lapwing			2					4	4					1			20			1	
	Black-fronted Dotterel	12	24	12	3		3		1		22	8	5	16						3		6
	Black-winged Stilt	11	1	59	78			10	2		192	24	3		8					4	22	15
	Comb-crested Jacana										1											
	Masked Lapwing	3		10	5		5	2	40	13	54	4	2	8	101				11	13	37	19
	Red-kneed Dotterel	7		20	2			11	5	2	16	17	1	3	2					10		9
	Red-necked Avocet										10	26										8
	Unidentified Dotterel																					
Dabbling and filter-feeding ducks	Australasian Shoveler			2			1				7								1	1		
	Chestnut Teal							2														
	Freckled Duck[V]			28																2		5
	Grey Teal	158	46	676	53	3	358	23	150	71	217	229	71	50	308		2		111	147	8	109
	Pacific Black Duck	39	67	588	31	6	309	153	259	142	62	36	42	44	427	17	12	9	134	222	430	173
	Pink-eared Duck	23		187	16		2	3			22	45	12	6			32		2	2		19
	Unidentified Duck																		20		6	
Diving ducks, aquatic gallinules and swans	Black Swan			25			12	3			10				2						2	4
	Dusky Moorhen	1	13	15	1	2	6	3	31	13	2		2	6	15				1	2	1	4
	Eurasian Coot	17	90	86	4		13	34	8	29	32	5	7		10				21	9	2	135
	Great Crested Grebe			4			2	1			11	1										
	Hardhead	7	8	34	2	1	22	3	1	9	54	3		14	82				6	10		4
	Hoary-headed Grebe									2										2		1
Grazing ducks and geese	Australian Wood Duck	39	12	25	18		131	25	228	42		13	22	44	7	3	2	36	115	2	29	3
	Magpie Goose[V]		1	1,305	1		4	259	1	53	5			1	13							3
	Plumed Whistling-Duck	6	26	893	165		1,054	57	150	428	1	57	13	100	25			2	1,147	308		118
	Wandering Whistling-Duck			1				1							4					2		9
Large wading birds	Australian White Ibis		42	156	32		44	122	101	107	35			77	64		4		3	9	56	17
	Black-necked Stork[E]		2								3											
	Brolga[V]			11			1	3	23		6			3	532				4			107
	Glossy Ibis[M]		4	148	4	1	41	236	32	260	918	2		35	139	3	3		1	40	297	46
	Royal Spoonbill		34	114	10		34	48	36	23	11			2	8					5	25	2

Monitoring Zone		Gingham Watercourse and Lower Gwydir River wetlands																				
System		Gingham													Lower Gwydir							
Functional Guild	Common Name	Baroona Waterhole	Boyanga Waterhole	Bunnor Bird Hide	Old Boyanga Wetlands	Gingham Bridge	Gingham Waterhole	Goddard's Lease	Jackson Paddock	Lynworth	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme N-W	Westholme S-E	Allambie Bridge	Belmont	Brageen Crossing	Gin Holes	Old Dromana Dam	Old Dromana Transect	Wandoona Waterhole
	Straw-necked Ibis		124	2	27		3	18	4	11	13			5	296		21			4	24	73
	Unidentified Spoonbill									10												
	Yellow-billed Spoonbill	5	17	50			18	4	6	10	7	2	2	11	9				1	1	8	14
Migratory Charadriiform shorebirds	Black-tailed Godwit[CJRM]			2				2														
	Common Greenshank[CJRM]							1													1	
	Common Sandpiper[CJRM]										33											
	Latham's Snipe[JRM]		10	5	1		1		1	1				12						20	16	11
	Marsh Sandpiper[CJRM]			11				25			53										1	5
	Red-necked Stint[CJRM]										8											
	Sharp-tailed Sandpiper[CJRM]		6	56				19			43			13						5	2	
	Unidentified Small Migratory Wader																					
	Wood Sandpiper[CJRM]			1																		
Piscivores	Australasian Bittern[E]			3																		
	Australasian Darter	1	12	41	4		80	7	7	9	13	2		2	6	1			3	4	2	
	Australasian Grebe	60	27	13	13	3	9	10		12	66	22	19		11				19	20	5	59
	Australian Gull-billed Tern		1	10	1						5						29					3
	Australian Little Bittern			2											1					1		
	Australian Pelican		10	120	2		178	23	18	5	48			1	5			1		2	10	6
	Caspian Tern																47					
	Cattle Egret[J]		19	122			12	220	104	24	21			16	22					2	39	4
	Eastern Great Egret[CJ]		45	58	19	3	29	8	34	74	6			1	14		1		3	23	65	7
	Great Cormorant		9	5			14	1	1	2	6										1	
	Intermediate Egret		20	30	20		2	18	25	17	7	1	1	114	40		7		2	2	11	70
	Little Black Cormorant		9	567	18		95	4	79	34	26			1	8				3	5	86	2
	Little Egret	1		3					5		12		1	1	4		2					
	Little Pied Cormorant		39	51	1	5	98	16	11	28	11			8	107			1	5	15	6	19
	Nankeen Night-Heron			5			152	1	2	3			1		3	1				1		
	Pied Cormorant		6	18	2		18		4	5	3				1				1	1		3
	Sacred Kingfisher	2	4		1		8		4	3	1	1		1		2		2	1	1	1	1
	Tern sp.														1							
	unidentified Cormorant														2							
	unidentified Egret			4			9			10					3						37	
	Whiskered Tern			23	22		3	2	1	2	11				2		10					30

Monitoring Zone		Gingham Watercourse and Lower Gwydir River wetlands																				
System		Gingham														Lower Gwydir						
Functional Guild	Common Name	Baroona Waterhole	Boyanga Waterhole	Bunnor Bird Hide	Old Boyanga Wetlands	Gingham Bridge	Gingham Waterhole	Goddard's Lease	Jackson Paddock	Lynworth	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme N-W	Westholme S-E	Allambie Bridge	Belmont	Brageen Crossing	Gin Holes	Old Dromana Dam	Old Dromana Transect	Wandoona Waterhole
	White-faced Heron	4	26	10	14	4	10	9	23	24	23	4	1	29	7		4	3	10	12	34	12
	White-necked Heron		23	5	10	1	22	6	30	10	23	1	3	16	6	1			1	7	44	16
Rails and shoreline gallinules	Australian Spotted Crake		1																			1
	Baillon's Crake		7																			
	Black-tailed Native-hen		8	12					113	1									42	17		
	Buff-banded Rail		1							1				1							2	1
	Purple Swamphen		9	35	3		9	18	1	18	2			1	24				1	15	7	11
	Spotless Crake														2							
	Unidentified Rail														1							
Raptors	Australian Hobby			1		1	2	1							2			1	1		1	1
	Black Falcon[V]			1																		
	Black Kite										1			1	1							
	Black-shouldered Kite			3	2		1	4	4					2	4		1			4	2	2
	Brown Falcon		2		6			4	8	3	3	2		1	4		1		2	1	44	1
	Brown Goshawk			1							1									1		1
	Little Eagle[V]										1											
	Nankeen Kestrel				4	1		1		2				4		2		1	2			3
	Peregrine Falcon							1						1								
	Red Goshawk[CE]																					
	Spotted Harrier[V]														1				1			
	Swamp Harrier		2	9				2	1	3				1	6							
	unidentified Falcon								1													
	Wedge-tailed Eagle	1	14		3		4		13	3	8	1	2	2	2	2		2		6	5	2
	Whistling Kite	2	12	16		1	16	7	5	14	10			4	8	3	4	3		3	10	6
	White-bellied Sea-Eagle[V]		8	3	1	2	8		1	1	1				6						1	1
Reed-inhabiting passerines	Australian Reed-Warbler	1	43	95	39		32	25	26	109	9			16	110					74	85	45
	Golden-headed Cisticola		2	22	4			16	10	28	7			6	31		3			12	112	7
	Little Grassbird		4	23	1			8	2	20	2			3	22					7	13	3
	Tawny Grassbird			1					1	2					4							
Total Abundance		**400**	**890**	**5,840**	**643**	**35**	**2,875**	**1,480**	**1,617**	**1,697**	**2,175**	**506**	**210**	**683**	**2,525**	**35**	**185**	**81**	**1,677**	**1,059**	**1,592**	**1,236**
Species Richness		**21**	**45**	**62**	**40**	**15**	**44**	**50**	**48**	**48**	**55**	**23**	**19**	**43**	**55**	**10**	**18**	**12**	**32**	**47**	**44**	**53**

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

Table K-4: Maximum count for all waterbird species recorded within Mehi River and Moomin Creek sites

Monitoring Zone		Mehi River and Moomin Creek							
System		Mallowa				Mehi			
Functional Guild	Common Name	Bungunya	Coombah	Gundare Weir	Valetta	Combadello Weir	Derra Waterhole	Tellegara Bridge	Whittaker's Lagoon
Australian-breeding Charadriiform shorebirds	Australian Painted Snipe[V]								
	Australian Pratincole								
	Banded Lapwing								
	Black-fronted Dotterel		1		3	4	1	1	15
	Black-winged Stilt				62				
	Comb-crested Jacana								
	Masked Lapwing		1		12		3		4
	Red-kneed Dotterel				6				
	Red-necked Avocet								
	Unidentified Dotterel						1		
Dabbling and filter-feeding ducks	Australasian Shoveler								
	Chestnut Teal								1
	Freckled Duck[V]								
	Grey Teal	16	93	10	95	6	7	2	88
	Pacific Black Duck	17	62	40	75	42	9	15	22
	Pink-eared Duck				2				9
	Unidentified Duck								
Diving ducks, aquatic gallinules and swans	Black Swan								
	Dusky Moorhen			4		1	2		4
	Eurasian Coot								6
	Great Crested Grebe								
	Hardhead						1		6
	Hoary-headed Grebe								
Grazing ducks and geese	Australian Wood Duck	6	36	30	172	8	10	2	11
	Magpie Goose[V]								
	Plumed Whistling-Duck				42		4		
	Wandering Whistling-Duck								
Large wading birds	Australian White Ibis		15	9	78	6			
	Black-necked Stork[E]								
	Brolga[V]								
	Glossy Ibis[M]		6		145				
	Royal Spoonbill		3	5	51		5		

Monitoring Zone		Mehi River and Moomin Creek							
System		Mallowa				Mehi			
Functional Guild	Common Name	Bungunya	Coombah	Gundare Weir	Valetta	Combadello Weir	Derra Waterhole	Tellegara Bridge	Whittaker's Lagoon
	Straw-necked Ibis		14		25				
	Unidentified Spoonbill								
	Yellow-billed Spoonbill	2	6	4	15	7	2		4
Migratory Charadriiform shorebirds	Black-tailed Godwit[CJRM]								
	Common Greenshank[CJRM]								
	Common Sandpiper[CJRM]								
	Latham's Snipe[JRM]		1		19				
	Marsh Sandpiper[CJRM]				1				
	Red-necked Stint[CJRM]								
	Sharp-tailed Sandpiper[CJRM]				86				
	Unidentified Small Migratory Wader				1				
	Wood Sandpiper[CJRM]								
Piscivores	Australasian Bittern[E]								
	Australasian Darter	1	1	1	2	2	3	1	
	Australasian Grebe		1		2		8		10
	Australian Gull-billed Tern					3			
	Australian Little Bittern								
	Australian Pelican		1	2	11		3	21	3
	Caspian Tern								
	Cattle Egret[J]		2		13		1		
	Eastern Great Egret[CJ]	1	9	3	21		3		1
	Great Cormorant		1	1	3				
	Intermediate Egret		18		50	1			1
	Little Black Cormorant		14	9	6		2		
	Little Egret				1				
	Little Pied Cormorant		4	2	10		3		4
	Nankeen Night-Heron	2	9	17			1		
	Pied Cormorant			1	1		1		1
	Sacred Kingfisher	4	3	7		8	1	9	4
	Tern sp.								
	unidentified Cormorant								
	unidentified Egret				12				
	Whiskered Tern				10				

Monitoring Zone		Mehi River and Moomin Creek							
System		Mallowa				Mehi			
Functional Guild	Common Name	Bungunya	Coombah	Gundare Weir	Valetta	Combadello Weir	Derra Waterhole	Tellegara Bridge	Whittaker's Lagoon
	White-faced Heron	7	19	2	83	7	5	5	6
	White-necked Heron	5	25	2	85		5		11
Rails and shoreline gallinules	Australian Spotted Crake								
	Baillon's Crake								
	Black-tailed Native-hen	1		1	15				
	Buff-banded Rail								
	Purple Swamphen				1				1
	Spotless Crake				1				
	Unidentified Rail								
Raptors	Australian Hobby				2				
	Black Falcon^{V}		2	1	1			1	1
	Black Kite								1
	Black-shouldered Kite				2				2
	Brown Falcon		1		4	1			
	Brown Goshawk								
	Little Eagle^{V}				1				
	Nankeen Kestrel				1	1		1	8
	Peregrine Falcon								
	Red Goshawk^{CE}				1				
	Spotted Harrier^{V}				1				
	Swamp Harrier				3				
	unidentified Falcon								
	Wedge-tailed Eagle		6	4	2	2	2	6	
	Whistling Kite		2	4	8	7	6	8	3
	White-bellied Sea-Eagle^{V}			2		4			
Reed-inhabiting passerines	Australian Reed-Warbler	11		1	6		1		
	Golden-headed Cisticola				1				
	Little Grassbird				1				
	Tawny Grassbird								
Total Abundance		**73**	**356**	**162**	**1,251**	**110**	**90**	**72**	**227**
Species Richness		**12**	**28**	**23**	**50**	**17**	**26**	**12**	**26**

^{J}= listed under JAMBA; ^{C}= listed under CAMBA; ^{R}= listed under ROKAMBA; ^{V}=Vulnerable (NSW BC Act); ^{E}= Endangered (NSW BC Act); ^{M}= Migratory (EPBC Act)

K.3.2 Community Composition

To further explain patterns in waterbird community composition, multivariate analysis was undertaken. The nMDS plot suggests there was some separation in the data based on wetland systems (Figure K-15) and inundation status, with a greater spread of data visible for dry, very low and moderate inundation (Figure K-16). This was confirmed by PERMANOVA that showed a significant separation in waterbird community composition between wetland systems (P = 0.001) and inundation status (P = 0.001), along with a significant interaction between these two factors (P = 0.017). There was also a significant difference in community composition between seasons (P = 0.001) and site types (P = 0.001), as well as a significant interaction between site types and wetland systems (P = 0.001). Pairwise comparison of the interaction between wetland system and inundation showed that Gingham sites were driving the patterns, with significant differences between all inundation status categories, excluding high and very high (P = 0.196), high and full (P = 0.288) and very high and full (P = 0.154; Table K-5). This contrasted with the other three wetland systems, which recorded fewer significant differences between inundation status categories, with the majority limited to dry and very low inundation status (Table K-5).

SIMPER analysis for Gingham and Lower Gwydir wetland systems was characterised by Pacific black duck contributing most to species groupings, with a large range of other species also contributing between 2-10% (Table K-6). In contrast, the Mallowa and Mehi wetland systems were characterised by overall fewer species contributing larger percentages (>10%) to groupings (Table K-6). SIMPER analysis for dry and very low inundation status displayed similar characteristics with overall fewer species contributing to groupings, including the raptor species wedge-tailed eagle (*Aquila audax*) and whistling kite (*Haliastur sphenurus*), which have less of a requirement for high inundation compared to other waterbird species. As was the case with the Gingham and Lower Gwydir wetland systems, high, very high and full inundation categories were also characterised by Pacific black duck contributing most to species groupings, with a large range of other species also contributing between 2-10% (Table K-7). These higher inundation categories and the Gingham and Lower Gwydir wetland systems are characterised by higher waterbird abundance and species richness results, compared to lower inundations categories and the Mallowa and Mehi wetland systems. This pattern indicates that higher waterbird abundance and species richness results in more species contributing to groupings.

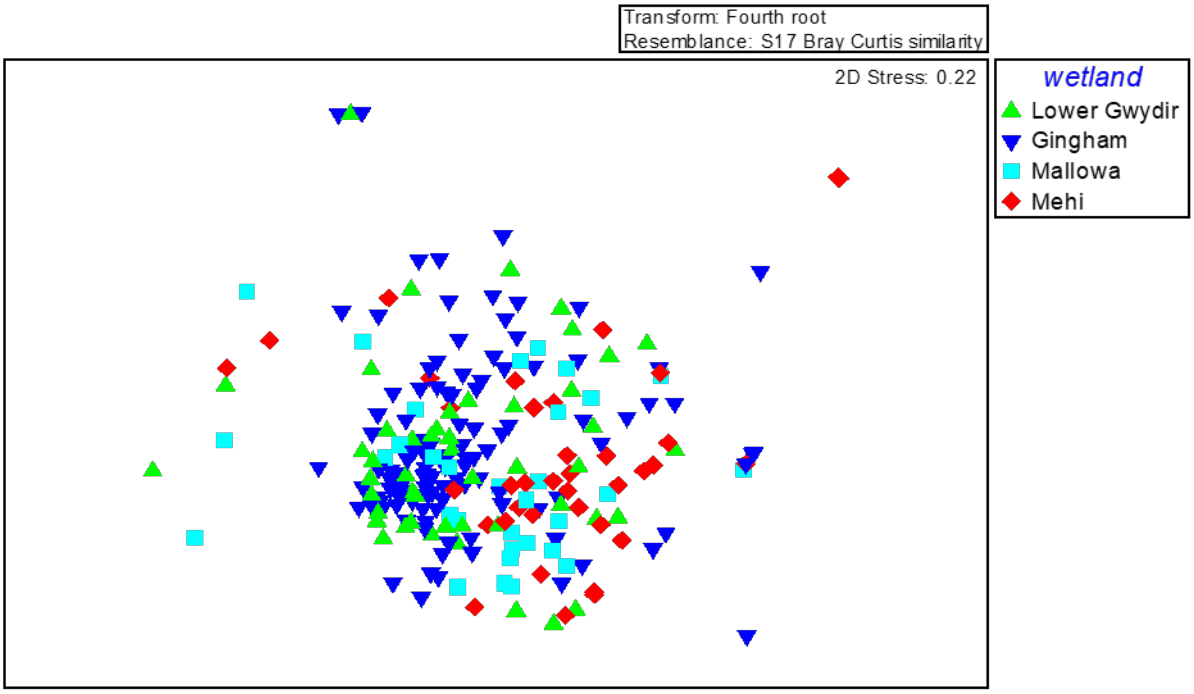


Figure K-15: nMDS plot of waterbird community composition grouped by wetland system

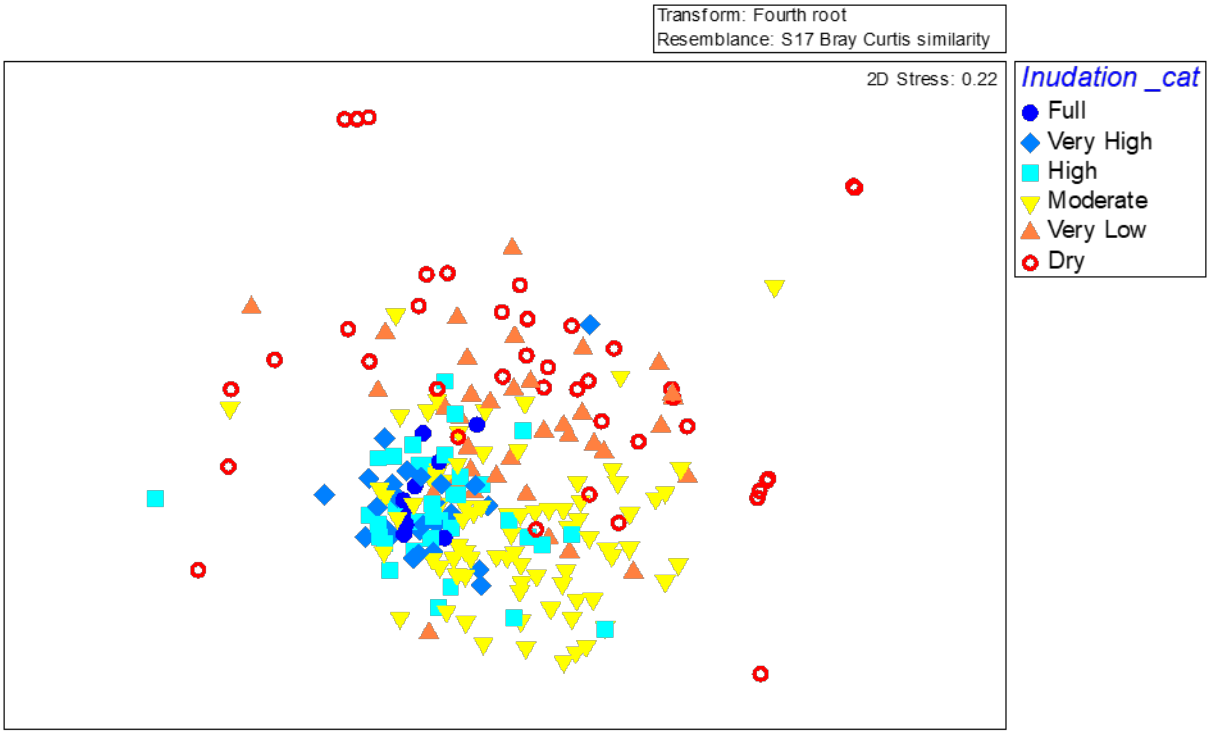


Figure K-16: nMDS plot of waterbird community composition grouped by inundation category

Table K-5: Pair-wise tests results for interaction between wetland system and inundation status.

Wetland System	Inundation Status	Dry	Very Low	Moderate	High	Very High	Full
Gingham	Dry		**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
	Very Low			**0.050**	**0.001**	**0.001**	**0.001**
	Moderate				**0.010**	**0.001**	**0.017**
	High					0.196	0.288
	Very High						0.154
	Full						
Lower Gwydir	Dry		0.723	**0.007**	**0.004**	**0.009**	0.614
	Very Low			**0.033**	**0.005**	**0.005**	0.483
	Moderate				0.162	0.108	0.371
	High					0.379	0.964
	Very High						0.170
	Full						
Mallowa	Dry		0.958	**0.001**	0.309	**0.012**	0.845
	Very Low			**0.004**	0.625	**0.021**	0.833
	Moderate				0.875	**0.006**	0.151
	High					0.301	0.660
	Very High						0.497
	Full						
Mehi	Dry		0.214	**0.001**	**0.009**	-	-
	Very Low			0.871	0.653	-	-
	Moderate				0.947	-	-
	High					-	-
	Very High *						-
	Full *						

***** No sites within these inundation categories.

Bold indicates significant difference of ***p<0.05***.

Table K-6: SIMPER results of species contributions to groupings in community composition data for each wetland system. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Gingham	Pacific Black Duck	11.38
Lower Gwydir	Pacific Black Duck	28.33
Mallowa	Australian Wood Duck	22.95
	White-faced Heron	17.52
	Whistling Kite	16.35
Mehi	Grey Teal	36.33
	Black-fronted Dotterel	33.45
	Pacific Black Duck	13.58

Table K-7: SIMPER results of species contributions to groupings in community composition data for each inundation status. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Dry	Wedge-tailed Eagle	19.91
	Whistling Kite	16.96
	White-faced Heron	12.40
Very Low	Whistling Kite	16.66
	White-faced Heron	16.66
	Pacific Black Duck	11.19
	Australian Reed-Warbler	10.72
Moderate	Pacific Black Duck	33.85
	White-faced Heron	10.19
High	Pacific Black Duck	19.17
Very High	Pacific Black Duck	12.22
Full	Pacific Black Duck	12.54

K.3.3 Waterbird breeding

Evidence of waterbird breeding was observed on 77 individual occasions, across 29 species and 22 sites (Table K-8). Evidence of breeding included the presence of immature waterbirds, as well nesting activity (Table K-8). Adult waterbirds in breeding plumage were not considered direct evidence of breeding activity and as such, associated records have not been included. Evidence of waterbird breeding was observed during all inundation status categories, with the majority of observations (42 of 77) recorded during both moderate and very high inundation with both recording 21 observations.

Table K-8: Summary of breeding activity observed during the LTIM project

Survey period	Site	Common name	Breeding Notes	Inundation status
spring 2014	Gundare Weir	Pacific Black Duck	8 ducklings	Moderate
	Boyanga Waterhole	White-bellied Sea-Eagle	2 immature	Very Low
autumn 2015	Boyanga Waterhole	White-bellied Sea-Eagle	Immature	Moderate
	Bunnor Bird Hide	Australasian Darter	3 large juveniles and 2 adults in nest	Very High
	Bunnor Bird Hide	Magpie Goose	12 Adult trampling, 1 nest with 3 juveniles	Very High
	Bunnor Bird Hide	Little Pied Cormorant	Adult on nest with chicks	Very High
	Bunnor Bird Hide	Whistling Kite	2 nests	Very High
	Gingham Waterhole	Australasian Darter	2 fledglings with fawn necks	Very High
	Goddard's Lease	Plumed Whistling-Duck	5 ducklings	Full
	Goddard's Lease	Wandering Whistling-Duck	4 ducklings	Full
	Lynworth	Australian Reed-Warbler	1 juvenile	Full
	Racecourse Lagoon	Wedge-tailed Eagle	1 immature	Very Low
	Wandoona Waterhole	Hoary-headed Grebe	8 young	Very High
	Wandoona Waterhole	Wandering Whistling-Duck	10 ducklings	Very High
	Valetta	Black-shouldered Kite	Nesting	Very High
	Valetta	Pacific Black Duck	5 ducklings	Very High
	Derra Waterhole	Australasian Darter	3 chicks on nest	Moderate
spring 2015	Boyanga Waterhole	Black-fronted Dotterel	3 juvenile	Moderate
		Australian Reed-Warbler	Adult with young	Moderate
	Bunnor Bird Hide	Australian Reed-Warbler	Heard young	High
	Old Boyanga Wetland	Black-winged Stilt	Includes1 immature	Very Low
		Australasian Grebe	Includes 2 juvenile	Very Low
		Red-kneed Dotterel	1 juvenile	Moderate
		Australian Wood Duck	Includes 2 juvenile	Moderate
		Grey Teal	Includes 1 juvenile	Moderate
	Gin Holes	Pacific Black Duck	4 ducklings	High
		Masked Lapwing	1 juvenile	High
	Gingham Waterhole	Black Swan	Juveniles too young to fly	High
	Goddard's Lease	Red-kneed Dotterel	Juveniles included in count	Very Low
		Whistling Kite	Nest, bird flew from it	Very Low
	Jackson Paddock	Red-kneed Dotterel	2 juveniles	Very Low
	Racecourse Lagoon	Masked Lapwing	4 juveniles	Very Low
		Australian Reed-Warbler	Heard young	Very Low
		Whistling Kite	Nest on edge of site	Very Low
	Old Dromana Dam	Australian Reed-Warbler	Juveniles included in count	Moderate
	Combadello Weir	Pacific Black Duck	2 juveniles	High
autumn 2016	Gundare Weir	Pacific Black Duck	3 ducklings	Dry
	Whittaker's Lagoon	Grey Teal	6 ducklings	Very Low
		White-faced Heron	Nest	Very Low
		White-necked Heron	2 nests, 1 with chicks	Very Low

Survey period	Site	Common name	Breeding Notes	Inundation status
autumn 2017	Gingham Waterhole	Plumed Whistling-Duck	Juveniles included in count	Dry
	Racecourse Lagoon	White-bellied Sea-Eagle	Immature	High
	Tillaloo Waterhole	Nankeen Night-Heron	Juvenile	Moderate
	Allambie Bridge	Nankeen Night-Heron	Juvenile	Moderate
	Old Dromana Dam	Australasian Grebe	7 chicks	Dry
	Coombah	Straw-necked Ibis	2 juveniles	Dry
	Coombah	Nankeen Night-Heron	Juvenile	Dry
	Whittaker's Lagoon	White-necked Heron	One nest	Dry
spring 2017	Boyanga Waterhole	White-necked Heron	1 fledgling	Very High
	Bunnor Bird Hide	White-belied Sea-Eagle	On nest	Very High
	Gingham Waterhole	Sacred Kingfisher	Nest	Moderate
		Black Swan	2 cygnets	Moderate
	Gin Holes	White-faced Heron	Nest	Moderate
	Gundare Weir	Nankeen Night-heron	1 juvenile	Moderate
	Whittaker's Lagoon	White-necked Heron	On nest	Dry
autumn 2018	Old Dromana Transect	Whistling Kite	Nest	Dry
spring 2018	Gin Holes	Pacific Black Duck	7 ducklings	Moderate
	Gin Holes	Pacific Black Duck	6 juveniles	Moderate
	Gin Holes	Pacific Black Duck	6 ducklings	Moderate
	Valetta	Australian Pelican	1 juvenile	Very High
	Valetta	Sharp-tailed Sandpiper	Immature	Very High
autumn 2019	Westholme SE	Brolga	Immature	Very Low

K.3.4 Functional guilds

Ten waterbird functional guilds were present in the Gwydir Selected Area, with all 10 functional guilds recorded during every survey period. Piscivores were the most diverse guild across all survey periods with 23 species, followed by raptors with 16 species. Grazing ducks and geese were the most abundantly recorded guild across all sites and survey periods, with a total of 7,330 individuals, followed by dabbling and filter-feeding ducks, with 7,049 individuals. Gingham, Lower Gwydir and Mallowa wetland systems recorded species from all 10 functional guilds, whilst migratory charadriiform shorebirds were absent from the Mehi wetland system. All 10 functional guilds were present at floodplain and waterhole sites, whilst migratory charadriiform shorebirds were absent from Creek sites. Migratory charadriiform shorebirds were also absent during dry inundation status surveys, whilst all other inundation status categories recorded all 10 functional guilds at some stage.

The Gingham wetland system recorded the highest average functional guild richness (9.7 ± 0.5), followed by Lower Gwydir (9.1 ± 1.2), Mallowa (6.7 ± 1.4) and Mehi (5.1 ± 2.0; Figure K-17a) wetland systems. Floodplain sites (10.0 ± 0.0) and waterhole sites (9.6 ± 0.7) recorded the highest average functional guild richness, whilst creek sites recorded relatively low richness (5.4 ± 1.8; Figure K-17b). Average functional guild richness was generally associated with increased inundation with full sites (9.3 ± 1.2) and high sites (9.3 ± 1.6) recording the highest richness, whilst dry sites (4.7 ± 2.8) and very dry sites (6.4 ± 2.3; Figure K-18) recorded the lowest species richness sites.

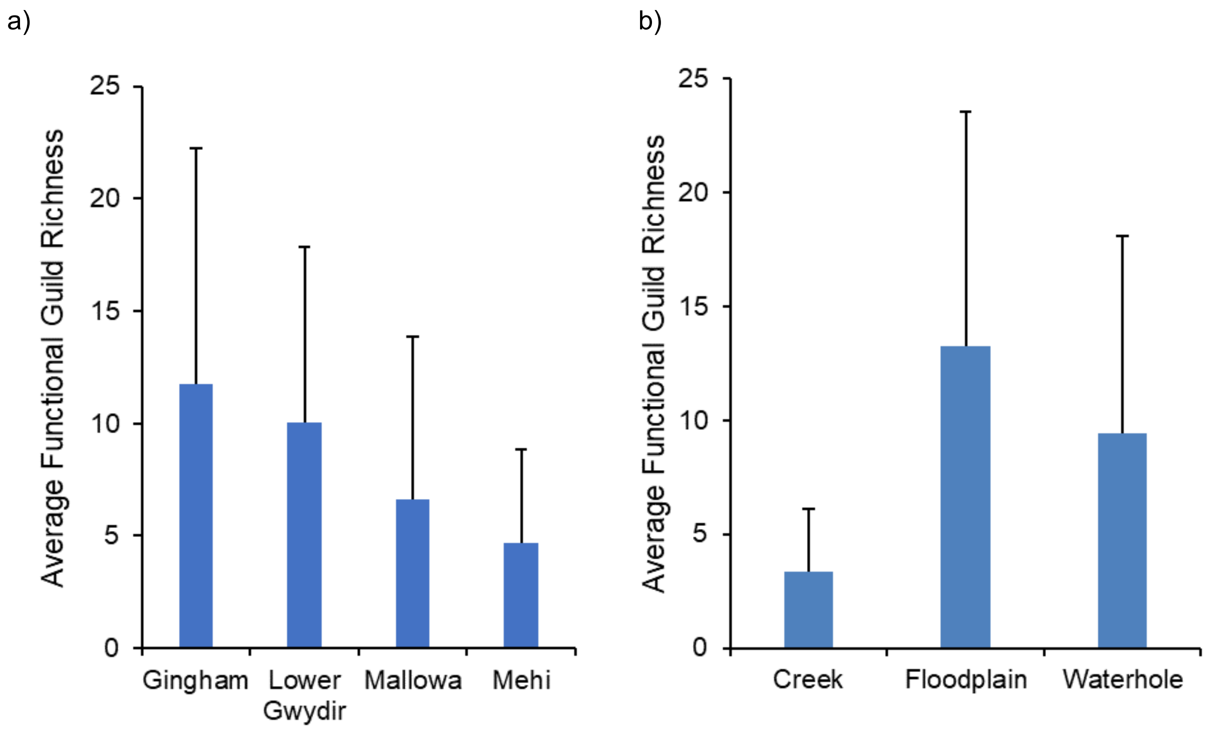


Figure K-17: a) Average functional guild richness (± SD) for each wetland system and; b) for each site type.

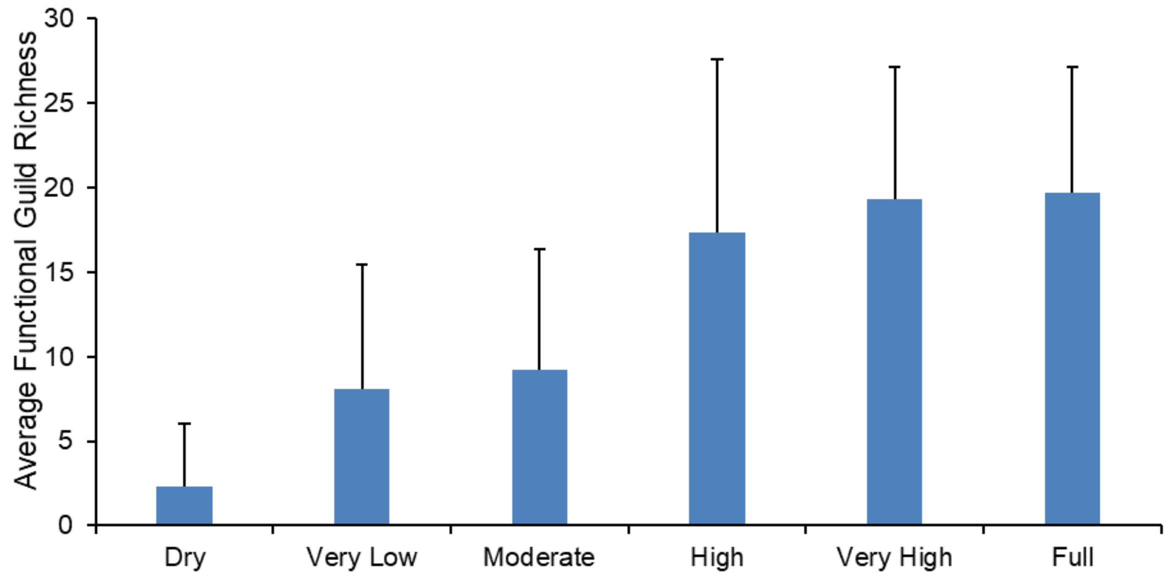


Figure K-18: Average functional guild richness (± SD) for each inundation status.

Grazing ducks and geese (135.15 ± 106.45) along with dabbling and filter-feeding ducks (122.65 ± 98.61; Figure K-19) recorded the highest average density across all functional guilds during the LTIM project. Large numbers of species from both functional guilds were consistently recorded, including plumed whistling-duck and magpie goose (Grazing ducks and geese), as well as grey teal and Pacific black duck (dabbling and filter-feeding ducks). These species were observed to congregate in large closely formed groups, particularly within the Gingham and Lower Gwydir wetland systems at sites such as Bunnor Bird Hide, Gingham Waterhole and Old Dromana Dam.

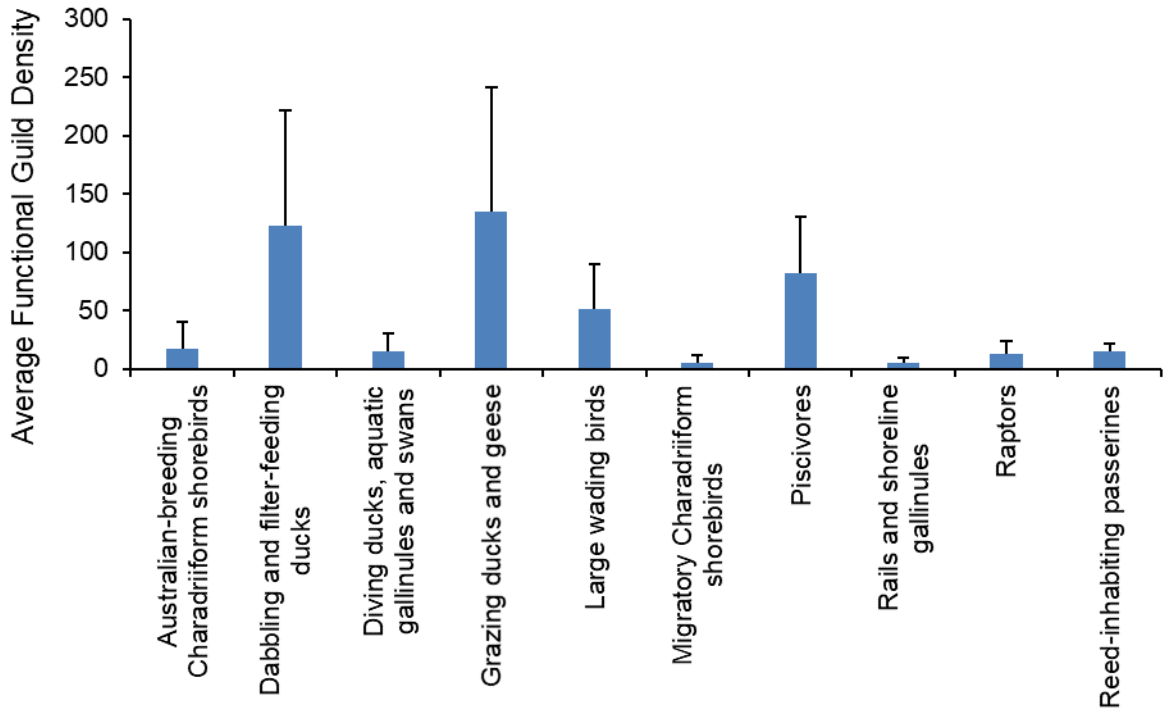


Figure K-19: Waterbird density (abundance/ha) (± SD) by functional guild across the LTIM project.

Multivariate analysis was undertaken to further explain patterns in waterbird functional guilds in the Gwydir Selected Area. The nMDS plot suggests there was some separation in the data based on wetland systems (Figure K-20) and inundation status, with a greater spread of data particularly visible for dry, very low and moderate inundation (Figure K-21). Pairwise comparison of inundation status further highlighted the separation of dry, very low and moderate inundation categories (Table K-9). This was confirmed by PERMANOVA that showed a significant separation in functional guild density between wetland systems ($P = 0.001$) and inundation status ($P = 0.001$), however, there was no significant interaction between these two factors ($P = 0.504$). There was also a significant difference in functional guild density between seasons ($P = 0.001$) and site types ($P = 0.001$), as well as a significant interaction between site types and seasons ($P=0.039$) and site types and wetland systems ($P = 0.002$).

SIMPER analysis revealed that piscivores dominated contributions to groupings across all wetland systems, in particular for the Mallowa (40.67%) and Mehi (41.84%) systems (Table K-10). The Mallowa and Mehi systems were generally characterised by fewer (three and five respectfully) functional guilds contributing to groupings, whilst the contributions to groupings were spread over a wider range of functional guilds at the Gingham and Lower Gwydir systems. Piscivores also dominated contributions to groupings for all inundation status categories, particularly dry (28.15%), very low (32.03%) and moderate (32.37%) categories (Table K-11). Raptors were also significant contributors to groupings during the above inundation categories, driven by large numbers of wedge-tailed eagles and whistling kites which are species with less of a requirement for high inundation compared to other waterbirds. In contrast, dabbling and filter-feeding ducks contributed large percentages to high (22.27%), very high (19.70%) and full (17.56%) inundation categories, with this functional guild more strongly reliant on inundation.

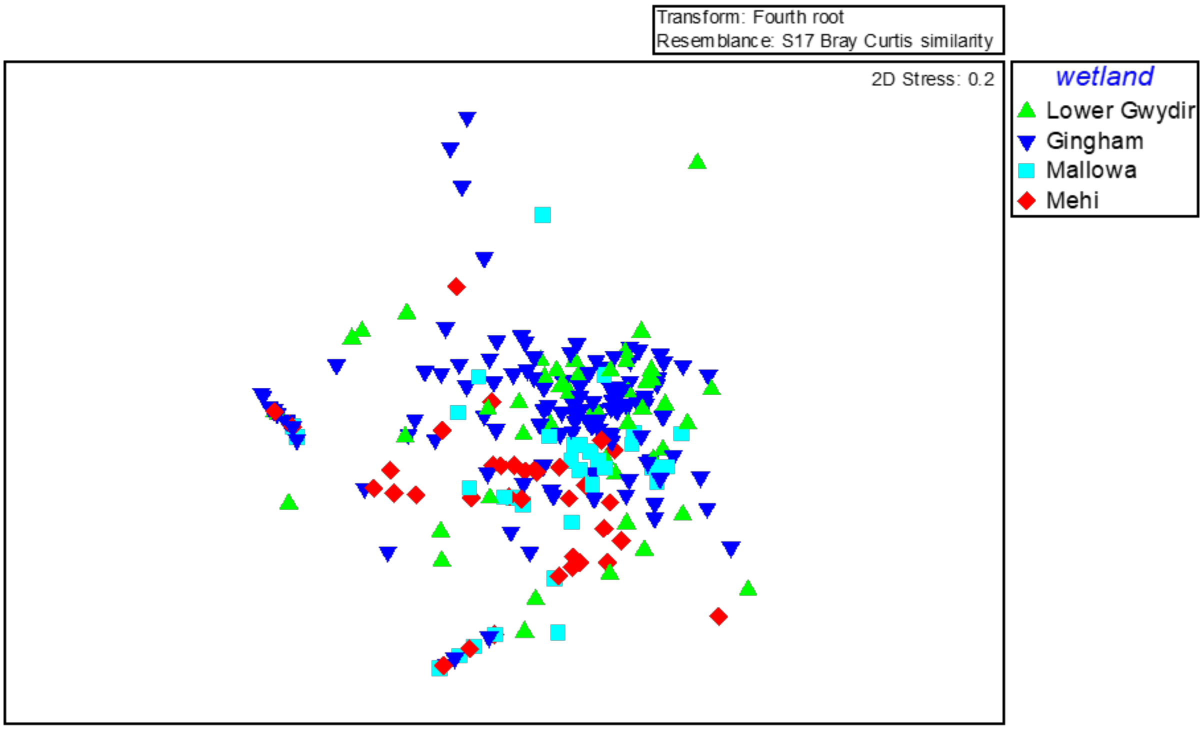


Figure K-20: nMDS plot of waterbird functional guild density grouped by wetland system.

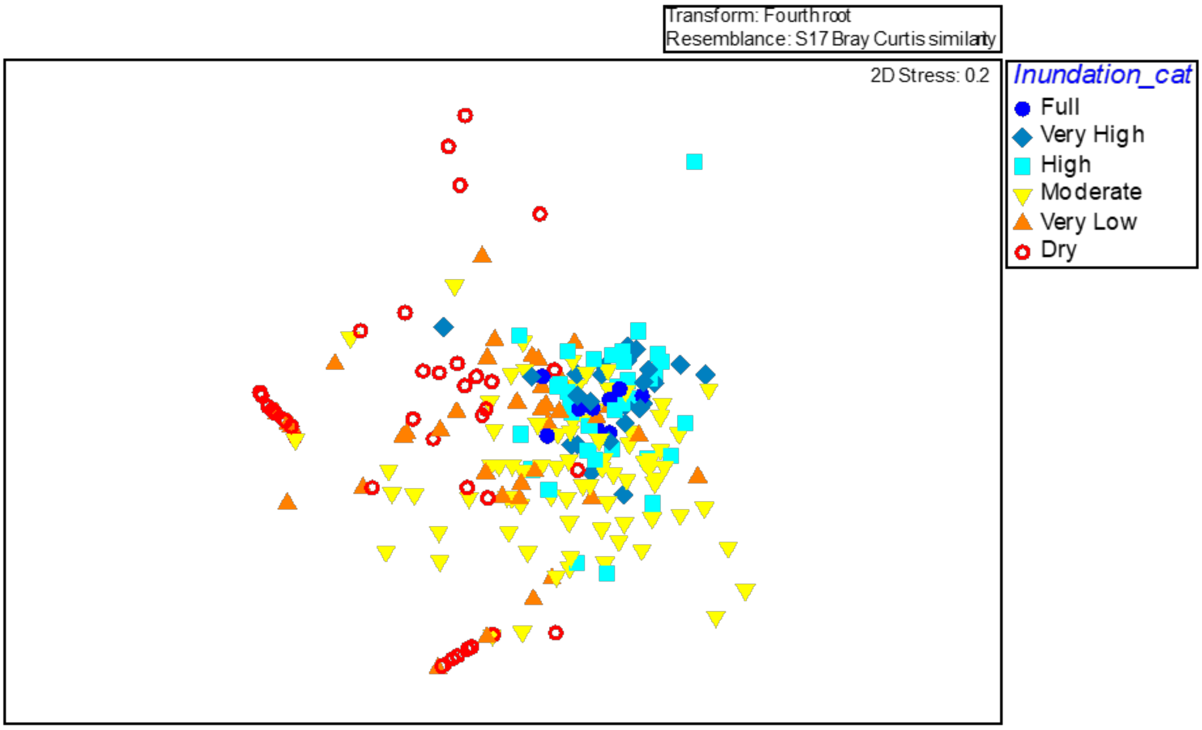


Figure K-21: nMDS plot of waterbird functional guilds grouped by inundation category.

Table K-9: Pair-wise tests results for inundation status based on waterbird functional guild density.

Inundation Status	Dry	Very Low	Moderate	High	Very High	Full
Dry		**0.006**	**0.001**	**0.001**	**0.001**	**0.001**
Very Low			**0.001**	**0.001**	**0.001**	**0.002**
Moderate				**0.001**	**0.001**	**0.023**
High					0.150	0.923
Very High						0.166
Full						

Bold indicates significant difference of ***p<0.05***.

Table K-10: SIMPER results of waterbird functional guild contributions to groupings for each wetland system. Contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Gingham	Piscivores	23.97
	Raptors	17.38
	Dabbling and filter-feeding ducks	14.90
	Reed-inhabiting passerines	10.76
Lower Gwydir	Dabbling and filter-feeding ducks	26.37
	Piscivores	24.52
	Raptors	15.08
Mallowa	Piscivores	40.67
	Dabbling and filter-feeding ducks	20.78
	Raptors	14.52
	Grazing ducks and geese	12.21
Mehi	Piscivores	41.58
	Raptors	27.59
	Dabbling and filter-feeding ducks	21.50

Table K-11: SIMPER results of waterbird functional guild contributions to groupings for each inundation status. Species contributions of less than 10% were not included.

Grouping	Species	Contribution to grouping (%)
Dry	Raptors	57.99
	Piscivores	28.15
Very Low	Piscivores	32.03
	Raptors	25.74
	Dabbling and filter-feeding ducks	14.62
	Reed-inhabiting passerines	11.48
Moderate	Piscivores	32.37
	Dabbling and filter-feeding ducks	29.49
	Raptors	13.82
	Grazing ducks and geese	10.66
High	Piscivores	24.32
	Dabbling and filter-feeding ducks	22.27
	Large wading birds	13.93
Very High	Piscivores	20.45
	Dabbling and filter-feeding ducks	19.70
	Diving ducks, aquatic gallinules and swans	10.10
Full	Piscivores	20.76
	Dabbling and filter-feeding ducks	17.56
	Large wading birds	16.76
	Grazing ducks and geese	12.35
	Reed-inhabiting passerines	10.27

K.4 Discussion

Waterbird species richness, density and diversity all varied significantly over time, between wetland systems and site types, and with varying levels of inundation within the Gwydir Selected Area over the course of the LTIM project. The lowest average results for each measure were recorded during dry inundation status, whilst the highest average results were recorded during very high and full inundation status, highlighting the importance of inundation to waterbird communities.

Waterbird monitoring was undertaken across creek, floodplain and waterhole sites within the Gwydir Selected Area, with floodplain sites recording the highest average richness, density and diversity results. These high results were largely driven by Bunnor Bird Hide site that recorded consistently high waterbird abundance and species diversity, including large groups of dabbling and filter-feeding ducks and grazing ducks and geese which accumulate in high densities. The results recorded at Bunnor Bird Hide were also largely responsible for the Gingham wetland system recording the highest average scores across all measures, along with consistently high inundation status. These results indicate that the Gingham wetland system provides important refuge habitat for waterbirds, including multiple listed migratory and threatened species.

It is not uncommon that the abundance and diversity of waterbirds vary in wetlands, as their presence is typically driven by the spatial and temporal availability of resources (Halse *et al.* 1998; Roshier *et al.* 2001). Piscivores have remained prevalent throughout the LTIM project, likely due to favourable resource and habitat conditions, such as established fish and invertebrate populations that develop during periods of inundation (Commonwealth of Australia, 2016). Flooding in inland rivers produces ‘boom’ conditions, resulting in increased habitat availability (Kingsford *et al.* 2001). Shallow waters of floodplains may only last a few months but can be extremely productive for all guilds of waterbirds and encourage breeding and successful recruitment (Kingsford & Norman 2002). This was best displayed during the 2016-17 water year, following a natural flood event in spring that was further supported by environmental water deliveries over summer, recording the highest waterbird abundance and diversity of the four years of the project.

Many Australian waterbirds can breed at any time of the year, with breeding typically associated with high habitat availability and food resources (Kingsford & Norman 2002). Across the LTIM project, recorded breeding was consistently higher in the spring surveys, which has often coincided with inundation events a few months prior to surveys. This pattern of breeding supports Kingsford *et al.* (2010) and Kingsford & Norman (2002), which indicate opportunistic patterns of waterbird breeding in relation to flooding events. Breeding activity was highest in the 2016-17 water year with over 10 species of waterbird observed breeding following significant wetland inflows.

The delivery of environmental water within the Gwydir Selected Area supports the range of habitats, which in turn support the variety of waterbirds that use these habitats. The highest average species richness, waterbird density and Shannon Diversity were recorded during spring 2018, which coincided with the largest environmental water delivery to the Gwydir River system during the LTIM project. High average results were also recorded across all metrics during the 2016-17 water year, which recorded the highest natural inflows recorded during the LTIM project. These results demonstrate the important contribution of both environmental water and natural inflows to waterbird populations in the Gwydir Selected Area.

K.5 Conclusion

The diversity of habitats present within the Gwydir Selected Area, and the delivery of environmental water to support this range of habitats is important for a range of waterbird species that use them. Throughout the five years of the LTIM project, waterbird monitoring has shown that inundation enhances the diversity and abundance of waterbirds, as well as being an important factor contributing to waterbird breeding and recruitment. Along with natural inflow, environmental water has been an important contributor in maintaining a healthy wetland system within the Gwydir Selected Area for food webs and the waterbirds they support.

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