Appendix A Ecosystem Type

A.1 Introduction

The Ecosystem type indicator contributes to the broader scale evaluation of Commonwealth environmental waters' influence on ecosystem diversity. While primarily designed to inform at larger basin scales, information on the types of ecosystems influenced by Commonwealth environmental water is also useful at the Selected Area scale. Several specific questions could be addressed by measuring ecosystem type within the Gwydir River Selected Area during the 2014-15 water year:

- What did Commonwealth environmental water contribute to sustainable ecosystem diversity?
- Was environmental water delivered to a representative suite of ecosystem types?

A.2 Methods

The ANAE classification for each sampling site in the Gwydir River Selected Area was mapped using a process of desk-top identification and field verification (Commonwealth of Australia 2014). Existing ANAE GIS layers (Brooks et al. 2013) were used to assign an ecosystem type to each monitoring site, and this was then verified in the field when monitoring took place. Sites where existing ANAE mapping did not provide coverage were assigned an ANAE classification using available desktop information and then verified in the field (Figure A-1). Field based verification was undertaken following a dichotomous key (Brooks et al. 2013).

A.3 Results

Eighty-three survey sites were sampled as part of the Gwydir River Selected Area LTIM project in 2014-15. These fell into 10 ANAE Ecosystem types, including five Riverine types, three Floodplain types and two Lacustrine types. The Rp1.4: The Permanent lowland streams type is represented by the most sites, with 30 sites falling into this ecosystem type (Table A-1). Nineteen sites fall into the F3.2: Sedge/forb/grassland floodplain type, while 16 sites fall into the Rt1.4: Temporary lowland stream ecosystem type (Table A-1). All other types are represented by 5 or less sites.

Within the Selected Area, most sites (72%) are situated in the Gwydir-Gingham watercourse zone. This zone containes all 10 ANAE Ecosystem types present within the Selected Area, with all 19 of the F3.2: Sedge/forb/grassland floodplain type occurring in this zone (Figure A-2). There are only two sites within the Gwydir River zone, and these fall into the Rp1.1: Permanent high energy upland streams and Rp1.4: Permanent lowland streams types. Sites in the Mehi-Moomin zone are located within Rp1.4: Permanent lowland streams and Rt1.4: Temporary lowland streams ecosystem types (Figure A-2).

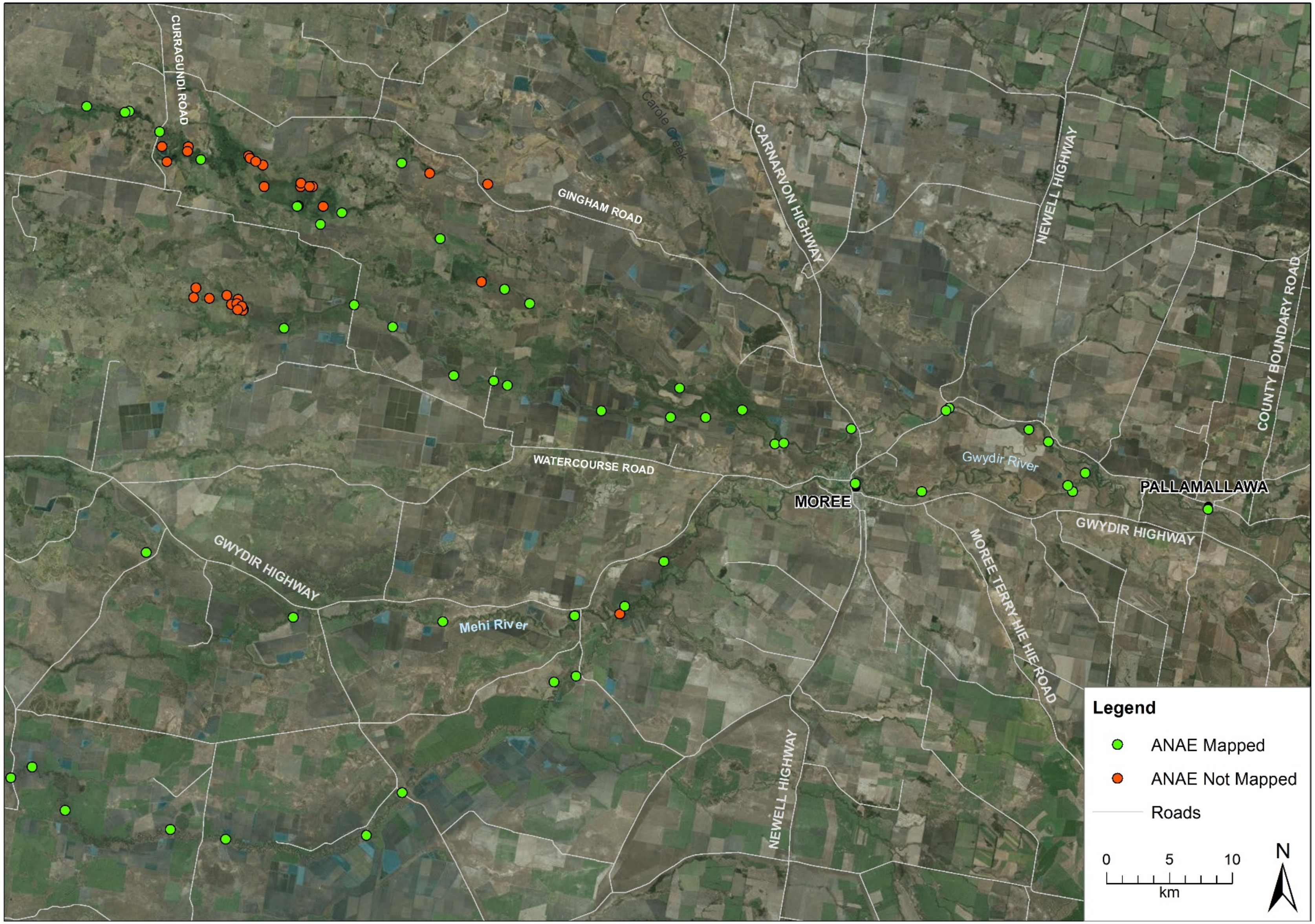

Figure A-1: Sites where existing ANAE mapping provided adequate coverage and sites where ANAE was assigned and verified in the field.

Table A-1: ANAE Ecosystem types covered by monitoring sites in the Gwydir River Selected Area LTIM project.

ANAE Typology	Number of sites (All Zones)	%
F1.10: Coolibah woodland and forest floodplain	3	4
F1.11: River Cooba Woodland Floodplain	1	1
F3.2 Sedge/forb/grassland floodplain	19	23
LP2.1: Temporary floodplain lake	2	2
LT2.2 Temporary floodplain lake with aquatic beds	4	5
Rp1.1: Permanent high energy upland streams	1	1
Rp1.3: Permanent low energy upland streams	5	6
Rp1.4: Permanent lowland streams	30	36
Rt1.3: Temporary low energy upland streams	2	2
Rt1.4: Temporary lowland streams	16	19
Total	**83**	

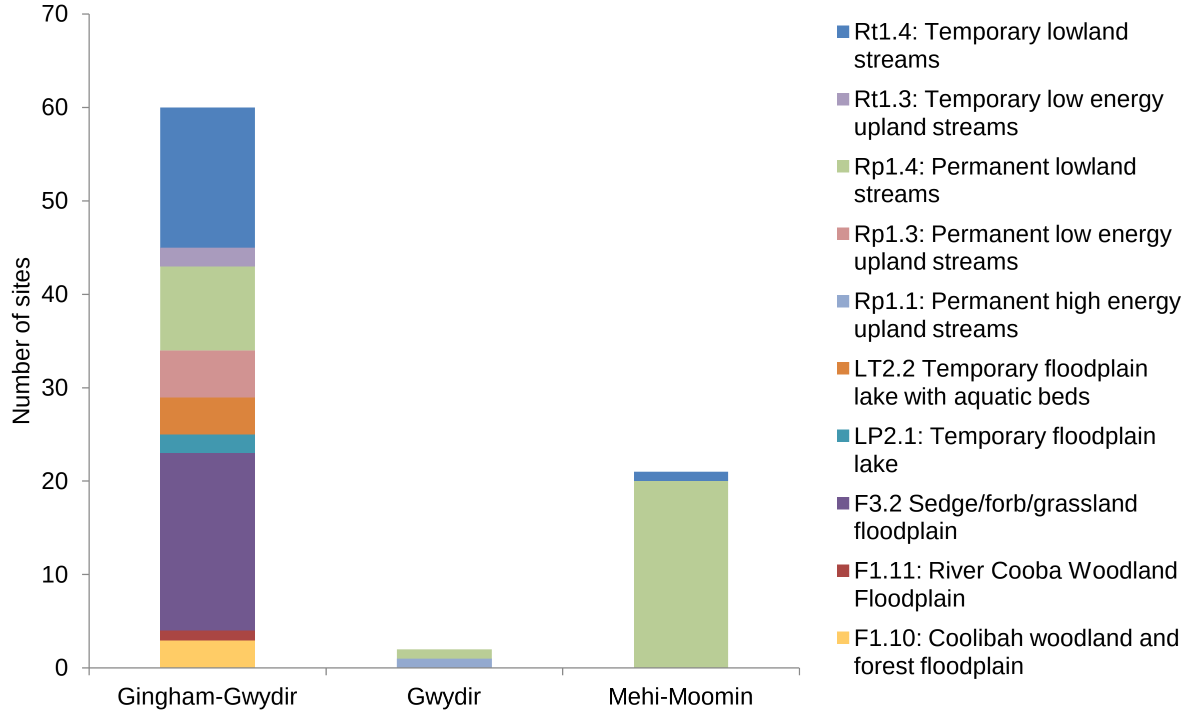

Figure A-2: Distribution of ANAE Ecosystem types represented by sites across the three monitoring zones within the Selected Area.

A.4 Discussion

The types of ecosystems monitored in this project are a reflection of the nature of the delivery of environmental water, and the indicators being assessed. Given the emphasis on eco-hydrology links in the project, the dominance of Riverine Ecosystem types is self-evident. The large representation of sites within the Sedge/forb/grassland floodplain type is a reflection of the dominance of this type in low lying areas of the Gwydir and Gingham Watercourse zone that commonly form the target for environmental watering. Other floodplain types have been targeted as, while sitting higher on the floodplain, also become inundated relatively often and are targeted for environmental water delivery.

During the 2014-15 water year, Commonwealth environmental water was delivered to sites representing all 10 ANAE Ecosystem types monitored in the project. Ecological responses to this water were observed for many of the indicators measured at these sites, suggesting that the delivery of this water is in part helping to sustain ecosystem diversity within the Gwydir River system.

A.5 References

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

Commonwealth of Australia (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Gwydir River System Selected Area, Canberra.

Appendix B Hydrology (River)

B.1 Introduction

The Hydrology (River) indicator provides in-channel hydrological information on the character of Commonwealth environmental water and other environmental water deliveries. In particular, this indicator focuses on hydrological connectivity, that is the transfer of water from one part of the landscape to another and the related physical movement of matter through the catchment (Lexartza-Artza & Wainwright 2009). The connectivity across the landscape affects the conveyance of water and matter spatially and temporally. It also influences biophysical and biogeochemical functions (Lexartza-Artza & Wainwright 2009). As such, this information is directly relevant to a number of other indicators measured in the Gwydir Selected Area including vegetation, waterbirds, fish and microinvertebrates. The particular 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 connectivity maintained through the Gwydir Selected Area during the 2014-15 water year. 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 Gingham-Gwydir Watercourse Wetlands?

B.1.1 Environmental watering in 2014-15

Available Commonwealth environmental water holdings totalled 79,784 ML in the 2014-15 water year. This was complemented by water entitlements held by NSW OEH in the Environmental Contingency Allowance (ECA) of 89,260 ML. Of this, a total of 56,639 ML of Commonwealth and 29,895 ML of ECA water were delivered in the 2014-15 season, via several events across several channels (Table B-1).

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.

Table B-1: Environmental water delivered in the Gwydir system in 2014-15.

<table>
<tr><th>Channel</th><th>Commonwealth Environmental Water delivered (ML)</th><th>NSW ECA Water delivered (ML)</th></tr>
<tr><td>Gingham Watercourse</td><td rowspan="2">30,000</td><td>14,868</td></tr>
<tr><td>Lower Gwydir</td><td>15,027</td></tr>
<tr><td>Carole Creek</td><td>3,656</td><td>n/a</td></tr>
<tr><td>Mehi River</td><td>13,316</td><td>n/a</td></tr>
<tr><td>Mallowa Creek</td><td>9,667</td><td>n/a</td></tr>
<tr><td>Total</td><td>56,639</td><td>29,895</td></tr>
</table>

B.1.2 Previous monitoring

Monitoring of hydrological connectivity was undertaken during the 2013-14 water year by Southwell et al. (2015). During this period, hydrological connection was achieved throughout the lower Gwydir system between 36% and 53% of the time, while the delivery of environmental water provided full connection through the Mehi channel to the Barwon River during October. Generally there was only a small influence of environmental water on longitudinal connectivity due to the relatively large proportion of irrigation water delivered to the Mehi River and Carole Creek channels. The Lower Gwydir channel had flows sufficient to provide connections down to the Millewa gauge (Figure B-1) for the majority of the summer, but this did not include any environmental water. In contrast, the Gingham system displayed the lowest level of longitudinal connection, with a 153 day period of no longitudinal connection down to the Gingham Road Bridge between October 2013 and late March 2014 (Southwell et al. 2015).

B.2 Methods

B.2.1 Hydrological connectivity

An assessment of the hydrological connectivity experienced throughout the zones in the Gwydir Selected Area was undertaken following the methods outlined in Southwell et al. (2015) and 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 B-1). These thresholds were then compared with known average stream losses provided by NSW State Water. 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. The gauging stations used for this analysis are presented in Figure B-1 and Table B-2 outlines the thresholds estimated to provide longitudinal connectivity.

Once the thresholds were identified, a SPELL 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 2014-15 season.

B.2.2 Targeted in-channel environmental flow event analysis

To assess the nature of the Commonwealth environmental water delivered down the Mehi channel during the 2014-15 season, a targeted analysis of this in-channel event was undertaken. This was done by comparing the target flow hydrograph with the actual hydrograph at the upstream Mehi River DS Combadello Weir (418037) and downstream Mehi River @ near Collarenebri (418055) river gauges.

A number of metrics were calculated to compare the target and actual flow hydrographs at these gauging stations. These included; the rate and duration of the rising and falling limbs of the flow; the magnitude and duration of the flow peak and the total volume of the delivered flows. The actual flow was rated as good if the metric was within 20% of the intended flow.

Table B-2: Thresholds at the various gauging stations used in the hydrological connectivity analysis.

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 @ Pallamallowa (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

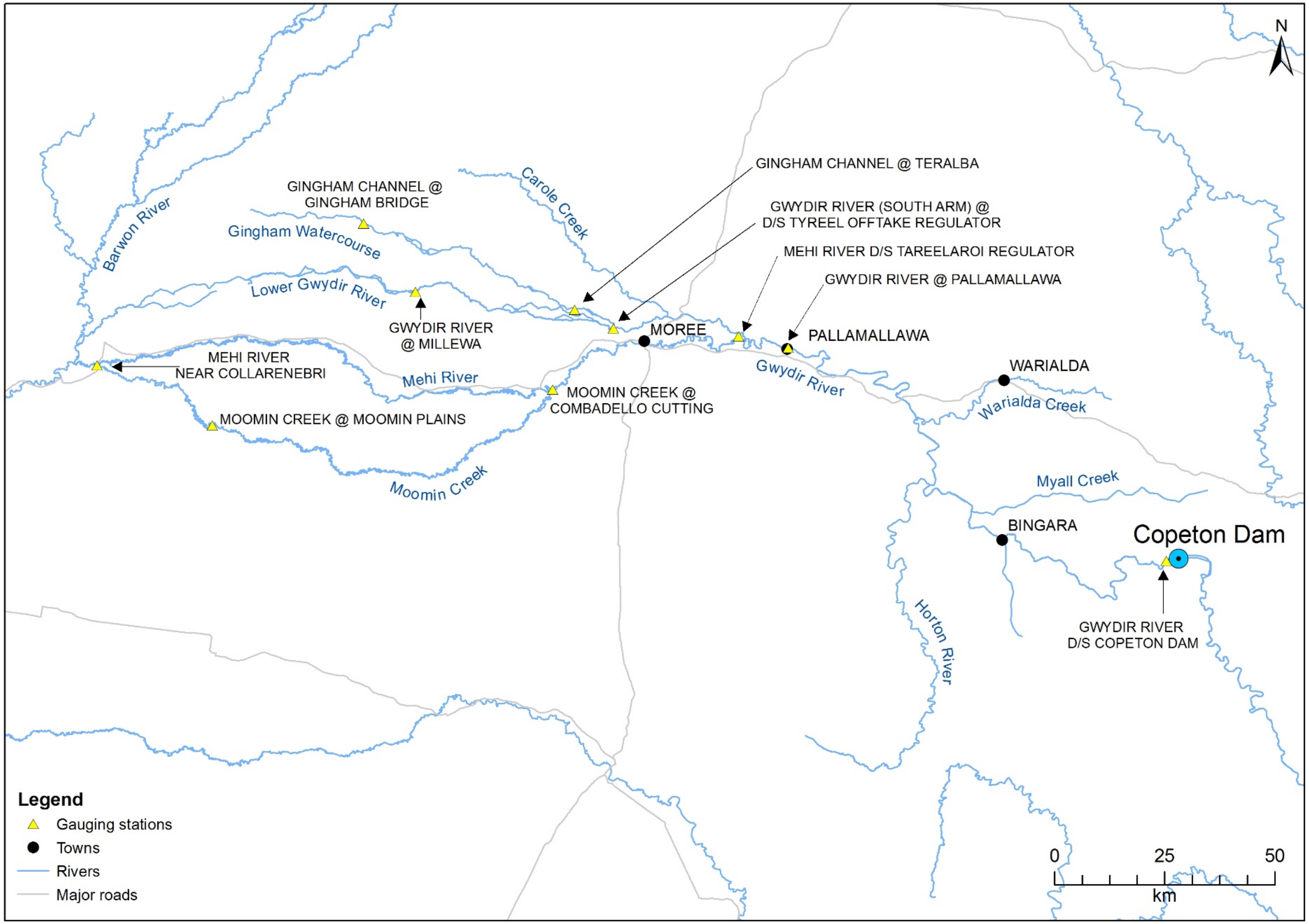

Figure B-1: Location of flow gauging stations used in the hydrological connectivity analysis.

B.3 Results

B.3.1 Longitudinal connectivity

In 2014-15, hydrological connectivity was experienced along the lower Gwydir River (Table B-3). The Gwydir River channel had 48% connection (i.e. 48% of days where flows were above the relevant connection threshold at both gauges within the 2014-15 water year), Lower Gwydir 62% connection, Gingham Watercourse 24% connection, Mehi River channel 21% connection and the Moomin River channel 15% connection. The Gwydir and Lower Gwydir channels experienced the longest average duration of connectivity (58 and 89 days respectively) while the Mehi River and Moomin Creek channels experienced the shortest average durations of connection (39 and 22 days respectively).

Table B-3: Variables describing the duration and character of hydrological connectivity within the channels of the Gwydir Selected Area.

Zone	Channel	Days connected (%)	No. of times connected	Average duration of connection events (days)	Longest wet (days)	Longest dry (days)
Gwydir River	Gwydir	48	3	58	129	105
Gwydir-Gingham Watercourse	Lower Gwydir	62	7	89	164	57
	Gingham	24	6	20	64	89
Mehi-Moomin	Mehi	21	8	10	39	91
	Moomin	15	4	14	22	167

Connection in the Gwydir River channel was dominated by two events of relatively long duration (39 and 129 days) during September to March (Figure B-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 which assumed full connection of this reach from Copeton Dam downstream to Pallamallawa.

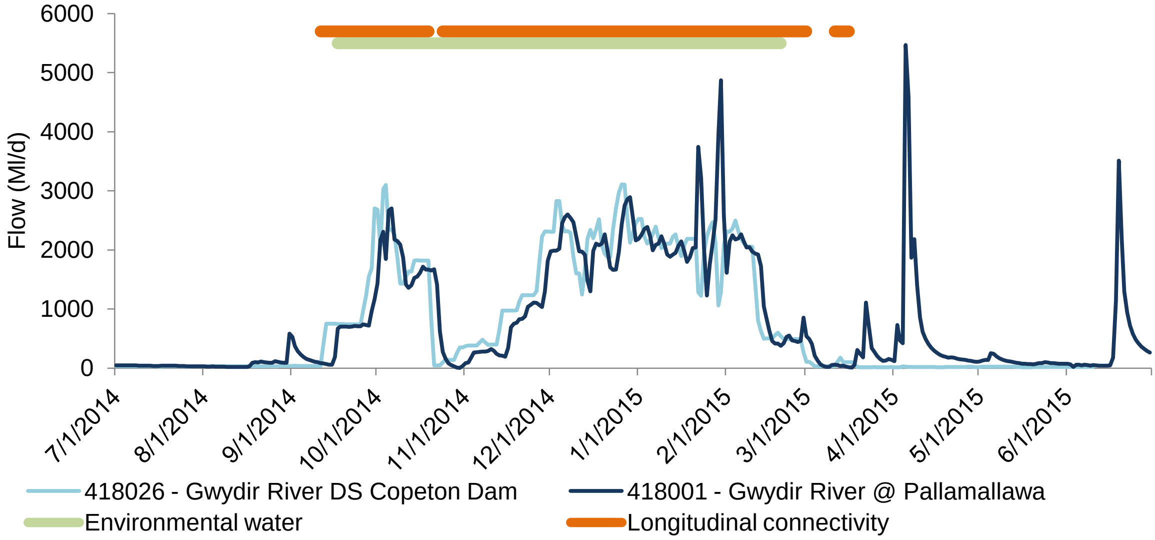

Figure B-2: River flows down the Gwydir River and the timing of environmental water releases and longitudinal connectivity down this channel.

Similarly, longitudinal connectivity down the Lower Gwydir was dominated by environmental water delivered through the September to March period (Figure B-3). While flows in the upstream section of this reach were pulsed during this period, longitudinal connectivity was maintained through to the wetlands. In addition, several shorter connection events were experienced as a result of the rainfall generated flows towards the end of the water year.

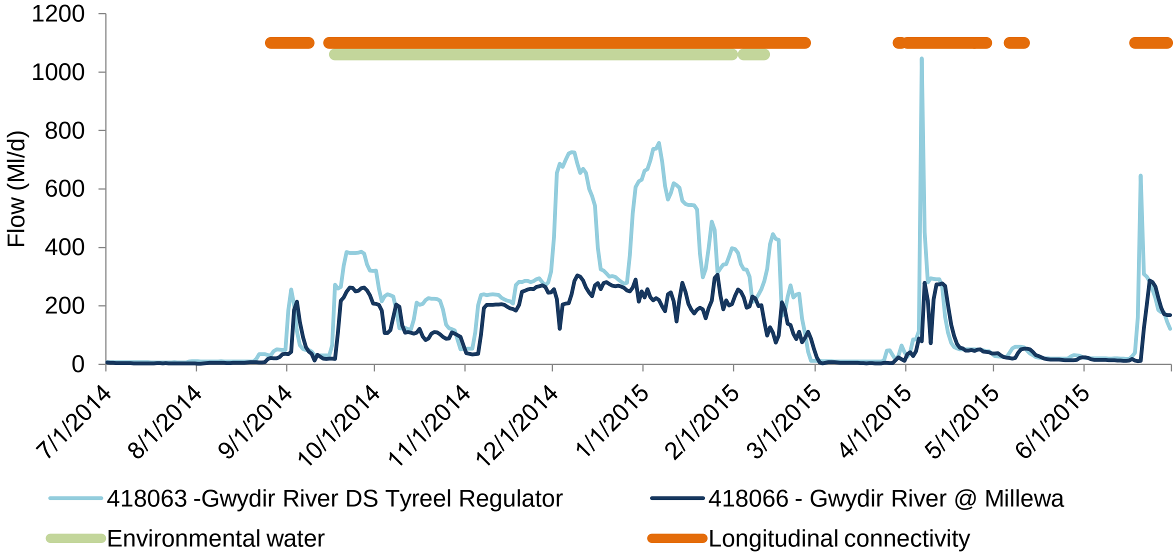

Figure B-3: River flows down the Lower Gwydir River and the timing of environmental water releases and longitudinal connectivity down this channel.

Instances of longitudinal connection along the Gingham Watercourse were shorter in duration being influenced by both environmental water and rainfall generated flow events (Figure B-4). Environmental water was delivered to the Gingham in two discrete parcels during September and November through March. 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.

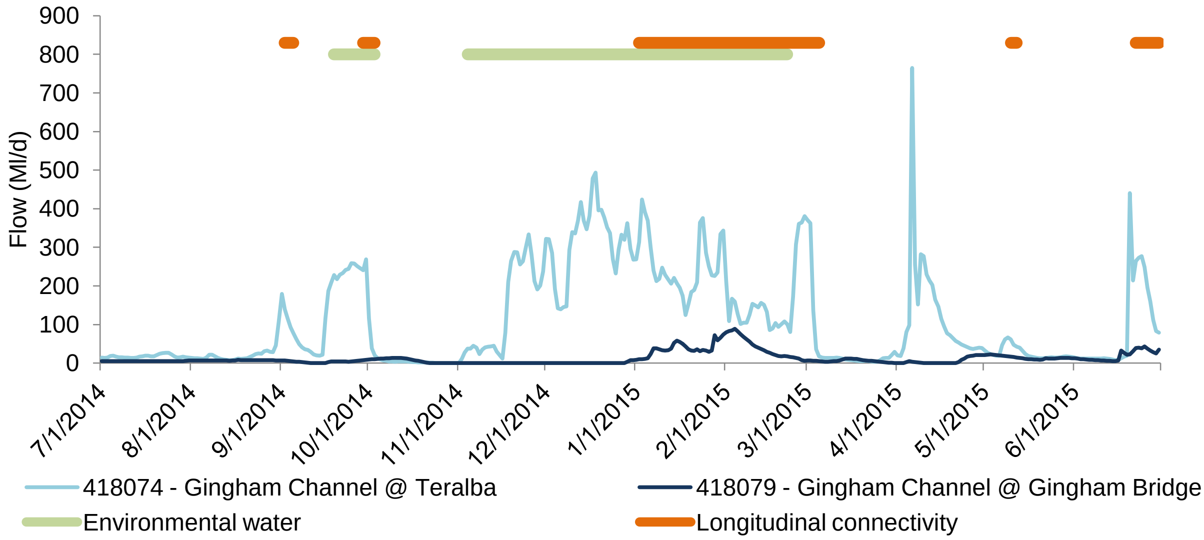

Figure B-4: River flows down the Gingham Watercourse and the timing of environmental water releases and longitudinal connectivity down this channel.

Longitudinal connectivity in the Mehi channel was characterized by shorter, relatively frequent events (Figure B-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 B-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.

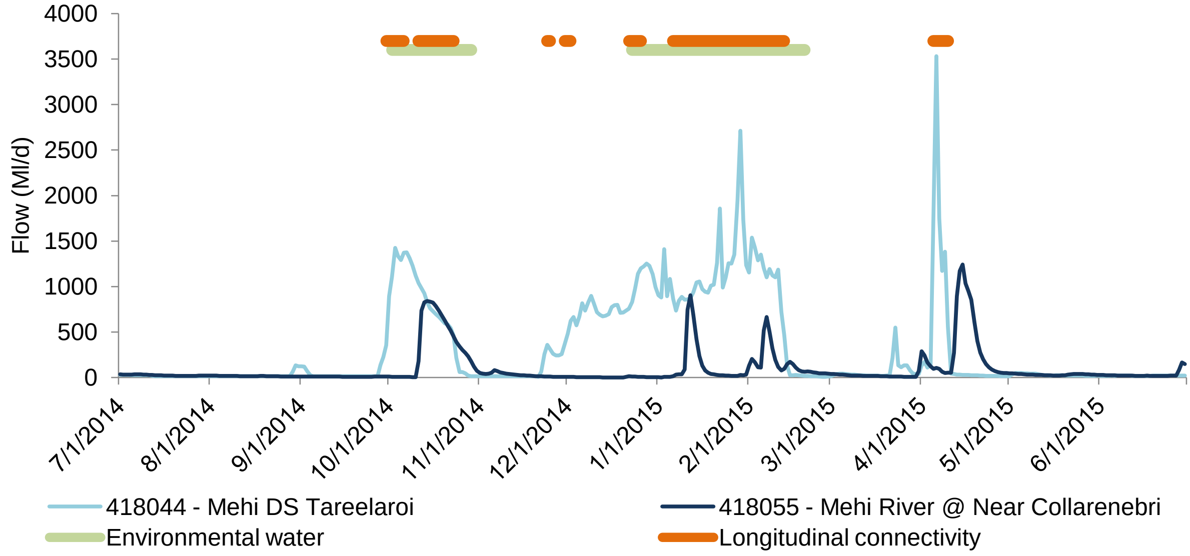

Figure B-5: River flows down the Mehi River and the timing of environmental water releases and longitudinal connectivity down this channel.

The Moomin Creek channel experienced longitudinal connection through the December 2014 – February 2015 period (Figure B-6). This connection was aided by stock and domestic water deliveries down this channel and included no environmental water. As with other channels in the Selected Area localised rainfall generated flows were important for longitudinal connectivity in the Moomin Creek channel.

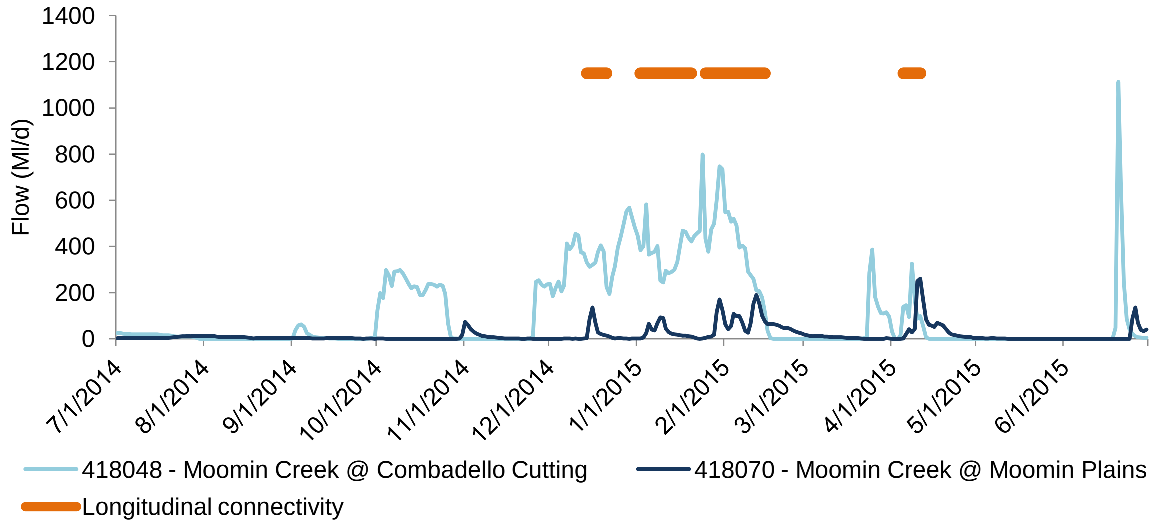

Figure B-6: River flows down Moomin Creek and the timing of longitudinal connectivity down this channel.

B.3.2 Targeted in-channel environmental flow event analysis

In the Mehi channel, the delivered in-channel flow was similar to the desired target flow event at both the upstream and downstream gauges (Table B-4; Figure B-7). The rising and falling limbs were both within 20% of the target flow hydrograph. The magnitude of the flow peaks was lower than planned (1095 ML/d DS of Combadello compared to the 1300 ML/d target). However, the duration of the flow peak was twice as long as the target. In terms of overall flow volume, the flow event at the upstream gauge was larger than the target by 1,505 ML.

Table B-4: Comparison of target and actual flow hydrographs for the in-channel Commonwealth environmental water released down the Mehi River during the 2013-14 water year. Green indicates result within 20% of target, orange indicates result is >20% target.

Hydrograph component		Target CEW flow	418037 – Mehi River D/S Combadello Weir	418055 – Mehi River near Collarenebri
Rising limb	Av. rate of increase	260 ML/d	219 ML/d	205 ML/d
	Duration	5 days	5 days	4 days
Peak	Discharge	1,300 ML/d	1,095 ML/d	840 ML/d
	Duration	2 days	4 days	4 days
Falling limb	Av. rate of decrease	52 ML/d	42 ML/d	45 ML/d
	Duration	22 days	25 days	17 days
Event total	Volume	15,000 ML	16,505 ML	10,555 ML

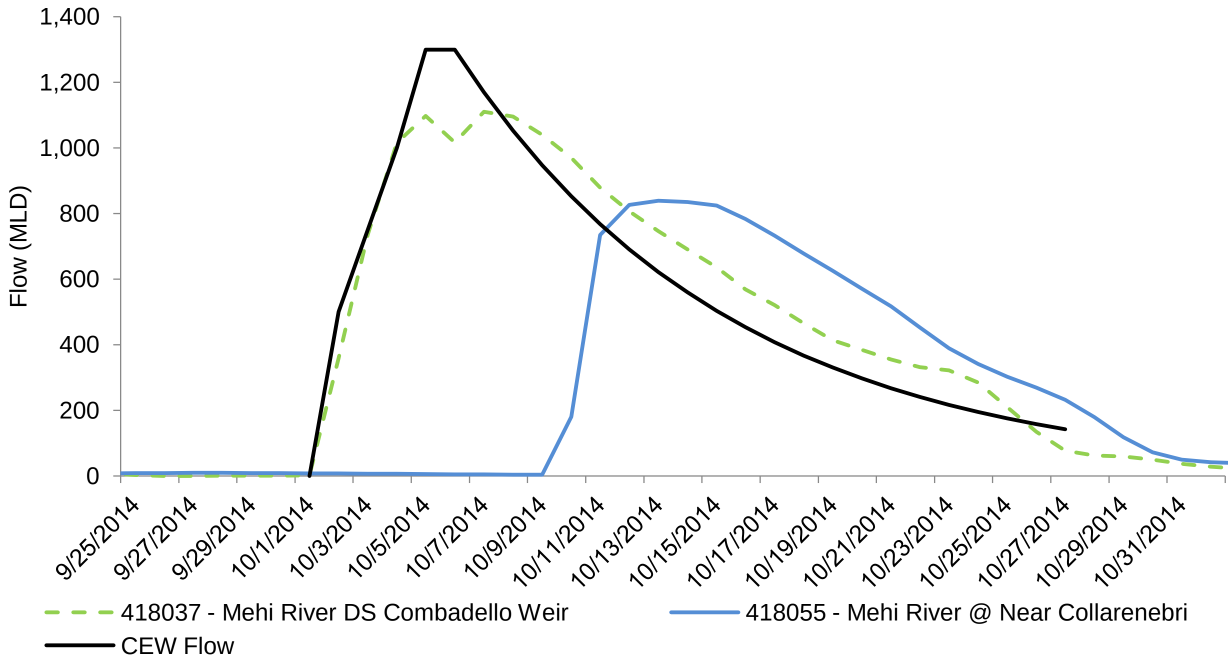

Figure B-7: Upstream (Mehi River DS Combadello Weir) and downstream (Mehi River @ Near Collarenebri) flow hydrographs compared to the target hydrograph for the Commonwealth in-channel environmental flow delivered within the Mehi River channel.

B.4 Discussion

The delivery of environmental and stock and domestic water dominated the flows down all channels in the lower Gwydir system during the early and mid-parts of the 2014-15 water year, with rainfall generating minor flows in the system. Increased rainfall in the catchment from April 2015 onwards resulted in a number of short flow events through the system which increased longitudinal connectivity in most channels. Longitudinal connectivity was greatest along the Lower Gwydir and Gingham channels during 2014-15, characterized by fewer but longer connection events. With channel capacity and timing constraints in both these channels, environmental water was delivered at smaller volumes (250-450 ML/d) over longer time periods. The break in environmental water delivery in October through November to allow access to cropping country upstream of the wetlands had the most influence on longitudinal connectivity in the Gingham watercourse, with a 3 month gap between full connection of this channel. Once environmental flows were reinstated in the Gingham channel it took nearly 2 months to re-establish full connection through these wetlands.

The lack of a gauging station at the downstream extent of the Lower Gwydir wetlands precluded analysis of longitudinal connectivity using the current methods. However, observations from a monitoring camera at Wondoona Waterhole in the western wetlands suggests that water was flowing into this wetland from December through early February, then again in late April to June. This suggests that environmental water delivered down this channel during the summer period made it through to the western extent of this wetland.

By contrast, flows down the Mehi and Moomin channels were of shorter duration, and while the targeted in-channel environmental flow in October delivered to the Mehi River produced a significant flow peak down the full length of this channel, further environmental flows delivered via this channel to the Mallowa Creek, did not. Flows down the Moomin channel were reflective of both stock and domestic water delivery and natural flows towards the end of the water year.

In general, the environmental flow pulse delivered to the Mehi River for in-channel benefit reflected the target flow hydrograph. While the peak of the flow was a little lower than intended, due to insufficient water being stored in Tareelaroi storage to allow the higher peak to be delivered (NOW unpublished data), it provided a distinct flow peak down the channel. Due to the combination of environmental and stock and domestic water used to produce this flow event, the overall volume was higher in the upstream reaches. This flow provided complete connection through this channel and into the Barwon River downstream. Compared to the environmental flow pulse provided to the Mehi River during the 2013-14 water year, this flow was more successfully separated from other deliveries down the system. In 2013-14 the falling limb of the environmental flow was quickly overtaken by other deliveries in the upstream reaches of the channel, impacting on the desired steady flow recession. This water year, however, the steady flow recession was successfully achieved throughout the whole length of the Mehi channel. A steady receding limb is thought to be important for allowing larval fish to better establish (Southwell et al. 2015).

B.5 Conclusion

Environmental water contributed to longitudinal connectivity in the Gwydir, Lower Gwydir, Gingham and Mehi channels through the 2014-15 water year. In all of these channels, environmental water was a major source of flows in the early and mid-stages of the year, with some rainfall generated flow events providing connection towards the end of the water year. Connection in the Lower Gwydir and Gingham channels through to the wetlands was largely a result of environmental water, although the break in delivery during October and November limited the effectiveness of the earlier water deliveries in terms of connection through the Gingham Watercourse.

The in-channel environmental flow pulse provided in the Mehi channel produced a noticeable flow peak down the full length of the channel to the Barwon River. The timing of delivery of this flow resulted in a flow event that better mimicked the planned hydrograph, compared to the previous year, where irrigation water deliveries impacted the falling limb of the flow pulse (Southwell et al. 2015).

B.6 References

Commonwealth of Australia (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Gwydir River System Selected Area, Canberra.

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

Lexartza-Artza, I. and Wainwright, J. (2009) Hydrological connectivity: Linking concepts with practical implications, *Catena*, **79**, pp. 146 – 152.

Southwell, M., Wilson, G., Ryder, D., Sparks, P. and Thoms, M (2015) Monitoring the ecological response of Commonwealth Environmental Water delivered in 2013-14 in the Gwydir River System. A report to the Department of the Environment. Armidale.

Appendix C Fish (River)

C.1 Introduction

The fish assemblages of the Gwydir valley are considered to be in a severely degraded state (Murray Darling Basin Authority 2012). The Sustainable River Audit (SRA) No. 2 Report stated that the fish in the upper sections (above 400 m ASL) of the valley were in 'Very Poor' condition, the Slopes (201-400 m ASL) were in 'Moderate' condition, whilst in the Lowland (31-200 m ASL) they were classified as 'Poor' (Murray Darling Basin Authority 2012). Overall the fish community across the valley was classified as 'Poor'. The SRA reported that the Gwydir in general had reduced numbers of species and abundance among the native fish, recruitment was variable and generally low on a site by site basis, and that 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 was to benchmark and describe the fish community in abundance, biomass and health across the four channels in the lower Gwydir system in relation 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?

C.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Table B-1). 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 (Appendix B). In addition, flows were delivered to the Lower Gwydir, Gingham watercourse and Mallowa Creek to provide for wetland inundation (Appendix G).

C.1.2 Previous monitoring

Recent sampling of the Lower Gwydir fish community was undertaken as part of the short term intervention monitoring project over the 2013-14 water year (Southwell et al. 2015). Here, a total of 10 native species and three exotic species were recorded in the channels of the lower Gwydir. Overall, the most abundant species sampled was Bony herring (*Nematolosa erebi*) which made up 41.6% of the total catch. Other large-bodied species such as Murray cod (*Maccullochella peelii*), Golden perch (*Macquaria ambigua*) and Freshwater catfish (*Tandanus tandanus)* were only caught in relatively low numbers. Australian smelt (*Retropinna semoni*) and Carp gudgeon (*Hypseleotris* sp.) dominated the catch among the small-bodied species. Common carp were the most abundant species sampled among the exotics. However, overall exotic species only made up ~10% of the total catch.

C.2 Methods

C.2.1 Sampling sites

Data were collated from 23 sites within the four channels across the lower Gwydir system for *Cat 3 Fish River* analyses (Figure C-1; Table C-1); the Gingham Watercourse, Gwydir River, Mehi River and

Moomin Creek (Commonwealth of Australia 2014). Sampling was undertaken over March-May 2015. Fifteen sites were sampled solely as part of the *Gwydir LTIM Cat 3* program; five each in the Mehi, Moomin and Gingham sub-catchments. A sub-set of the data from six (randomly chosen) of the 10 *LTIM Cat 1 Fish River* sites from the lower Gwydir River was also used in the analyses. For these sites, 1080 sec of boat or 1200 sec of backpack electrofishing (or where applicable combinations of both) was used as the sampling effort. Data from an additional site in each of the Mehi and Moomin channels were also used in the analyses, collected by Fisheries NSW using the same protocols as part of the Murray Darling Basin Plan program.

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 across all four channels tended to be turbid and relatively shallow. There were also distinct pool/run/riffle sequences present within many of the sites. In the Gwydir River upstream of Tyreel Weir and in the Mehi River, the river channel tended to be 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 (~8-16 m) and shallower (~0.5 m). Each of the four channels was typified by wider, deeper pools at the upstream sites, whilst at the lower ends of each the watercourse became almost discontinuous in places, with minimal above surface flow apparent between pools at some sites.

In-stream habitat across all four sub-catchments was dominated by submerged timber and undercut banks. The substratum at most sites was typically mud; however, gravel, sand and silt substrates were also present in some areas. In general, the majority of sites were highly disturbed as a result of anthropogenic influences such as agriculture, altered flows, and terrestrial and aquatic exotic species. Nearly all sites were adjacent to irrigated and dryland cropping land. Most sites were fringed by only a narrow riparian zone, dominated by native trees and exotic shrubs. Notable terrestrial weeds included African boxthorn (*Lycium ferocissimum*), Noogoora burr (*Xanthium pungens*) and Lippia (*Phyla canescens*).

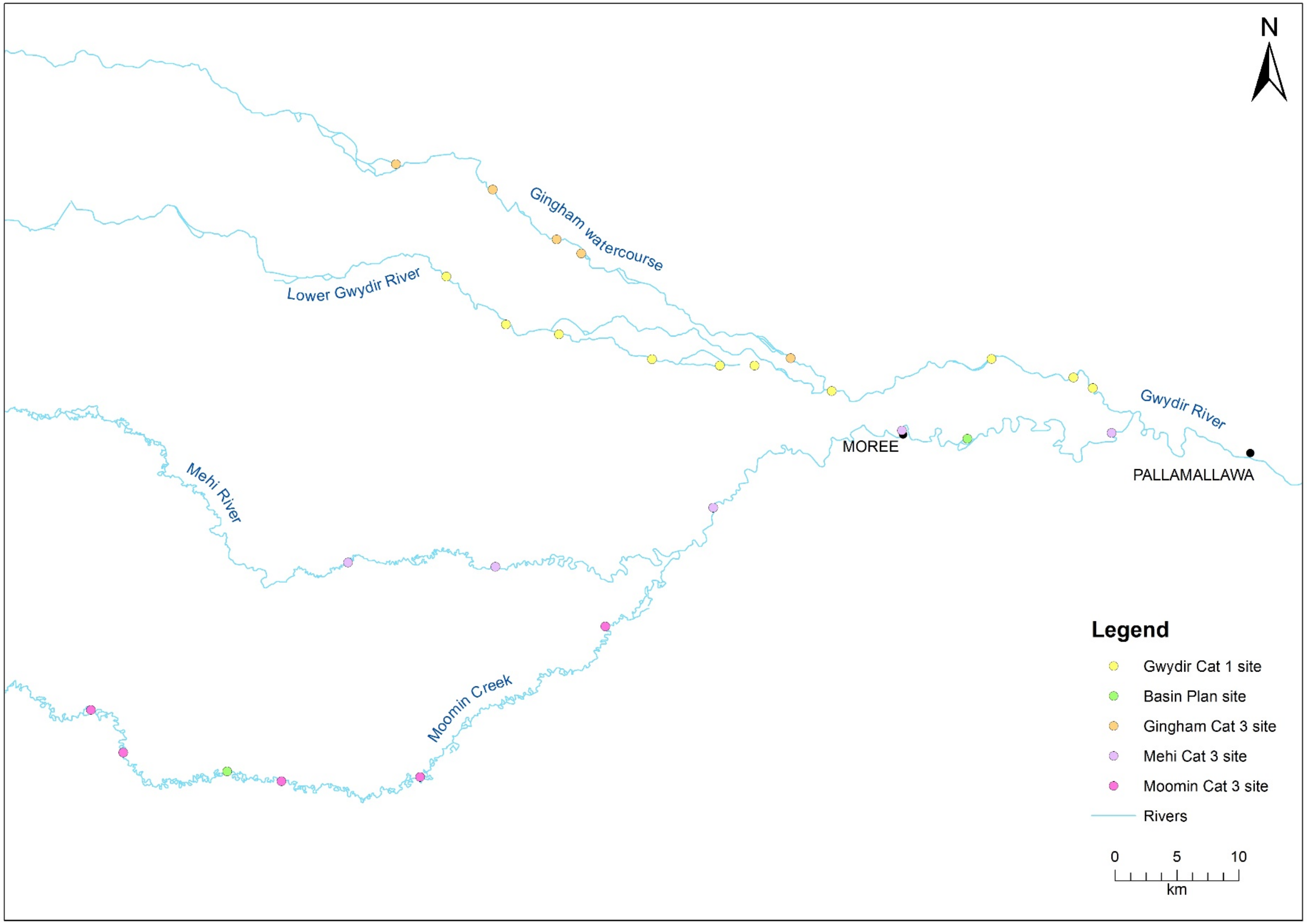

Figure C-1: Location of monitoring sites in the Gwydir, Mehi, Moomin and Gingham channels sampled for the Fish (River) indicator.

Table C-1: Locations and details of sites used in the analysis of Gwydir LTIM Category 3 Fish River.

Site Name	River	Source	Latitude	Longitude	Zone	Effort
Gingham 27	Gingham Watercourse	LTIM CAT 3	-29.34100	149.57700	Lowland	Backpack
Gingham 38	Gingham Watercourse	LTIM CAT 3	-29.29600	149.50000	Lowland	Backpack
Bullerana	Gingham Watercourse	LTIM CAT 3	-29.33100	149.55100	Lowland	Backpack
Gingham 49	Gingham Watercourse	LTIM CAT 3	-29.27900	149.41900	Lowland	Backpack
Gingham 4	Gingham Watercourse	LTIM CAT 3	-29.41400	149.75100	Slopes (L)	Medium boat
Braggeen Crossing	Gwydir River	LTIM CAT 1	-29.41679	149.63554	Lowland	Backpack
GLTIM C1 S9	Gwydir River	LTIM CAT 1	-29.39400	149.51300	Lowland	Backpack
GLTIM C1 S6	Gwydir River	LTIM CAT 1	-29.42200	149.69000	Lowland	Backpack
Norwood	Gwydir River	LTIM CAT 1	-29.43597	149.78444	Slopes (L)	Medium boat / backpack
Redbank	Gwydir River	LTIM CAT 1	-29.43086	150.00138	Slopes (L)	Small boat / backpack
GLTIM C1 S2	Gwydir River	LTIM CAT 1	-29.42300	149.98800	Slopes (L)	Backpack
Mehi 16	Mehi River	LTIM CAT 3	-29.57000	149.38600	Lowland	Backpack
Mehi 49	Mehi River	LTIM CAT 3	-29.57100	149.50900	Lowland	Backpack
Mehi 82	Mehi River	LTIM CAT 3	-29.52010	149.69300	Lowland	Small boat
Moree	Mehi River	MDBP	-29.46958	149.89977	Slopes (L)	Small boat
Mehi 126	Mehi River	LTIM CAT 3	-29.46200	149.84900	Slopes (L)	Medium boat
Chinook	Mehi River	LTIM CAT 3	-29.47556	149.97713	Slopes (L)	Small boat
Moomin 45	Moomin Creek	LTIM CAT 3	-29.68000	149.17400	Lowland	Backpack
Wirrallah	Moomin Creek	LTIM CAT 3	-29.71172	149.20145	Lowland	Backpack
Heathfield	Moomin Creek	MDBP	-29.72413	149.28851	Lowland	Backpack
Kiri	Moomin Creek	LTIM CAT 3	-29.72811	149.43867	Lowland	Backpack
Courallie	Moomin Creek	LTIM CAT 3	-29.61283	149.60136	Lowland	Small boat / backpack
Moomin 100	Moomin Creek	LTIM CAT 3	-29.64600	149.57100	Lowland	Backpack

C.2.2 Sampling protocols

Sampling effort was a combination of electrofishing and bait trapping (Commonwealth of Australia 2014). Electrofishing included small and medium boats (3.5 kW or 5 kW Smith-Root electrofisher unit respectively), backpack (Smith Root model LR20) or a combination of boat and backpack. 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 was 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 was 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; undertaken at the same times as electrofishing. Traps were set haphazardly throughout the site in water depths of 0.5 – 1 m.

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

C.2.3 Data analyses

Fish community

Electrofishing and bait trapping data were combined for statistical analyses of the fish community. Non-parametric multivariate analysis of variances (PERMANOVA) was used to determine if there were differences between the fish assemblages in each of the four channels (PRIMER 6 & PERMANOVA; Anderson et al. 2008). Prior to analyses, the data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where differences were identified by PERMANOVA, pair-wise comparisons were used to determine which groups differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities among groups.

Non-parametric Kolmogorov-Smirnov Z tests were used to determine if there were differences in the lengths of the six more abundant small- and large-bodied species in each of the four sub-catchments. Prior to analysis, the data were initially sorted into equal bins of 10 mm for small-bodied and 50 mm for large-bodied species. The results were then transformed to provide relative proportions (%) of each size class of fish for the four individual channels. Only channels where <20 individuals were sampled were included in the analyses. Species included were: large bodied - Murray cod, Common carp and Bony herring and small bodied – Murray Darling rainbowfish, Carp gudgeon and Australian smelt.

Health Metrics

Reference Condition

The predicted pre-European fish community of the lower Gwydir catchment 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 C-2; Table C-3). The RC-F process involves using available historical and contemporary data, museum collections and expert knowledge to estimate the probability of collecting each species at any randomly selected site within an altitude zone if it were sampled using the standard sampling protocol prior to 1770 (Davies et al. 2008). Rare species were allocated a RC-F probability of capture of 0.1 (collected at 0 < 0.2 of samples), occasional species (collected at 0.21 < 0.7 of samples) an RC-F of 0.45 and common species (collected at 0.71 < 1.0

samples) an RC-F of 0.85 (RC-F scores being the median capture probability within each category) (Table C-2).

The definition of a recruit was derived using a similar process as that applied in the SRA and MER programs (Dean Gilligan unpublished data). For large-bodied and generally longer lived species (>three years), an individual was considered to be a recruit if its body length was less than that of a one-year-old of the same species. For small-bodied and generally short-lived species that reach sexual maturity in less than one year, recruits were considered to be those individuals that were less than the species known average length at sexual maturity. The recruitment lengths used for both large- and small-bodied species were derived from published scientific literature or by expert opinion where that was not available (Table C-3).

Table C-2: Native freshwater fish species predicted to have occurred across the lower Gwydir catchment prior to European colonisation. Descriptions of predominance (occurrence) correspond to RC-F categories for the Murray Darling Basins Sustainable Rivers Audit program.

Species	Common name	Occurrence
Ambassis agassizii	Olive perchlet	Rare
Bidyanus bidyanus	Silver perch	Occasional
Craterocephalus amniculus	Darling River hardyhead	Rare
Craterocephalus stercusmuscarum fulvus	Un-specked 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	Occasional
Macquaria ambigua	Golden perch	Common
Retropinna semoni	Australian smelt	Occasional
Tandanus tandanus (MDB)	Freshwater catfish	Common

Table C-3: Sizes used to distinguish new recruits for species likely to be sampled across the lower Gwydir catchment. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)	Non-juv. caught	Juveniles caught
Native species			
Olive perchlet	26 mm (Pusey et al. 2004)		
Silver perch	75 mm (Mallen-Cooper 1996)		
Darling River hardyhead	40 mm (expert opinion)		
Un-specked hardyhead	38 mm (Pusey et al. 2004)	✓	✓
Carp gudgeon	35 mm (Pusey et al. 2004)	✓	✓
Spangled perch	68 mm (Leggett & Merrick 1987)	✓	✓
Murray Darling rainbowfish	45 mm (Pusey et al. 2004: for *M. duboulayi*)	✓	✓
Southern purple-spotted gudgeon	40 mm (Pusey et al. 2004)		
Bony herring	67 mm (Cadwallader 1977)	✓	✓
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)	✓	✓

Metrics, Indicators and the Overall Fish Condition Index

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

The Expectedness Indicator (SR-FI_e) represents the proportion of native species that are now found within the basin, compared to that which was historically present. The Expectedness Indicator is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the channel over the total number of species predicted to have existed within the channel historically (Robinson 2012). The two metrics were aggregated using the Expectedness Indicator Expert Rule set (Carter 2012).

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

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

The three indicators were combined using the Fish Index Expert Rule set (Carter 2012) to calculate an overall Fish Condition Index (ndxFS). The Fish Index Expert Rules analysis is weighted as SR-FI$_e$ > SR-FI$_r$ > SR-FI$_n$. The output generated by the Expert Rules analysis is scaled between 0 and 100, with higher values representing a 'healthier' fish community. The index was then partitioned into five equal bands to rate the condition of the fish community; "Good" (81-100), "Moderate" (61-80), "Poor" (41-60), "Very Poor" (21-40), or "Extremely Poor" (0-20) (Figure C-2).

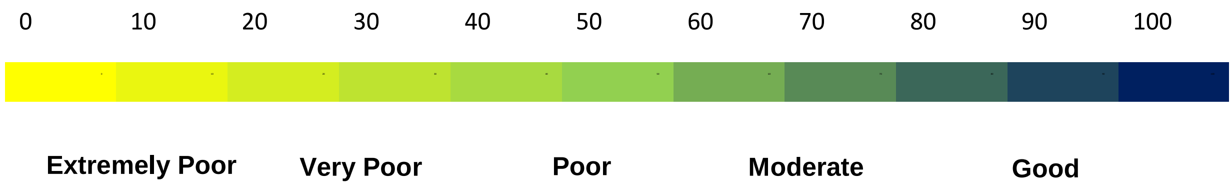

Figure C-2: Colour scale used to represent results of the health indices calculated for the 23 sites sampled across the lower Gwydir Basin.

C.3 Results

C.3.1 Abundance

In total 1,670 fish were caught (*n* = 1,346) or observed (*n* = 324) across all sites and for all methods combined. Species composition comprised 11 species in total (Figure C-3); eight native species and three exotic species. Only one of the five threatened species thought to occur in the past or present across the lower Gwydir Basin were captured; Murray cod (vulnerable; EPBC Act) (*n* = 62). No Olive perchlet, Silver perch, Southern purple-spotted gudgeon (*Mogurnda adspersa*) or Freshwater catfish were sampled. Captures within channels included: 297 (observed = 73) among 11 species from the five sites sampled in the Gingham Watercourse, 275 (observed = 47) among 10 species from the six sites in the Gwydir, 441 (observed = 163) among 10 species from the six sites in the Mehi, and 333 (observed = 41) among 10 species from the six sites in Moomin Creek. Among the large-bodied species (those that grow to >100 mm), the Common carp was generally the most abundant species caught in all four channels, with the exception being in the Mehi where Bony herring dominated the catch. Overall, Bony herring made up 31% of the total catch, whilst Common carp made up 21%. Among the small-bodied species (those that don't grow >100 mm), Australian smelt (*n* = 134) were the most abundant species sampled, followed by Carp gudgeon (*n* = 116) and Murray Darling rainbowfish (*n* = 84).

Overall, there were significant differences among the fish assemblage across the four different channels ($Pseudo\text{-}F_{3,19}$ = 2.62, P = 0.01). Pair-wise comparisons revealed differences between the Gingham and Gwydir (t = 2.11, P = 0.02), Gingham and Mehi ((t = 1.81, P = 0.03), Gwydir and Moomin (t = 1.90, P =

0.04) and Mehi and Moomin (*t* = 1.86, *P* = 0.02). There was no significant differences between the Gingham and Moomin (*t* = 0.65, *P* = 0.75) and the Gwydir and Mehi (*t* = 0.94, *P* = 0.46). SIMPER analysis suggested differences between the Gingham and Gwydir were a result of large numbers of the exotic Goldfish in the Gingham and none in the Gwydir (contribution = 17.61%) as well as larger catches of Australian smelt (contribution = 10.99%) and Bony herring (contribution = 10.80%) in the Gwydir compared to the Gingham. Similarly, Goldfish (contribution = 14.66%) were the primary contributor to differences between the Gingham and Mehi, followed by greater numbers of Bony herring (contribution = 13.14%) in the Mehi and by more Mosquitofish in the Gingham (contribution = 11.93%). Between the Gwydir and Mehi, differences were driven primarily by Bony herring (contribution = 17.69%; >Mehi), followed by Australian smelt (contribution = 12.47%; >Gwydir) and Golden perch (contribution = 11.94%; >Gwydir). Mosquitofish were the highest contributor to differences between the Mehi and Moomin (contribution = 13.79%; >Moomin), followed by Bony herring (contribution = 13.27%; >Mehi) and Australian smelt (contribution = 10.80%; >Moomin).

C.3.2 Biomass

Based on estimated and measured weights, in total 303.7 kg of fish were sampled across all sites and for all methods combined. Similar to total abundance, Common carp had the highest overall biomass (*n* = 162.3 kg) among the 11 species sampled, and also had the highest biomass within each of the four channels, ranging from 15.1 kg in the Moomin up to 63.2 kg in the Gwydir (Figure C-4). Murray cod had the next highest overall biomass (*n* = 74.5 kg) across all four channels combined, followed by Bony herring (*n* = 48.4 kg) and Golden perch (*n* = 15.5 kg). Among the small bodied species, Australian smelt (*n* = 108 g), Murray Darling rainbowfish (*n* = 87 g) and Carp gudgeon (*n* = 49 g) had the first, second and third highest biomass respectively.

There was no significant difference in biomass among the four channels ($Pseudo\text{-}F_{3,19}$ = 1.53, *P* = 0.16). Pair-wise comparisons revealed this was also the case between each of the channels individually; Gingham and Gwydir (*t* = 1.62, *P* = 0.09), Gingham and Mehi ((*t* = 1.52, *P* = 0.11), Gingham and Moomin (*t* = 0.63, *P* = 0.84), Gwydir and Mehi (*t* = 0.56, *P* = 0.82), Gwydir and Moomin (*t* = 1.28, *P* = 0.18) and Mehi and Moomin (*t* = 1.43, *P* = 0.10).

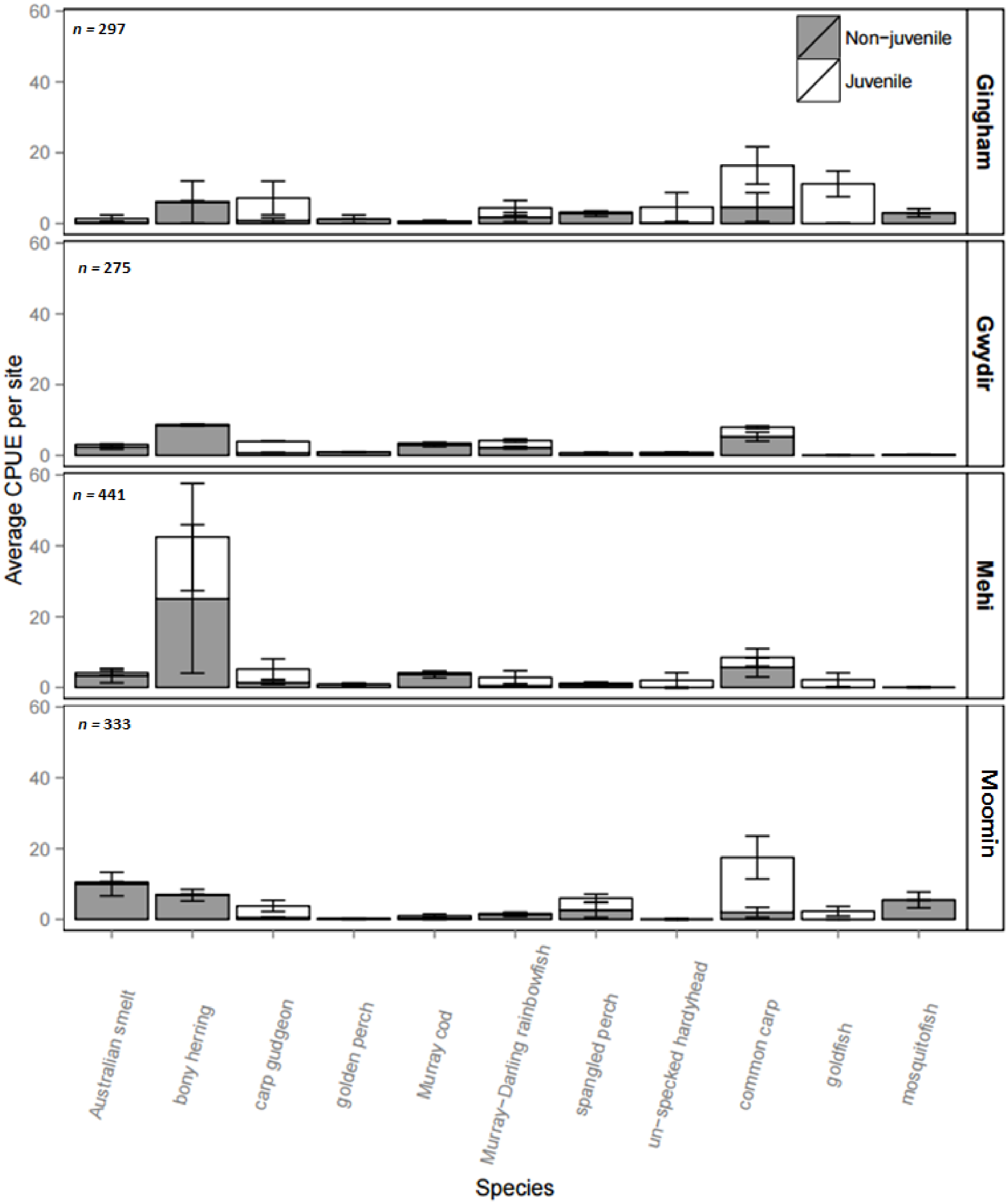

Figure C-3: Average catch per unit effort (CPUE) ± S.E. for the 11 fish species sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek during 2014-15.

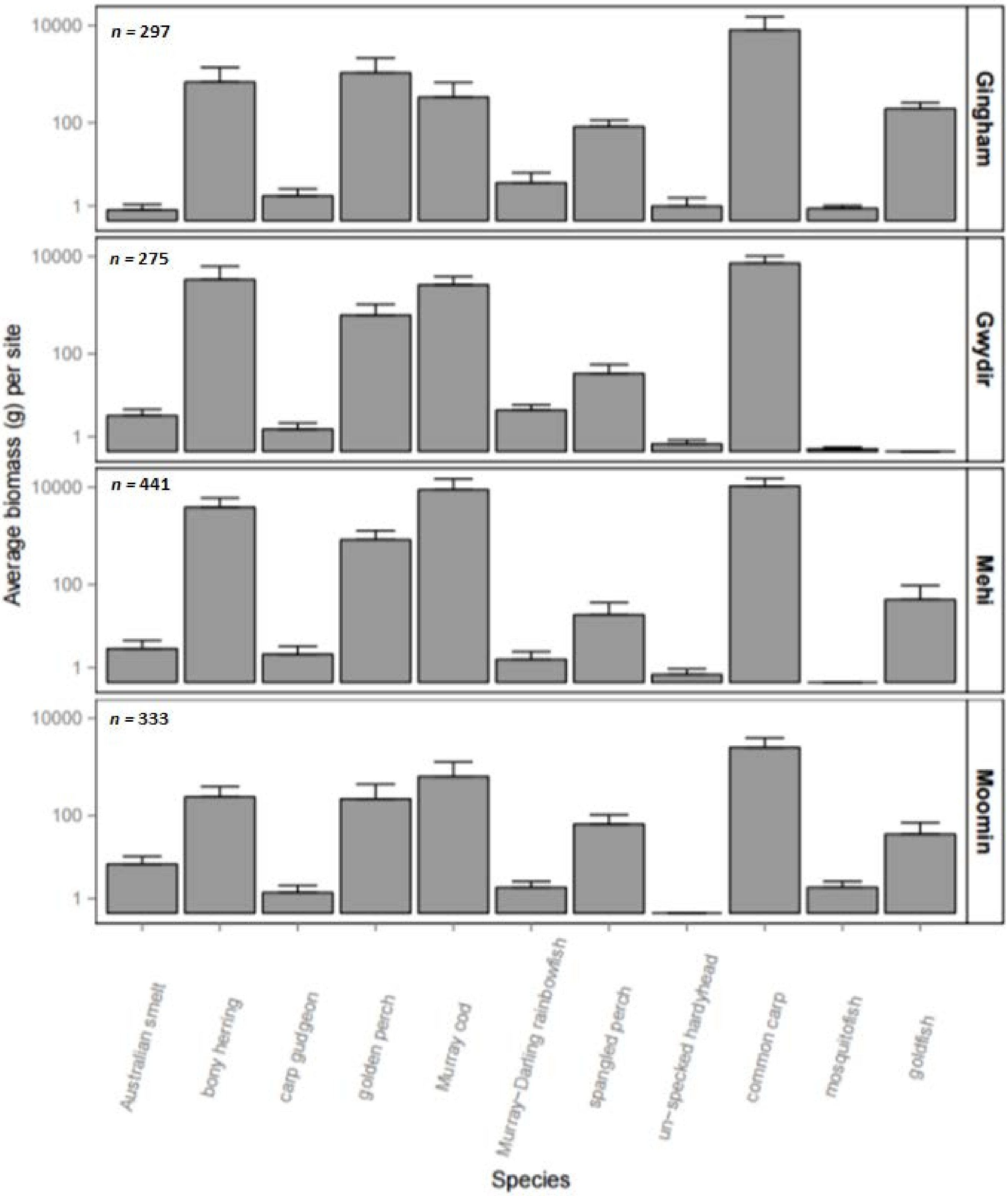

Figure C-4: Average biomass ± S.E. (log transformed) for the 11 fish species sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek as part of the Gwydir Long Term Intervention Monitoring Program, Year 1, 2015.

C.3.3 Length frequency

There were differences in both abundance and in the length-frequency among the three more abundant small-bodied species in each of the four channels (Australian smelt, Carp gudgeon, Murray Darling rainbowfish) (Figure C-5). Carp gudgeon differed significantly in length between the Gingham and all other channels and between the Mehi and Moomin (Table C-4). The Gingham and the Mehi were the only channels where fish in the 10-20 mm range were sampled (Figure C-5). Contrastingly, whilst there were too few numbers to test between all waterways for Australian smelt and Murray Darling rainbowfish, in general length-frequency was not significantly different among the majority of channels (Table C-4). The populations of all three species in the majority of catchments tended to be unimodal but asymmetrical, with little evidence of distinct cohort structuring (Figure C-5).

There were significant differences in length frequencies among the large-bodied species between the majority of channels (Common carp, Murray cod, Bony herring) (Figure C-6), with the exception being between the Gingham and Moomin (Table C-4). For Carp, the similarity between the Gingham and Moomin was driven by the dominance of juveniles below 150 mm. In the Gwydir and Mehi, the size frequency of Carp tended to be more evenly distributed, with both small and large individuals caught in approximately the same numbers (Figure C-6). Similarly, catches of Bony herring in the Moomin and Gingham tended to be dominated by juveniles <150 mm, with very few individuals between 150 and 250 mm, and only a small number >250 mm (Figure C-6). Whilst there were also large numbers of Bony herring juveniles caught in the Mehi, as with the Gwydir there were also individuals caught among most size classes up to ~350 mm (Figure C-6). The small numbers of Murray cod caught meant tests could only be undertaken between the Gwydir and Mehi channels. The trend was for greater numbers of individuals below 350 mm in the Gwydir compared to the Mehi, and for greater numbers of bigger Cod (>800 mm) in the Mehi. Among all three species there was evidence of binomial and in the case of Murray cod, potentially multinomial structuring, in most populations.

Table C-4: Kolmogorov-Smirnov test results of length frequency comparisons between the Gingham Watercourse (channel 1), Gwydir River (channel 2), Mehi River (channel 3) and Moomin Creek (channel 4). Shading indicates significant difference <0.05.

		Channel					
		1 V 2	1 V 3	1 V 4	2 V 3	2 V 4	3 V 4
Common carp	*Z*	4.264	3.160	1.148	1.477	4.721	4.243
	P	<0.001	<0.001	0.143	0.025	<0.001	<0.001
Murray cod	*Z*	--	--	--	3.253	--	--
	P	--	--	--	<0.001	--	--
Bony herring	*Z*	2.701	3.306	0.995	3.004	3.269	3.947
	P	<0.001	<0.001	0.275	<0.001	<0.001	<0.001
Carp gudgeon	*Z*	0.729	2.245	0.846	1.909	0.636	1.414
	P	0.663	<0.001	0.472	0.001	0.813	0.037
Rainbowfish	*Z*	0.636	--	--	--	--	--
	P	0.813	--	--	--	--	--
Australian smelt	*Z*	--	--	--	1.980	3.041	1.061
	P	--	--	--	0.001	<0.001	0.211

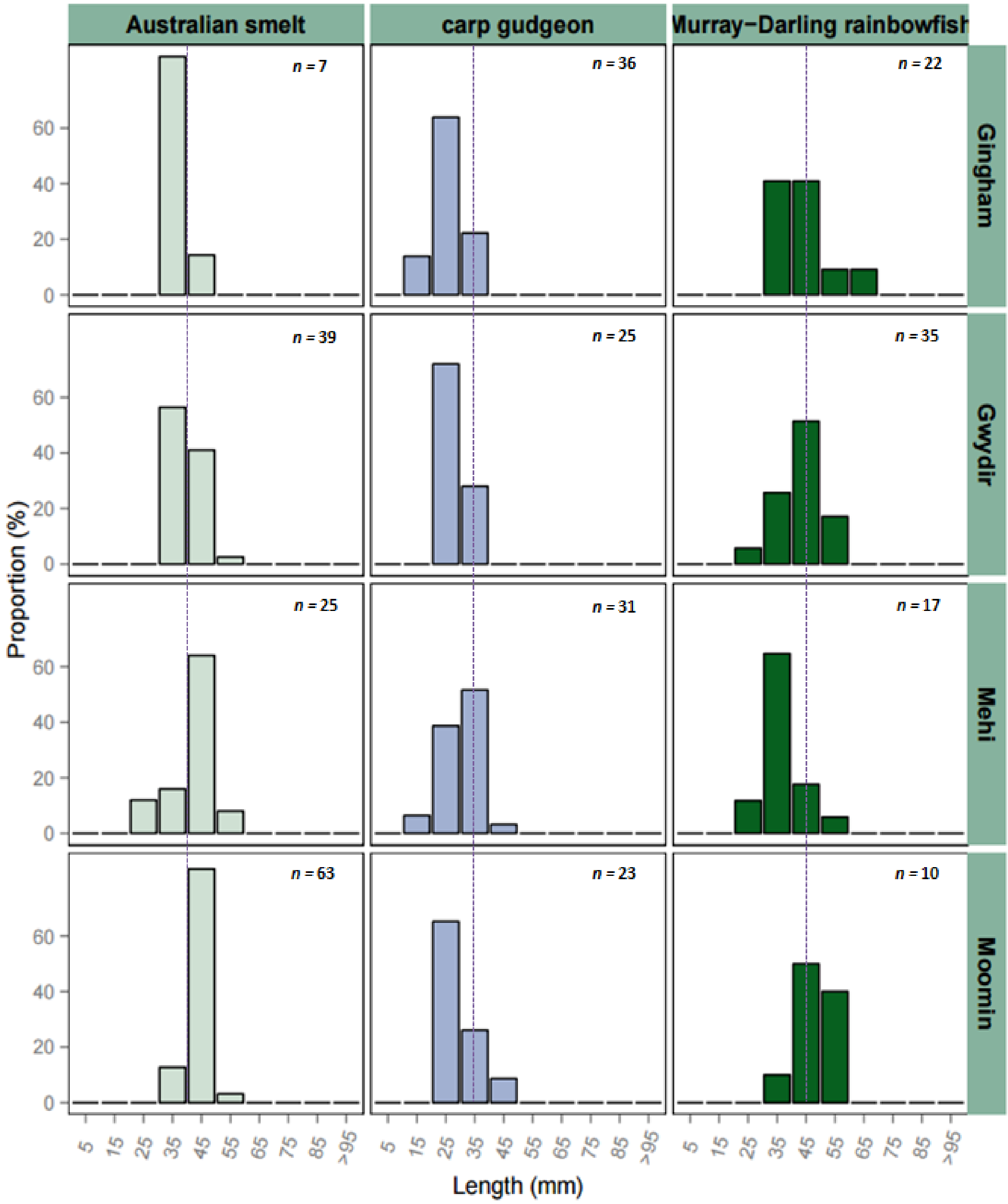

Figure C-5: Length frequency distribution (proportion (%)) of small-bodied fish, Australian smelt, Carp gudgeon and Murray Darling Rainbowfish sampled in the Gingham, Gwydir, Mehi and Moomin channels during 2014-15. NB# Dashed line is approximate length of one-year-old individual.

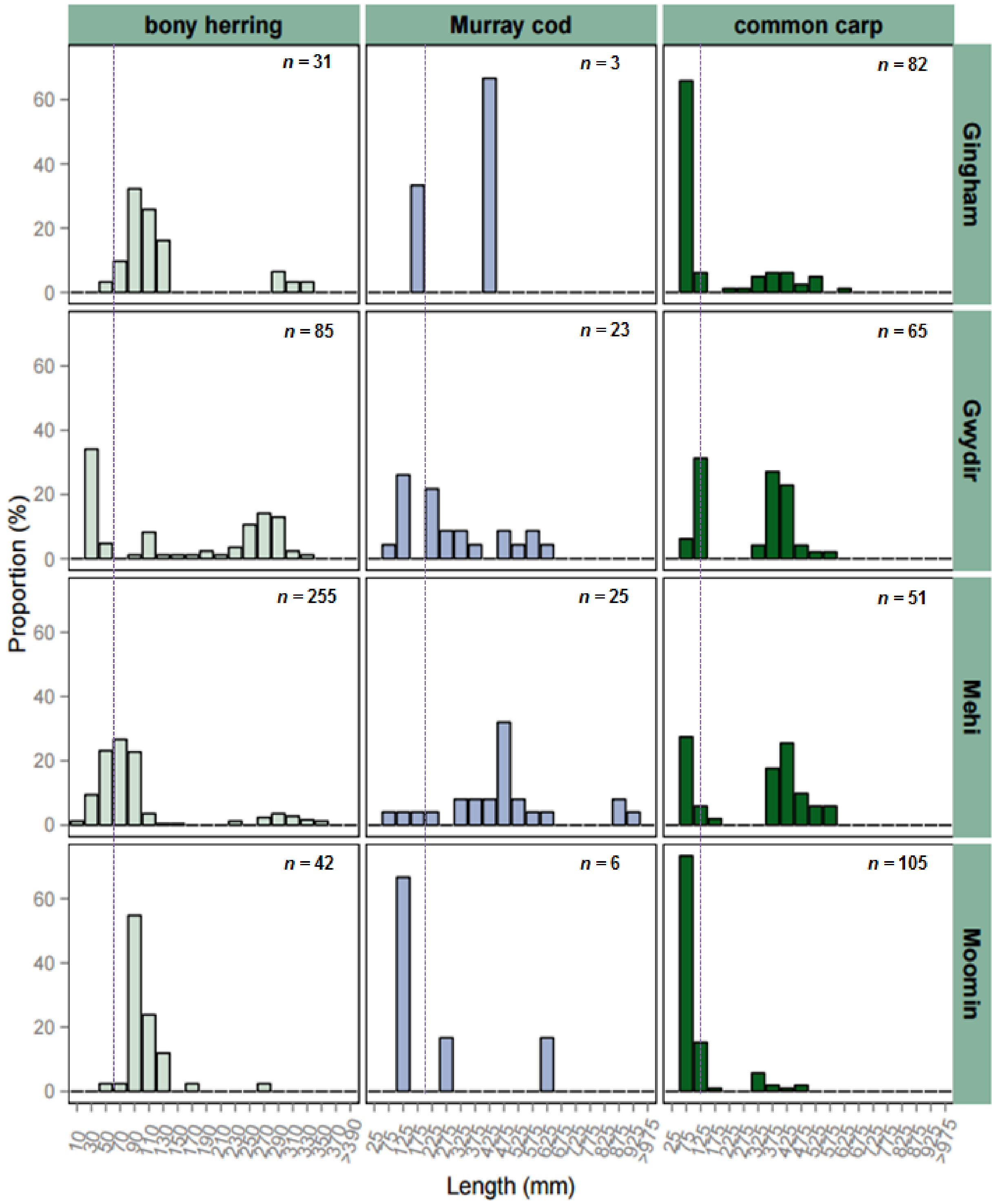

Figure C-6: Length frequency distribution (proportion (%)) of large-bodied fish, Bony herring, Murray cod and Common carp sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek. Dashed line is approximate length of one-year-old individual.

C.3.4 Health Indicators

Expectedness

Of the 13 native fish species that potentially could have been sampled across the lower Gwydir catchment, eight were caught at a minimum of one site in the current study. The five species not caught were Olive perchlet, Silver perch, Southern purple-spotted gudgeon, Freshwater catfish and Darling River hardyhead (*Craterocephalus amniculus*). Of the five, Olive perchlet, Southern purple spotted gudgeon and Darling River hardyhead are all considered to have been 'Rare' prior to European settlement. Similarly, Silver perch would most likely only have been caught 'occasionally' across the lower Gwydir system. However, Freshwater catfish were considered to most likely have been 'common' in the past.

Of the 23 sites sampled as part of the current study, for *Expectedness*, eight sites scored a rating of 'Good', 10 sites scored a rating of 'Moderate', two sites a rating of 'Poor' and three sites a rating of 'Very Poor' (Table C-5). Scores ranged from 92.3 for the Gingham 4 site, down to 37.3 for three individual sites in Moomin Creek (Table C-5). By channel, the Gwydir River had the highest average (± S.E.) rating by site for *Expectedness* scoring 82.7 ± 4.23 or an overall rating of 'Good', whilst Moomin Creek had the lowest average rating, scoring a 'Poor with 56.7 ± 9.29. Although Moomin Creek scored an overall 'Poor' rating, two of the six sites sampled scored an individual rating of "Good' (Table C-5). Both the Gingham Watercourse and Mehi River rated an average score of 'Moderate' for *Expectedness*, with scores 64.3 ± 7.43 and 74.4 ± 6.6, respectively (Table C-5).

Nativeness

Three of the 11 fish species sampled in the current study were exotic; Eastern mosquitofish, Goldfish and Common carp (Figure C-4). Of these, the Common carp was the most abundant (*n* = 287) and also the most widespread, having been caught at all but one of the 23 sites. By channel the highest catches of Carp were in Moomin Creek (*n* = 105), followed by the Gingham Watercourse (*n* = 82) with the Gwydir and Mehi both recording catches of ~50 for all sites combined. Eastern mosquitofish (*n* = 50) were the next most widespread exotic species sampled, being caught at 11 sites and in all channels except the Mehi River. Goldfish (*n* = 83) were more abundant than Eastern mosquitofish but were less widespread being caught at only nine sites across three channels; the Gingham Watercourse, Mehi River and Moomin Creek. The highest catches of goldfish were in the Gingham (*n* = 56), with 13 and 14 sampled in the Mehi and Moomin, respectively.

The high abundance of Common carp and goldfish is reflected in the relatively low *Nativeness* scores for most sites. Of the 23 sites sampled, only four rated as 'Good' and two as 'Moderate', whilst 10 rated as 'Poor', one as 'Very Poor' and six as 'Extremely Poor' (Table C-5). Individual site ratings ranged from 99.3 at the Moomin 100 site in Moomin Creek, down to 2.9 at the Gingham 38 site in the Gingham Watercourse, where the only native fish sampled were four spangled perch (*Leiopotherapon unicolor*). By channel, the Mehi River had the highest average site score at 75.3 ± 4.71, giving it an overall rating of 'Moderate' for *Nativeness*. In contrast, the Gingham Watercourse sites were on average 28.1 ± 11.59, with three of the five sites rating as 'Extremely Poor' and one as 'Very Poor'. Similarly, the average site score for the Moomin was also relatively low at 40.6 ± 17.19 giving it a rating of 'Poor', whilst the average score for the Mehi was 69.5 ± 4.89 giving it a rating of 'Moderate' (Table C-5).

Recruitment

In comparison to the *Expectedness* and *Nativeness* scores, the *Recruitment* Indicator scores were relatively consistent across the four river channels (Table C-5). *Recruitment* rated as 'Poor' in the Gingham Watercourse, Gwydir River and Moomin Creek, and as 'Moderate' in the Mehi River, with this channel scoring 69.7 (Table C-5). Whilst abundance varied between sites and channels, recruits of most native species were sampled at a minimum of six sites. The exception was golden perch, with no recruits captured at any site but 1+ individuals caught at seven. By number, recruits from all native species and across all sites combined represented ~42% of the total catch. Among the four large-bodied native species sampled (excluding golden perch), recruits of all species were caught at a minimum >26% of those sites where adults or 1^+ age fish of the same species were caught. Similarly, among the four small-bodied species, recruits were also present at a minimum of 23 of sites where adults were present.

While not considered in the calculation of the *Recruitment* Indices, there was also evidence of recruitment among the exotic species sampled, except Eastern mosquitofish. All Goldfish sampled were considered as potentially being less than 1 year old, with no individuals >127 mm recorded. There were also large numbers of juvenile Carp present, with 66% of the total catch <1 year old. By channel, the greatest numbers of Carp recruits were caught in the Moomin and Gingham, representing 80% and 71% of the total catches, respectively. Contrastingly, in the Gwydir and Mehi channels, total Carp captures were much lower, with recruits represented in the catch also considerably less at ~30% in both channels.

Overall score

The *Overall Fish Condition* (*ndx-FS*) scores for individual sites across the lower Gwydir Basin varied considerably. Of the 23 sites sampled, four rated as 'Good', 10 as 'Moderate', five as 'Poor' and four as 'Very Poor' (Table C-5). Scores ranged from 94.8 for the Mehi 126 site in Mehi River, down to 23.6 for the Moomin 45 site in Moomin Creek (Table C-5). By channel, the Mehi rated the highest with an average of 75.9 ± 5.85 giving it an overall rating of 'Moderate', whilst the Gwydir also rated the same with a site average of 70.3 ± 4.23. In general most sites in both channels either rated as 'Moderate' or 'Good'. In contrast, the Gingham and Moomin both scored an overall condition rating of 'Poor', with average scores of 47.6 ± 8.29 and 45.9 ± 10.03, respectively (Table C-5). Unlike the Mehi and Gwydir, a number of sites scored low for *ndx-FS*, particularly in the Moomin where three of the six sites sampled rated as 'Very Poor' (Table C-5).

Table C-5: Recruitment, Nativeness, Expectedness and ndxFS Indicator values for fish at sites sampled in the Gingham Watercourse, Gwydir River, Mehi River and Moomin Creek.

	Site name	Health Metrics			
		Recruitment	Nativeness	Expectedness	ndxFS
Gingham	Gingham 49	58.8	20.0	60.5	41.6
	Gingham 38	58.8	2.9	47.7	32.3
	Bullerana	58.8	28.7	60.5	42.9
	Gingham 27	58.8	17.5	60.5	41.4
	Gingham 4	58.8	71.4	92.3	79.9
	Average (± S.E.)	**58.8 (NA)**	**28.1 (11.59)**	**64.3 (7.43)**	**47.6 (8.29)**
Gwydir	GLTIM C1 S9	55.5	54.2	70.7	57.1
	GLTIM C1 S2	55.5	69.7	90.5	76.1
	Braggeen Crossing	55.5	66.4	70.7	59.9
	GLTIM C1 S6	55.5	65.3	80.1	68.4
	Norwood	55.5	90.8	92.2	83.5
	Redbank	55.5	70.8	92.2	76.8
	Average (± S.E.)	**55.5 (NA)**	**69.5 (4.89)**	**82.7 (4.23)**	**70.3 (4.23)**
Mehi	Mehi 16	69.7	65.0	70.7	68.1
	Mehi 49	69.7	66.9	60.5	61.1
	Mehi 82	69.7	66.4	90.5	84.3
	Mehi 126	69.7	94.5	92.2	94.8
	Moree	69.7	81.4	80.1	85.8
	Chinook	69.7	77.4	52.2	61.0
	Average (± S.E.)	**69.7 (NA)**	**75.3 (4.71)**	**74.4 (6.60)**	**75.9 (5.85)**
Moomin	Moomin 45	54.1	5.3	37.3	23.6
	Wirrallah	54.1	3.0	37.3	23.7
	Heathfield	54.1	3.1	37.3	23.7
	Krui	54.1	63.7	84.3	69.9
	Moomin 100	54.1	99.3	61.3	62.7
	Courallie	54.1	69.2	82.7	71.6
	Average (± S.E.)	**54.1 (NA)**	**40.6 (17.19)**	**56.7 (9.29)**	**45.9 (10.03)**

C.4 Discussion

In general, the fish community at most sites in the current round of sampling was found to be in a relatively poor state, with low abundances of most native species and relatively high numbers of exotic species. These results are similar to previous reports for the lower Gwydir in recent times (Murray–Darling Basin Authority 2012; Southwell et al. 2015). There were also a number of species that have been previously recorded in the Gwydir Basin that were not recorded in the current study. These include threatened species that were once abundant in the Gwydir such as the Freshwater catfish and Silver perch. Both species were reported to be among the most prevalent caught in the Gwydir in the 1940-50’s (Copeland et al. 2003) but none at all were caught in the current sampling round. Other species such as Golden perch and Spangled perch were also reported to be highly abundant in the past but were only caught in low numbers in the current sampling round.

Exotic species dominated the biomass at most sites sampled across the lower Gwydir system. Common carp, Goldfish and Eastern mosquitofish made up ~54% of the total biomass of captures across all sites combined. By channel, the Gingham Watercourse and Moomin Creek had the highest biomass of exotics present; 79% and 69%, respectively. These results differ from that reported by Southwell et al. (2015), who found that across the 15 sites they sampled in 2013-14, exotics contributed only ~10% to the total biomass. The difference in the findings is most likely a reflection on the gear types used in each of the studies. Southwell et al. (2015) used passive sampling techniques which rely on the fish moving to be caught, whilst in the current study active sampling techniques (electrofishing) were employed, which removes the reliance on fish moving to get sampled. Also, common carp are known to move more during periods of increasing flow and consequently become easier to catch in drum and fyke nets (Graham et al. 2005). Given the low flow conditions when Southwell et al. (2015) sampled and during the current sampling period, it seems most likely the current study gives a more accurate estimate of true numbers of exotics present, in particular Common carp numbers.

The length-frequency analysis of the three more abundant small- and two large-bodied native species suggests that some level of recruitment is occurring for all five species in at least some areas of the Gwydir Basin. Similarly, while only in low numbers, recruits of two of the remaining three native species present were also sampled. While the numbers of recruits were low for most species, it suggests that if the conditions are right, breeding and recruitment can be successful in at least some areas of the lower Gwydir. This is potentially best demonstrated by the variance in the length-frequency of Bony herring in each of the four channels. In all four systems sampled there were adult fish present that could have potentially bred. However, whilst in the Gwydir and Mehi there was evidence of recent (<1 year) recruitment, in the Gingham and Moomin only small numbers of <1 year olds were caught.

Baumgartner et al. (2014) described Bony herring as being a “foraging generalist” that as a guild are a species capable of resisting prolonged low-flow conditions and are not dependent on flow events to stimulate breeding. However, Pusey et al. (2004) suggested Bony herring may be heavily reliant on the presence of abundant plankton to ensure survival during the “critical” transition stage for larvae from endogenous to exogenous feeding. For this to occur requires the system to be “pre-charged” with carbon well before breeding occurs to align plankton blooms with larval needs. As such, if carbon levels are low and Bony herring breeding takes place, recruitment will be negligible or may not occur at all. While it can only be hypothesized that this may be occurring in the lower Gwydir system, given the different discharge amounts and connectivity periods experienced in each of the four systems 2014-15, what may be occurring is that by “accident” the flow regimes in the Gwydir and Mehi may align better with the needs of Bony herring than those regimes experience in the other two systems. Using environmental flows to effectively “charge” systems rather than purely as a means of providing a stimulus for spawning or as a means of dispersing larvae, should be a major consideration for environmental watering strategies in the lower Gwydir system.

The Fish Health Indices calculated for the current sampling round suggests that the fish community across the lower Gwydir is under extreme stress. This was particularly apparent in the two smaller systems; Moomin Creek and the Gingham Watercourse. However, there were some positives among the results. *Expectedness* consistently rated the best of the three indices, with a number of sites and channels scoring an ‘Good’ rating. In effect, this suggests that the overall structure of the fish community in at least some parts of the lower Gwydir system is largely as it was at the time of European settlement. Whilst this is a positive outcome for recovery, high scoring sites were isolated and scattered throughout the system, implying that localized factors such as the degradation of habitat or the numbers of exotic species present within in area, are most likely dictating the localized presence and absence of individual species.

Sites that scored highly for the *Nativeness* index were also isolated and scattered throughout the lower Gwydir system. As with *Expectedness*, this again suggests localized factors are likely controlling the abundances of exotic species. For example, Common carp require access to off-stream areas such as wetlands or inundated floodplains to successfully breed and recruit in large numbers (Stuart and Jones 2006). The high numbers of Common carp recruits in both the Gingham and Moomin channels implies that these systems may be functioning as recruitment hotspots in the Lower Gwydir system. While these variable spatial trends are not ideal, high *Nativeness* scores suggests that native species are at least still present in most channels. This coupled with the fact that there also appears to be hotspots of exotic species recruitment, highlights the importance of managing environmental flows to ensure maximum benefit for natives while at the same time minimizing the benefit for exotics. Through time, managing flows to target native fish will hopefully result in a general improvement in the health of the native fish community in the Gwydir.

Whilst the *Recruitment* Index was generally low in all four channels across the lower Gwydir system, there were some positive trends among the three individual recruitment metrics. Of the three metrics, the average proportion of total abundance of native recruits across species (RC-F adjusted) within a channel was lowest, ranging from 34% in the Moomin up to only 47% in the Mehi. In contrast, the average number of sites within a channel where recruitment was occurring for each native taxon sampled (RC-F adjusted) (*PropRSites*) and the proportion of native fish that occurred within a channel that were recruiting (*PropRTaxa)*, were both much higher. *PropRTaxa* was >85% for all channels, whilst *PropRSites* ranged from 60% up to 71%. These results suggest that whilst recruit abundances were low, breeding and recruitment was occurring for most native species at most sites and even more so for most species at the channel scale. As with the *Expectedness* and *Nativeness* results, the *Recruitment* results bode well for the recovery of at least some species in the lower Gwydir.

Based on the results of the current sampling round, the poor state of the fish community across the lower Gwydir system will require actions to take a multi-disciplinary approach over an extended period. While this must include environmental water releases, environmental water alone will most likely not result in a quantifiable improvement in the fish community in the short-term given the poor condition of much of the habitat and the complete absence of some species. To initiate a quicker native fish response, environmental watering will need to be done in conjunction with in-stream and riparian restoration to improve habitat, and will also require direct action in the form of translocation or restocking of those species that are absent or in critically low numbers. Without including all of the activities in the one holistic approach it is unlikely the general health of the native fish community will improve.

C.5 Conclusion

The current round of monitoring and reporting provides bench mark information for the next five years of quantifying the fish communities across the lower Gwydir LTIM selected area. Data from the current round of sampling will assist in determining if releases of environmental water result in a general improvement in the health and abundance of fish within the system through time.

Given that most native fish species present are recruiting and that there was some evidence of cohort structuring among at least some of the longer lived species (i.e. surviving multiple years), this suggests that the system is at least functioning to some degree, all be it at a reduced capacity. Future environmental watering strategies should consider releases that not only target breeding and recruitment but also the health and survival of adults among long-lived species.

Native fish are recruiting and surviving in at least some parts of the systems given that there were juveniles and adults present for most of the native species recorded. This cannot be wholly attributed to environmental water releases, however, based on empirical evidence environmental water is most likely contributing. Whilst native fish are recruiting and surviving to adults, given there is already a high biomass of exotic species present in the system, in particular Common carp, any future environmental watering strategy must consider the cost/benefit of releases to ensure the problem is not further exacerbated.

In the short-term, given the almost total absence of ‘flow dependent’ specialists like silver perch and golden perch, targeting in-channel environmental flow releases to benefit ‘long-lived apex predators’ and ‘foraging generalists’ (see Baumgartner et al. 2014 for descriptions) may yield more immediate improvements for some of the species that are currently present in the system. Flow strategies that aim to effectively “charge” the system to facilitate recruitment may be of more benefit compared to those that target flow releases purely at stimulating breeding and/or dispersing larvae.

Based on the Expectedness values, in general, the native fish diversity in the system is close to what it should be within the majority of the four channels sampled. However, a number of the native species present were in relatively low abundances and number of the ‘rarer’ species were absent from samples all together. As such, a multi-disciplinary approach will be required to dramatically improve native fish diversity across the lower Gwydir, which includes environmental water but also other measures such as habitat restoration and the reintroduction of species that are absent or at critically low numbers.

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Appendix D Vegetation Diversity

D.1 Introduction

The Lower Gwydir and Gingham watercourses support a number of water dependent vegetation communities, including flood dependent woodlands (supporting ecological vegetation communities with dominant tree species such as Coolibah and to the west, Black box), floodplain wetland communities (supporting River red gum, Coolibah woodlands, and River cooba and Lignum shrubland species) and semi-permanent wetlands (supporting species such as Water couch, Marsh club-rush, Spike rush, Tussock rushes, Sedges and Cumbungi) (Bowen and Simpson 2010). The areas occupied by these communities has declined since river regulation as a result of both restricted flows and clearing for agriculture (Wilson et al. 2009, Bowen and Simpson 2010). Maintaining the current extent and improving and then maintaining the health of these communities has become a target for environmental water management in the Gwydir catchment (Commonwealth of Australia 2014a). Several specific questions were addressed through the monitoring of vegetation diversity in the 2014-15 water year in the Lower Gwydir wetlands:

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

D.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendix B and G). 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 wetland inundation (Table B-1).

Environmental water delivered to the Gingham and Lower Gwydir wetlands inundated a number of sites that were surveyed for vegetation diversity (Table D-1). In December 2014, 22% of the plots surveyed were inundated. In March 2015, 50% of the sites were wet. Of the 32 plots, 18 (56%) went from dry in December 2014 to wet in March 2015, 6 (19%) went from wet to dry, 1 (3%) remained wet, and 7 (22%) remained dry between the two surveying times.

D.1.2 Previous Monitoring

Previous monitoring was undertaken in the Gingham and Lower Gwydir wetlands by Southwell et al. (2015) as part of the Short Term Intervention Monitoring project in 2013-14. NSW OEH has also undertaken vegetation monitoring in the Gingham and Lower Gwydir (since 2008) and Mallowa (since 2012). The NSW Office of Water (now DPI Water) also previously undertook monitoring under the Integrated Monitoring of Environmental Flows program from 2004-2010 until funding for this program ceased.

From the Short Term Intervention Monitoring project in 2013-14, Southwell et al. (2015) noted different vegetation patterns in the Gingham and Lower Gwydir wetlands during the season, primarily influenced by rainfall events and wildfire, given the limited flows both systems received. Gingham vegetation communities tended to expand in coverage later in the season reflecting good march rainfalls, with increases in Water couch (*Paspalum distichum)* and exotic species such as Burr medic (*Medicago polymorpha)* and Lippia (*Phyla canescens)*, albeit at relatively low coverages (<3% coverage). In the Lower Gwydir sites, changes in the vegetation community composition were primarily driven by the wildfire that occurred through the reserve in late March 2014, which was then followed by local heavy rainfall and small inflows one week later that inundated some areas. This increased the dominance of bare ground and litter in these communities as a result of the reduced vegetation cover. Species that were quick to respond following the fire and successive good rainfalls such as Marsh club-rush (*Bolboschenus fluviatilis)*, Tall spike-rush (*Eleocharis spathulata*) and Budda pea (*Aeschynomene indica)* tended to characterize these communities at the end of the water year.

D.2 Methods

Thirty-two plots were monitored at 12 locations throughout the Gwydir and Gingham watercourses during December 2014 and March 2015. These plots were located in five broad wetland vegetation communities, and experienced a range of inundation conditions (Figure D-1). Vegetation surveys were completed in conjunction with OEH staff, following OEH data collection protocols (Commonwealth of Australia 2014b), which recorded vegetation diversity and structure within each 0.04 ha plot. A number of environmental variables including the degree of inundation and grazing impact were also noted.

Species diversity measures were analysed using a Poisson regression on count data which investigated the influence of environmental water, survey time (2014-15) and vegetation community. As the presence of environmental water and survey time were shown to be collinear, a secondary measure of survey time was developed to assess seasonal change. Here, sites that experienced the same inundation conditions between both survey times (either dry or wet on both occasions) were compared. To further explain changes in diversity, individual species were grouped into the four following functional groups (Brock and Cassanova 1997; Hale et al. 2013):

- Amphibious responders (AmR) – plants which change their growth form in response to flooding and drying cycles (including morphologically plastic (ARp) and floating/stranded (ARf);
- Amphibious tolerators (AmT) – plants which tolerate flooding patterns without changing their growth form;
- Terrestrial damp plants (Tda) – plants which are terrestrial species but tend to grow close to the water margin on damp soils; and
- Terrestrial dry plants (Tdr) - those which are terrestrial species which don’t normally grow in wetlands but may be encroaching into the area due to prolonged drying.

Changes in these functional groups were then compared between survey times using F-tests to test for equality of variances and then t-tests to test for differences in means.

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

Figure D-1: Location of vegetation monitoring sites.

Table D-1: Sites surveyed in December 2014 and March 2015 for vegetation diversity. Map projection AGD94 Zone 55. Sites that were inundated with environmental water at the time of sampling are coloured blue ('wet') and those that were not coloured yellow ('dry').

Vegetation communities	Sites	Easting	Northing	2014 Env water	2015 Env water
Water couch marsh grassland	Bunnor_1_1	6760771	728826	Dry	Wet
Water couch marsh grassland	Bunnor_1_2	6760658	728917	Dry	Wet
Water couch marsh grassland	Bunnor_1_3	6760630	728812	Dry	Wet
Water couch marsh grassland	Goddards _Lease_Ramsar_1_1	6760882	731652	Dry	Wet
Water couch marsh grassland	Goddards _Lease_Ramsar_1_2	6760784	731738	Dry	Wet
Water couch marsh grassland	Goddards _Lease_Ramsar_1_3	6760678	731749	Dry	Wet
River Cooba Lignum	Lynworth_1_1	6763482	727443	Dry	Wet
River Cooba Lignum	Lynworth_1_2	6763219	727574	Dry	Wet
River Cooba Lignum	Lynworth_1_3	6762965	726906	Dry	Wet
Coolibah Woodlands	Lynworth_1_4	6763330	728359	Dry	Wet
Water couch marsh grassland	Lynworth_3_1	6762487	728716	Dry	Wet
Water couch marsh grassland	Lynworth_3_2	6762446	728809	Dry	Wet
Water couch marsh grassland	Lynworth_3_3	6762544	728885	Dry	Wet
Water couch marsh grassland	Mungwonga_1_1	6764005	722759	Dry	Wet
Water couch marsh grassland	Mungwonga_1_2	6763930	722771	Dry	Wet
Water couch marsh grassland	Mungwonga_1_3	6764083	722726	Dry	Dry
Water couch marsh grassland	Old_Dromana_Elders_1_1	6752745	723443	Dry	Dry
Water couch marsh grassland	Old_Dromana_Elders_1_2	6752603	723435	Dry	Dry
Water couch marsh grassland	Old_Dromana_Elders_1_3	6752706	723395	Dry	Dry
Coolabah Woodland - wet understorey	Old_Dromana_Elders_1_4	6752918	723552	Dry	Dry
Coolabah Woodland - wet understorey	Old_Dromana_Nursery_1	6751431	726197	Wet	Dry
Coolabah Woodland - wet understorey	Old_Dromana_Nursery_2	6751888	724473	Dry	Dry
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_1	6750977	727152	Wet	Dry
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_2	6750992	727184	Wet	Dry
Eleocharis tall sedgelands	Old_Dromana_Ramsar_1_3	6751075	727098	Wet	Dry
Water couch marsh	Old_Dromana_Ramsar_3_1	6751426	726741	Wet	Wet

Vegetation communities	Sites	Easting	Northing	2014 Env water	2015 Env water
grassland					
Water couch marsh grassland	Old_Dromana_Ramsar_3_2	6751456	726641	Wet	Dry
Water couch marsh grassland	Old_Dromana_Ramsar_3_3	6751515	726746	Wet	Dry
Coolabah Woodland - wet understorey	Westholme_Coolibah_1	6764083	722726	Dry	Dry
Water couch marsh grassland	Westhome_1_1	6759094	733487	Dry	Wet
Water couch marsh grassland	Westhome_1_2	6759189	733523	Dry	Wet
Water couch marsh grassland	Westhome_1_3	6759157	733591	Dry	Wet

D.3 Results

D.3.1 Species diversity

A total of 154 flora species from 45 families were recorded across all vegetation plots. The average number of species recorded at each location during each survey period was 21.8. The highest average species diversity was 40.5, recorded at Old Dromana Nursery in December 2014, while the lowest average diversity was recorded at Westholme in December 2014 (10.33). Possion regression results suggest that vegetation community type was the most influential factor on species diversity (Pr<0.001), followed by the presence of environmental water (Pr<0.005) and then survey time (Pr<0.05). River Cooba/Lignum association had an average of 27.2 species, followed by Coolibah Woodland-wet understory 26.5, *Eleocharis* tall sedgeland 25.83 and then Coolibah Woodlands and Water couch marsh grassland with 23.5 and 18.9 species respectively. Sites that were wet during sampling tended to have lower species diversity (18.3) than those that were dry (23.7). Sites that were dry during 2014 and then wet in 2015 tended to decrease in species diversity, with significant reductions in species that cannot tolerate waterlogging and submersion (i.e. the *Terrestrial* functional group), including terrestrial damp plants (Tda) i.e. terrestrial plants that often grow close to the water margin (T=4.69, Pr<0.001), and terrestrial dry plants (Tdr) i.e. terrestrial species that encroach in wetlands only after prolonged drying (T=6.62, Pr<0.001). These groups reduced in average species number by 50% and 93% respectively (Figure D-2). Species in the *Amphibious* functional group including amphibious responders and amphibious tolerators (AmT) increased with wetting, with AmR species increasing significantly (T=2.2, Pr<0.05), from an average number of 2.8 in 2014 when the sites were dry, to 4 in 2015 when sites were wet.

Species diversity was lower at all locations in March 2015 compared to December 2014 except Westholme Coolibah that increased in species diversity over the 2014-15 season (Figure D-3). Forb species displayed the greatest reduction over the sampling period, with a total significant reduction in species of 77 in December 2014 to 47 in March 2015 (T=15.54, Pr<0.001) (Figure D-4). Again, this reduction in species diversity was driven by reductions in *Terrestrial* functional group species including terrestrial damp (Tda) and dry (Tdr) plants (Figure D-5).

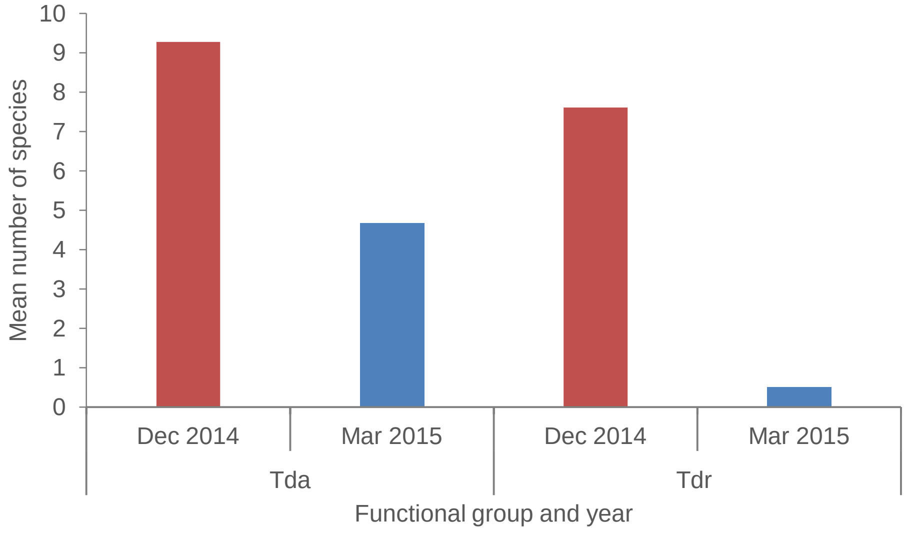

Figure D-2: Mean number of Tda and Tdr functional group species recorded in sites that were dry in December 2014 and wet in March 2015.

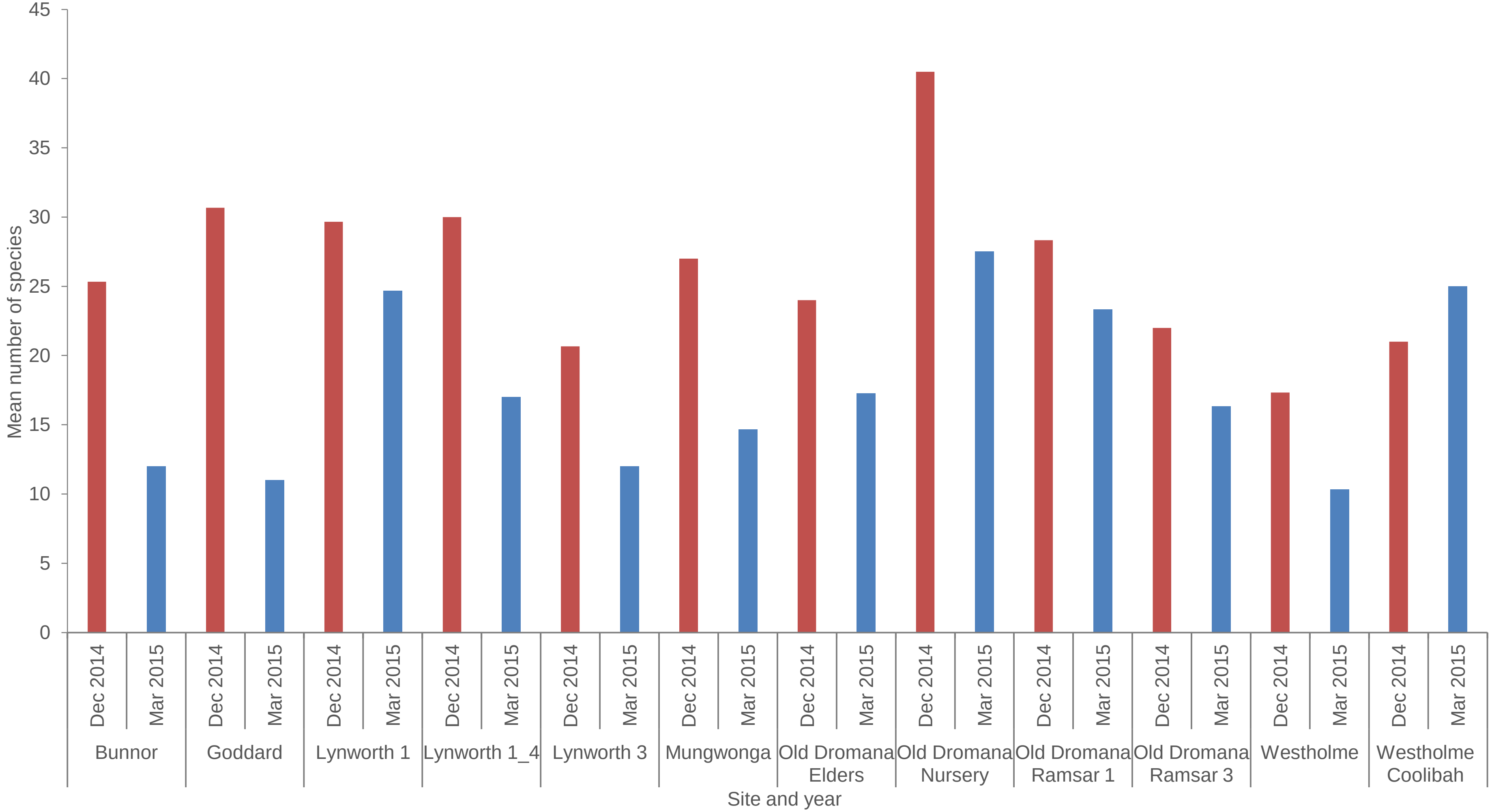

Figure D-3: Mean number of species recorded at each site during the December 2014 and March 2015 surveys.

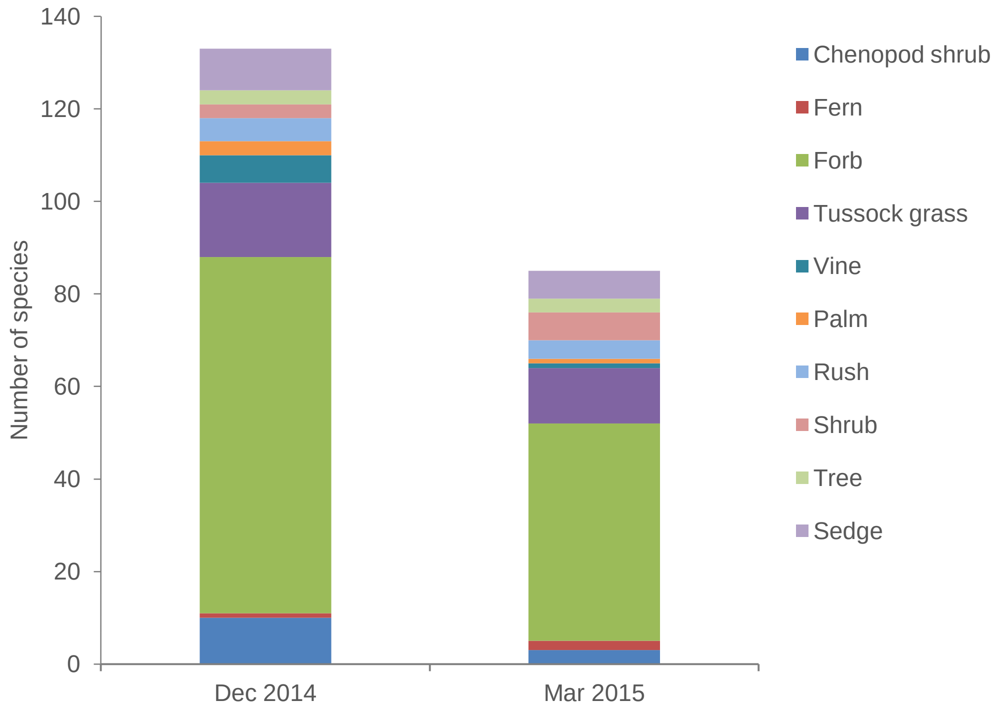

Figure D-4: Total number of species and the proportion of the differing growth forms recorded across all vegetation plots in December 2014 and March 2015 sampling periods.

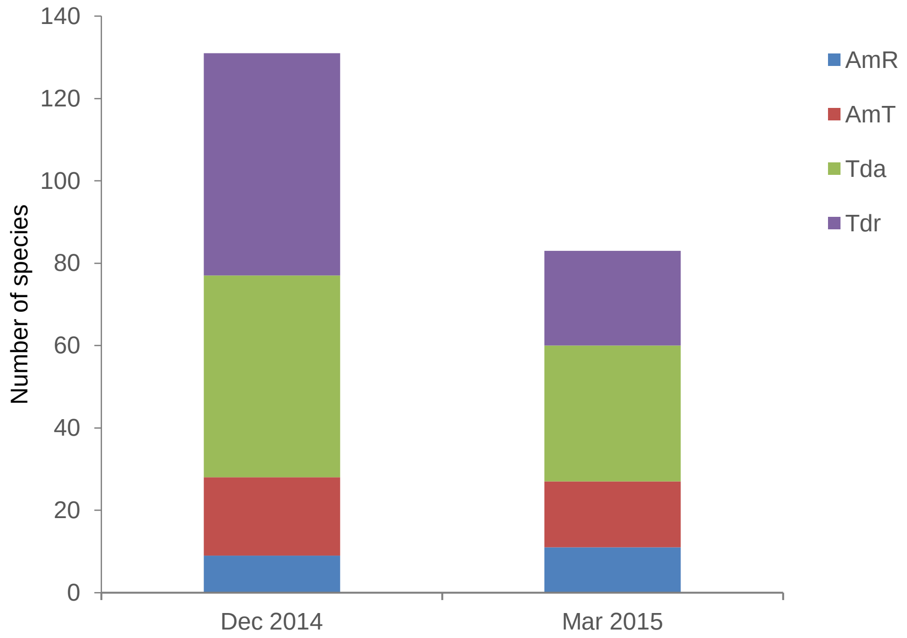

Figure D-5: Total number of species and the proportion of the differing functional groups recorded across all vegetation plots in December 2014 and March 2015 sampling periods.

D.3.2 Vegetation composition

Permanova tests undertaken on the vegetation community composition from all plots suggested that survey time had the greatest influence on the observed patterns in the data (Pseudo-F = 8.76, Pr<0.001). However, vegetation community (Pseudo-F = 5.64, Pr<0.001), and the presence of environmental water (Pseudo-F = 3.751, Pr<0.005) were also significant. When grouped by survey time and the presence of environmental water, wet sites plotted closer to each other, suggesting more similar community composition between plots, especially within survey periods (Figure D-6).

SIMPER analysis showed that the main species or variables responsible for grouping the data by survey time and the presence of environmental water were Water couch, the percentage of bare ground and litter cover within a plot, Lippia*,* Spike-rush and Water primrose *(Ludwigia peploides)* (Table D-2).

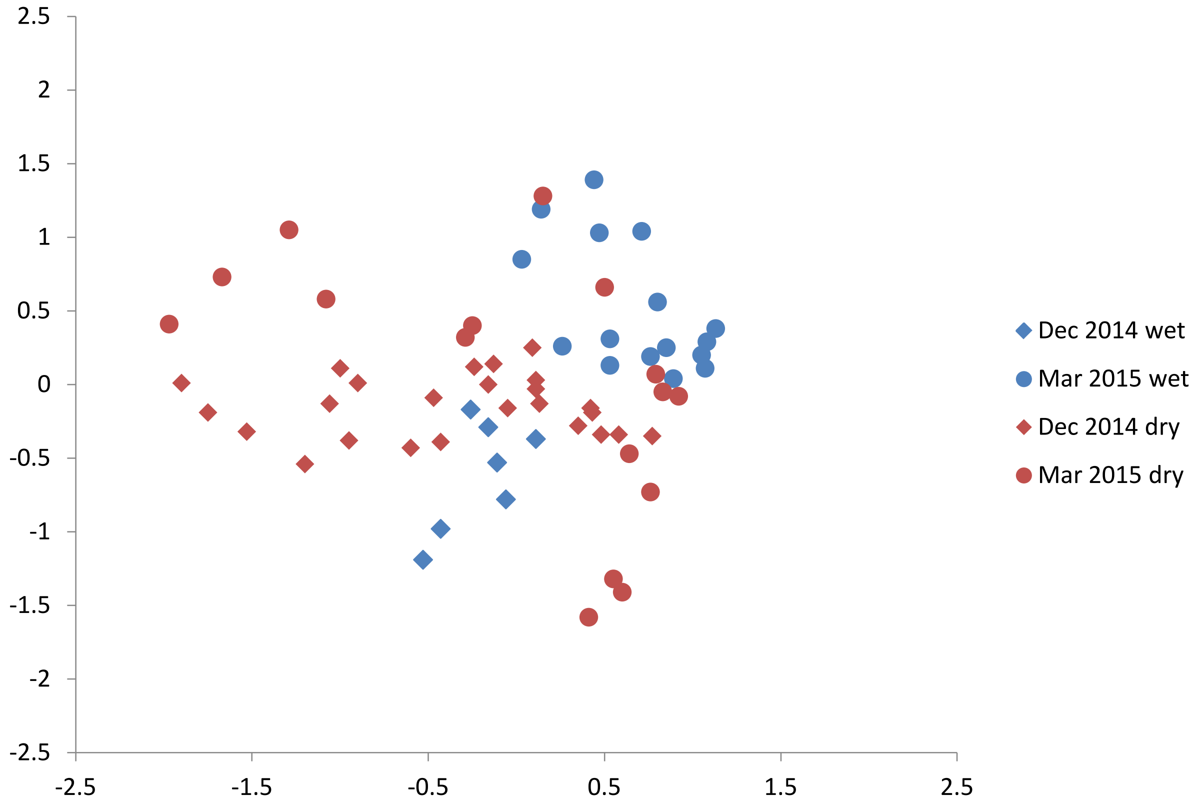

Figure D-6 : nMDS plot of vegetation community composition data grouped by survey time and the presence (‘wet’) or absence (‘dry’) of environmental water at the time of sampling.

Table D-2: Dominant species and variables contributing to vegetation community composition groupings based on survey time and the presence of environmental water. 'dry' means no environmental water was present, 'wet' means environmental water was present at the time of surveying.

Data grouping	Species contributing to grouping	Contributed %	Cumulative %
December 2014 x dry	Water couch	30.24	30.24
	Bare ground	13.05	43.29
	Litter	7.75	51.04
	Lippia	7.42	58.46
December 2014 x wet	Water couch	16.72	16.72
	Bare ground	13.17	29.89
	Litter	11.24	41.13
	Spike rush	5.74	46.87
March 2015 x dry	Water couch	21.23	21.23
	Bare ground	17.53	38.76
	Lippia	8.30	47.06
	Spike rush	5.74	52.8
March 2015 x wet	Water couch	72.48	72.48
	Water primrose	5.93	78.41
	Spike rush	4.64	83.05

Water couch was the most dominant species recorded in terms of cover across the study area, being found at 31 of 32 (97%) plots surveyed. Water couch cover was significantly greater in wet plots on average ($T=2.3$, $Pr<0.05$; Figure D-7) and while increases in cover of Water couch were also observed towards the end of the season (2014 vs 2015) they were not significant (Figure D-8). The percentage of bare ground in each plot decreased significantly ($T=2.01$, $Pr<0.05$) towards the end of the season from an average cover of 15.8+/-16.2% in December 2014 to 7.8+/-15.3% in March 2015 (Figure D-9). Sites that were dry in December 2014 but wet in March 2015 decreased in percentage bare ground from 11.2+/-13.6% to 2.7+/-4.7% (Figure D-10). Lippia was most dominant in dry plots, with significantly higher cover (9.5+/-14.7%) in dry plots as opposed to wet plots (0.7+/-1.4%; $T= 3.61$, $Pr<0.001$) (Figure D-11). Similarly, there was significantly less Lippia recorded in March 2015 in plots that were dry in December 2014, but were wet during the second survey period ($T= 2.43$, $Pr<0.05$; Figure D-12). Flat spike-sedge (*Eleocharis plana*) showed an opposite trend to Lippia, increasing significantly ($T=2.46$, $Pr<0.05$) from December 2014 to March 2015 (Figure D-13). This trend was driven primarily by increases in the cover of Flat Spike-sedge in plots that were dry in December 2014, but were inundated in March 2015, having covers of 0.9+/-1.2% and 6.6+/-12.2% respectively (Figure D-14).

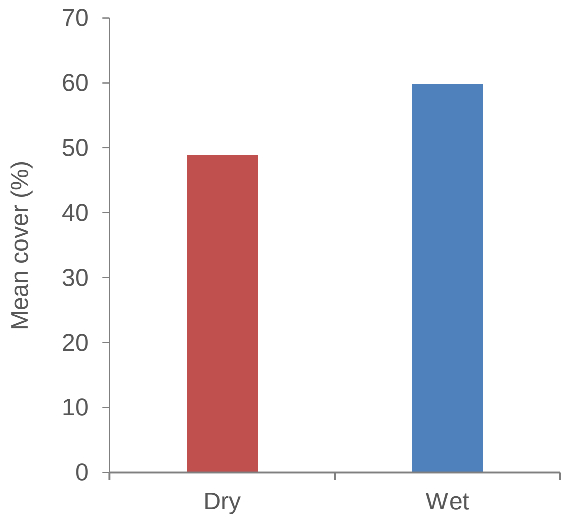

Figure D-7: Mean cover (%) of Water couch at dry and wet sites, regardless of time.

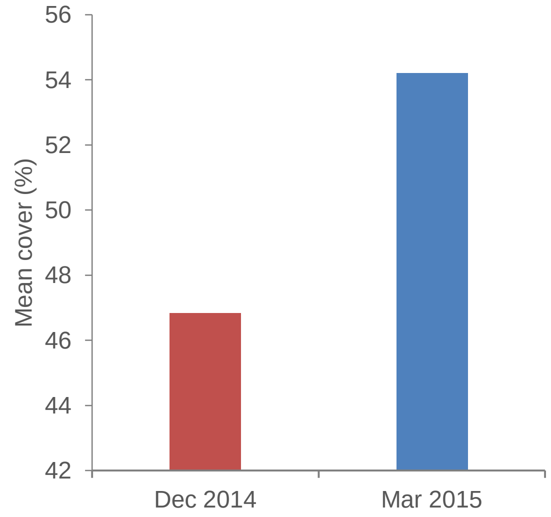

Figure D-8: Mean cover (%) of Water couch at sites in December 2014 and March 2015 sampling periods.

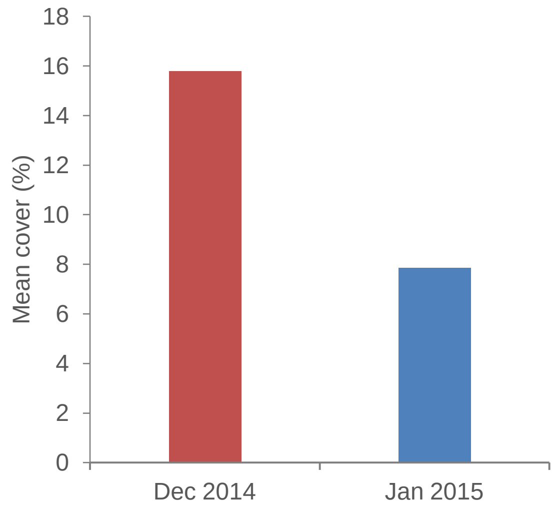

Figure D-9: Mean cover (%) of bare ground at sites in each survey period.

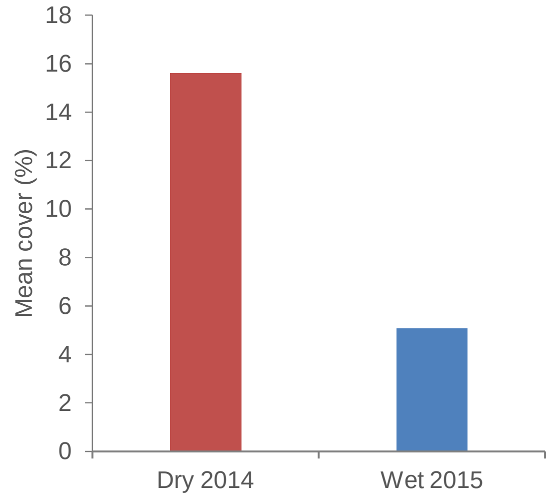

Figure D-10: Mean cover (%) of bare ground at sites that were dry in 2014 and wet in 2015.

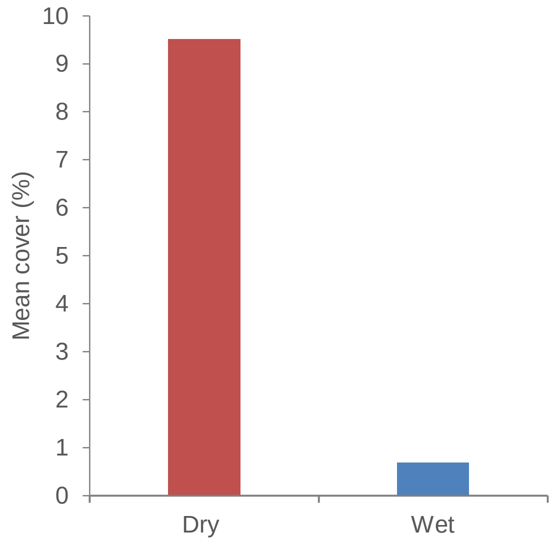

Figure D-11: Mean cover (%) of Lippia at dry and wet sites, regardless of time.

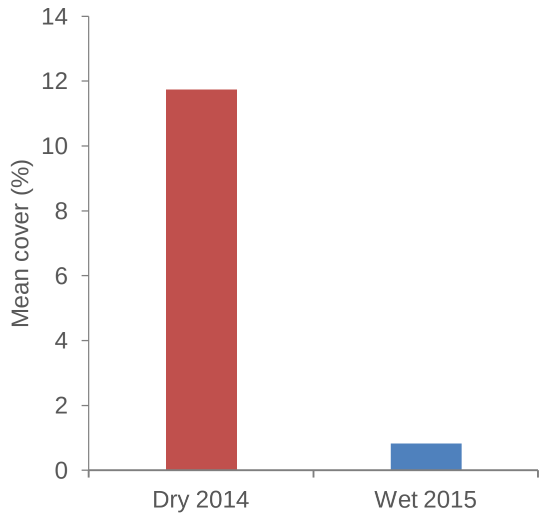

Figure D-12: Mean cover (%) Lippia at sites that were dry in 2014 and wet in 2015.

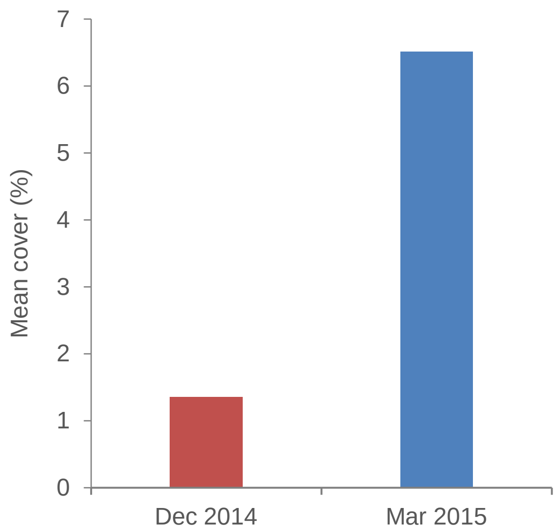

Figure D-13: Mean cover (%) of Flat spike-sedge at sites in December 2014 and March 2015 sampling periods.

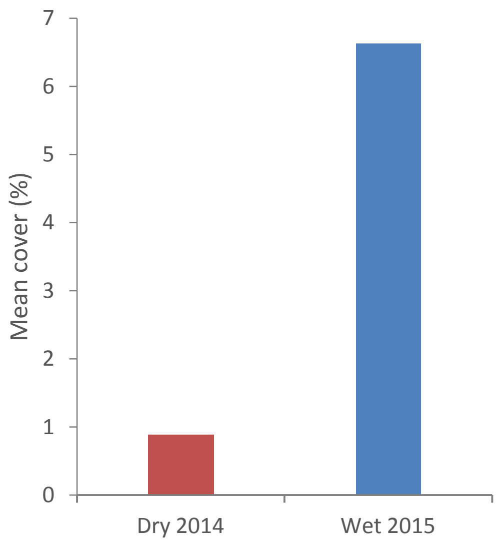

Figure D-14: Mean cover (%) of Flat spike-sedge at sites that were dry in 2014 and wet in 2015.

D.4 Discussion

Species diversity was relatively high across all sites compared to surveys carried out in the previous water year, especially in sites within the Gwydir watercourse. Vegetation monitoring undertaken in the 2013-14 year showed sites in the Gwydir had significantly lower diversity than in the Gingham watercourse with average diversities of between 6 and 14 species (Southwell et al. 2015). The increase in overall species diversity during the 2014-15 season may be a result of increased recovery from the fire that occurred in March 2014. Bare ground was also shown to be a large contributor to the similarity of plots in the Gwydir watercourse in 2013-14, a trend which was not so apparent in the 2014-15 water year. In addition, the percentage of bare ground in plots across all sites in 2014-15 appeared to decrease with the addition of environmental water through the season, suggesting an improvement in vegetation cover throughout. Future monitoring will continue to track the recovery of vegetation communities impacted by the 2014 fire in the Gwydir system.

Environmental water influenced all five vegetation community types surveyed for this project. Generally, the presence of water tended to result in a reduced diversity of plants, predominantly through a positive influence on the targeted wetland species (Amphibious functional group species). One exception to this was the Coolibah Woodland wet understory community, where the single plot that was inundated had 48 species recorded; much higher than the average of the other plots in this community which remained dry (average of 23.4+/-7.1 species). In this vegetation community, inundation appears to have stimulated the growth of understory species that failed to germinate in the other dry plots.

The influence of environmental water was also observed in the cover of vegetation species recorded in each plot. The weed species Lippia which exploits areas of bare ground during moist or dry conditions showed a significantly reduced coverage in inundated plots. By contrast, native wetland species such as water couch and flat spike-rush displayed significantly greater coverage in wet plots. It is likely that the increased growth of these native species in wet plots is assisting them to out compete the Lippia, leading to a suppression of this weed species in inundated locations. The ability of native wetland species to out compete Lippia under favourable conditions has previously been observed in the Gwydir wetlands by Price et al. (2011) and is another positive outcome for the application of environmental water.

D.5 Conclusion

The delivery of environmental water into the Gingham and Lower Gwydir wetlands during the 2014-15 water year influenced all five water dependent vegetation communities surveyed. While season was shown to be an influencing factor, the presence of environmental water had the largest influence on vegetation patterns. The application of environmental water tended to favour wetland species. Wetland species that were better able to withstand inundation increased in number. In particular, Water couch and Flat spike-rush increased in cover, to an extent where they appeared to out compete Lippia and reduce its coverage at sites that became inundated. The amount of bare ground present in survey plots also decreased with the application of environmental water, which is an encouraging sign for the health of these wetland communities.

D.6 References

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Appendix E Waterbird Diversity

E.1 Introduction

The Gingham and Lower Gwydir wetlands are recognised as an important area for waterbirds, and support some of the largest breeding colonies in Australia (DECCW 2011). They also support a number of species listed under international agreements. In addition to the Gingham and Lower Gwydir wetlands being an important habitat for waterbirds, the birds themselves constitute a useful indicator of river and wetland health at both a regional and local scale, with surveys previously being undertaken in the Gwydir system for a number of years (Spencer et al. 2014). Several specific questions were addressed through the monitoring of waterbird diversity in the 2014-15 water year in the Gingham and Lower Gwydir wetlands:

- 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?

E.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendix B and G). 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 wetland inundation (Table B-1).

Environmental water delivered to the Gingham and Gwydir wetland systems inundated a number of sites surveyed for waterbird diversity (Table E-1). While some sites contained water during the December 2014 survey, the proportion of sites that were inundated during the March 2015 survey increased as the delivery of environmental water increased the extent of inundation towards the end of the water year. Similarly, the degree of inundation at each site tended to increase in the March 2015 survey period (Table E-1). Three sites were dry during both survey periods.

E.1.2 Previous monitoring

Seasonal ground counts for waterbirds are undertaken by NSW OEH in five wetland regions, including the Gwydir wetlands (Spencer et al. 2014; NSW OEH 2014). The 2012-13 and 2013-14 surveys were undertaken after two years of major natural flooding that occurred across the Murray Darling Basin (MDB). The spring surveys undertaken in November 2012 along the Gwydir wetlands followed major widespread flooding in February 2012, although wetted sites along the Lower Gwydir and Gingham watercourses were beginning to dry by the November surveys. The autumn surveys undertaken in May 2013 preceded environmental flow releases delivered to the Lower Gwydir watercourse and eastern Gingham in December 2012 onwards, which resulted in inundation of semi-permanent wetland vegetation in the core wetlands in the eastern Lower Gwydir and eastern Gingham watercourses (Spencer et al. 2014). Similarly, waterbird numbers responded to the delivery of environmental water to the Gingham and Mallowa wetlands over December 2013-March 2015 (NSW OEH).

The results of the 2012-13 and 2013-14 seasons indicated that waterbird abundance and diversity corresponded to habitat availability, with greater numbers of waterbirds observed in wetlands that had received inflows in winter-spring 2012 and summer 2014 and/or remained wet from the natural flooding that occurred in spring-autumn 2012. Along the Gwydir wetlands, the largest waterbird counts were recorded in the spring-summer surveys with the most abundant species being Plumed whistling-duck (*Dendrocygna eytoni*), Grey teal (*Anas gracilis*), Nankeen night-heron (*Nycticorax caledonicus*) and Eurasian coot (*Fulica atra*). Threatened waterbirds were also detected with a large flock of 178 Brolga (*Grus rubicunda*) recorded in the Gingham watercourse during autumn 2013, and Freckled duck (*Stictonetta naevosa*), Black-necked stork (*Ephippiorhynchus asiaticus*) (NSW TSC Act 1995) and nationally endangered Australian Painted snipe (*Rostratula australis*) (Commonwealth EPBC Act 1999) recorded during the autumn 2014 surveys (Spencer et al. 2014; NSW OEH 2014).

Table E-1: Inundation area (%) in December 2014 and March 2015 at Gingham and Gwydir Wetland sites. Sites that were inundated by environmental water are highlighted blue ('wet') and those that were not are highlighted yellow ('dry').

Wetland	Site Name	Inundation Area (%)		Difference between seasons (%)
		Dec 14	Mar 15	
Gingham	Baroona Waterhole	0	0	0
	Boyanga Waterhole East	0	20	20
	Boyanga Waterhole West	2	40	38
	Bunnor Bird Hide	80	80	0
	Gingham Waterhole	10	80	70
	Goddard's Lease	0	100	100
	Jackson	60	50	-10
	Little Lagoon	0	30	30
	Lynworth Dam	0	95	95
	Lynworth Floodplain	0	60	60
	Munwonga Wetland	0	70	70
	Racecourse Lagoon	0	5	5
	Talmoi Waterhole	0	0	0
	Tillaloo Waterhole	0	0	0
	Westholme NW	0	60	60
	Westholme SE	75	100	25
Lower Gwydir	Old Dromana Dam	50	85	35
	Old Dromana Floodplain	50	85	35
	Wandoona Waterhole	0	80	80

E.2 Methods

A total of 19 sites were surveyed in both December 2014 and March 2015. These sites were spread between the Gingham and Gwydir watercourses (Table E-2; Figure E-1). Monitoring for this indicator was done in conjunction with staff from NSW OEH, using ground surveys (Commonwealth of Australia

2014). These surveys were undertaken by moving around each wetland and recording birds from various points that were generally out of sight of one another. At each point all birds were observed and recorded. New birds were recorded enroute to new points and their species and number were noted. At larger sites, transects were traversed and a running tally was recorded as observers moved along each transect. During the survey, as much of each wetland as possible was accessed. Surveys were undertaken for at least 20 minutes but no more than 1 hour at each wetland in order to gain a representative, not necessarily complete, count of all waterbirds in the wetland. Replicate surveys were undertaken in the morning and evening when possible in order to capture a representative measure of maximum species diversity. The maximum waterbird count for individual species from either of the replicate surveys was used in the analysis. The area of inundation of the wetland was estimated at the time of each survey.

Factorial regressions were undertaken on species diversity, total bird abundance and waterbird functional guild data to compare between survey times and the presence of environmental water. F-tests were used to test for equality of variances, and appropriate t-tests were employed thereafter. Multivariate nMDS analysis undertaken in PRIMER 6 was used to decipher patterns of bird community composition. Permanova tests were then performed to compare between survey time and the presence of environmental water.

Table E-2: Locations of sites within the Gingham and Gwydir wetlands surveyed for waterbird diversity.

Site Name	Management	Survey Type	Zone	Easting	Northing
Baroona Waterhole	Gingham	Point(s)	55	739764	6762643
Boyanga Waterhole (Eastern)	Gingham	Point	55	718064	6766759
Boyanga Waterhole (Western)	Gingham	Point	55	717729	6766685
Bunnor Bird Hide	Gingham	Point	55	731404	6759072
Gingham Waterhole	Gingham	Point(s)	55	723781	6762914
Goddard's Lease	Gingham	Point	55	731755	6761058
Jackson	Gingham	Point(s)	55	746148	6753187
Little Lagoon	Gingham	Point	55	721085	6762748
Lynworth Dam	Gingham	Point	55	727702	6763011
Lynworth Transect	Gingham	Transect	55	728151	6762769
Mungwonga Wetland	Gingham	Transect	55	722701	6763569
Racecourse Lagoon	Gingham	Point	55	720676	6763950
Talmoi Waterhole	Gingham	Point	55	746631	6760958
Tillaloo Waterhole	Gingham	Point(s)	55	742019	6761842
Westholme NW	Gingham	Transect	55	732439	6760783
Westholme SE	Gingham	Transect	55	733314	6757778
Old Dromana Dam	Lower Gwydir	Transect	55	725856	6752106
Old Dromana Transect	Lower Gwydir	Transect	55	727143	6750921
Wandoona Waterhole	Lower Gwydir	Point	55	721191	6751367

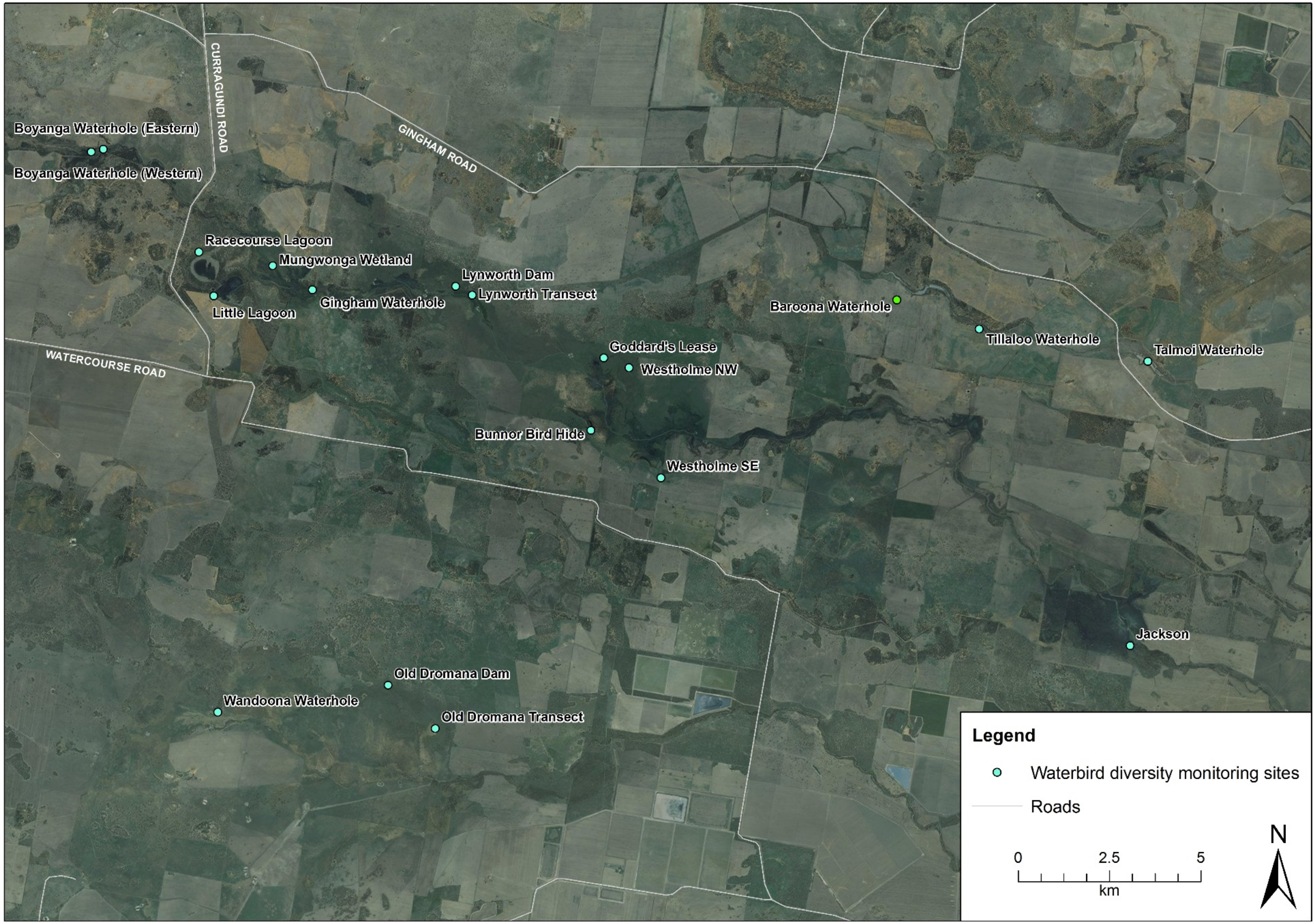

Figure E-1: Location of waterbird diversity monitoring sites.

E.3 Results

E.3.1 Species diversity and abundance

In total 148 bird species, including 59 waterbird species were recorded in the Gingham and Lower Gwydir wetlands during the December 2014 and March 2015 survey period. This included six waterbird species listed under one or more international migratory bird agreements (JAMBA, CAMBA and ROKAMBA) and two threatened species listed under the NSW TSC Act: Brolga and Magpie goose (*Anseranas semipalmata*). Migratory shorebirds recorded included Common greenshank (*Tringa nebularia*), Latham's snipe and Sharp-tailed sandpiper (*Calidris acuminata*). A relatively large flock of Latham's snipe (19 birds) was recorded in the flooded sedgeland at Little Lagoon in the upper Gingham.

The maximum count of waterbirds per hectare in the Gingham and Lower Gwydir wetlands was 116 individuals in December 2014 and 807 in March 2015, consisting of 42 waterbird species in December 2014 and 55 in March 2015. Accordingly, waterbird abundance and diversity were greater in March 2015 than in December 2014 (abundance; $T=2.08$, $Pr=0.05$, diversity; $T=3.86$, $Pr<0.005$). The mean waterbird count per site was 6 waterbirds per ha in December 2014 and 42 waterbirds per hectare in March 2015, and the mean diversity per site was 7 species in December 2014 and 18 species in March 2015 (Figure E-2; Figure E-3). A comparison of sites between those that received environmental water and those that did not regardless of the survey period indicated significantly higher waterbird abundance ($T=2.58$, $Pr<0.05$) and diversity ($T=9.95$ $Pr<0.001$) at sites that received environmental water.

Bunnor Bird Hide recorded the highest species diversity (34 in the March 2015 survey) and the highest waterbird abundance (332 waterbirds per ha in the March 2015 survey), comprising 36% of the maximum waterbird count per ha in the 2014-15 survey period (Figure E-2; Figure E-3; Table E-3). In March 2015, flocks of 100-400 birds were recorded for the species Grey teal, Magpie goose, Pacific black duck (*Anas superciliosa*) and Plumed whistling-duck at the Bunnor Bird Hide. Little Lagoon on the Gingham Watercourse did not record any waterbirds in December 2014 when the site was dry, but recorded 22 species in March 2015 when the site was inundated (Figure E-2; Figure E-3; Table E-3).

nMDS plots show that there was separation in the data based on both sampling season and the presence of environmental water (Figure E-4). Sites sampled in December 2014 that were dry tended to show greater spread in comparison to sites that were wet in either season, they tended to group closer together suggesting more similar community composition at these sites. PERMANOVA suggested that the differences between season (Psueadu-F=1.59, $P<0.05$) and the presence of environmental water (Psueadu-F=3.64, $P<0.001$) were both significant, but that there was no interaction between these factors ($P=0.057$).

Waterbird breeding was only observed during March 2015 over the 2014-15 survey period and occurred at four of the survey sites (Bunnor Bird Hide, Gingham Waterhole, Wandoona Waterhole and Goddard's Lease) (Table E-4; Table E-5). During the March 2015 survey period, breeding activity (broods and/or nests) was observed in eight waterbird species, including Australasian darter (*Anhinga novaehollandiae*), Australian white ibis (*Threskiornis moluccus*), Eurasian coot, Hoary-headed grebe (*Poliocephalus poliocephalus*), Little pied cormorant (*Microcarbo melanoleucos*), Magpie goose, Plumed whistling-duck and Wandering whistling-duck (*Dendrocygna arcuata*) (Table E-4; Table E-5). All sites that recorded waterbird breeding activity or evidence of breeding received environmental water over the 2014-15 summer. No breeding activity (broods and/or nests) was recorded in December 2014, although a juvenile white-bellied sea-eagle was observed at Boyanga Waterhole (west) (Table E-5).

Table E-3: Species diversity, abundance and the number of waterbird functional groups recorded at sites within the Gingham and Gwydir Wetlands during 2014-15.

Wetland	Site Name	Waterbird species diversity (maximum total species count)		Waterbird abundance/ ha (maximum waterbird count/ha)		Waterbird functional guilds	
		Dec 14	Mar 15	Dec 14	Mar 15	Dec 14	Mar 15
Gingham	Baroona Waterhole	0	0	0	0	0	0
	Boyanga Waterhole E	8	20	7.5	58.3	4	8
	Boyanga Waterhole W	12	17	18.7	60.0	5	9
	Bunnor Bird Hide	13	34	15.5	332.5	8	9
	Gingham Waterhole	19	25	11.8	82.9	9	9
	Goddard's Lease	5	33	0.2	4.7	3	9
	Jackson	13	28	4.9	11.1	9	9
	Little Lagoon	0	21	0	9.0	0	10
	Lynworth Dam	7	22	1.7	44.6	4	9
	Lynworth Floodplain	1	24	0.2	86.0	1	8
	Munwonga Wetland	5	16	0.6	15.1	2	5
	Racecourse Lagoon	0	4	0	0.2	0	3
	Talmoi Waterhole	0	0	0	0	0	0
	Tillaloo Waterhole	0	0	0	0	0	0
	Westholme NW	0	29	0	19.5	0	9
	Westholme SE	15	21	13.4	33.3	7	8
Lower Gwydir	Old Dromana Dam	16	14	36.5	13.2	8	7
	Old Dromana Floodplain	18	20	3.0	4.5	9	7
	Wandoona Waterhole	4	20	1.8	31.7	4	9
	Average	**7.2**	**18.4**	**6.1**	**42.5**	**4.2**	**6.7**
	Std dev	**6.9**	**10.6**	**9.5**	**75.5**	**3.8**	**3.4**

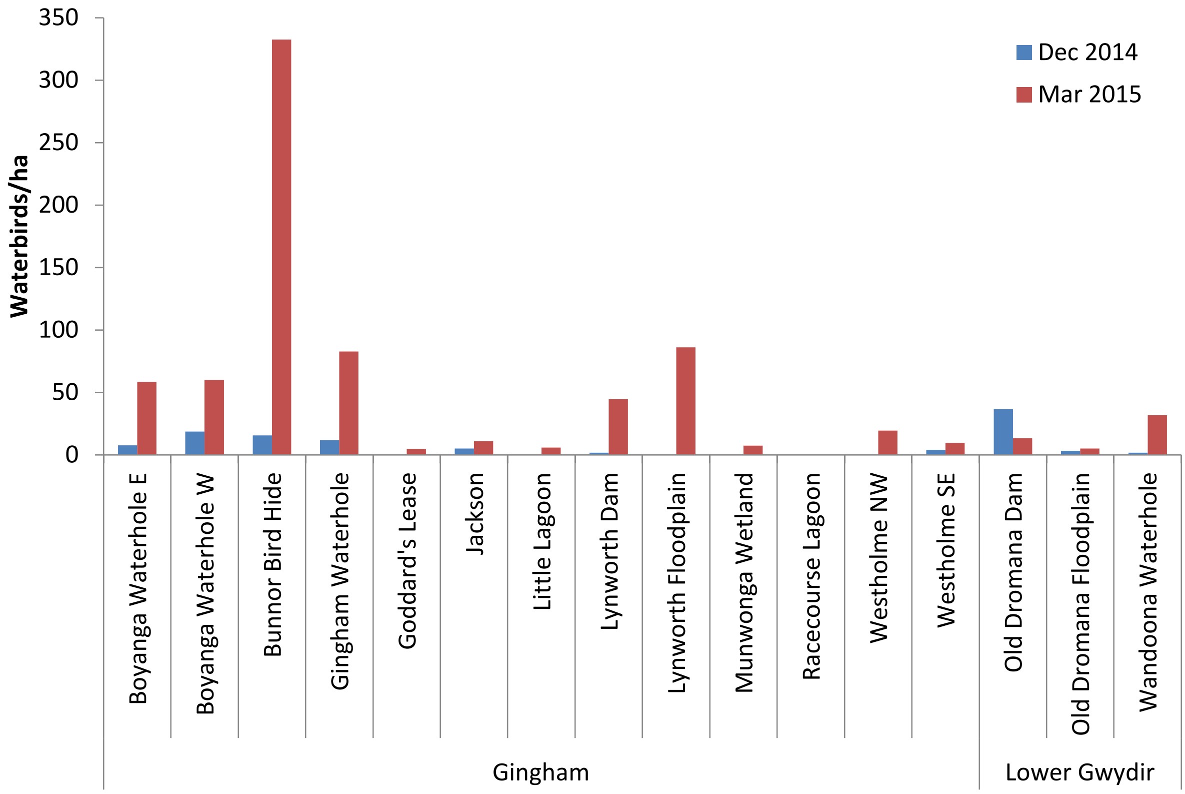

Figure E-2: Waterbird counts per hectare recorded at sites in the Gingham and Lower Gwydir wetlands in December 2014 and March 2015.

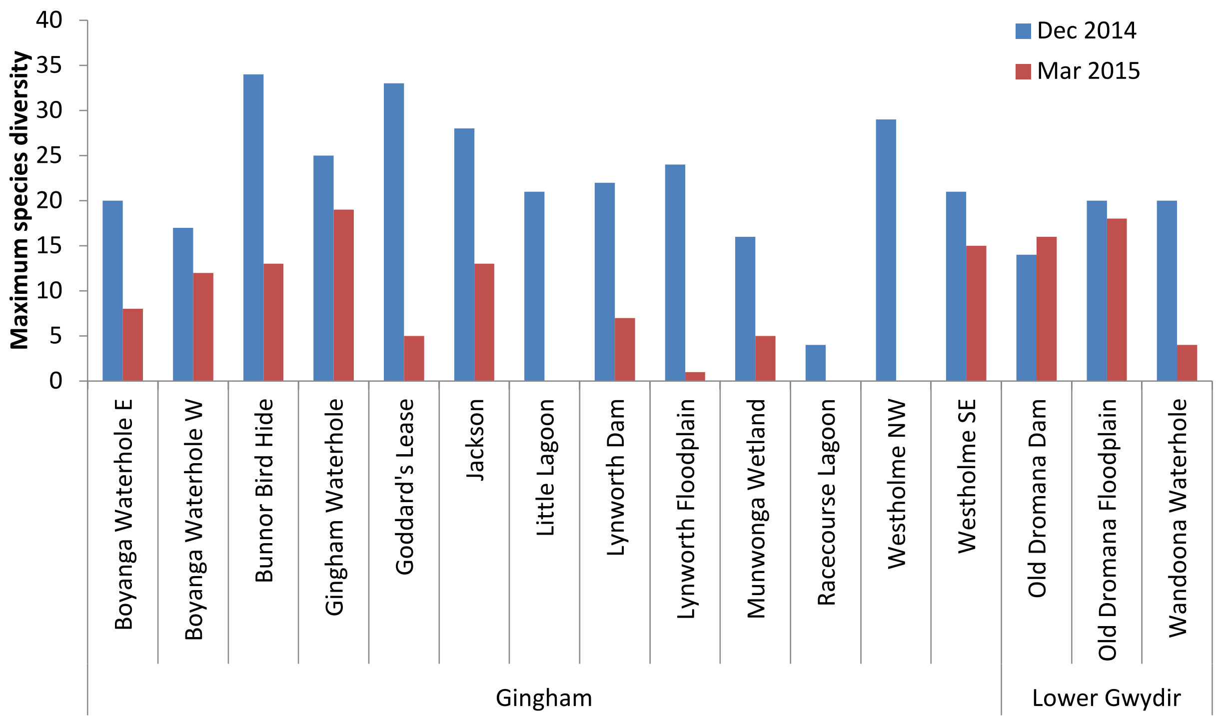

Figure E-3: Maximum total species diversity recorded at sites in the Gingham and Lower Gwydir Wetlands in December 2014 or March 2015.

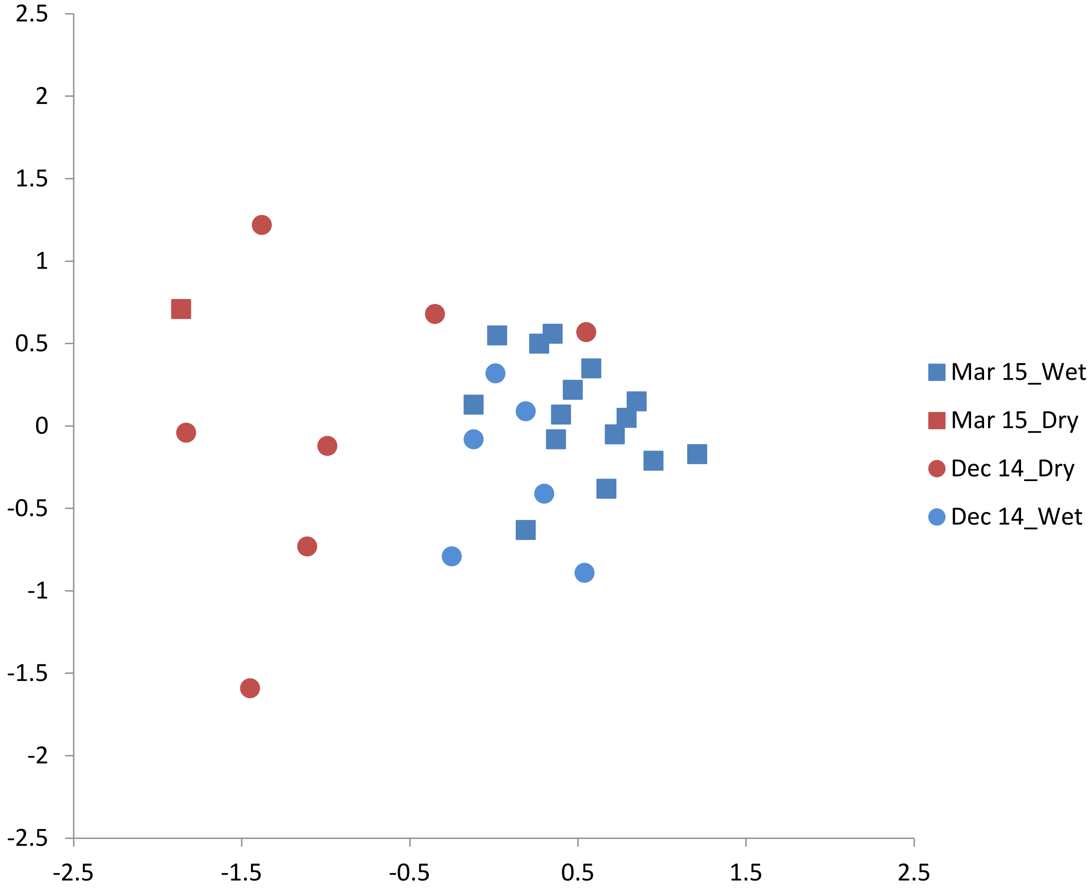

Figure E-4: nMDS plot of waterbird species abundance data grouped by sampling season and the presence of Commonwealth environmental water ("Wet") or not ('Dry").

Table E-4: Summary of breeding activity over the 2014-15 survey period.

Survey period	Site name	Common name	Breeding activity (no. broods or nests)	Notes and additional evidence of breeding (breeding plumage, juveniles and empty nests)
Dec 2014	Boyanga Waterhole West	White-bellied sea-eagle	0	1 adult 1 juvenile
March 2015	Boyanga Waterhole East	White-bellied sea-eagle	0	Immature
	Bunnor Bird Hide	Australasian darter	3	Adult on nest
		Australasian darter	1	2 adults, 3 large juveniles on nest
		Australian white ibis	22	Adults on nests
		Eurasian coot	2	Adult on nest
		Little pied cormorant	2	Adult on nest
		Little pied cormorant	3	Nest with chicks
		Little pied cormorant	4	Adult on nest
		Magpie goose	37	12 adult trampling, 1 nest with 3 juveniles, approx. 24 empty nests
		Plumed whistling-duck	6	Adults on nest, and/or with young
		Sacred kingfisher	0	1 juvenile
		Whistling kite	0	Empty nest
	Gingham Waterhole	Australasian darter	1	2 fledglings
	Goddard's Lease	Plumed whistling-duck	1	5 ducklings
		Wandering whistling-duck	1	4 ducklings
	Lynworth Dam	Australian reed-warbler	0	1 juvenile
	Racecourse Lagoon	Wedge-tailed eagle	0	1 juvenile
	Wandoona Waterhole	Hoary-headed grebe	1	8 juveniles
		Wandering whistling-duck	1	10 ducklings

E.3.2 Functional guilds

All ten functional guilds were represented across the wetlands in both December 2014 and March 2015 (Figure E-5). The average number of functional guilds recorded at sites that recorded waterbird species was four in December 2014, which increased significantly to seven in March 2015 ($T=2.45$, $Pr<0.05$) (Table E-3). Eight of the 10 functional guilds increased in the number of waterbirds per ha from December 2014 to March 2015. Australian-breeding Chardadriiform shorebirds and Migratory Charadriiform shorebirds decreased slightly (between 0.1 and 6 waterbirds per hectare) from December 2014 to March 2015 (Figure E-5). Grazing ducks and geese; dabbling and filter-feeding ducks; large wading birds; piscivores birds; and, diving ducks, aquatic gallinules and swans displayed the greatest increases in waterbird abundance across the wetlands over the 2014-15 season (between 51 and 325 waterbirds per ha).

Large wading birds and piscivores were dominant in December 2014 and grazing ducks and geese were dominant in March 2015, and overall grazing ducks and geese dominated the waterbird community over the 2014-15 season. Grazing ducks and geese include the Plumed whistling-duck and the Magpie goose, and large flocks of these species (100-400 birds) were recorded in the Gingham wetlands during March 2015. The most widespread species recorded in the 2014-15 season included the Pacific black duck, Little pied cormorant, Australian white ibis, White-faced heron (*Egretta novaehollandiae*) and Grey teal (Table E-5). The top six waterbird species recorded in the 2014-15 seasons represented approximately 63% of all waterbirds recorded during the surveys, including Magpie goose, Eurasian coot, Australian white ibis, Grey teal, Pacific black duck and Plumed whistling-duck. The Plumed whistling-duck contributed 26% to the number of waterbirds recorded, although were only recorded in March 2015 (Table E-5).

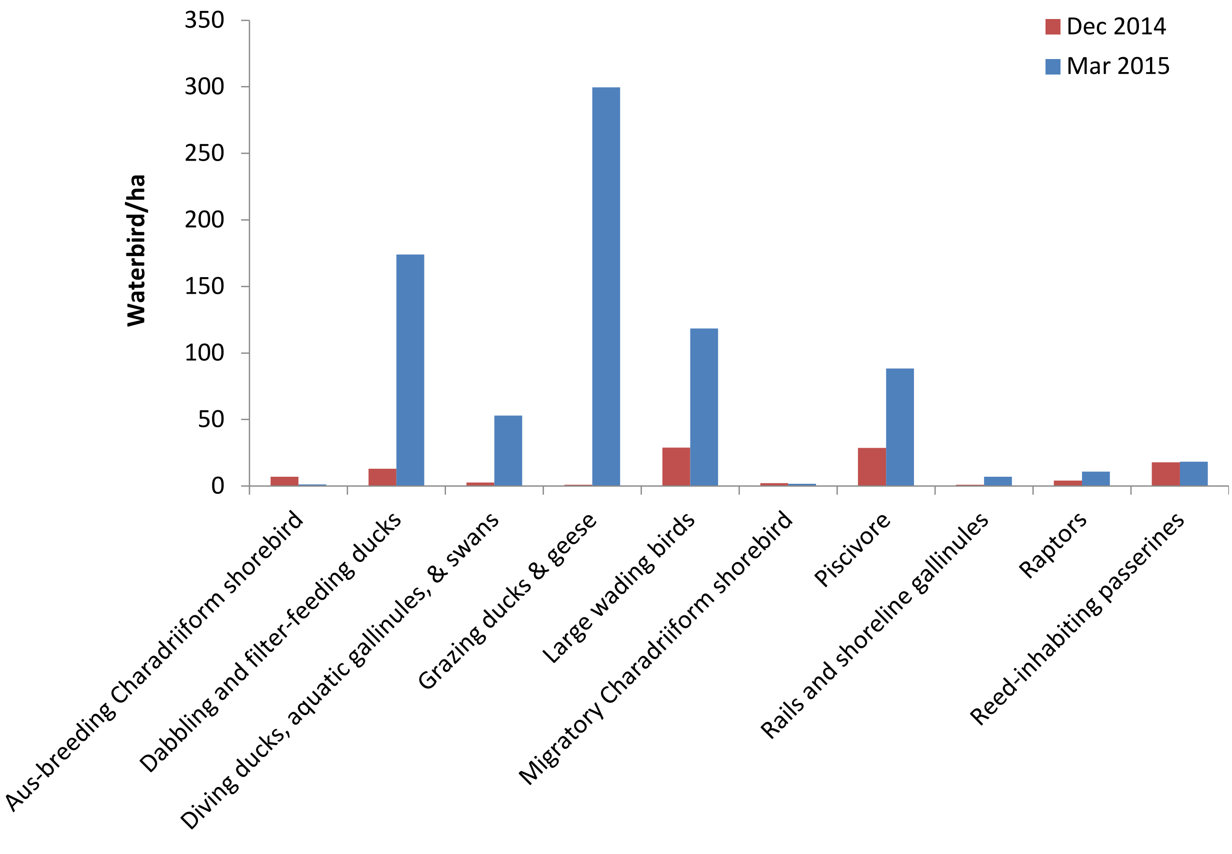

Figure E-5: Waterbird count per hectare per functional group recorded in December 2014 and March 2015 across all sites.

Table E-5: Maximum counts and percent occurrence of the 59 waterbird species recorded in the Gwydir wetlands in 2014-2015.

Functional group (guild)	Common name	Gingham																Lower Gwydir			% Occurrence
		Baroona Waterhole	Boyanga Waterhole E	Boyanga Waterhole W	Bunnor Bird Hide	Gingham Waterhole	Goddard's Lease	Jackson	Little Lagoon	Lynworth Dam	Lynworth Floodplain	Munwonga Wetland	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme NW	Westholme SE	Old Dromana Dam	Old Dromana Floodplain	Wandoona Waterhole	
Australian-breeding Charadriiform shorebird	Black-Fronted Dotterel					1		1								16					16
	Black-Winged Stilt				4													4	4		16
	Masked Lapwing							2	2							4	5	6	12	2	37
	Red-kneed Dotterel									2						3					11
Dabbling and filter-feeding ducks	Australasian Shoveler				2	1															11
	Grey Teal		1	2	137	47	10	80	13	24	7					49	4		3	3	68
	Hardhead				8	15	2									12					21
	Pacific Black Duck		5	25	203	91	25	80	23	11	44					30	7	4	52	24	73
	Pink-eared Duck						3									6					11
Diving ducks, aquatic gallinules, and swans	Black Swan				4		2		5											2	21
	Eurasian Coot*		1	60	27	5	15		4	3										83	42

Functional group (guild)	Common name	Gingham																Lower Gwydir			% Occurrence
		Baroona Waterhole	Boyanga Waterhole E	Boyanga Waterhole W	Bunnor Bird Hide	Gingham Waterhole	Goddard's Lease	Jackson	Little Lagoon	Lynworth Dam	Lynworth Floodplain	Munwonga Wetland	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme NW	Westholme SE	Old Dromana Dam	Old Dromana Floodplain	Wandoona Waterhole	
Fish-eater	Whiskered Tern				1	2											1				16
	White-faced Heron		2	1	2	1	1	7	8		1	4	2			23		5	2	5	74
	White-necked Heron		10	1	2		2	11		4	4	11				16	1	5	29	7	68
Grazing ducks and geese	Australian Wood Duck			7	1	6		32								12	1				32
	Magpie Goose* **V**				176		108	1								1					21
	Plumed Whistling-duck*			18	399	274	55	100		120	200					100	4			10	52
	Wandering Whistling-duck*						1													7	11
Large wading birds	Australian White Ibis*		5	11	59	9	13	42	3	24	31	7				60	41	8	25		74
	Brolga **V**								2							3	22				16
	Glossy Ibis **C**				40	14	7		2	26	17	16				35	5		1		53
	Royal Spoonbill*		6	10	2	18	37	6	20	4	1	20							15		58
	Straw-necked Ibis		120		2		6	1	5	3	1					5		3			47
	Yellow-billed Spoonbill		4	10		6	1	2	1		1	1				11		1			52

Functional group (guild)	Common name	Gingham																Lower Gwydir			% Occurrence
		Baroona Waterhole	Boyanga Waterhole E	Boyanga Waterhole W	Bunnor Bird Hide	Gingham Waterhole	Goddard's Lease	Jackson	Little Lagoon	Lynworth Dam	Lynworth Floodplain	Munwonga Wetland	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme NW	Westholme SE	Old Dromana Dam	Old Dromana Floodplain	Wandoona Waterhole	
Migratory Charadriiform shorebird	Common Greenshank **JCR**																		1		5
	Latham's Snipe* **JCR**								19							4			6	1	21
	Sharp-tailed Sandpiper **JCR**															13		5			11
Piscivore	Australasian Darter*		1	2	6	12	1	3									3	1	2		47
	Australasian Grebe		1		2		10			9							2			12	32
	Australian Little Bittern																	1			5
	Australian Pelican		1	3	8	14	10	2		1							3				42
	Cattle Egret* **JC**				1		8	3		4	5					16	20	2			42
	Eastern Great Egret **JC**		10	1	19	2	2	16	1	2		10					6	15	1	1	68
	Great Cormorant				5	1					1								1		21
	Hoary-headed Grebe*									2										1	11
	Intermediate Egret*		2		13	1	7	8	21		12	78				107	30	1	4		63

Functional group (guild)	Common name	Gingham																Lower Gwydir			% Occurrence
		Baroona Waterhole	Boyanga Waterhole E	Boyanga Waterhole W	Bunnor Bird Hide	Gingham Waterhole	Goddard's Lease	Jackson	Little Lagoon	Lynworth Dam	Lynworth Floodplain	Munwonga Wetland	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme NW	Westholme SE	Old Dromana Dam	Old Dromana Floodplain	Wandoona Waterhole	
Piscivore (cont.)	Little Black Cormorant			3	10	11		25			1						8		61		36
	Little Egret*								2							1					11
	Little Pied Cormorant*		2	10	19	2	2	4	3	2	3	3					1	1	1	2	74
	Pied Cormorant			1	1	5					1										21
	Sacred Kingfisher*		1		3	2	2		1	2			1			1		1	1	1	57
Rails and shoreline gallinules	Black-tailed Native-hen							10													5
	Dusky Moorhen		2	1	5	1	1				2										32
	Purple Swamphen				5	1	10	1	1	7	2						1	1	2		52
Raptors	Australian Hobby											1								1	10
	Black Kite																1				5
	Black-shouldered Kite				1	1	1					3				1		1	1	1	42
	Brown Falcon			2				2				2						1	1		26
	Brown Goshawk												1					1	1	1	21
	Nankeen Kestrel											1									5

Functional group (guild)	Common name	Gingham																Lower Gwydir			% Occurrence
		Baroona Waterhole	Boyanga Waterhole E	Boyanga Waterhole W	Bunnor Bird Hide	Gingham Waterhole	Goddard's Lease	Jackson	Little Lagoon	Lynworth Dam	Lynworth Floodplain	Munwonga Wetland	Racecourse Lagoon	Talmoi Waterhole	Tillaloo Waterhole	Westholme NW	Westholme SE	Old Dromana Dam	Old Dromana Floodplain	Wandoona Waterhole	
Raptors (cont.)	Peregrine Falcon						1									1					11
	Swamp Harrier				4		2	1		1	1					1	1		1		42
	Wedge-tailed Eagle		3	2		1		1		1		2	3								37
	Whistling Kite		1		5	1	1	3	1	2	1	1				2	2		1	1	68
	White-bellied Sea-eagle **C**		1	2		2				1							2				26
Reed-inhabiting passerines	Australian Reed-warbler*		2	2	10	4	1	1		7	6	2					10	20	14	1	68
	Golden-headed Cisiticola				3		1	1		1	1	1				1	8	2	11	2	58
	Little Grassbird			1	2		1	1	1	4	4					1	3	1	2		58
	Tawny Grassbird				1			1		1	1						3				26
Species diversity (max total species)		**0**	**21**	**22**	**37**	**30**	**33**	**30**	**21**	**26**	**24**	**17**	**4**	**0**	**0**	**29**	**27**	**23**	**27**	**21**	
Species abundance (max total count)		**0**	**181**	**175**	**1,192**	**551**	**349**	**448**	**138**	**268**	**348**	**163**	**7**	**0**	**0**	**535**	**195**	**90**	**255**	**168**	

^Status: V=vulnerable (NSW *TSC Act*), J= Listed under JAMBA, C=listed under CAMBA, R=listed under ROKAMBA migratory bird agreements. * Breeding activity (nests/broods) or evidence of breeding (breeding plumage, juveniles and empty nests)

E.4 Discussion

The December 2014 waterbird surveys followed a prolonged dry period along the Gingham and Lower Gwydir wetlands; 13 of the 19 sites surveyed were dry. Environmental water was released over summer 2014-15 and 16 of the 19 sites surveyed in the 2014-15 survey period had received environmental water by March 2015. In total 59 waterbird species were recorded over the 19 sites across the Gingham and Lower Gwydir wetlands during the 2014-15 survey period. Waterbird abundance and diversity was greater in March 2015 compared to December 2014, although the increase in waterbird abundance between the two seasons was not significant. A comparison of sites that were wet against those that were dry regardless of time showed a significant increase in both species abundance and diversity, indicating that increases in species diversity and abundance were driven by inundation. Species diversity included two threatened species listed under the NSW TSC Act (Brolga and Magpie goose) and six species listed under one or more migratory bird agreements (Cattle egret, Eastern great egret, Glossy ibis, Common greenshank, Latham's snipe and Sharp-tailed sandpiper).

The results of the 2014-15 survey period follow the 2012-13 and 2013-14 seasons where waterbird abundance and diversity responded to habitat availability, and greater numbers of waterbirds were observed in wetlands that had received inflows during the season. However, along the Gingham and Lower Gwydir wetlands in 2014-15, the largest waterbird counts were recorded in the March 2015 surveys as opposed to the spring surveys in the 2012-13 survey period, where nine of the 12 sites surveyed recorded greater maximum waterbird counts in spring compared to autumn (Spencer et al. 2014). The results of the current study indicate that wetland inundation levels may be more influential to the number of waterbirds that frequent an area compared to seasonal timing. However, the 2015 sampling was undertaken in March rather than May when the 2013 autumn survey was undertaken meaning that cooler temperatures and migration patterns may have reduced waterbird counts in the 2013 survey.

Grazing ducks and geese dominated the waterbird community in the 2014-15 season and in previous water years (Spencer et al. 2010; Spencer et al. 2014; NSW OEH 2014). In the 2014-15 survey period this included the Plumed whistling-duck and the Magpie goose and large flocks of these species (100-400 birds) were recorded along the Gingham wetlands during March 2015. The Plumed whistling-duck was only recorded in March and contributed 26% of the total number of waterbirds recorded over the 2014-15 survey period. The top five waterbird species recorded in the 2014-15 survey period represented approximately 63% of all waterbirds recorded during the surveys, including Magpie goose, Eurasian coot, Australian white ibis, Grey teal, Pacific black duck and Plumed whistling-duck.

Breeding activity (broods and nests) was recorded during March 2015 within both the Gingham and Lower Gwydir wetlands. Species observed breeding included Australasian darter, Australian white ibis, Eurasian coot, Hoary-headed grebe, Little pied cormorant, Magpie goose, Plumed whistling-duck and Wandering whistling-duck. Evidence of breeding (i.e. juveniles and empty nests) was observed in an additional five species. All sites that recorded waterbird breeding activity or evidence of breeding received environmental water over the 2014-15 summer. No breeding activity (broods and/or nests) was recorded in December 2014, although a juvenile White-bellied sea-eagle was sighted at Boyanga Waterhole West. Waterbird breeding species diversity varied from the 2012-13 survey period, with breeding activity observed in only four species, none of which overlapped between survey periods (Black-necked stork, Dusky moorhen (*Gallinula tenebrosa*) and Red-kneed dotterel (*Erythrogonys cinctus*) in the 2012-13 survey period and only Dusky moorhen, Masked lapwing (*Vanellus miles*) and Red-kneed dotterel in the 2013-14 survey period). This suggests that although breeding activity in the 2014-15 survey period improved compared to the 2012-13 and 2013-14 water years, breeding activity remained relatively low compared to historical records, with only small-scale colonial waterbird breeding observed.

E.5 Conclusion

Delivered environmental water was the primary source of water to the Gingham and Lower Gwydir wetlands between December and March during the 2014-15 water year. Thus, changes as a result of increased inundation could be attributed directly to the application of Commonwealth and state environmental water. Significant increases were observed in both waterbird species diversity and total abundance at sites that received environmental water, and this appeared to be a greater influence than season. In addition, low levels of breeding of several species were observed at a number of sites on the Gingham watercourse that received environmental water, contributing to the continued survival of these species in this system. Additional natural inflows that have occurred into the wetlands towards the end of the season have prolonged the duration of inundation in these areas, lengthening the availability of suitable habitat for many bird species.

E.6 References

Commonwealth of Australia (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Gwydir River System Selected Area, Canberra.

Department of the Environment, Climate Change and Water (DECCW) (2011). Gwydir Wetlands Adaptive Environmental Management Plan, Sydney.

NSW OEH (2014). Gwydir Wetlands Waterbird Monitoring: Survey Results from 2013-14. NSW Office of Environment and Heritage.

Spencer, J.A., Heagney, E.C. and Porter, J. (2010). Final report on the Gwydir waterbird and fish habitat study. NSW Wetland Recovery Program. Rivers and Wetlands Unit, Department of Environment, Climate Change and Water NSW and University of New South Wales, Sydney.

Spencer, J., Hosking, T., Ewin, P., Webster, R., Hutton, K., Allman, R., Thomaws, R., Humphries, J., Berney, P. and Mulholland, M. (2014) Waterbird Monitoring in Inland NSW: Summary Report 2012-13. NSW Office of Environment and Heritage. Sydney.

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Appendix F Water Quality

F.1 Introduction

The Water Quality indicator seeks to assess the contribution of Commonwealth environmental water to the improved quality of water entering lower Gwydir ecological assets. As such this indicator is linked to the vegetation diversity, waterbird diversity and breeding, fish (river) and hydrology (river and watercourse) indicators. Several specific questions could be addressed by assessing water quality within the Gwydir River during the 2014-15 water year:

- 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?

F.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendices B and G). 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 wetland inundation (Table B-1).

The Gwydir River zone experienced environmental water delivery from September through to February, as it is the main conduit for environmental water delivered to downstream zones (Appendix B).

F.1.2 Previous monitoring

Previous water quality monitoring was undertaken by Southwell et al. (2015) as part of the Short Term Intervention Monitoring project in 2013-14. They noted that for the most part water quality in all sampled lower Gwydir channels was within the limits acceptable for aquatic biota. They did note, however, a deterioration of water quality in a downstream direction especially in the Gingham system, where waterholes lower in the system tending to have poorer water quality, especially when inflows and water levels were low.

F.2 Methods

A single monitoring site for water quality was located in the Gwydir River zone from Copeton Dam to Tareelaroi Weir, as this reach has permanent surface water connectivity in a defined channel and all Commonwealth environmental water delivered to the lower Gwydir must pass through this reach (Commonwealth of Australia 2014). The single station was located at Pallamallawa and allows all-weather access, is co-located with the NoW telemetered gauged site (NSW418001) and provides data on influent water quality to the lower Gwydir throughout all flow deliveries.

Continuous monitoring of dependant variables Temperature (°C), pH, Turbidity (NTU), Salinity (mS/cm) and Dissolved oxygen (DO) (mg/L) occurs at this location using a Hydrolab DS5-X logger. The probe was mounted to a floating pontoon at the Pallamallawa Gauge on the Gwydir River, and connected via a 3-G telemetered system in the hydrometric station to an RMTek website for data monitoring and download. Each water quality variable is logged at a 10 minute interval.

The probe was installed on Feb 6th 2015 due to delays in equipment being sourced and access arrangements with NoW to the hydrometric station shed. Issues with power supply and inundation of electronics from minor flooding meant that a complete dataset is not available in Year 1.

Daily means (midnight to midnight) were calculated from 10 minute interval data, with analyses based on the assumption that daily means were temporally independent. A one way ANOVA based on thirty six daily means from the environmental water delivery period (6-2-15 to 13-3-15), and 43 daily means from the non-environmental water delivery period (1-6-15 to 23-7-15) were used to test for differences between the two flow periods.

Daily means were compared between environmental water period and non-environmental water periods for each variable. Regression analyses were used to explore relationships between discharge volume and each water quality variable in an attempt to separate the time/season of delivery from the discharge volume.

F.3 Results and discussion

Mean daily temperature was significantly higher ($p = 0.001$, Figure F-1) in the environmental water delivery period; however this is to be expected given the difference in season between collection periods. Mean daily pH was significantly higher ($p = 0.001$, Figure F-1) in the non-environmental water delivery period by over 1 pH unit. Mean daily conductivity was significantly higher ($p = 0.001$, Figure F-1) in the non-environmental water delivery period, highlighting the dilution effects provided by environmental water to the lower Gwydir wetlands. Mean daily DO was significantly higher ($p = 0.001$, Figure F-1) in the non-environmental water delivery period, and was associated with reduced discharge volumes and increased water column chlorophyll *a* concentrations compared with periods of environmental water deliveries.

Regression analyses of mean daily pH, conductivity and dissolved oxygen concentration show distinct differences in the relationship between each attribute and discharge within each of the flow periods (Figure F-2). The small dataset of the non-environmental water delivery period lacks the range of discharges to facilitate equivalent volume comparisons. However, clear differences in each of the variables within the same discharge range suggests that environmental water deliveries of equivalent volumes to non-environmental water deliveries will provide reduced pH, conductivity and dissolved oxygen to downstream reaches. Untangling the effects of season, discharge and water quality will continue as more complete datasets are collected over the coming water years.

Figure F-1: Mean daily temperature (°C), pH, Turbidity (NTU), Salinity (mS/cm) and Dissolved oxygen (mg/L) at the Pallamallawa gauge (NSW418001) in the Gwydir River. Blue indicates Non-environmental water delivery and red indicates environmental water delivery.

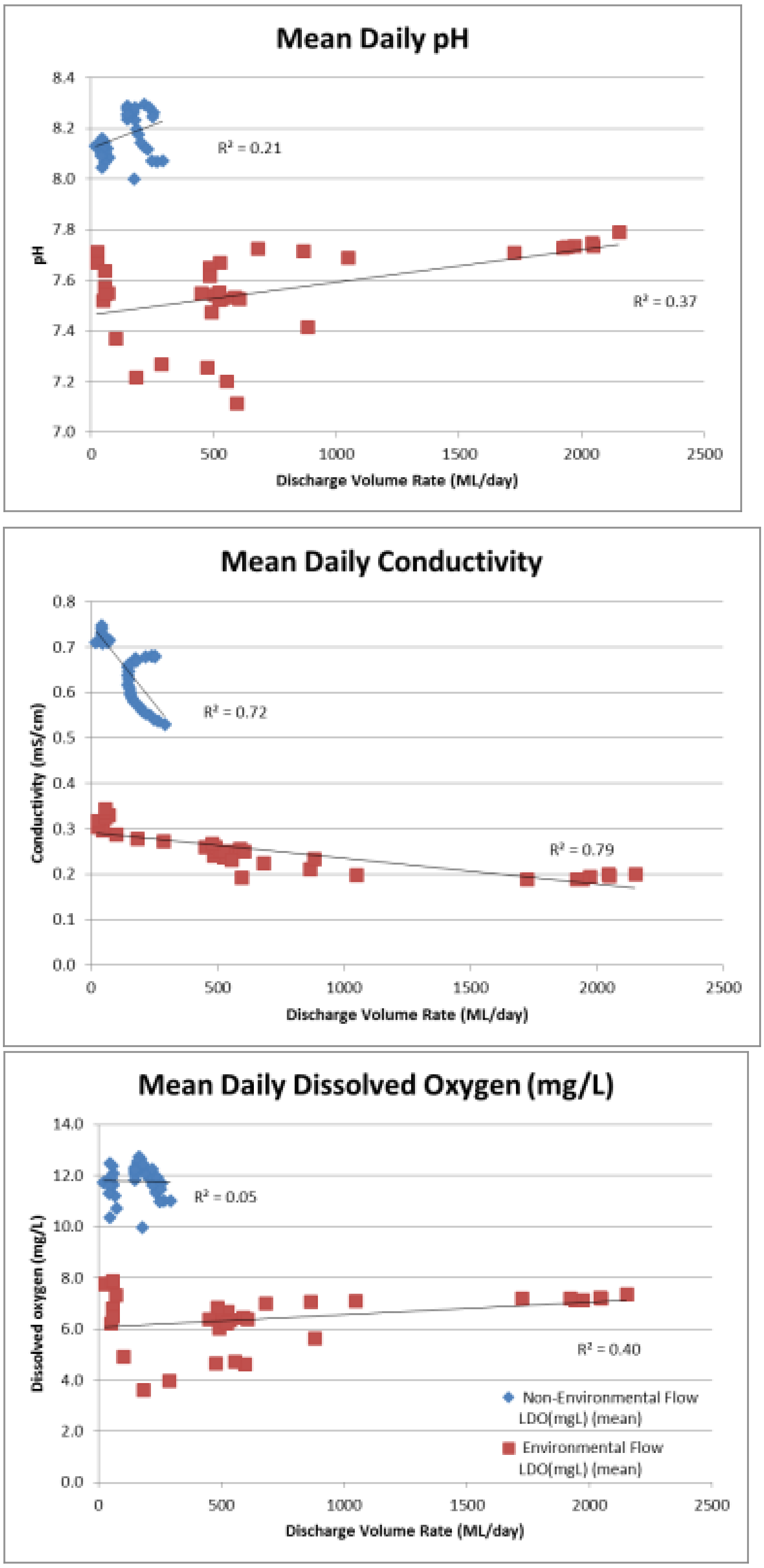

Figure F-2: Regressions between mean daily pH, Salinity (mS/cm) and Dissolved oxygen (mg/L) and discharge at the Pallamallawa gauge (NSW418001) in the Gwydir River. Blue indicates non-environmental water delivery and red indicates environmental water delivery.

F.4 Conclusion

The delivery of environmental water significantly reduced mean daily pH, conductivity and dissolved oxygen concentrations when compared to non-environmental water delivery periods. These chemical processes reflect the dilution effects provided by environmental water (e.g. conductivity) and the changes in water chemistry (increased DOC) associated with the increased wetted area of channels with higher volumes delivered as environmental water. Changes in mean daily temperature were significant between the environmental water and non-environmental water delivery periods; however, this result is attributed to seasonal changes, rather than the effects of environmental water. Regression analyses indicate that environmental water deliveries provided reduced pH, conductivity and DO as seen by the clear differences in each variable within the same discharge range. Further data collection over the next watering year will create more complete datasets allowing separation of the effects of season, discharge and water quality.

F.5 References

Commonwealth of Australia (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Gwydir River System Selected Area, Canberra.

Southwell, M., Wilson, G., Ryder, D., Sparks, P. and Thoms, M (2015) Monitoring the ecological response of Commonwealth Environmental Water delivered in 2013-14 in the Gwydir River System. A report to the Department of the Environment. Armidale.

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Appendix G Hydrology (Watercourse)

G.1 Introduction

The Lower Gwydir wetlands have long been targets for environmental water due to their extensive wetland vegetation communities and waterholes which 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 do this, by combining information from a range of sources, to build relationships between inflows, inundation extent and volumes of water in the Gwydir and Gingham wetlands. Specifically, this chapter addresses the following question:

- What did Commonwealth environmental water contribute to hydrological connectivity of the Gingham and Lower Gwydir Wetlands?

G.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendix B). 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 wetland inundation (Table B-1).

Environmental water was delivered to both the Gingham and Lower Gwydir wetlands from September through February (Appendix B). While water was delivered to the Lower Gwydir system for this entire period, delivery to the Gingham watercourse was stopped during October 2014, to allow landholder access across this channel, with deliveries recommencing in November. Connection was achieved through to Wandoona waterhole in the western Lower Gwydir system (Figure G-1) from December through to early February, then again in late May to June (Appendix B). Full connection through the Gingham Watercourse was more fragmented with water flowing through to the Gingham Bridge in the western Gingham Watercourse with short periods of connection in September and October 2014, then again in January to March 2015. Both systems received natural flow events in April and June 2015 (Figure G-2).

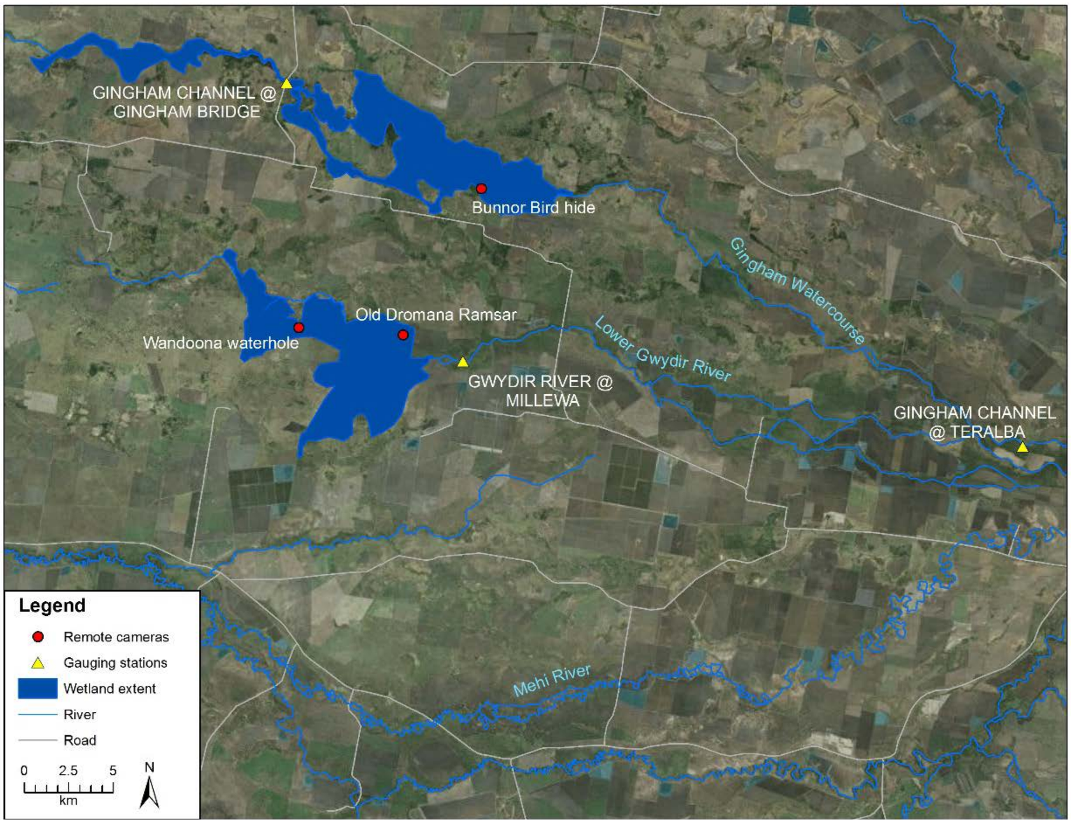

Figure G-1: Location of the Gingham and Lower Gwydir wetlands, gauging stations and remote monitoring cameras.

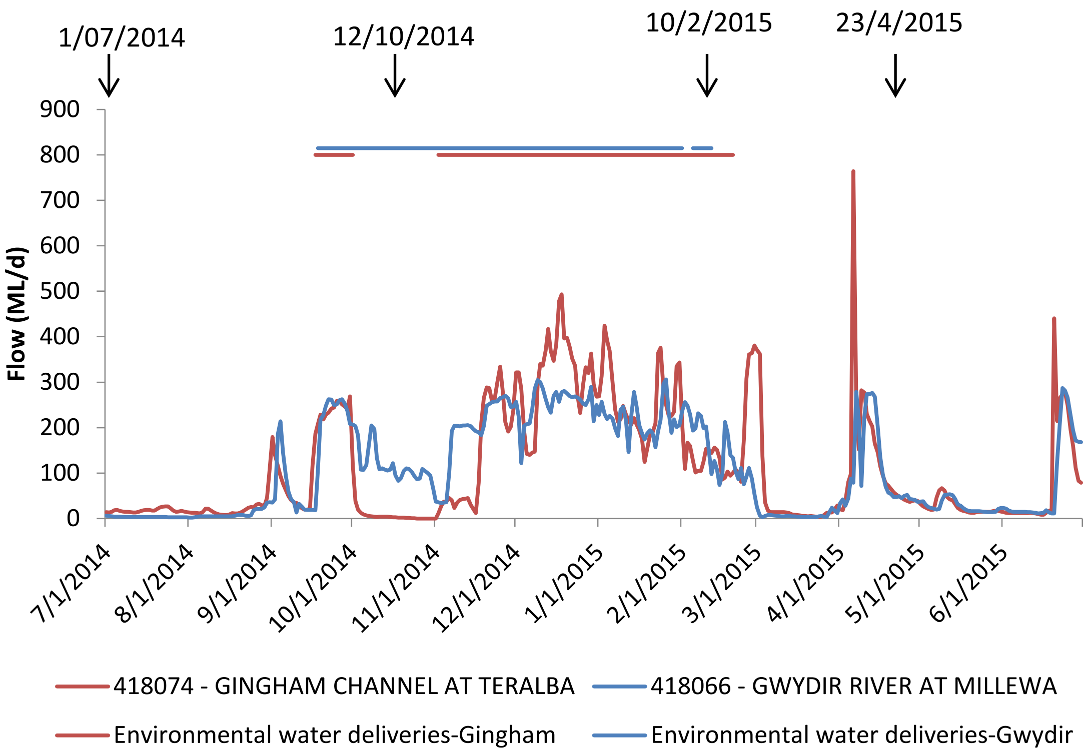

Figure G-2: River flows entering the Gingham and Lower Gwydir wetlands during 2014-15. Horizontal lines represent the timing of environmental water in each system. Arrows indicate timing of Landsat image capture.

G.1.2 Previous monitoring

Inundation extent in the Gingham and Lower Gwydir wetlands was measured by Thomas and Heath (2015) during the 2013-14 water year. Through the analysis of Landsat imagery, they calculated that a total of 1,964 ha were inundated in both systems - 1,164 ha in the Gingham system and 800 ha in the Gwydir system. Inflows to these wetlands during 2013-14 was below average with no environmental water delivered to either system (Southwell et al. 2015)

G.2 Methods

Five data sources were used to build a model of inundation extent and volume in the Gingham and Lower Gwydir wetlands (Commonwealth of Australia 2014). These included:

- Lidar data
- Landsat imagery
- Existing vegetation mapping
- Water level records associated with remote cameras
- 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 both wetland systems.

G.2.1 Digital Elevation Modelling

Lidar data were obtained from the NSW OEH Spatial Imagery Services branch. Lidar data were captured over the Lower Gwydir system in 2008. From the raw point cloud data, a 5 m DEM was produced covering the study area. In an attempt to produce a ‘closed’ system by which to estimate volumes of inundation for key areas of the wetlands, sections of the DEM were ’tilted’ to remove the influence of the regional scale east-west relief gradient (Figure G-3). This was done by applying a plane layer across the DEM where the average height of the western edge of the DEM (ASL) was raised to match the average height of the eastern edge of the DEM (Figure G-3). In this way, the DEM could be virtually ‘flooded’ with water at various known water levels within each DEM section to determine the corresponding extent and volume.

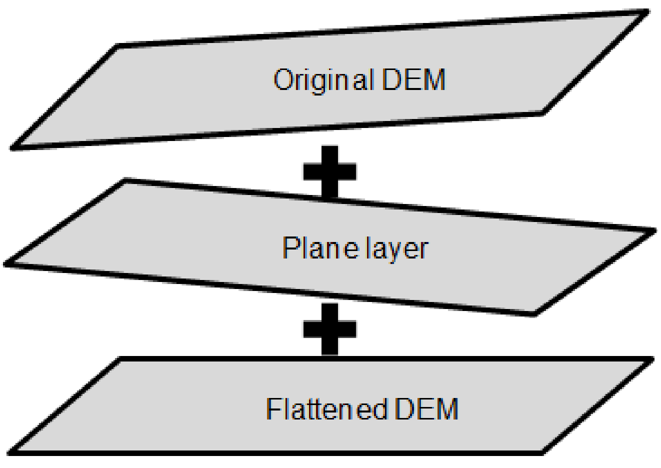

Figure G-3: Adjustment of the DEM to remove regional gradient.

G.2.2 Inundation mapping

Four Landsat 8 images were obtained through the USGS Glovis website (http://glovis.usgs.gov/). All available images captured during the 2014-15 season were assessed and those with no cloud cover or problems were chosen for further analysis. Four images spanning the season (Figure G-2) were selected for analysis, being captured on the following dates; 1 July 2014, 12 October 2014, 10 February 2015 and 23 April 2015.

Each image was classified into areas of inundated, likely inundated and dry using density slicing of band 6 as described in Frazier and Page (2000) with the resultant image saved as a GIS shape file layer (Figure G-4). Inundated areas were those identified via the density slicing alone, while likely inundated areas were informed using density slicing, composite images (derived using bands 6, 5 and 7 (Figure G-5), and bands 4, 3 and 2) and field validation. 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 file of inundated and likely inundated areas for each capture time (Figure G-6) was then intersected with Gwydir vegetation community layers to determine the extent of inundation within each vegetation community (Figure G-7). Inundated and likely inundated areas were combined within each image to provide an area of maximum inundation for each capture time. The vegetation layer for the Gingham Watercourse was derived from vegetation mapping undertaken for the Gingham Watercourse Restoration project. The vegetation layer for the Gwydir wetlands was based on mapping undertaken by Simpson and Bowen (2010), with some additional detail provided by air photograph interpretation and field validation during the 2014-15 year.

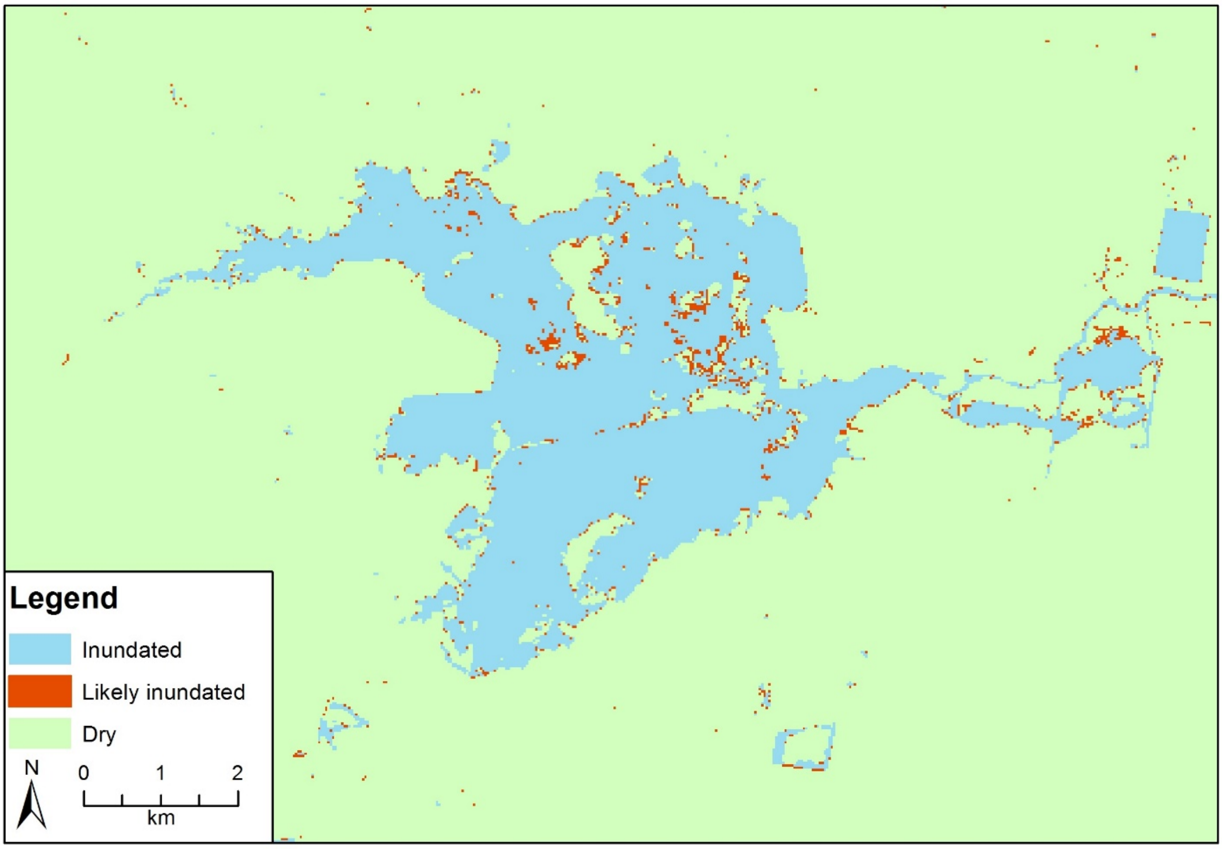

Figure G-4: Density slice of Band 6 of Landsat 8 showing areas inundated, likely inundated and dry, including non-wetland features such as farm storages.

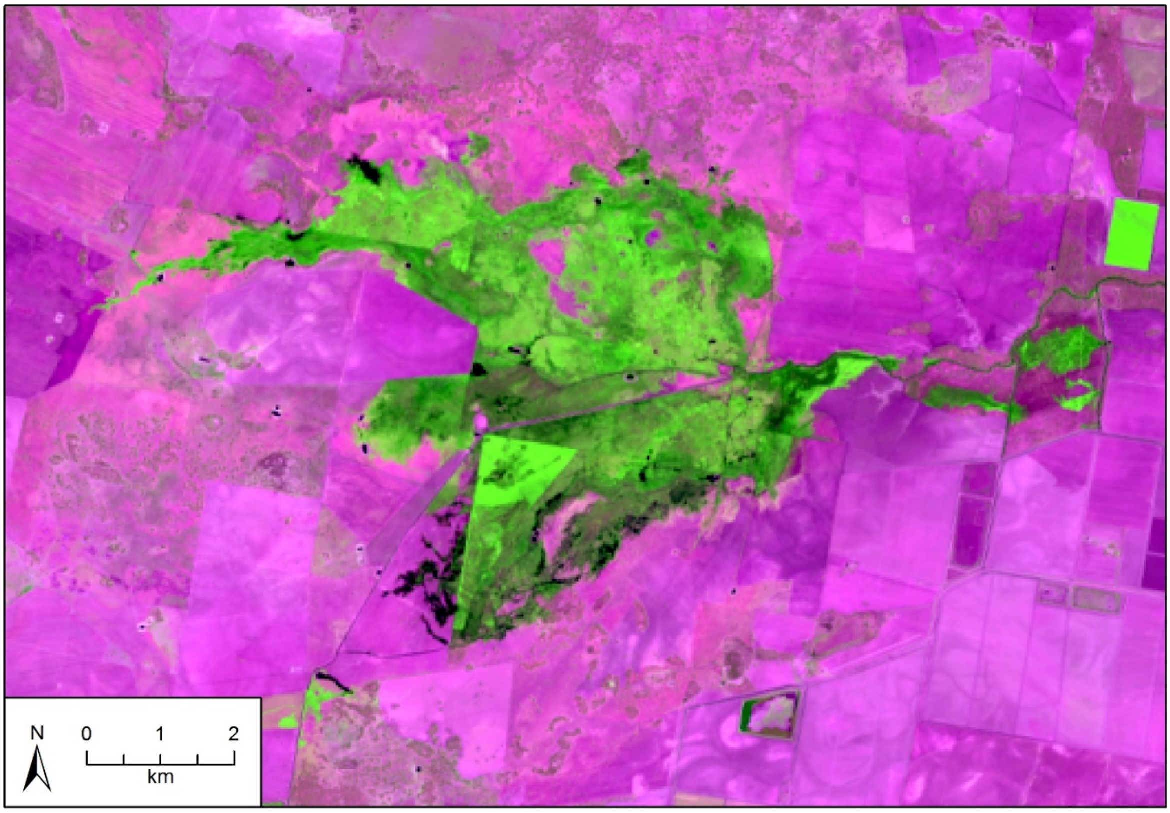

Figure G-5: Landsat 8 composite image of Band 6, 5 and 7.

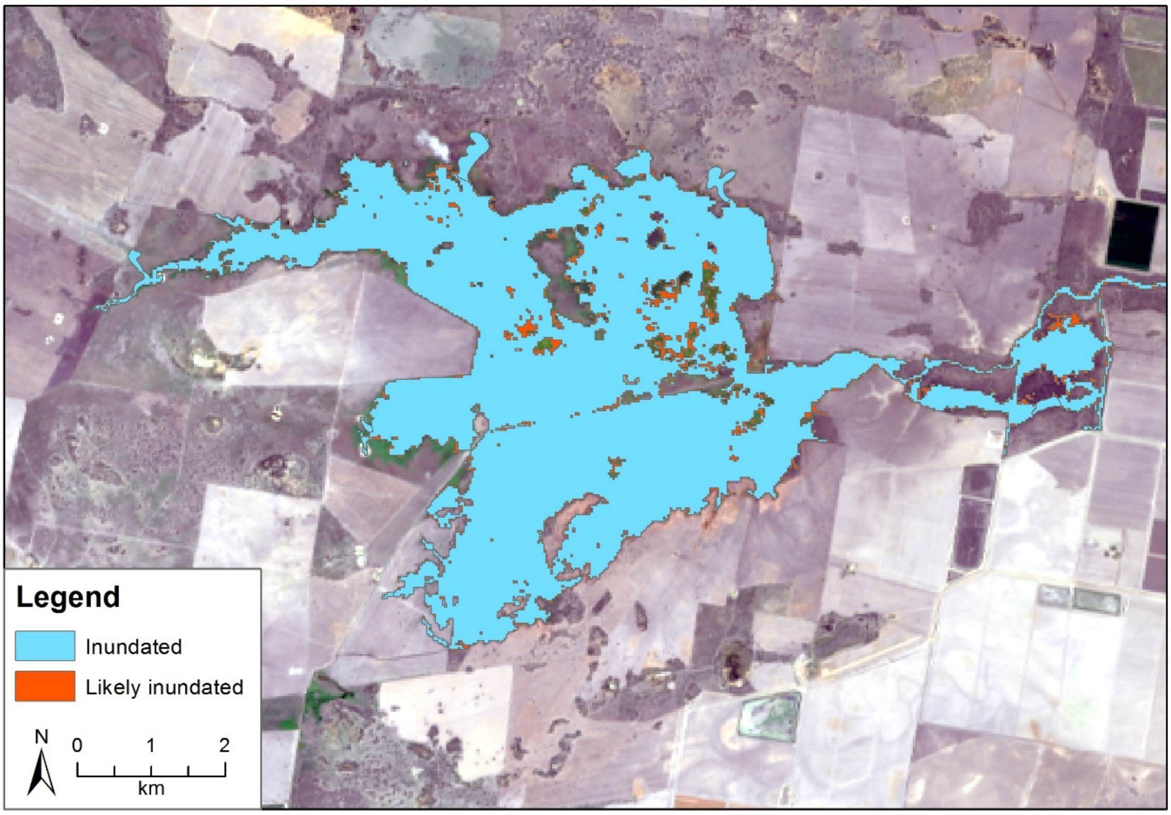

Figure G-6: Areas inundated and likely inundated.

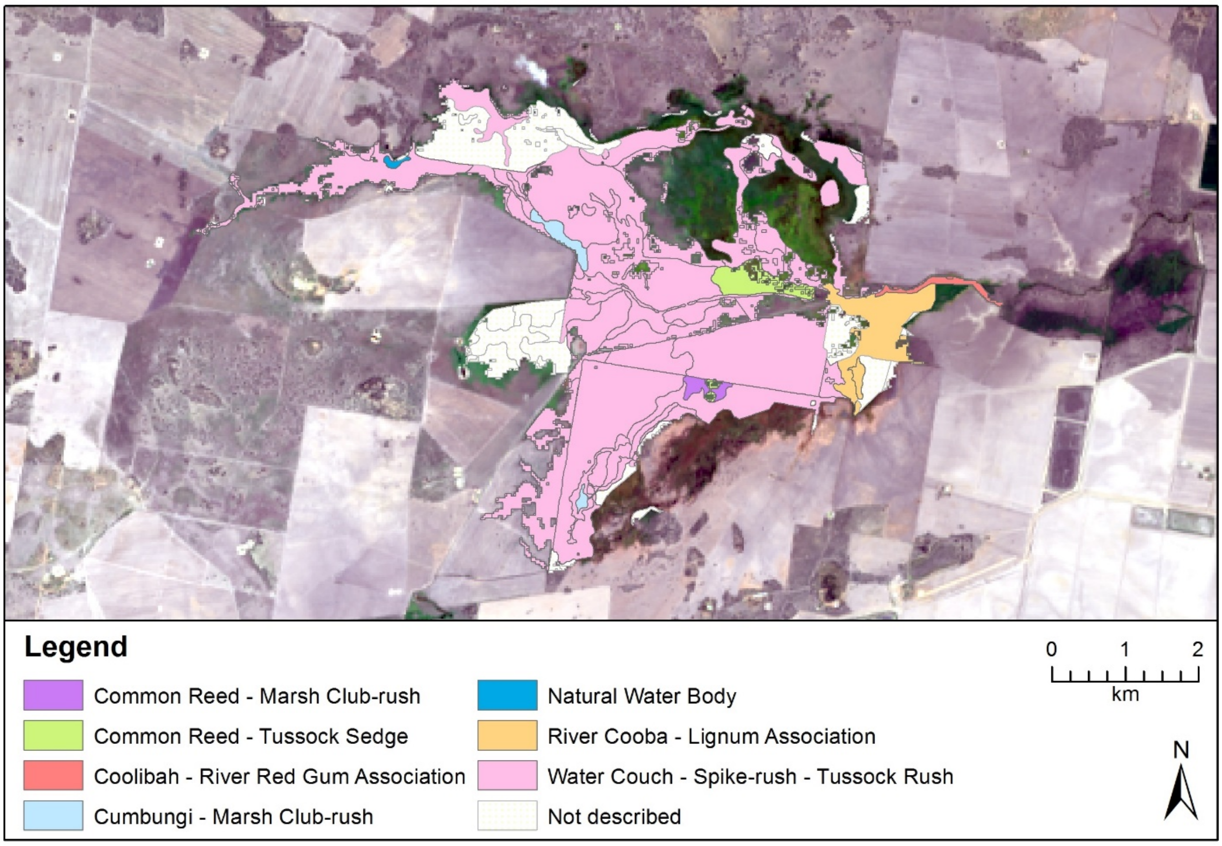

Figure G-7: Inundated vegetation.

G.2.3 Calculation of inundation volumes

Volumes of inundation for each vegetation community within the Gingham and Lower Gwydir wetlands were estimated for each of the Landsat image times. To do this, average inundation depths were estimated for each vegetation community at each image capture time. This was done using water depth information from level loggers at the Bunnor birdhide and Old Dromana remote camera sites (Figure G-1), water depth estimates within vegetation plots surveyed during December 2014 and March 2015 (Appendix D) and observations of inundation during field visits in May 2015. As point depth measurements were taken at specific points in time, water level data from the Remote Camera sites were used to adjust these measurements over time. Average depths for each vegetation community were estimated to the nearest 0.1 m, except where minimal depth of inundation was estimated, then a figure of 0.05 m was used (Table G-1). 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. Areas classified as inundated were used to define the inundation extent in each Landsat image.

Table G-1: Average depth (m) of inundation for vegetation communities during the four image capture times.

Wetland	Vegetation community	Average depth of inundation (m)			
		1/07/14	21/10/14	10/02/15	15/04/14
Gwydir	Common Reed - Marsh Club-rush	0.05	0.10	0.20	0.20
	Common Reed - Tussock Sedge	0.05	0.10	0.20	0.20
	Coolibah - River Red Gum Association	0.05	0.20	0.20	0.20
	Coolibah woodland	0	0.10	0.20	0.20
	Cumbingi-Marsh Club Rush	0	0.05	0.10	0.20
	River Cooba - Lignum Association	0.10	0.20	0.20	0.20
	Water Couch - Spike-rush - Tussock Rush	0.10	0.20	0.20	0.20
	Natural Water Body	0.50	0.60	0.60	0.60
	Cultivated Land	0.05	0.10	0.20	0.20
Gingham	Baradine Red Gum shrubby open forest	0.05	0.20	0.20	0.20
	Belah grassy woodland	0.10	0.20	0.20	0.20
	Carbeen grassy woodland	0	0.10	0.10	0.10
	Coolibah - River Coobah grassy woodland	0.05	0.20	0.20	0.20
	Cumbungi swamp rushland	0.30	0.40	0.40	0.40
	Derived grasslands	0.05	0.20	0.20	0.20
	dry wetland with rehabilitation potential	0	0.10	0.20	0.10
	Marsh Club-rush swamp sedgeland	0	0.10	0.20	0.10
	Myall - Rosewood shrubby woodland	0.05	0.10	0.20	0.20
	Poplar Box shrubby woodland	0.01	0.10	0.10	0.10
	Quinine Bush - Coobah tall shrubland	0	0.10	0.10	0.10
	River Cooba - Lignum Association	0.20	0.30	0.30	0.30
	River Coobah - Lignum swamp shrubland	0.20	0.30	0.30	0.30
	River Red Gum - Coolibah open forest	0.05	0.20	0.20	0.20
	Spike-rush - Cumbungi swamp sedgeland	0	0.10	0.20	0.10
	Tussock Rush swamp rushland	0.10	0.20	0.20	0.20
	Water Couch - Spike-rush - Tussock Rush	0.10	0.20	0.20	0.20
	Natural water body	0.40	0.50	0.50	0.50
	Cultivated land	0.05	0.20	0.20	0.20

G.3 Results

G.3.1 Digital Elevation Modelling

The eastern extent of the Gwydir wetlands (Old Dromana) was chosen to test the DEM based modelling approach for estimating inundation volumes and extents. A significant relief gradient could be seen over the area from the Raw 5m DEM (Figure G-8). The difference in elevation of similar landscape features in the east and west of the test area was around 8.8 m over the 13 km extent of the area. After the tilt layer was used to readjust the DEM to remove the regional relief gradient, local scale features were more evident (Figure G-9). While the resulting DEM appeared to be a better representation of the local scale topography within the test site, several cross sections (Figure G-9) obtained from the adjusted DEM running North-South appeared to suggest that the surrounding areas of the wetlands were lower in elevation that the central wetlands areas (Figure G-10; Figure G-11). These results are in contrast to field observations and the distribution of vegetation communities in this area. Accordingly Lidar-based inundation assessment was not considered suitable for this study.

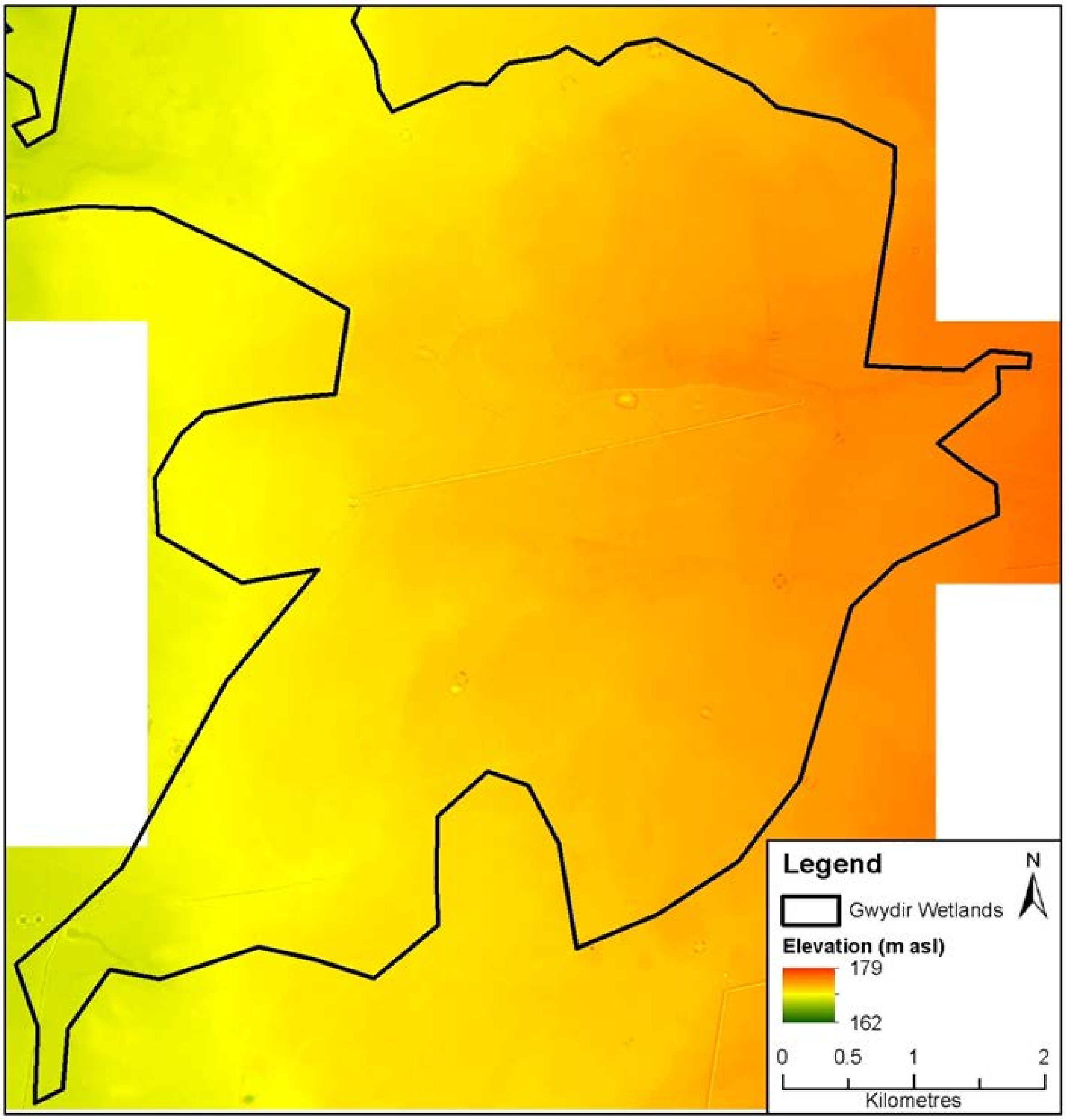

Figure G-8: 5m DEM of the Old Dromana test area in the Gwydir Wetlands.

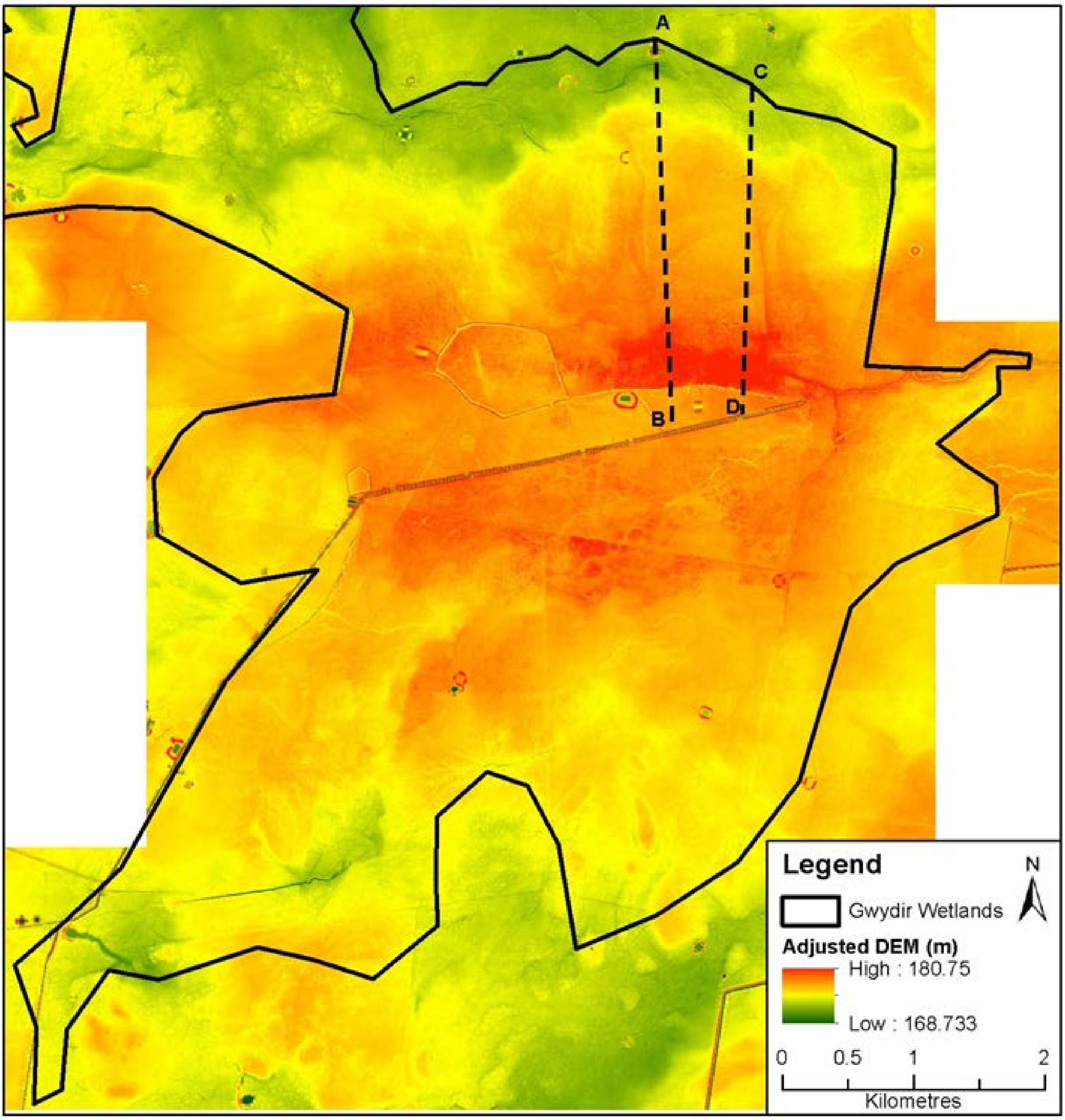

Figure G-9: Adjusted 5m DEM of Old Dromana test area. Dotted Lines show transect locations.

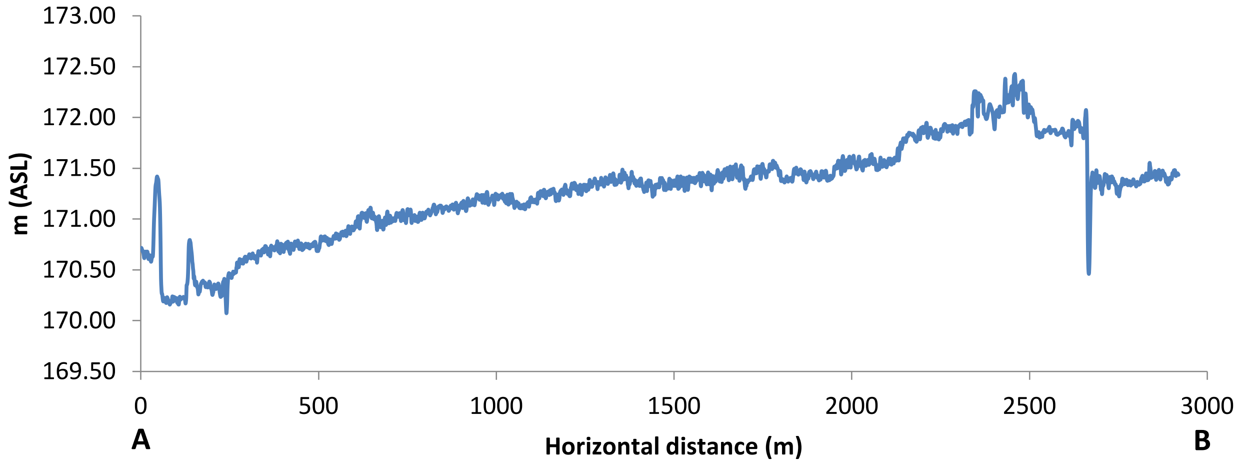

Figure G-10: Cross section from point A - B in Figure G-9.

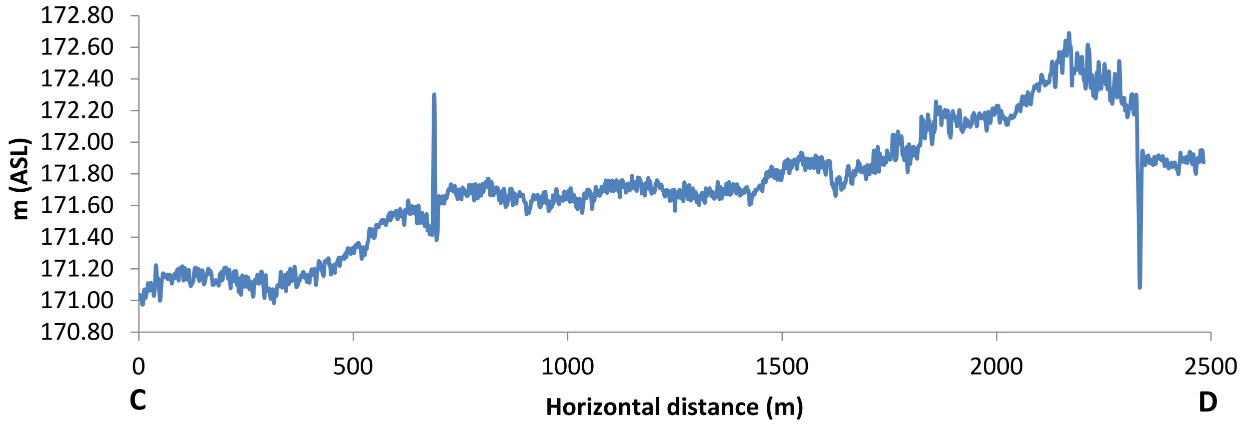

Figure G-11: Cross section from point C - D in Figure G-9.

G.3.2 Inundation extent and volume modelling

Inundation mapping using the Landsat imagery showed that the total extent of inundation 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 (Figure G-12). 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 G-12). Inundation extent reached a maximum of 3,908 ha in February 2015, before falling to 1,398 ha in April 2015.

Total volumes in the Gingham and Lower Gwydir wetlands and their relationship to inflows and area inundated are presented in Table G-2. Patterns in volume followed inundation extent, with the maximum recorded volume being 4,829 ML in the Lower Gwydir wetlands and 8,977 ML in the Gingham watercourse during February 2015 (Table G-2). Notably, total wetland inundation and volume appeared to reduce to a greater extent 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.

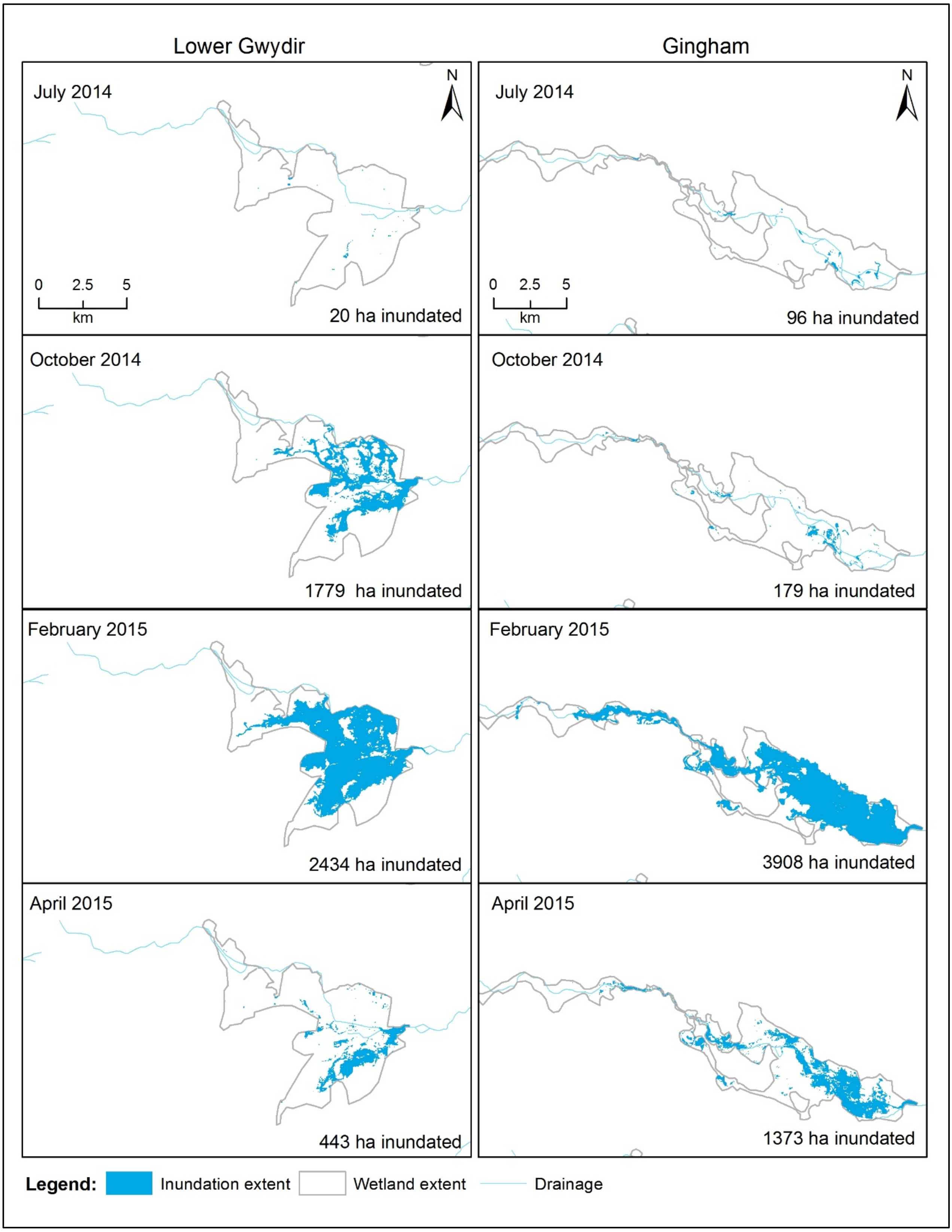

Figure G-12: Inundation extents mapped in the Gingham and Lower Gwydir wetlands at four occasions throughout the 2014-15 water year.

Table G-2: Inflows, inundation extent and volume of water in the Gingham and Lower Gwydir wetlands throughout the 2014-15 water year

Wetland	Date	Inflows (GL)	Inundation extent (ha)	volume (ML)
Lower Gwydir	1/07/2014	0	20	21
	21/10/2014	724	1,779	3,292
	10/02/2015	25,236	2,434	4,829
	15/04/2015	35,152	444	879
Gingham	1/07/2014	0	96	190
	21/10/2014	3,697	179	583
	10/02/2015	25,237	3,909	8,977
	15/04/2015	32,471	1,398	3,505

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 G-3). 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 watercourse, 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 G-4). 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.

Table G-3: Wetland inundation extent and volumes for different vegetation communities within the Lower Gwydir Wetlands during 2014-15.

Wetland	Vegetation community	Area inundated - ha (%)				Volume - ML (%)			
		1/07/2014	21/10/2014	10/02/2015	15/04/2014	1/07/2014	21/10/2014	10/02/2015	15/04/2014
Lower Gwydir	Common Reed - Marsh Club-rush	0 (0)	44 (2)	56 (2)	5 (1)	0 (0)	44 (1)	111 (2)	10 (1)
	Common Reed - Tussock Sedge	0 (0)	44 (2)	38 (2)	1 (0)	0 (0)	44 (1)	75 (2)	3 (0)
	Coolibah - River Red Gum Association	1 (5)	16 (1)	15 (1)	8 (2)	1 (3)	32 (1)	30 (1)	15 (2)
	Coolibah woodland	0 (0)	39 (2)	67 (3)	6 (1)	0 (0)	39 (1)	133 (3)	12 (1)
	Cumbingi-Marsh Club Rush	0 (0)	62 (3)	36 (1)	6 (1)	0 (0)	31 (1)	36 (1)	11 (1)
	River Cooba - Lignum Association	2 (11)	166 (9)	100 (4)	81 (18)	2 (11)	331 (10)	199 (4)	160 (18)
	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)
	Natural Water Body	2 (11)	5 (0)	3 (0)	1 (0)	11 (53)	33 (1)	17 (0)	6 (1)
	Cultivated Land	4 (21)	49 (3)	264 (11)	151 (34)	0 (2)	49 (1)	528 (11)	302 (34)
	Farm Dam*	4 (19)	9 (0)	6 (0)	5 (1)				
	Total	**19**	**1,779**	**2,434**	**444**	**20**	**3,292**	**4,827**	**879**

Table G-4: Wetland inundation extent and volumes for different vegetation communities within the Gingham Watercourse during 2014-15.

Wetland	Vegetation community	Area inundated - ha (%)				Volume - ML (%)			
		1/07/2014	21/10/2014	10/02/2015	15/04/2014	1/07/2014	21/10/2014	10/02/2015	15/04/2014
Gingham Watercourse	Baradine Red Gum shrubby open forest	0 (0)	7 (4)	37 (1)	17 (1)	0 (0)	14 (2)	74 (1)	35 (1)
	Belah grassy woodland	1 (1)	4 (2)	299 (8)	31 (2)	1 (1)	8 (1)	598 (7)	62 (2)
	Carbeen grassy woodland	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)
	Coolibah - River Cooba grassy woodland	1 (1)	5 (3)	433 (11)	79 (6)	1 (0)	9 (2)	866 (10)	158 (5)
	Cumbungi swamp rushland	31 (32)	88 (49)	274 (7)	244 (17)	92 (48)	351 (60)	1,098 (12)	974 (28)
	Derived grasslands	0 (0)	0 (0)	11 (0)	0 (0)	0 (0)	0 (0)	23 (0)	0 (0)
	dry wetland with rehabilitation potential	0 (0)	0 (0)	281 (7)	15 (1)	0 (0)	0 (0)	561 (6)	15 (0)
	Marsh Club-rush swamp sedgeland	0 (0)	0 (0)	10 (0)	8 (1)	0 (0)	0 (0)	19 (0)	8 (0)
	Myall - Rosewood shrubby woodland	0 (0)	0 (0)	13 (0)	24 (2)	0 (0)	0 (0)	25 (0)	0 (0)
	Poplar Box shrubby woodland	0 (0)	2 (1)	43 (1)	5 (0)	0 (0)	2 (0)	43 (0)	5 (0)
	Quinine Bush - Cooba tall shrubland	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)
	River Cooba - Lignum Association	8 (9)	0 (0)	42 (1)	32 (2)	17 (9)	1 (0)	127 (1)	96 (3)
	River Cooba - Lignum swamp shrubland	0 (0)	13 (7)	689 (18)	247 (18)	0 (0)	38 (6)	2,067 (23)	740 (21)
	River Red Gum - Coolibah open forest	3 (3)	5 (3)	21 (1)	16 (1)	2 (1)	9 (2)	42 (0)	33 (1)
	Spike-rush - Cumbungi swamp sedgeland	0 (0)	2 (1)	8 (0)	7 (0)	0 (0)	2 (0)	15 (0)	7 (0)
	Tussock Rush swamp rushland	0 (0)	0 (0)	4 (0)	4 (0)	0 (0)	1 (0)	8 (0)	8 (0)
	Water Couch - Spike-rush - Tussock Rush	19 (20)	34 (19)	1,485 (38)	607 (43)	19 (10)	68 (12)	2,970 (33)	1,214 (35)
	Natural water body	13 (13)	15 (8)	21 (1)	17 (1)	51 (27)	74 (13)	105 (1)	85 (2)
	Cultivated land	15 (16)	3 (2)	226 (6)	40 (3)	8 (4)	6 (1)	332 (4)	65 (2)
	Farm Dam*	3 (3)	2 (1)	9 (0)	5 (0)				
	Total	**94**	**180**	**3,908**	**1,398**	**191**	**583**	**8,975**	**3,505**

* Farm dams were not included in volume calculations

G.4 Discussion

Multiple methods were employed to estimate inundation extent and volume within the wetlands of the lower Gwydir. The DEM created from Lidar data captured in 2008 did not appear to represent the true land surface within the wetlands with reliable accuracy - areas covered in very thick vegetation (in some places 2 m in height) in the inner sections of the wetlands appeared to be higher in elevation than the surrounding land surface. Thick vegetation has been shown to reduce the accuracy of Lidar acquisition within other river systems (Scown 2015, Charlton et al. 2003, Hopkinson et al. 2005). Potential inaccuracies in the Lidar could be quiet significant in the Lower Gwydir system given the flatness of the landscape. Therefore, Lidar was not used in the calculation of inundation extents and volumes in the first year, with further field validation planned to assess the degree to which Lidar may be used for inundation mapping in this system in the future.

Environmental water produced significant inundation (6,342 ha in total) within the Gingham and Lower Gwydir wetland systems during the 2014-15 water year. This followed a reasonably dry year (2013-14) in these wetland systems where no environmental water was delivered to either system, with localised rainfall towards the end of the season providing the only significant natural inflows to the wetlands (OEH 2014). In these systems in 2014-15, the delivery of environmental water from September through February constituted the main source of water to the wetlands until around March when several rainfall driven flow events ‘topped’ up inundation of the wetlands towards the end of the season. This was particularly true for the Lower Gwydir with water levels persisting at the Old Dromana and Wandoona waterhole locations through to the end of the season.

As was noted in the hydrology (River) indicator (Appendix B) the break in the delivery of environmental water to the Gingham system during October – November 2014 had implications for the connectivity within this wetland system. By October, 80% less water was delivered down the Gingham system compared to the Lower Gwydir resulting in an inundation extent in the Gingham that was an order of magnitude lower than in the Lower Gwydir. Once deliveries recommenced, pulsed releases between 250 and 450 ML/d down the Gingham system produced significant inundation throughout the watercourse.

Environmental water inundated a high proportion of the wetland vegetation communities present within both wetlands, with the increased number of communities inundated in the Gingham system most likely being a product of the more detailed vegetation mapping available for this wetland. Key semi-permanent wetland species such as the Water couch, Spike-rush, Tussock rush, Lignum and Cooba were all well represented in the communities that were significantly inundated, with inundation of some areas lasting for at least 4-6 months. Key floodplain species such as Coolibah and River Red Gum were also inundated for extended periods throughout the season.

G.5 Conclusion

Significant proportions (6,342 ha) of the Gingham and Lower Gwydir wetlands were inundated throughout the 2014-15 season, with inflows the result of environmental water deliveries early in the season. The extent and volume of inundation were then maintained by rainfall induced flows in the later stages of the season. This resulted in a range of key semi-permanent and floodplain vegetation species being inundated for extended periods of time (4-6 months). These findings confirm the intended watering objectives in the Gingham and Lower Gwydir wetlands for prolonged inundation of key areas during the season.

G.6 References

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Appendix H Macroinvertebrates

H.1 Introduction

Macroinvertebrates form an important link in the food webs of aquatic systems, being a food source for many fish, reptile and bird species. While not a core indicator of the Gwydir LTIM project, macroinvertebrates were sampled along with microinvertebrates at wetland sites within the Gingham and Gwydir wetlands. The specific question being addressed for macroinvertebrates was:

- What did Commonwealth environmental water contribute to macroinvertebrate diversity?

H.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendix B and Appendix G). 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 wetland inundation (Table B-1).

Environmental water delivered to the Gingham and Gwydir wetlands from September 2014 to February 2015 resulted in substantial inundation of both wetlands systems (Appendix G).

H.1.2 Previous monitoring

Previous macroinvertebrate monitoring was undertaken by Southwell et al. (2015) as part of the Short Term Intervention Monitoring project in 2013-14. They noted that the abundance of macroinvertebrates increased with time in the Carole and Mehi channels, while numbers tended to fluctuate in both the Gingham and Gwydir channels. These patterns suggest that the increased flows associated with the delivery of both environmental water and irrigation flows may have influenced the abundance of macroinvertebrates within these channels, with an increase in abundances as flows receded towards the end of the season. These patterns also suggest that there would have been an increase in food availability for animals in higher trophic levels in these channels. However, it appeared that environmental water had little influence on the diversity of macroinvertebrate communities.

H.2 Methods

H.2.1 Sites

Monitoring of macroinvertebrates was undertaken in the Gwydir channel sites aligned to category 3 Fish (river) sampling, and in the Gingham and Lower Gwydir wetlands (Commonwealth of Australia 2014) (Figure H-1; Table H-1). Hereafter, the Gingham wetlands are referred to as Bunnor wetlands, and the Gwydir wetlands as Old Dromana wetlands.

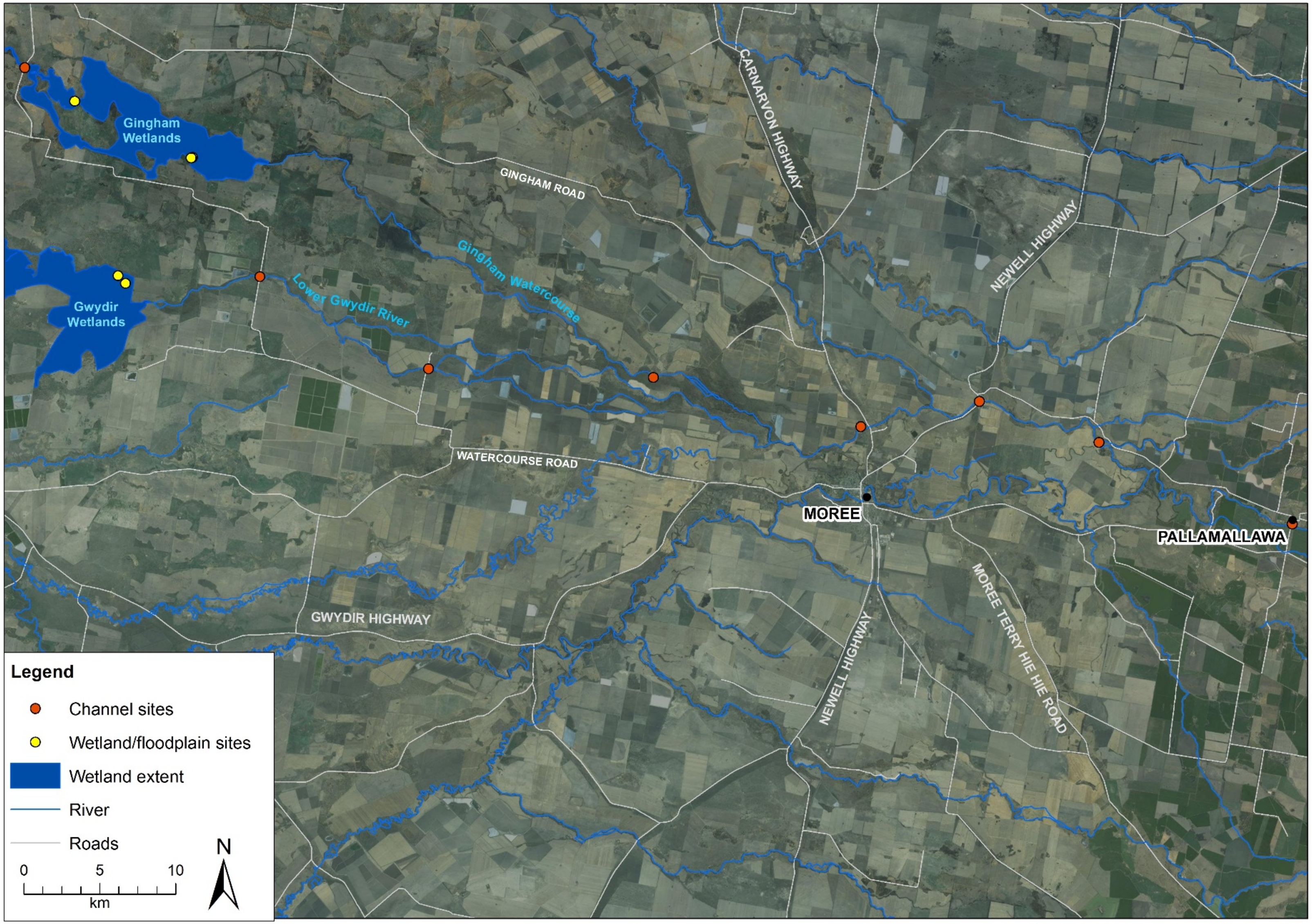

Figure H-1: Location of macroinvertebrate sampling sites in the Gwydir River Selected Area.

Table H-1: Site details of the macroinvertebrate sampling sites in the Gwydir River Selected Area.

Sample Zone	Site	Latitude	Longitude
Gingham-Gwydir	Bunnor Water Couch	-29.27470	149.38346
Gingham-Gwydir	Gwydir River @ DS Tyreelaroi	-29.43160	150.00260
Gingham-Gwydir	Gwydir River @ Bogabilla Rd	-29.40910	149.92075
Gingham-Gwydir	Gwydir River @ Canarvon Bridge	-29.42570	149.84066
Gingham-Gwydir	Old Dromana Rushes	-29.34590	149.33458
Gingham-Gwydir	Gwydir River @ Brageen Crossing	-29.39730	149.54650
Gingham-Gwydir	Gingham @ Gingham Waterhole	-29.24280	149.30262
Gingham-Gwydir	Gwydir @ Allambie Bridge	-29.34490	149.43069
Gingham-Gwydir	Gingham @ Gingham Bridge	-29.22330	149.26850
Gingham-Gwydir	Bunnor Bird Hide	-29.27510	149.38232
Gingham-Gwydir	Old Dromana Floodplain Transect	-29.35040	149.33966
Gingham-Gwydir	Gingham @ Teralba	-29.39950	149.66911
Gwydir River	Gwydir @ Pallamallawa	-29.47700	150.13511

H.2.2 Field and laboratory methods

The relative percent cover of four major habitats (bare substrate, snags, macrophyte beds and leaf packs) was visually assessed for each 100 m site. Macroinvertebrates were sampled semi-quantitatively using a 40x25 cm sweep-net (250 μm mesh size). A total of 10 linear metres was sampled at each site comprising the four major habitats in proportion to their percent cover. Samples were placed into labelled jars and preserved in 70% ethanol.

In the laboratory, samples were rinsed through 1 mm and 250 μm sieves and the retained material placed into sorting trays. Invertebrates were picked from the trays until all individuals had been collected from the 1 mm fraction, and after 30 minutes picking the 250 μm fraction. Invertebrates were placed in labelled jars. Macroinvertebrates were identified to the lowest possible taxonomic level using a stereo-microscope. Both the residual debris and sorted macroinvertebrate samples were preserved in 70% ethanol for quality control audits.

H.2.3 Statistical methods

Taxonomic diversity was calculated using the Shannon Weiner Index. Univariate data were checked for normality using the Shapiro-Wilk test, and heterogeneity of variances using Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. With density data square-root transformed, all data met the ANOVA assumptions of normality and homogeneous variances. Factors comprised REGION (with 3 fixed levels, Bunnor, Old Dromana and Gwydir River), TIME (with 4 random levels, December 2014, February 2015, March 2015 and April 2015), and SITE (with 3 fixed levels, (Water Couch (wetlands only), Reeds (wetlands only) and Open Water (both wetlands and river).Two-way crossed ANOVAs were used to test REGION x TIME, and SITE x TIME across wetlands only (Bunnor and Old Dromana). Post-hoc pairwise comparisons were performed on significant ANOVA terms using Tukey's HSD test as group variances were homogeneous. All univariate analyses were performed using SYSTAT Version 13 (SYSTAT Software Inc, 2009).

Multivariate analyses of macroinvertebrate community composition were used to test for differences over TIME, among REGIONS and among HABITATS. Square-root or presence/absence transformations were applied to density data prior to the calculation of resemblance matrices using Bray-Curtis similarities in PRIMER Version 6.1.13 (PRIMER-E Ltd, 2009). nMDS, ANOSIM and SIMPER routines in PRIMER were used to visualize and test dissimilarities among samples, and determine the taxa contributing to these patterns, respectively.

H.3 Results and Discussion

In Bunnor wetlands, the Open Water site (BUNOW) was dominated by bare substrate, with emergent *Typha* spp. stands comprising the macrophyte habitat and a large, submerged tree trunk comprising the snag habitat (Table H-2). The Water couch sites at Bunnor and Old Dromana wetlands (BUNWC and OLDWC, respectively) were dominated by macrophytes comprising emergent Water couch. The sites on the Gwydir River were predominantly bare substrate, with scattered large snags, macrophyte beds and *Eucalyptus* spp. (River Red Gum and Coolibah) leaf packs (Table H-2).

Statistical differences were not found for macroinvertebrate density or diversity when comparing among the Bunnor wetland, Old Dromana wetland, or Gwydir River REGIONS, or over TIME (Figure H-2). Similarly, macroinvertebrate diversity was statistically similar among wetland SITES (Table H-2). However, macroinvertebrate density differed significantly among wetland SITES ($F_{3,9}$ = 11.342, p = 0.002, Figure H-3), with density in the Water Couch at Old Dromana significantly greater than the Reeds at Old Dromana (p = 0.012), the Water Couch at Bunnor (p = 0.004) or the Open Water at Bunnor (p = 0.003).

Table H-2: Percentage cover of the four major habitats within each 100 m site.

Site	% Bare Substrate	% Snag	% Macrophyte Bed	% Leaf Pack
BUNOW	55	15	30	0
BUNWC	10	0	85	5
OLDBS	0	0	100	0
OLDWC	0	0	100	0
GW2	75	10	5	10
GW3	50	30	0	20
GW4	60	20	15	5

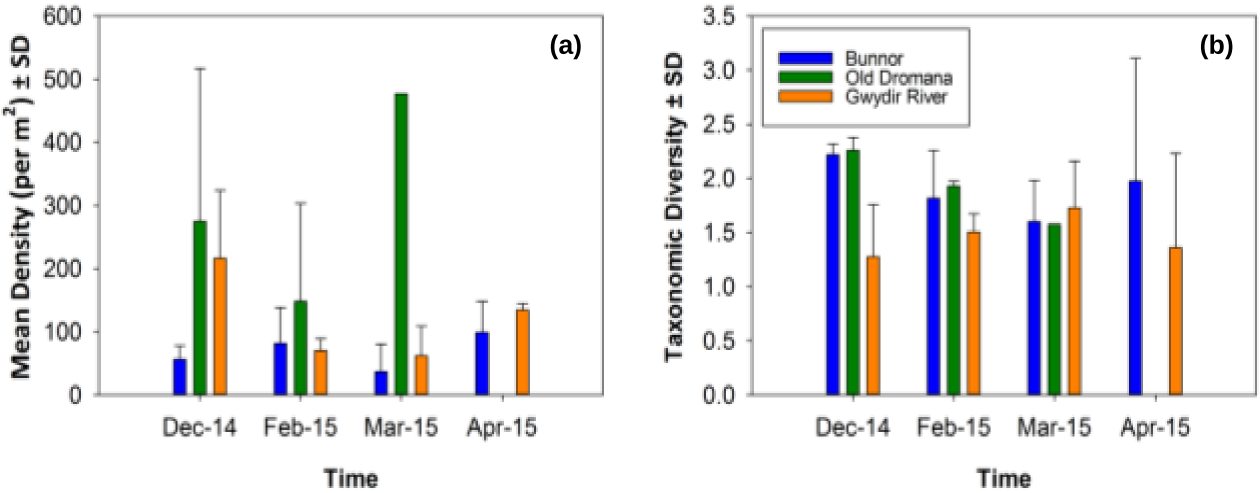

Figure H-2: (a) Mean density (per m^2) ± one standard deviation (SD), and (b) Mean taxonomic diversity ± SD of macroinvertebrate communities across sites in the Bunnor wetlands, Old Dromana wetlands and the Gwydir River.

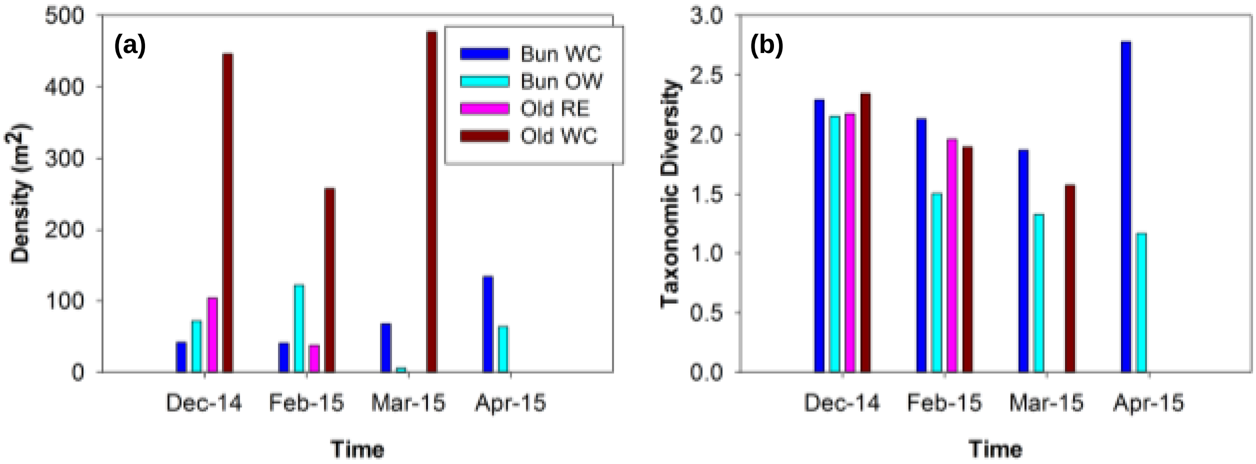

Figure H-3: (a) Density (m^2) and (b) taxonomic diversity of macroinvertebrate communities over time in wetland sites. “Bun” and “Old” represent Bunnor and Old Dromana wetlands, while “WC”, “OW” and “RE” represent “Water Couch”, “Open Water”, and “Reed” Sites, respectively.

There were clear differences in macroinvertebrate community composition between wetland sites and river channel sites (Figure H-4a, ANOSIM Global R = 0.510, p = 0.001). This pattern was slightly stronger when analysing the presence/absence data, suggesting these differences were driven more by taxonomic composition than densities (Figure H-4b, ANOSIM Global R = 0.576, p = 0.001). Fewer taxa dominated wetland sites than river sites, with only Chironomidae and Micronecta commonly dominating both wetland and river sites when analysing densities (Table H-3).

Macroinvertebrate communities did not differ significantly when comparing between the Gwydir and Gingham systems, among wetland sites only, or among sampling times. However, a two-way crossed ANOSIM (without replicates) of Time and sites composited into Bunnor wetland, Old Dromana wetland and Gwydir River Regions, found these Regions – rather than Time - explained much of the variability within community composition (Region Global R > 0.999, p = 0.024; Time Global R = 0.267, p = 0.246, Figure H-5a). This pattern was driven largely by the taxonomic composition of Regions as evidenced by an analysis of the presence/absence data (Figure H-5b), but taxonomic composition alone (Region Global R = 0.744, p = 0.09) explained less of the variability among Regions than did densities.

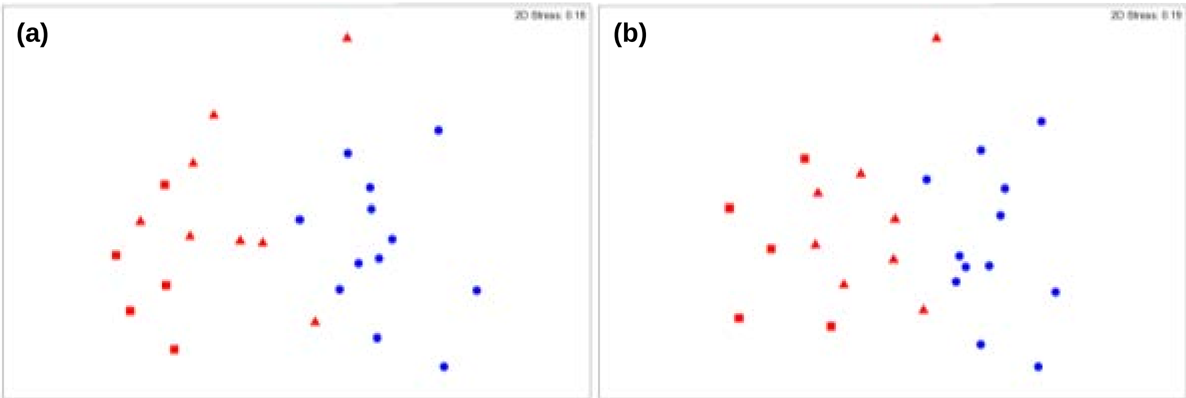

Figure H-4: Two-dimensional MDS ordination of macroinvertebrate community composition using (a) densities and (b) presence/absence. Blue circles represent Gwydir River sites, red triangles represent Bunnor wetland sites and red squares represent Old Dromana wetland.

Table H-3: Taxa contributing most of the similarities among community composition within wetland sites and river sites were typically the same whether analysing densities or presence/absence.

Wetland Sites					
SIMPER analysis of densities			SIMPER analysis of presence/absence		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Chironominae	21.75	21.75	Chironominae	19.23	19.23
Ischnura	15.01	36.76	Ischnura	15.50	34.74
Micronecta	12.08	48.84	Anisops	10.67	45.41
Diplonychus	10.37	59.21	Diplonychus	9.85	55.26
Anisops	9.94	69.14	Hydrochus	8.33	63.59
Hydrochus	6.23	75.38	Micronecta	6.32	69.91
Berosus	3.84	79.22	Berosus	5.61	75.52
Glyptophysa	2.30	81.52	Sigara	2.28	77.80
Hemicordulia	2.23	83.75	Hemicordulia	2.20	80.00
Sigara	1.99	85.74	Necterostoma	1.60	81.60
Hydrophilidae	1.83	87.57	Chostonectes	1.59	83.19
Chostonectes	1.39	88.96	Baetidae	1.55	84.74
Necterostoma	1.16	90.12	Hydrophilidae	1.48	86.22
			Glyptophysa	1.37	87.59
			Homeodytes	1.23	88.82
			Ceratopogonidae	1.12	89.93
			Hydraena	0.84	90.78
River Sites					
SIMPER analysis of densities			SIMPER analysis of presence/absence		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Paratya	24.87	24.87	Paratya	19.71	19.71
Baetidae	20.56	45.43	Micronecta	15.38	35.09
Micronecta	12.56	57.99	Tenagogerris	15.00	50.09
Chironominae	11.10	69.00	Baetidae	14.75	64.84
Tenagogerris	9.67	78.76	Caenidae	10.60	75.44
Caenidae	8.19	86.96	Chironominae	7.87	83.32
Anisops	2.52	89.48	Hydrochus	4.04	87.35
Hydrochus	2.38	91.86	Anisops	3.05	90.40

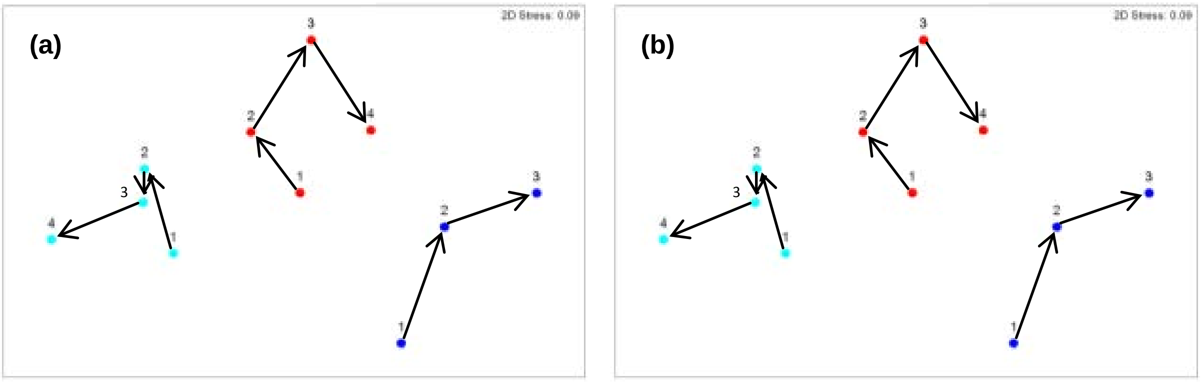

Figure H-5: nMDS ordination of macroinvertebrate community composition using (a) density and (b) taxonomic presence/absence for Regions where cyan circles represents the Gwydir River, blue circles represent Old Dromana wetland and red circles represent Bunnor wetland.

H.4 Conclusion

Over the period sampled for macroinvertebrates the inundation of the Gingham and Lower Gwydir wetlands was driven exclusively by environmental water deliveries. Therefore, the counterfactual outcome for these systems in Year 1 is a dry wetland complex in the lower Gwydir system. Delivery of environmental water to the Gingham and Lower Gwydir wetlands increased regional scale density and diversity of aquatic macroinvertebrates. The significant difference in aquatic macroinvertebrate community composition between the Gingham and Lower Gwydir wetlands indicates the benefits for delivery of environmental water to both wetland systems in maintaining regional level diversity. The delivery of sufficient volumes of environmental water to the Gingham and Lower Gwydir wetlands to inundate a mosaic of vegetative habitats (Appendix G) significantly increased the density and diversity of aquatic macroinvertebrates. In addition, the resultant long term (over 5 month) duration of inundation in both the Gingham and Lower Gwydir wetlands contributed to the development and succession of different aquatic macroinvertebrate communities between wetland systems.

H.5 References

Commonwealth of Australia (2014) Commonwealth Water Office Long Term Intervention Monitoring Project; Gwydir River System Selected Area, Commonwealth of Australia.

Southwell, M., Wilson, G., Ryder, D., Sparks, P. and Thoms, M (2015) Monitoring the ecological response of Commonwealth Environmental Water delivered in 2013-14 in the Gwydir River System. A report to the Department of the Environment. Armidale.

Appendix I Microinvertebrates

I.1 Introduction

The microinvertebrate indicator aims to assess the contribution of Commonwealth environmental watering to microinvertebrate abundance and diversity. Several specific short-term (1 year) questions could be addressed by assessing microinvertebrates within the Gwydir River Selected Area during the 2014-15 water year:

- What did environmental water contribute to the timing of microinvertebrate productivity?
- What did environmental water contribute to connectivity of microinvertebrate communities between the river and wetlands?
- What did environmental water contribute to patterns and rates of primary productivity?

I.1.1 Environmental watering in 2014-15

During 2014-15 environmental water was delivered to a number of assets within the Gwydir River system (Appendix B and Appendix G). 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 wetland inundation (Table B-1).

Environmental water delivered to the Gingham and Gwydir wetlands from September 2014 to February 2015 resulted in substantial inundation of both wetlands systems (Appendix G).

I.1.2 Previous monitoring

Previous water quality monitoring was undertaken by Southwell et al. (2015) as part of the Short Term Intervention Monitoring project in 2013-14. They noted that the abundance of microinvertebrates increased with time in the channels of the lower Gwydir, which was likely a result of increased breeding throughout the season (shown by higher catches of Nauplii or juvenile zooplankton in April and June) and lower flows concentrating zooplankton numbers. Significant differences were noted between the Gingham channel and the other three channels studied (Gwydir, Mehi and Carole). They also found that Rotifers dominated samples within all channels.

I.2 Methods

I.2.1 Sites

Monitoring of microinvertebrates was undertaken in the Gwydir channel sites aligned to Category 3 Fish (river) sampling, and in the Gingham and Lower Gwydir wetlands (Commonwealth of Australia 2014) (Figure I-1; Table I-1). Hereafter, the Gingham wetlands are referred to as Bunnor wetlands, and the Gwydir wetlands as Old Dromana wetlands

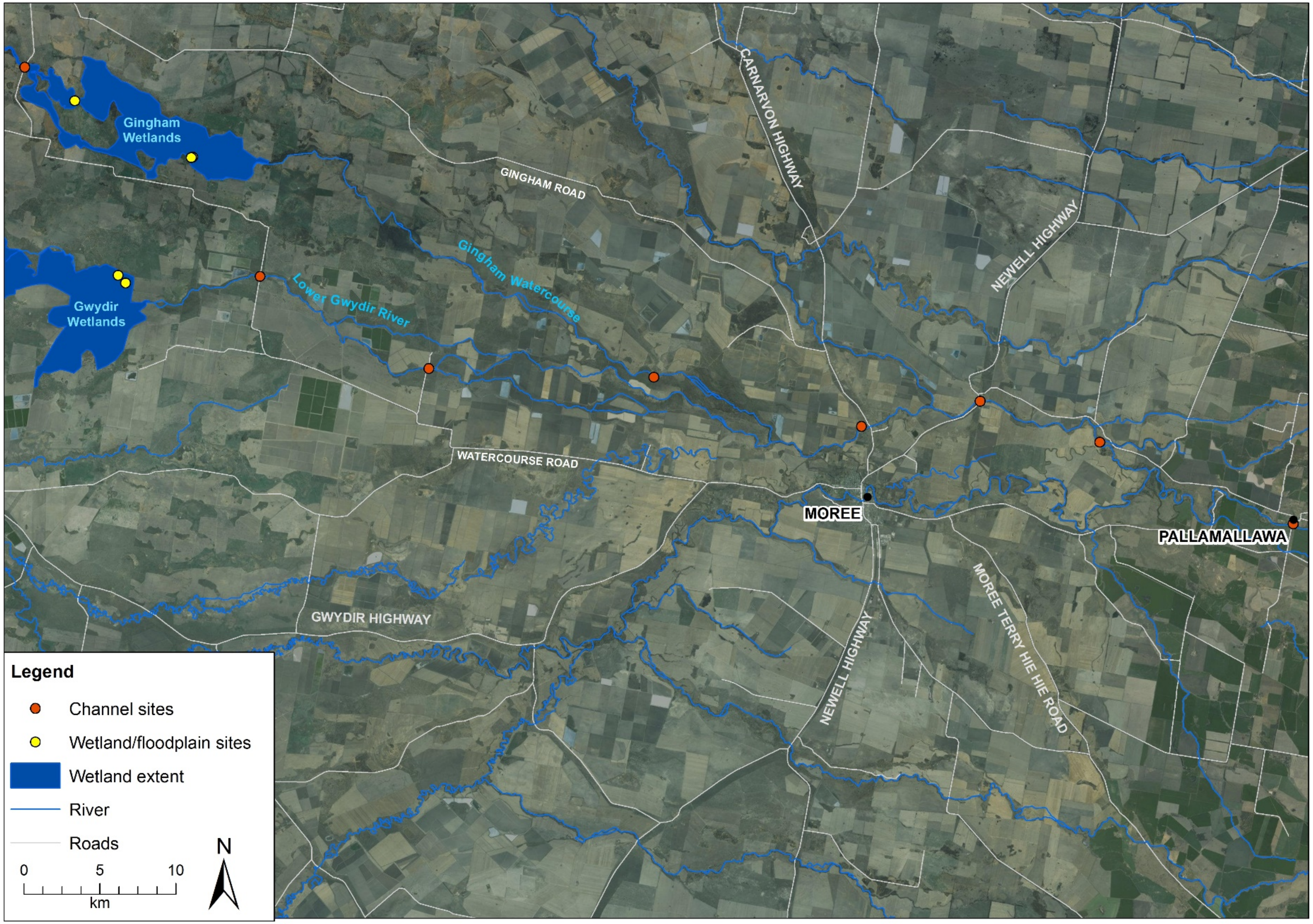

Figure I-1: Location of microinvertebrate sampling sites in the Gwydir River Selected Area.

Table I-1: Site details of the microinvertebrate sampling sites in the Gwydir River Selected Area.

Sample Zone	Site	Latitude	Longitude
Gingham-Gwydir	Bunnor Water Couch	-29.27470	149.38345
Gingham-Gwydir	Gwydir River @ DS Tyreelaroi	-29.43160	150.00260
Gingham-Gwydir	Gwydir River @ Bogabilla Rd	-29.40910	149.92075
Gingham-Gwydir	Gwydir River @ Canarvon Bridge	-29.42570	149.84067
Gingham-Gwydir	Old Dromana Rushes	-29.34590	149.33458
Gingham-Gwydir	Gwydir River @ Brageen Crossing	-29.39730	149.54650
Gingham-Gwydir	Gingham @ Gingham Waterhole	-29.24280	149.30262
Gingham-Gwydir	Gwydir @ Allambie Bridge	-29.34490	149.43069
Gingham-Gwydir	Gingham @ Gingham Bridge	-29.22330	149.26850
Gingham-Gwydir	Bunnor Bird Hide	-29.27510	149.38232
Gingham-Gwydir	Old Dromana Floodplain Transect	-29.35040	149.33966
Gingham-Gwydir	Gingham @ Teralba	-29.39950	149.66911
Gwydir River	Gwydir @ Pallamallawa	-29.47700	150.13511

I.2.2 Microinvertebrate field methods

Benthic microinvertebrates were haphazardly sampled by compositing five cores (50 mm diameter x 120 mm long with 250 mL volume) for each site. Replicates were separated by a minimum of 20 linear metres. The composite sample was allowed to settle for a minimum of 1 hr and then the supernatant was poured through a 63 µm sieve. The retained sample was washed into a labelled jar and stored in ethanol (70% w/v with Rose Bengal stain) until laboratory analysis.

Pelagic microinvertebrates were sampled by haphazardly sampling 20 L of the water column at each of five locations throughout the site. Samples were poured through a plankton net (63 µm) into a single, 100 L composite sample. Retained samples were stored in ethanol (70% w/v) with Rose Bengal stain until laboratory analysis.

I.2.3 Nutrient field methods

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

Chlorophyll *a* was sampled by filtering as much sample water as possible (100-1000 mL) through a Whatman GF/C Glass Microfibre filter paper using an electric vacuum pump (EYELA Tokyo Rakahikai Corporation Aspirator A-35 at approximately 7 PSI). The sample volume was recorded and the filter paper placed into a prelabelled 10-mL vial which was then sealed, wrapped in aluminium foil, placed inside a labelled ziplock bag and then refrigerated below 4 °C.

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

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

Dissolved Organic Carbon samples were filtered through Whatman Microfibre filter papers (effective pore size of 0.2 μm).

A 10% subsample of randomly selected samples were sent to the Environmental Analytical Laboratories at Southern Cross University NATA accredited laboratory as part of the project Quality Assurance Plan.

I.2.4 Metabolism field methods

At each sampling period, D-Opto dissolved oxygen (DO) loggers were deployed ensuring they were positioned in the water column well above sediment or where the logger would be exposed to air. Loggers were allowed to equilibrate and measured temperature, DO percent saturation and DO concentration (mg/L) at 10-minute intervals over a minimum 48-hour period from midnight to midnight. A Hobo PAR logger was simultaneously deployed in the air and recorded at 10 minute intervals. Barometric pressure data were retrieved from the BoM for Moree as the nearest locality.

I.2.5 Microinvertebrate laboratory methods

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

I.2.6 Nutrient laboratory methods

Chlorophyll *a* was analysed by placing 10 mL of 90% acetone solution in the vial and refrigerating the sample for 24 hours. Samples were then centrifuged and the absorption spectra recorded using a UV-1700 Pharmaspec UV-visible spectrometer at 665 and 750 nm.

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

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

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

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

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

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

I.2.7 Microinvertebrate statistical methods

Taxonomic diversity was calculated using the Shannon Weiner Index. Univariate data were checked for normality using the Shapiro-Wilk test, and heterogeneity of variances using Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. All data met the ANOVA assumptions of normality and homogeneous variances with the exception of Density which was Log (x+1) transformed. Density and Diversity were analysed for both microcrustaceans and complete microinvertebrate communities.

ANOVA factors comprised HABITAT (with 2 fixed levels, Benthic and Pelagic), REGION (with 3 fixed levels, Bunnor, Old Dromana and Gwydir River), TIME (with 4 random levels, December 2014, February 2015, March 2015 and April 2015), and SITE (with 3 fixed levels, (Water Couch (wetlands only), Reeds (wetlands only) and Open Water (both wetlands and river)). A three-way crossed ANOVA was used to test POSITION x REGION x TIME across all Sites. Individual two-way crossed ANOVAS were used to text TIME x REGION and TIME x HABITAT within Pelagic or Benthic communities. Post-hoc pairwise comparisons were performed on significant ANOVA terms using Tukey's HSD test as group variances were homogeneous. All univariate analyses were performed using SYSTAT Version 13 (SYSTAT Software Inc, 2009).

Multivariate analyses of microinvertebrate and microcrustacean community compositions were used to test for differences over TIME, among REGIONS and among HABITATS. Square-root or presence/absence transformations were applied to density data prior to the calculation of resemblance matrices using Bray-Curtis similarities in PRIMER Version 6.1.13 (PRIMER-E Ltd, 2009). nMDS, ANOSIM and SIMPER routines in PRIMER were used to visualize and test dissimilarities among samples, and determine the taxa contributing to these patterns, respectively.

I.2.8 Nutrient statistical methods

Univariate data were checked for normality using the Shapiro-Wilk test, and heterogeneity of variances using Bartlett's test for comparing between two groups and Levene's test for comparing more than two groups. All data met the ANOVA assumptions of normality and homogeneous variances. ANOVA factors comprised, REGION (with 3 fixed levels, Bunnor, Old Dromana and Gwydir River) and TIME (with 4 random levels, December 2014, February 2015, March 2015 and April 2015).

I.2.9 Metabolism statistical methods

Metabolism equipment was not available for the first sample period due to delivery delays from the supplier. Ten minute interval dissolved oxygen, PAR, conductivity and barometric pressure data were used as input metrics for the BASE model (Grace et al. 2015) to calculate mean daily gross primary productivity (GPP), ecosystem respiration (ER) and net primary productivity (NPP). The use of the BASE model to determine daily rates of GPP, ER and NPP has resulted in a number of diurnal oxygen profiles not meeting model requirements (R^2 >0.8). As such, it is not possible to undertake statistical analyses on the Yr 1 dataset.

I.3 Results and Discussion

I.3.1 Nutrients

Total Nitrogen concentrations were exceptionally high, reaching a mean of over 3000 µg/L following inundation in December 2014. Significant differences between Regions (*p* = 0.02, Figure I-2), with the Gwydir River channel significantly different to the Gingham and Gwydir wetlands. Time 1 (filling) and time 3 (full) were significantly different (*p* = 0.03, Figure I-2) to the remaining times.

Nitrogen oxide concentrations were consistently below 200 µg/L, with the exception of the Gwydir channel in March where the mean value exceeded 500 µg/L. Significant differences between Regions (*p* = 0.04, Figure I-2), were recorded between the Gwydir channel and the wetland sites. There was no significant difference between times.

Total Phosphorus concentrations were exceptionally high, reaching a mean of over 480 µg/L following inundation of the Gingham wetlands in December 2014, and then remained below 150 µg/L for the remainder of the study period. Significant differences were recorded between Regions (*p* = 0.02, Figure I-2) with the Gwydir River channel significantly different to the Gingham and Gwydir wetlands. Time 1 (filling) was significantly different (*p* = 0.01, Figure I-2) to the remaining times.

Filterable Reactive Phosphorus concentrations were consistently below 40 µg/L throughout the study period, with the exception of Bunnor wetlands were very high (>380 µg/L) FRP mirrored very high TP immediately following wetland filling. There were no significant differences between Regions, however, Time 1 (filling) was significantly different (*p* = 0.01, Figure I-2) to the remaining times.

Chlorophyll *a* concentrations were highly variable within and between sites, and throughout the study period, ranging from less than 1 µg/L to over 53 µg/L. This high variability led to no significant differences between Regions, however, Times 1 (filling) and 3 (full) were significantly different (*p* = 0.01, Figure I-2) to the remaining times.

The Gwydir River channel had very high, and significantly higher (*p* = 0.01, Figure I-2), TSS concentrations compared with wetland sites. The peak in TSS concentration of >280 mg/L in the

Gwydir channel coincided with reduced discharge, and was longitudinally transported to the lower Gwydir and Gingham wetland sites that also had peak concentrations in March 2015.

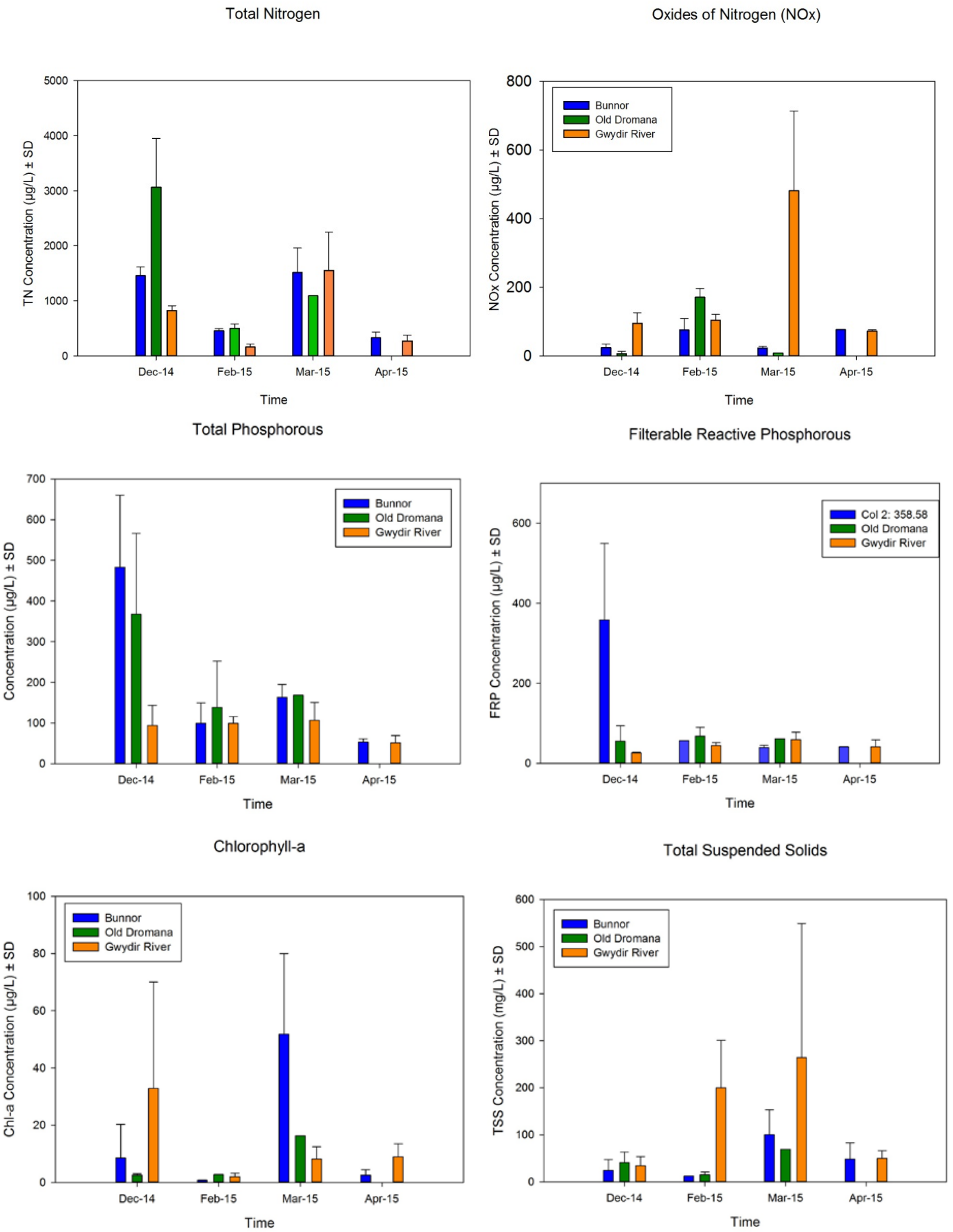

Figure I-2: Concentrations of Total Nitrogen (µg/L), nitrogen oxides (µg/L), Total Phosphorus (µg/L), filterable reactive phosphorus (µg/L), water column chlorophyll a (µg/L) and total suspended solids (mg/L) in the Bunnor wetlands, Old Dromana wetlands and Gwydir River.

I.3.2 Metabolism

All sites and habitats were net heterotrophic throughout the period of environmental flow delivery and wetland inundation (Figure I-3). Water couch habitats in the Bunnor and Old Dromana wetlands were the most net heterotrophic with rates between 9.7 mg/L/day and 7.3 mg/L/day.

The open water habitats in the Bunnor consistently had the highest rates of GPP (up to 4.4 mg/L/day), and the heavily vegetated areas of wetlands (100% cover of emergent vegetation) consistently the lowest rates of GPP (0.35 to 1.55 mg/L/day). The rates of ER were consistently highest in dense, inundated water couch habitats, peaking at over 10 mg/L/day of oxygen consumption in the Old Dromana wetlands.

The rates of GPP in the Gwydir River channel were consistently less than 2 mg/L/day with a peak in March as environmental water deliveries were reducing in volume and wetted channel area was decreasing.

At the system scale, rates of NPP were similar between the Bunnor and Old Dromana wetlands at between 6 and 7 mg/L/day, however Bunnor wetlands had substantially higher rates of GPP and ER compared with the Old Dromana wetlands (Figure I-4).

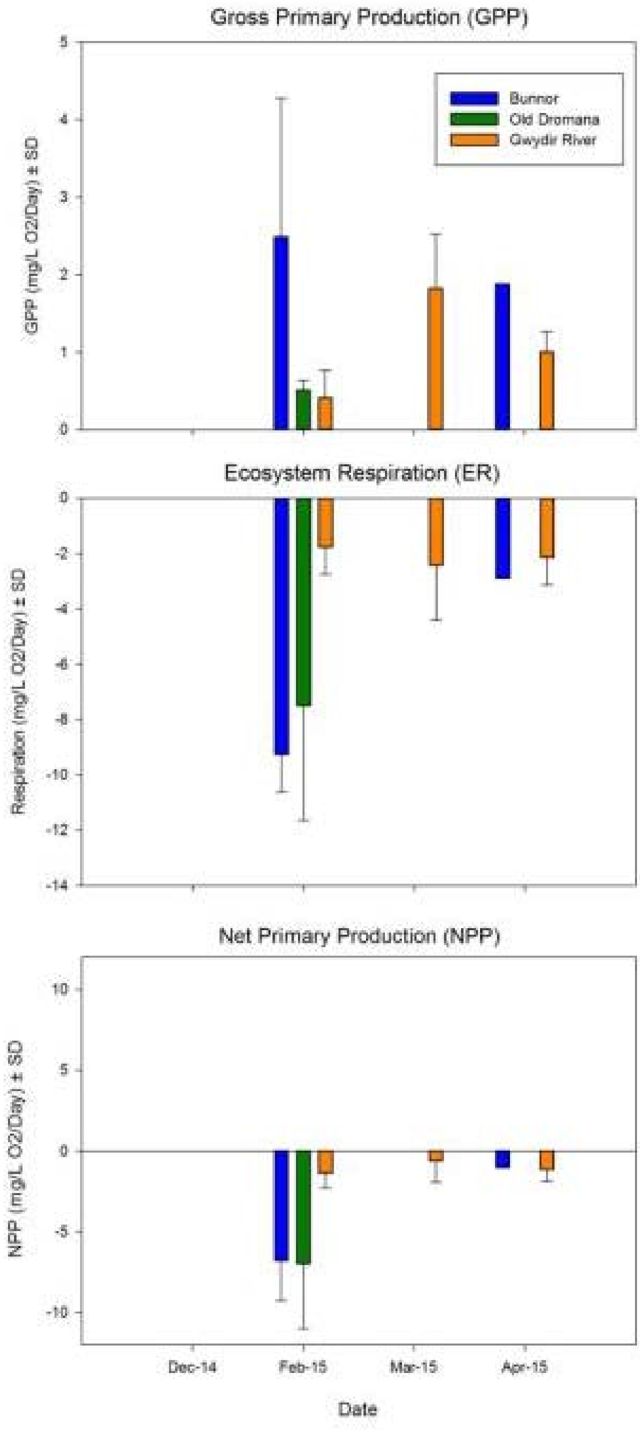

Figure I-3: Rates of GPP, ER and NPP (mgDO/L/day) in the Bunnor wetlands, Old Dromana wetlands and Gwydir River.

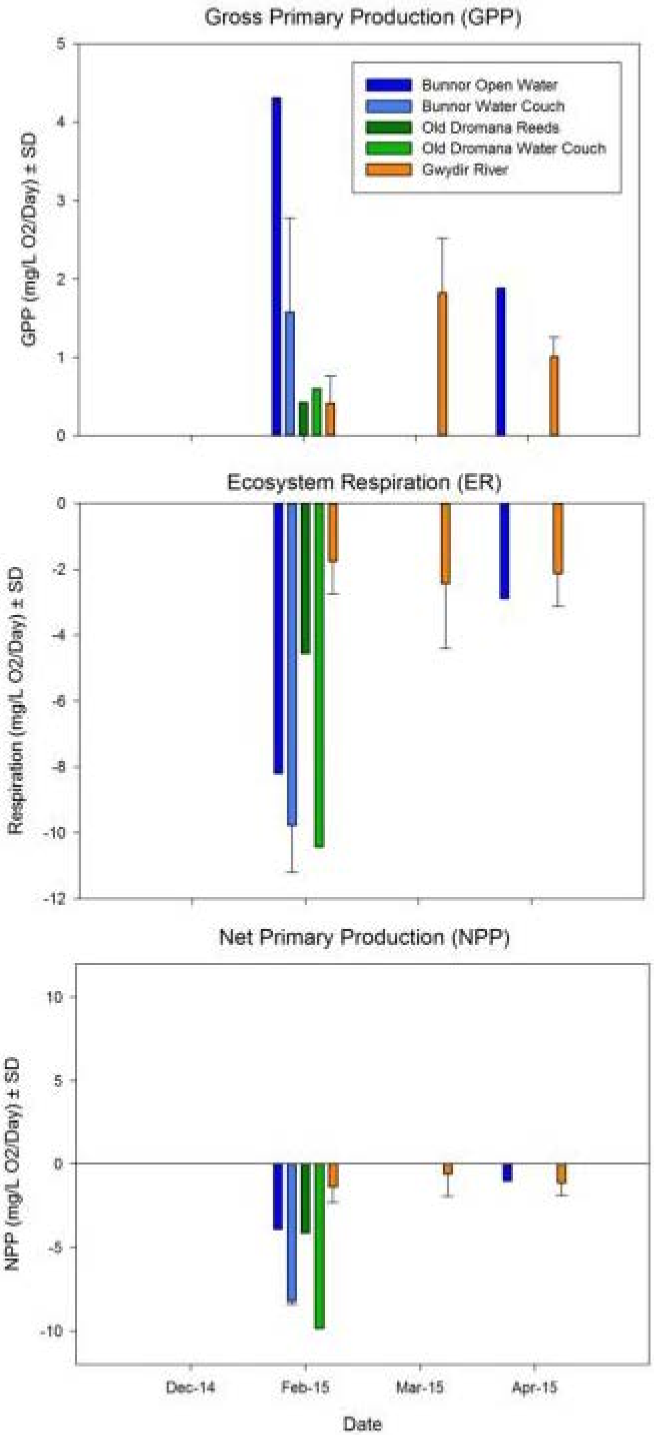

Figure I-4: Rates of GPP, ER and NPP (mgDO/L/day) in wetland habitats in the Bunnor wetlands, Old Dromana wetlands and Gwydir River.

I.3.3 Microinvertebrates

There was no clear trend in microinvertebrate densities with a significant POSITION x REGION x TIME interaction masking main spatial and temporal effects ($F_{3,31} = 5.611$, $p = 0.003$). When analysed separately, there were no significant temporal or spatial differences in benthic microinvertebrate densities (Figure I-5a), but significant temporal - spatial interactions in pelagic microinvertebrate densities when comparing Bunnor wetland, Old Dromana wetland and Gwydir River sites (Figure I-5b). Similar results were observed for microinvertebrate diversity with a significant POSITION x REGION x TIME interaction masking main temporal and spatial effects ($F_{3,31} = 8.263$, $p < 0.001$). When analysed separately, there were no significant temporal or spatial differences in benthic microinvertebrate diversity (Figure I-5c), but significant temporal – spatial interactions in pelagic microinvertebrate diversities (Figure I-5d).

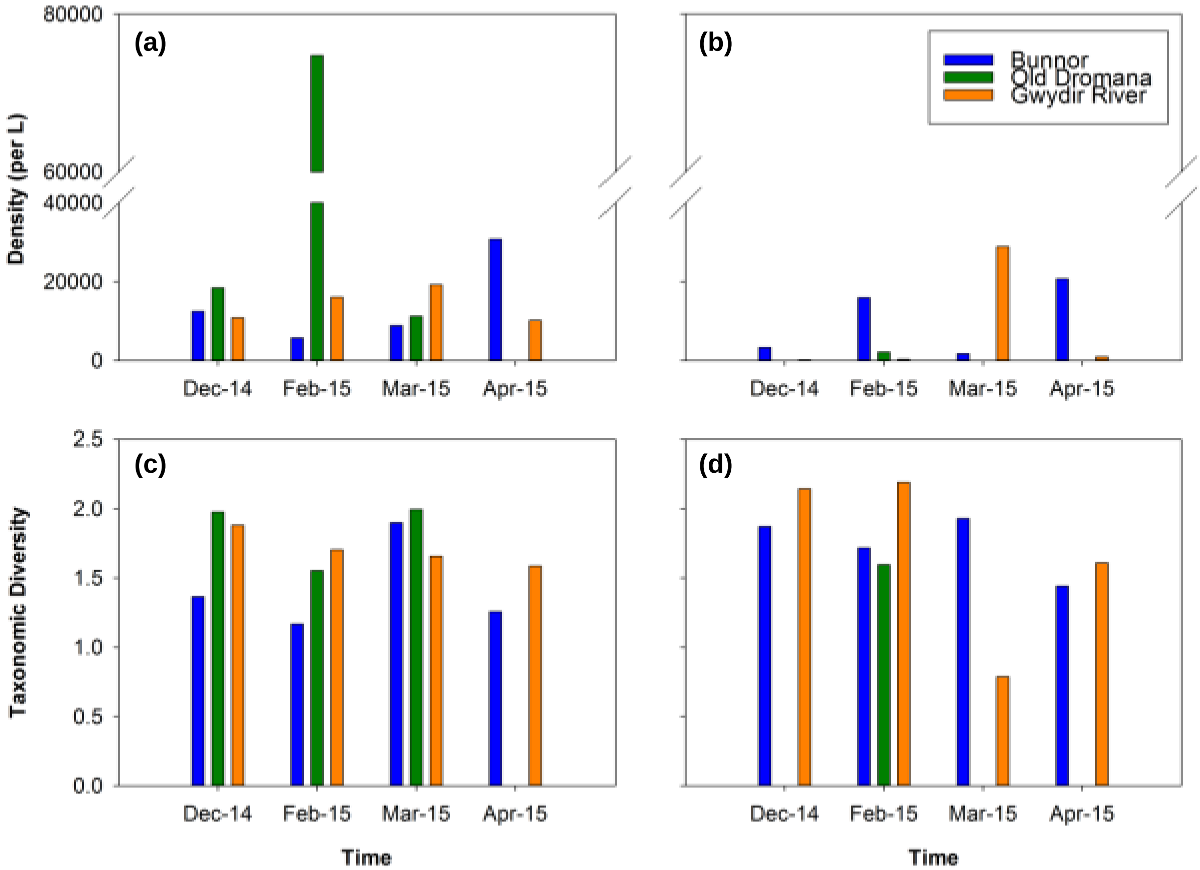

Figure I-5: Microinvertebrate density (per L) in (a) benthic and (b) pelagic communities, and microinvertebrate taxonomic diversity in (c) benthic and (d) pelagic communities across habitats in the Bunnor wetlands, Old Dromana wetlands and Gwydir River.

Densities of the microcrustacean component of the microinvertebrate communities were very similar to the total microinvertebrate densities (Figure I-3). This suggests that microcrustaceans drive microinvertebrate community patterns. Microcrustacean densities were also extremely variable, with a significant POSITION x REGION x TIME interaction masking the main spatial and temporal effects ($F_{3,31} = 3.019$, $p = 0.045$). Benthic microcrustacean densities in wetlands and the river were statistically similar (Figure I-6a), but pelagic microcrustacean densities varied with time between wetlands and the river (TIME x REGION $F_{3,14} = 8.467$, $p = 0.002$, Figure I-6b).

There were no clear patterns in microcrustacean diversities, with the POSITION x REGION x TIME interaction masking main spatial and temporal effects ($F_{1,31} = 3.288$, $p = 0.034$). There were no significant differences in benthic diversity (Figure I-6c), but pelagic diversity differed over time between wetlands and the river (TIME x REGION $F_{3,14} = 12.189$, $p < 0.001$, Figure I-6d).

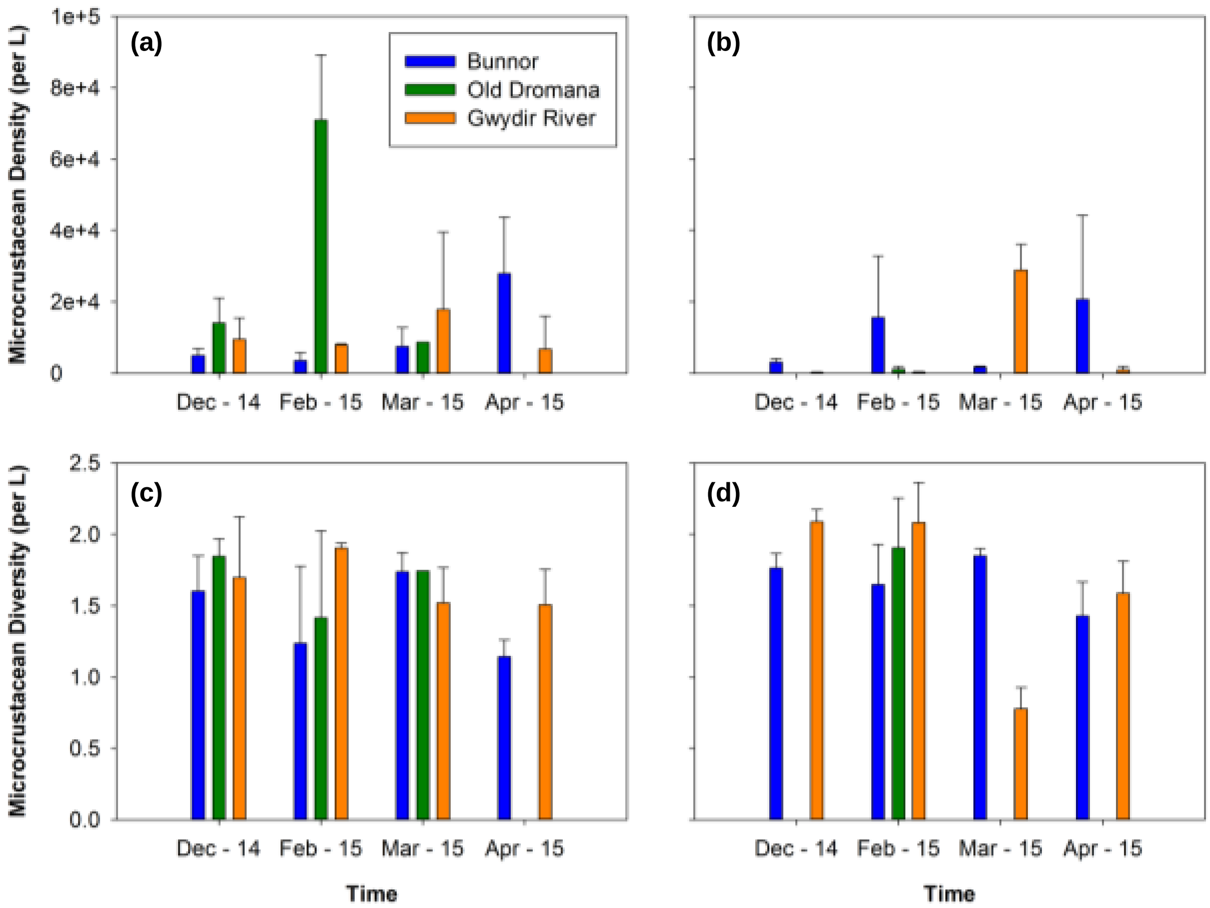

Figure I-6: Microcrustacean density (per L) in (a) benthic and (b) pelagic communities, and microcrustacean taxonomic diversity in (c) benthic and (d) pelagic communities across sites in the Bunnor wetlands, Old Dromana wetlands and Gwydir River. Taxonomic diversity calculated using the Shannon Weiner Index.

Microinvertebrate density peaked in benthic communities during February 2015 at the Water couch site at Old Dromana wetland (Figure I-7a, Figure I-7b). However, patterns among wetland sites were unclear as there were no significant differences amongst diversity of benthic microinvertebrate communities and the TIME x HABITAT interaction was significant for pelagic microinvertebrate communities ($F_{12,9}$ = 9.457, p = 0.001, Figure I-7d). Similar patterns were observed for microcrustaceans, suggesting that these are driving the microinvertebrate community diversity in wetlands ($F_{12,9}$ = 12.559, p < 0.001, Figure I-8).

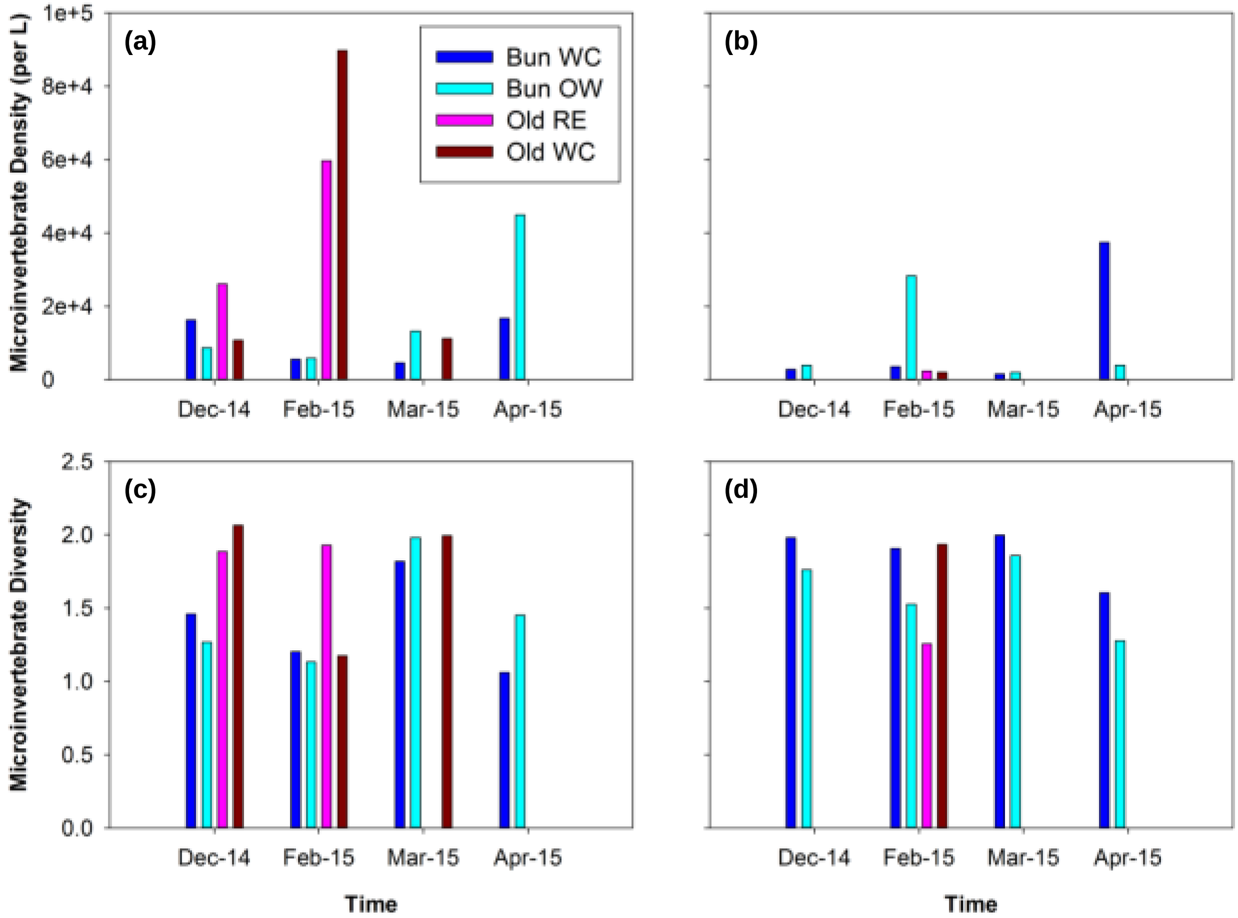

Figure I-7: Microinvertebrate density (per L) in (a) **wetland benthic communities,** (b) **wetland pelagic communities, and microinvertebrate diversity in** (c) **wetland benthic communities, and** (d) **wetland pelagic communities. "Bun" and "Old" represent Bunnor and Old Dromana wetlands, while "WC", "OW" and "RE" represent "Water Couch", "Open Water", and "Reed" habitats, respectively. Microinvertebrate diversity calculated using the Shannon Weiner Index.**

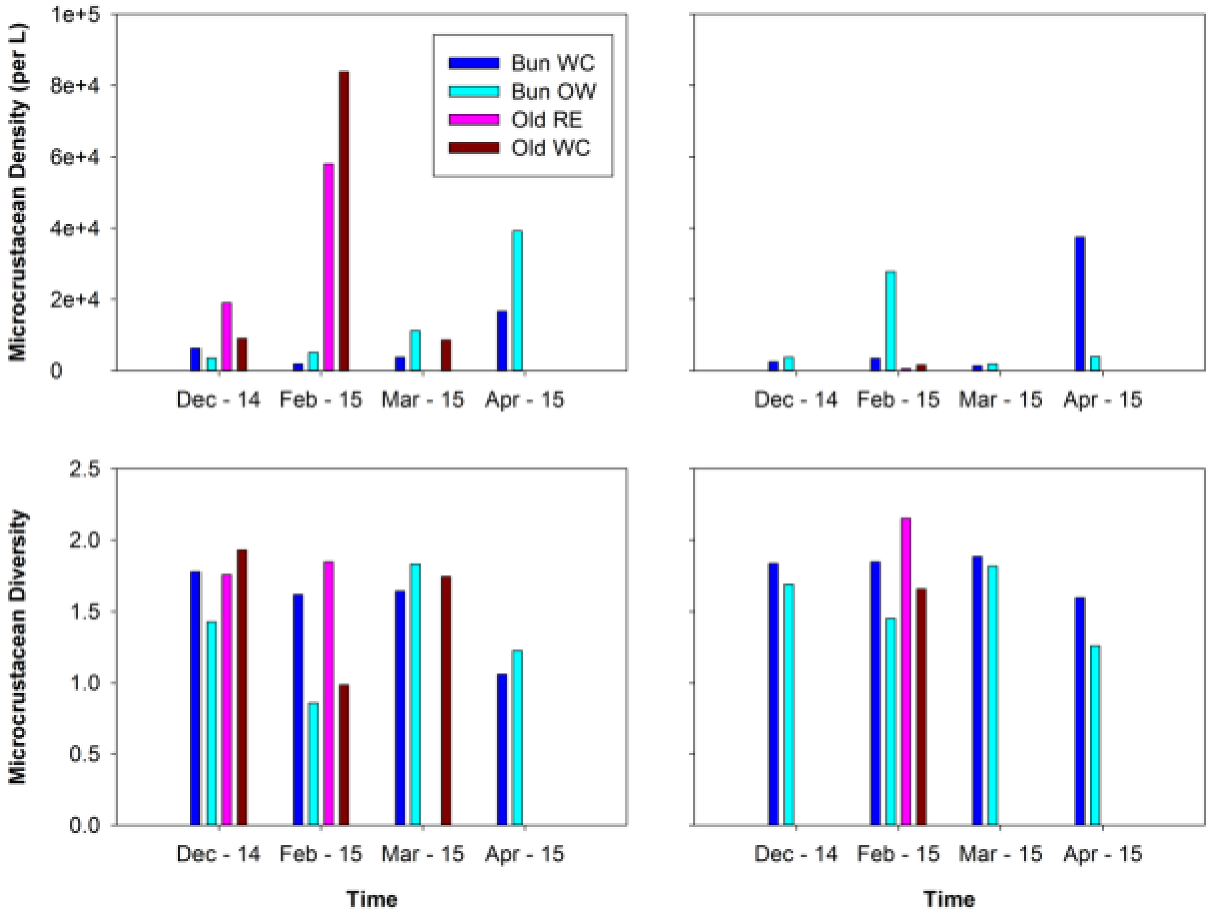

Figure I-8: Microcrustacean density (per L) in (a) **wetland benthic communities,** (b) **wetland pelagic communities, and microcrustacean diversity in** (c) **wetland benthic communities, and** (d) **wetland pelagic communities. "Bun" and "Old" represent Bunnor and Old Dromana wetlands, while "WC", "OW" and "RE" represent "Water Couch", "Open Water", and "Reed" habitats, respectively. Microcrustacean diversity was calculated using the Shannon Weiner Index.**

The strongest difference in microinvertebrate community composition (density) was between pelagic and benthic habitats (Global R = 0.823, p = 0.001, Figure I-9a, Table I-2). This pattern was closely replicated in microcrustacean composition (Density Global R = 0.939, p = 0.001, Figure I-9a), suggesting microcrustaceans were driving microinvertebrate community dynamics (Figure I-9b). This was supported by SIMPER analyses that found microcrustaceans were predominantly contributing to dissimilarity between pelagic and benthic communities (Table I-2). Temporal differences were not significant for microcrustacean density (Global R = 0.072, p = 0.074) but were significant for microinvertebrate density although the temporal pattern was very weak (Global R = 0.211, p = 0.008). There were no differences in microcrustacean community composition between the Gingham and Gwydir River systems.

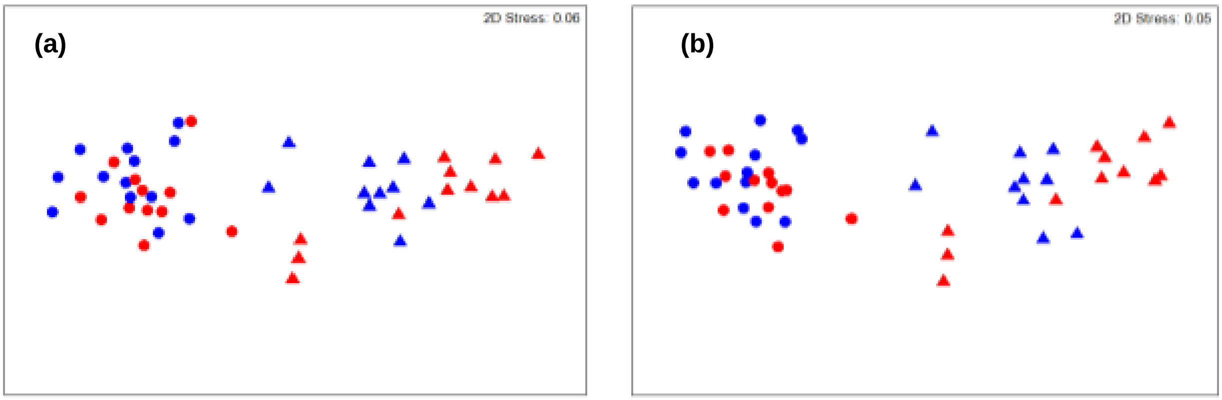

Figure I-9: nMDS ordination of wetland and watercourse (a) microinvertebrate density and (b) microcrustacean density. Blue circles represent wetland benthic samples, red circles represent watercourse benthic samples, blue triangles represent watercourse benthic samples and red triangles represent watercourse pelagic samples.

Table I-2: Significant pairwise tests for a two-way ANOSIM of water column position in wetlands or watercourses. Values above the grey diagonal are for microinvertebrate densities and those below the grey diagonal are for microcrustacean densities.

	Wetland Benthic	Wetland Pelagic	Watercourse Benthic	Watercourse Pelagic
Wetland Benthic		*R* = 0.992, *p* = 0.001		*R* = 0.967, *p* = 0.001
Wetland Pelagic	*R* = 0.944, *p* = 0.001		*R* > 0.999, *p* = 0.011	
Watercourse Benthic		*R* = 0.892, *p* = 0.001		*R* = 0.942, *p* = 0.001
Watercourse Pelagic	*R* > 0.999, *p* = 0.001	*R* = 0.662, *p* = 0.001	*R* > 0.999, *p* = 0.001	

Table I-3: Microinvertebrate taxa contributing most of the similarities between pelagic and benthic densities across wetland and watercourse sites.

Pelagic Communities					
SIMPER analysis of microinvertebrate densities			SIMPER analysis of microcrustacean densities		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Nauplii	20.32	20.32	Nauplii	18.79	18.79
Lecanidae	10.32	30.63	Lecanidae	12.77	31.56
Euclanidae	9.65	40.29	Euclanidae	10.90	42.46
Calanoida	9.18	49.47	Chydoridae	10.29	52.75
Brachionidae	8.70	58.17	Brachionidae	9.38	62.13
Chydoridae	8.41	66.58	Calanoida	9.36	71.49
Collurellidae	6.71	73.29	Collurellidae	7.26	78.76
Notomatidae	6.10	79.39	Notomatidae	6.20	84.96
Nematoda	5.15	84.53	Filiniidae	4.02	88.97
Cyclopoida	3.99	88.53	Cyclopoida	3.00	91.97
Filiniidae	3.69	92.21			
Benthic Communities					
SIMPER analysis of microinvertebrate densities			SIMPER analysis of microcrustacean densities		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Nematoda	20.55	20.55	Calanoida	18.82	18.82
Calanoida	14.60	35.15	Nauplii	16.38	35.19
Nauplii	12.63	47.78	Chydoridae	15.95	51.15
Chydoridae	12.26	60.04	Lecanidae	10.23	61.37
Lecanidae	8.20	68.24	Cyclopoida	8.71	70.08
Cyclopoida	7.46	75.70	Euclanidae	8.64	78.72
Euclanidae	7.26	82.97	Notomatidae	7.29	86.01
Notomatidae	5.35	88.31	Collurellidae	4.00	90.01
Daphniidae	3.48	91.79			

Two-way ANOSIM of the taxonomic composition (presence/absence) of microinvertebrates found the differences among water column position in wetlands or watercourses were significant but weak (Global R = 0.179, p = 0.006, Figure I-10a), with common dominant taxa between pelagic and benthic communities (Table I-4). Temporal differences were also significant but weak (Global R = 0.217, p = 0.001). The analysis of taxonomic composition (presence/absence) of microcrustaceans found a similar pattern (Time Global R = 0.229, p = 0.004; Position Global R = 0.206, p = 0.008, Figure I-10b). This suggests that densities of microcrustaceans are the key driver of microinvertebrate community composition.

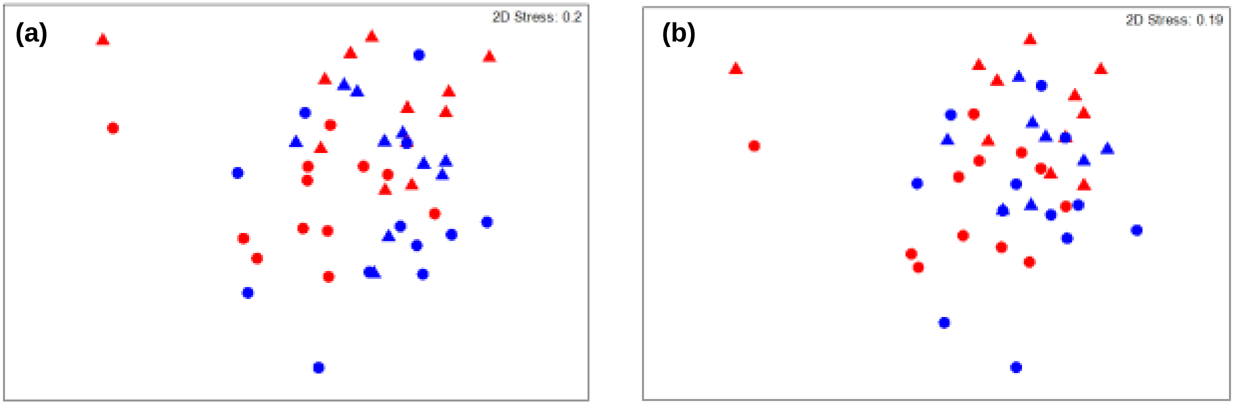

Figure I-10: nMDS ordination of wetland and watercourse (a) **microinvertebrate and** (b) **microcrustacean presence/absence. Blue circles represent wetland benthic samples, red circles represent watercourse benthic samples, blue triangles represent wetland pelagic samples and red triangles represent watercourse pelagic samples.**

Table I-4: Microinvertebrate taxa contributing most of the similarities between pelagic and benthic taxonomic composition (presence/absence) across wetland and watercourse sites.

Pelagic Communities					
SIMPER analysis of microinvertebrate taxonomic composition			SIMPER analysis of microcrustacean taxonomic composition		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Chydoridae	9.93	9.93	Chydoridae	10.72	10.72
Euclanidae	9.93	19.86	Euclanidae	10.72	21.44
Nauplii	9.93	29.78	Nauplii	10.72	32.15
Calanoida	8.90	38.68	Calanoida	9.66	41.81
Brachionidae	8.60	47.28	Brachionidae	9.27	51.08
Lecanidae	8.60	55.88	Lecanidae	9.27	60.35
Collurellidae	7.66	63.54	Collurellidae	8.26	68.62
Nematoda	7.08	70.62	Notomatidae	7.44	76.05
Notomatidae	6.88	77.50	Filiniidae	6.09	82.14
Filiniidae	5.72	83.22	Asplanchnidae	5.94	88.08
Asplanchnidae	5.62	88.84	Cyclopoida	3.71	91.79
Cyclopoida	3.44	92.28			
Benthic Communities					
SIMPER analysis of microinvertebrate taxonomic composition			SIMPER analysis of microcrustacean taxonomic composition		
Taxa	Contributed %	Cumulative %	Taxa	Contributed %	Cumulative %
Nauplii	11.26	11.26	Nauplii	12.62	12.62
Calanoida	10.40	21.66	Calanoida	11.63	24.25
Nematoda	10.33	31.99	Chydoridae	11.53	35.78
Chydoridae	10.28	42.27	Lecanidae	11.34	47.11
Lecanidae	10.13	52.40	Euclanidae	10.50	57.62
Euclanidae	9.37	61.76	Notomatidae	8.55	66.17
Notomatidae	7.63	69.40	Cyclopoida	8.48	74.65
Cyclopoida	7.52	76.92	Collurellidae	7.27	81.92
Collurellidae	6.53	83.45	Brachionidae	5.26	87.18
Brachionidae	4.70	88.15	Daphniidae	4.70	91.88
Daphniidae	4.20	92.35			

I.3.4 Wetland scale microinvertebrate abundances

The wetland scale abundance of total microinvertebrates followed a predictable cycle of maximum abundances when wetland area and volume were at a maximum, with maximum abundances of 16.9 x 10^9 in the Gingham and 69.2 x 10^9 in the Gwydir wetlands (Table I-5). The succession of microcrustaceans is evident in the total abundances, however different taxa dominate in each of the wetland systems. In the Gingham, Calanoida are dominant (90.4 x 10^9) immediately following filling, Chydoridae (4.1 x 10^9) and Calanoida (3.4 x 10^9) dominant during the full phase, and Nauplii (7.1 x 10^8) dominant during wetland drawdown. In the Gwydir, Chydoridae are dominant (349.7 x 10^9) immediately following filling, Daphniidae (4 x 10^9) dominant during the full phase, and Chydoridae (5.4 x 10^9) dominant during wetland drawdown.

Table I-5: The total abundance of dominant microcrustaceans, and total microinvertebrates scaled to whole-of-wetland for the Gingham and Gwydir wetlands in each of the sample periods from filling (Dec-14), maximum extent (Feb and Mar-14) and drying (April-15). Abundances require 10^9 multiplication.

Taxa	Gingham				Gwydir		
	Dec-14	Feb-15	Mar-15	Apr-15	Dec-14	Feb-15	Mar-15
Calanoida	90.4	772.2	3716.3	293.0	134.9	9,015.0	435.4
Chydoridae	10.1	4,094.8	730.5	650.4	349.7	3,509.9	541.6
Cyclopoida	16.3	238.8	171.4	4.5	68.3	799.5	85.0
Daphniidae	1.9	118.0	257.2	0.0	20.4	40,098.5	0.0
Nauplii	22.3	241.2	1,135.1	705.9	82.6	1,288.5	339.8
Ostracod	28.8	11.4	128.6	12.3	21.6	710.6	0.0
Total	**489.6**	**10,517.5**	**15,988.8**	**1,959.3**	**1,533.4**	**69,176.0**	**2,485.1**

I.4 Conclusion

Over the period sampled for microinvertebrates the inundation of the Gingham and Gwydir wetlands was driven exclusively by environmental water deliveries. Therefore, the counterfactual outcome for these systems in Year 1 was a dry wetland complex in the lower Gwydir system. Delivery of environmental water to wetland systems resulted in a pulse of N and P concentrations immediately following inundation. The drawdown of environmental water delivery in March 14 resulted in a second pulse of increased nutrient concentrations with a concomitant spike in water column chlorophyll *a*. All systems were net heterotrophic in all flow periods and acted as carbon sinks throughout the period of inundation. Rates of GPP and ER differed substantially over time and between wetland systems, with NPP consistently most negative in wetland vegetated habitats. The delivery of environmental water to the Gingham and Gwydir wetlands increased regional scale abundance and diversity of aquatic microinvertebrates. Significantly lower pelagic compared with benthic microinvertebrate densities, and significant differences in community composition were evident between in each vegetation habitat, wetland or river system and time. The significant difference in aquatic microinvertebrate community composition between the Gingham and Gwydir wetlands indicates the benefits for delivery of environmental water to both wetland systems in maintaining regional level diversity. The delivery of sufficient volumes of environmental water to the Gingham and Gwydir wetlands to inundate a mosaic of vegetative habitats (Appendix G) significantly increased the density and diversity of aquatic microinvertebrates. In addition, the resultant long term (over 5 month) duration of inundation in both the Gingham and Gwydir wetlands contributed to the development and succession of different aquatic microinvertebrate communities between wetland systems.

I.5 References

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