River Health Assessment of the Murray River, Western Australia

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Peel-Harvey Catchment Council

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Frontispiece: The site on the Murray River Farm upstream. (Above) Jesse and Jo at the picturesque Murray River Farm upstream site.

Contents

List of Figures

Summary

River Health Assessments (RHAs) were conducted at three sites on the Murray River in May and November 2021 using the South West Index of River Condition (SWIRC) protocols to provide baselines of ecological condition and to produce SWIRC scores. One of the sites (Marrinup Brook confluence) was previously surveyed by DWER in 2017.

All three sites had a reasonable diversity of instream aquatic habitat. Native riparian vegetation was mostly in good condition at all sites, including evidence of ongoing natural recruitment. However, the ground cover was generally dominated by introduced weeds. All sites also had elevated salinity concentrations; with other water quality parameters being within limits known to support native aquatic fauna.

Aside from the Freshwater Cobbler, freshwater native fish species expected to be present were in very low abundances or absent at all sites. Smooth Marron were present at all sites with some level of annual recruitment occurring. The fish and crayfish fauna present at the Marrinup Brook confluence site during the current survey periods was similar to that recorded in 2017; although a greater number of freshwater fish species was detected in 2021. Macroinvertebrate communities during the current survey were indicative of impaired ecological condition based on AUSRIVAS assessment with the greatest richness occurring in November.

While the total discharge during 2021 in the Murray River was well above the long-term average (i.e. 408000 ML compared to a mean long term average of ~251000 ML), similar to other south-west river systems, there has been an overall significant decline in annual discharge in the Murray River due to climate change since the 1970s. The two years preceding the current survey also had well below average discharge. As the spawning migration and thus recruitment of native fishes is positively associated with winter-spring discharge, the very low abundances of most native freshwater fishes at the three sites may be at least partially explained by low levels of recruitment in 2019 and 2020.

Although reductions in river flow pose a serious long-term threat to freshwater species in the Murray River, it is also likely that secondary salinisation of the main channel of the Murray River has caused a major impact on the aquatic ecosystem. The salt tolerance of the majority of native freshwater fishes is poorly understood, particularly for the more vulnerable early life-history stages. However, the Western Minnow is known to persist at much greater salinities than were recorded at the current sites (including in the upper Murray River catchment) and thus further investigation on the low abundances of this and other freshwater fishes is warranted.

It is recommended that programs that help address secondary salinisation in the upper catchment of the Murray River be supported. Protection and restoration of riparian zones in both upstream and also the freshwater downstream reaches of the Murray Rive could help offset some of the impacts of ongoing flow declines and temperature increases to the aquatic fauna. It is also recommended that ecological surveys be conducted in other freshwater tributaries of the Murray River, such as the Dandalup River, to help identify and priority habitats for restoration as these may be critical in maintaining populations of salt-sensitive taxa in the system.

Scope

Key aims of the *Healing Bilya - Restoring the Murray and Serpentine Rivers* (and the *Peel-Harvey Estuary Grants*) being conducted by the Peel Harvey Catchment Council (PHCC) is to improve the ecological condition of the Murray, Serpentine and Harvey rivers including improving fish habitat. River Health Assessments (RHAs) are a key component of this as it provides baseline information upon which chances in condition may be monitored. The RHAs follow the South West Index of River Condition (SWIRC) protocols to enable ecological baselines to be obtained that will in turn allow measurement of the effectiveness of restoration activities.

RHAs were conducted at two sites in the Murray River system in 2017 by the PHCC, in partnership with the Department of Water and Environmental Regulation (DWER) (Heald et al. 2018a, 2018b). The current project conducted RHAs in autumn and spring 2021 at one of those sites surveyed in 2017 (i.e. the Marrinup Brook confluence site (Heald et al. 2018a)). As the latter assessment did not calculate SWIRC scores, where possible these were also calculated herein based on the data in the latter report. The current study also assessed two additional sites in the Murray River during autumn and spring 2021.

The current study aimed to increase the spatial and temporal understanding of the ecological condition of the Murray River and provide recommendations for further monitoring and restoration activities to enhance the health of its aquatic ecosystem.

Methods

The RHAs were conducted between the 5th-21st May and 16th-17th November 2021 at three sites in the Murray River (Figure 1). Sampling methods included the following DWER South West Index of River Condition (SWIRC) protocols:

- Sampling for fish movements and relative abundance involved the use of dual fyke-netting set overnight at upstream and downstream points (~100m apart) at the site, and fish traps between the fyke nets. Sampling for crayfish involved the use of box-style crayfish traps.
- All native fauna captured were identified, enumerated, and a sub-sample of fish and crayfish measured (total length (TL) for fish and orbital carapace length (OCL) for crayfish). This was undertaken to determine population structure and viability. All native fish and crayfish were released unharmed at the site of capture and all introduced species were euthanased in an ice-slurry.
- Sampling for macroinvertebrates involved an invertebrate sweep at each site (of two minute duration) using a macroinvertebrate net (250µm mesh) in a macrophyte-dominated area (where present) and the channel. The samples were immediately preserved in 100% ethanol for identification in the laboratory.
- Habitat and water quality data collection included those outlined in the DWER South

West Index of River Condition (SWIRC) Information protocols, which included:

i. General site description.
ii. Connectivity.
iii. Aquatic habitat.
iv. Vegetation – this included additional mapping that occurred by H. Anderson.
v. Physical form and potential pollution.
vi. Water quality was logged for a period of ~20 hours at each site and included water temperature, dissolved oxygen (% saturation and mg/L), conductivity (mS/cm), total dissolved solids (g/L), salinity (ppt), pH, and ORP (mV), Total Nitrogen, Total Phosphorus, Turbidity. In addition, total metal concentrations were analysed from the most downstream site. The latter parameters were analysed by *ChemCentre*.
vii. Photographs were taken at fixed locations at each site.

- SWIRC scores were calculated for the above fauna, habitat and water quality themes aside from two of the GPS based Sub-themes (i.e. longitudinal connectivity, extent of the fringing zone extent).

Measuring Freshwater Cobbler at the Murray River Farm upstream site, November 2021

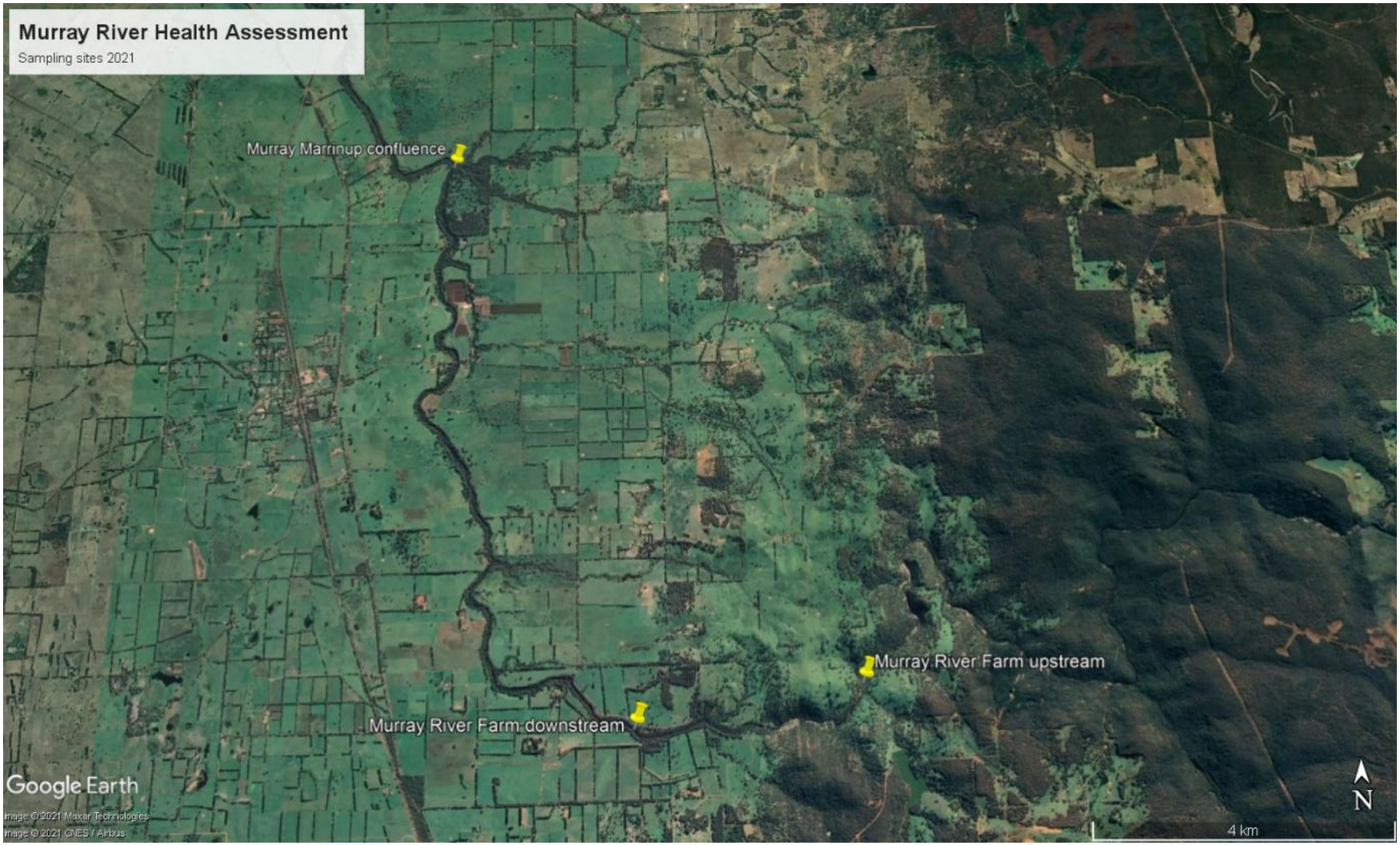

Figure 1 Sites where River Health Assessments were undertaken in the Murray River.

May **November**

Marrinup Brook Confluence


Murray River Farm downstream


Murray River Farm upstream


Figure 2 Sites surveyed in May (left column) and November (right column) in the Murray River.

Results and Discussion

The SWIRC scores are presented in Table 1 (over page). Each SWIRC theme is discussed in more detail in subsequent sections of the report.

Figure 3 View to the Murray River Farm upstream site in May 2021. N.B. the mixture of pasture and remnant forest.

*Table 1 South West Index of River Condition scores in May 2021 and November 2021. N.B. Also presented are the DWER scores for the Marrinup Brook confluence site (MR384MARR1) surveyed in December 2017. * denotes Sub Themes that require GIS based desktop assessment. As macroinvertebrate SWIRC score is based on the Western Australian spring channel AUSRIVAS model, this was only calculated for the November 2021 survey.*

	May 2021				Nov 2021			DWER 2017
	Murray Marrinup Brook confluence	**Murray River Farm downstream**	**Murray River Farm upstream**		**Murray Marrinup Brook confluence**	**Murray River Farm downstream**	**Murray River Farm upstream**	**Murray Marrinup Brook confluence**
WQI theme score	**0.5**	**0.5**	**0.5**		**0.5**	**0.5**	**0.5**	**0.5**
TN score	1	1	1		1	1	1	1
TP score	1	1	1		1	1	1	1
Turbidity score	1	1	1		1	1	1	1
Temperature score	0.80	0.80	0.80		0.80	0.80	0.80	0.80
Mean (TN, TP, Turb & Temp)	0.95	0.95	0.95		0.95	0.95	0.95	0.95
Salinity score	0.50	0.50	0.50		0.50	0.50	0.50	0.50
DO score	1	1	1		1	1	1	
PFI theme score*	-	-	-		-	-	-	
Artificial channel	1	1	1		1	1	1	1
Longitudinal Connectivity *	-	-	-					
Erosion	0.52	0.63	0.69		0.44	0.56	0.67	0.46
FZI theme score*	-	-	-		-	-	-	
Fringing zone length score*	-	-	-		-	-	-	
Fringing zone width score*	-	-	-		-	-	-	
Nativeness score	0.20	0.10	0.20		0.60	0.10	0.50	0.10
Aquatic Biota Index					0.51	0.68	0.47	
Fish and crayfish score	0.90*	0.83*	0.89*		0.81	0.88	0.69	
Expectedness	0.88	0.75	0.88		0.63	0.75	0.38	
Nativeness	0.93	0.91	0.90		1.00	1.00	1.00	
Macroinv. AUSRIVAS score	-	-	-		0.2	0.48	0.25	

Habitat summaries

Below summarises the key habitat characteristics of each site.

Marrinup Brook confluence

Marrinup Brook confluence site consisted of a series of pools and runs within a meandering channel (Figure 4). A high-flow period anabranch was present on the left bank in the middle of the site. Water depth in both seasons was variable as was flow velocity (>1.5m/sec maximum in both seasons). The bank slope and shape was variable due to high levels of erosion mostly on the right bank (5-19%) within an otherwise low gradient section of river. The site was connected with no barriers to fish movement in either season. The substrate was dominated by sand and had high levels of stream shading due to relatively intact riparian overstory (see Vegetation in Appendix 1). There was a moderate abundance of woody debris with a diverse range of sizes.

Landuse outside of the fenced riparian zone at the site was grazing for meat cattle production. While the major water quality parameter influencing the biota is likely to be salinity (see the section *Water quality and its influence on fauna* below), the surrounding and upstream grazing landuse would also represent a source of non-point pollution in this section of the river through nutrient inputs. Sedimentation would also be occurring due to input from cleared land and bank erosion along the channel.

Figure 4 Marrinup Brook confluence site looking upstream (top) and downstream (bottom) from the right bank in November, 2021.

Murray River Farm downstream

Murray River Farm downstream site was dominated by a large pool with runs at each of the upstream and downstream ends. While the site was relatively straight, the section was still relatively meandering. Water depth in both seasons was slightly variable and relatively deep (>2 m maximum in the pool). Flow velocity was variable due to the presence of the runs (upper flow range 0.6-1.5 m/sec in both seasons). The channel shape was trapezoid and bank stepped with some bank erosion, mostly on the left bank. The site was connected with no barriers to fish movement in either season. However, there was a pipe culvert road crossing ~1km downstream that would represent a barrier to fish passage during the majority of the year (Figure 5). The substrate at the site was variable (from silt through to boulders) and had high levels of stream shading with a relatively intact riparian overstory (see Vegetation in Appendix 2). Woody debris was abundant consisting of a diverse range of sizes (Figure 6).

The site was also fenced from cattle access with landuse outside of the riparian zone grazing for meat cattle production. As with the other two sites, salinity would be having a major influence on the biota with the other non-point pollution sources being nutrients and sedimentation from surrounding cleared land and bank erosion along the channel.

Figure 5 Pipe culvert road crossing ~1km downstream of Murray River Farm downstream site.

Figure 6 Murray River farm downstream site looking upstream (top) and downstream (bottom) from the right bank in November, 2021.

Murray River Farm upstream

Murray River Farm upstream site was situated in a high-gradient landscape and the section was relatively straight and would have high energy flow during peak flow periods (Figure 7). The site consisted of a diverse range of aquatic habitats (pool, riffle, runs) with variable water depth and velocities (Figure 5). Bank erosion was least evident at this site with the substrate having the greatest amount of bedrock and larger sized boulders compared to the other downstream sites. The section of river downstream had several natural bars and falls that would provide some level of restriction to movement of fishes (see *Freshwater Fish and Decapods*). The streamline had low levels of shading from the riparian zone. Woody debris was sparse although variable sizes were present.

The riparian zone was unfenced and grazed but had some remnant vegetation (see Vegetation section Appendix 1). It was also located ~600m upstream of the Marrarup Nature Research that borders the left bank of the river. Salinisation due to clearing in the upper catchment would be the major source of pollution along with nutrient inputs from the surrounding pasture.

Figure 7 Murray River farm upstream site looking upstream (top) and downstream (bottom) from the right bank in November, 2021. N.B. the hills of Marrarup Nature Reserve can be seen in the distance.

Freshwater fish and decapods

A total of 1414 fish, crayfish and shrimp were captured across May and November 2021 (Table 2). The fauna consisted of four south-western Australian endemic freshwater fishes, three native fishes found in both estuaries and freshwater environments, two south-western Australian endemic crayfishes, one endemic native shrimp, and one introduced freshwater fish.

Approximately 97% of fishes were native with only 12 invasive Eastern Gambusia recorded. Freshwater Cobbler dominated abundances of fish in both seasons representing ~71% of all fish captured (Table 2, Figure 8). The native freshwater fishes Western Minnow, Nightfish, Western Pygmy Perch were present in very low abundances (Table 2). The estuarine Western Hardyhead was the second most abundant fish present with smaller numbers of estuarine Bluespot Goby and Southwestern Goby also recorded (Table 2, Figure 8). Only dead shells of the threatened Carter's Freshwater Mussel *W. carteri* were observed during the surveys. All sites also housed the Oblong Turtle *Chelodina oblonga.*

Marrinup Brook confluence

Marrinup Brook confluence housed the greatest relative abundance of the Freshwater Cobbler of any site in both May and November. The Western Minnow and Western Pygmy Perch were also detected in very low abundances at the site in May, but not November. Western Hardyheads and Southwest Goby were present in both seasons with the Blue-spot Goby only detected in November (Table 2, Figure 8). Southwest Glass Shrimp were in relatively high abundance in both seasons with Smooth Marron also present in low abundances and a single Gilgie was captured in November and Eastern Gambusia in May.

The length frequency distribution of both Freshwater Cobbler and Western Hardyhead revealed that there were multiple size/age cohorts present and thus the populations were sustainable at the site (Figure 9). Moreover, November coincides with the onset of their breeding season (Beatty et al. 2010), and ~64% of mature female Freshwater Cobbler at the site then were in breeding condition as evidenced by releasing eggs upon gentle manipulation.

The Smooth Marron at the site were also represented by two-four size classes in May and November (OCL ranging between 27-69 mm and 34-63 mm in May and November, respectively), indicating some annual recruitment was occurring. Noting that 0+ individuals are usually under-represented in nets. There was also some evidence of fishing activity at the site.

Faunal comparison with DWER December 2017 survey, Marrinup Brook Confluence

River condition at the Marrinup Brook confluence site was assessed in December 2017 by DWER in collaboration with the PHCC (Heald et al., 2018a). The fish and crayfish observed during that study were broadly similar in abundance and composition with the current surveys with a few exceptions (Table 2). All species detected in December 2017 were captured during the current combined survey periods; with the exception of the Nightfish (a single individual was capture in 2017). More Freshwater Cobbler were captured in December 2017 compared with the current survey. That could have been attributed to reduced discharge during the former survey enabling greater gear efficiency in capturing the species (i.e. blocking a greater percentage of the stream channel).

Three additional species were captured in 2021 that were not detected in 2017; the Western Minnow, Western Pygmy Perch and Southwestern Goby. However, these were in very low abundances and not captured in both seasons in 2021 (and two of the three only captured in the Mary 2021 sampling). Thus, it is likely that they were present in very low abundances in 2017 at the site but not at detectable levels.

Murray River farm downstream

The Murray River farm downstream site housed considerable abundances of Freshwater Cobbler and Western Hardyheads in both months surveyed (Table 2, Figure 8). It lacked Western Pygmy Perch and a single Nightfish was recorded in each month with two Western Minnows in November. It had the greatest numbers of Southwest Goby but they were still in relatively low abundances.

Decapods again included relatively high numbers of Southwest Glass Shrimp and low abundances of Smooth Marron and Gilgies. Four Eastern Gambusia were recorded in May (Table 2). The more abundant Freshwater Cobbler and Western Hardyhead were represented by multiple size cohorts and annual recruitment was clearly occurring (Figure 9). As per all sites in November, approximately two-thirds of mature female Freshwater Cobbler were in breeding condition.

Murray River farm upstream

Murray River Farm upstream had very low abundances of all four native freshwater fishes in May 2012, however in November Freshwater Cobbler numbers increased and the majority (~63%) of females were in spawning condition (Figure 10). This suggests that there was fish passage connectivity for this large bodied species during its key breeding period during November; particularly over the track crossing that could have represented a barrier to the species.

There are other natural barriers that exist further downstream between the Murray farm downstream and upstream sites. It is unclear the degree they are restricting upstream movement of other freshwater species. However, it is likely that they are posing a major barrier to the obligate estuarine Black Bream *Acanthopargrus butcheri* that is known to be present as far upstream as the pool at foot of the first cascades of Darling Scarp located between the two sites.
The native The Western Hardyhead was also not detected at this site suggesting that the numerous natural riffles and cascades between the two Murray River farm sites is also preventing it moving upstream into the site and possibly further up the Murray River.

Morgan and Beatty (2004) surveyed 22 sites within the Hotham, Williams, Bannister and Crossman rivers, and Minniging, Fourteen Mile, Wandering, Marradong Brooks, Warrening, and Marling Gullies, and Wurrungnulling Creek and recorded Western Minnow, Western Pygmy Perch, Nightfish, Swan River Goby and Eastern Gambusia. Therefore, the current distribution of the fish fauna is likely to have been shaped by a combination of historical distributions and topography (i.e. river gradient) along with the variable effects of secondary salinisation on their critical life-history stages and thus population viabilities.

Table 2 Abundance of fish and crustaceans from the Murray River sampling in May and November 2021. N.B. also presented are the catch data from the DWER/PHCC survey in December 2017 for the Marrinup Confluence site.

	Marrinup Confluence			**Murray River Farm Downstream**		**Murray River Farm Upstream**		**TOTAL**
Species	May	Nov	Dec 2017	May	Nov	May	Nov	**2021**
NATIVE FISHES								
Western Minnow *G. occidentalis*	1	0	0	0	2	7	0	**10**
Western Pygmy Perch *N. vittata*	1	0	0	0	0	1	0	**2**
Nightfish *B. porosa*	0	0	1	1	1	4	2	**8**
Freshwater Cobbler *T. bostocki*	81	87	167	54	30	4	68	**324**
Western Hardyhead *L. wallacei*	11	3	6	23	44	0	0	**81**
Southwest Goby *A. suppositus*	3	2	0	7	4	0	1	**17**
Bluespot Goby *P. olorum*	0	2	6	0	0	2	0	**4**
NATIVE CRUSTACEANS								
Southwest Glass Shrimp *P. australis*	39	75	-	28	51	1	31	**225**
Smooth Marron *C. cainii*	7	5	7	0	4	20	0	**18**
Gilgie *C. quinquecarinatus*	0	1	1	0	2	1	2	**6**
INVASIVE FISHES								
Eastern Gambusia *G. holbrooki*	1	0	0	4	0	7	0	**12**

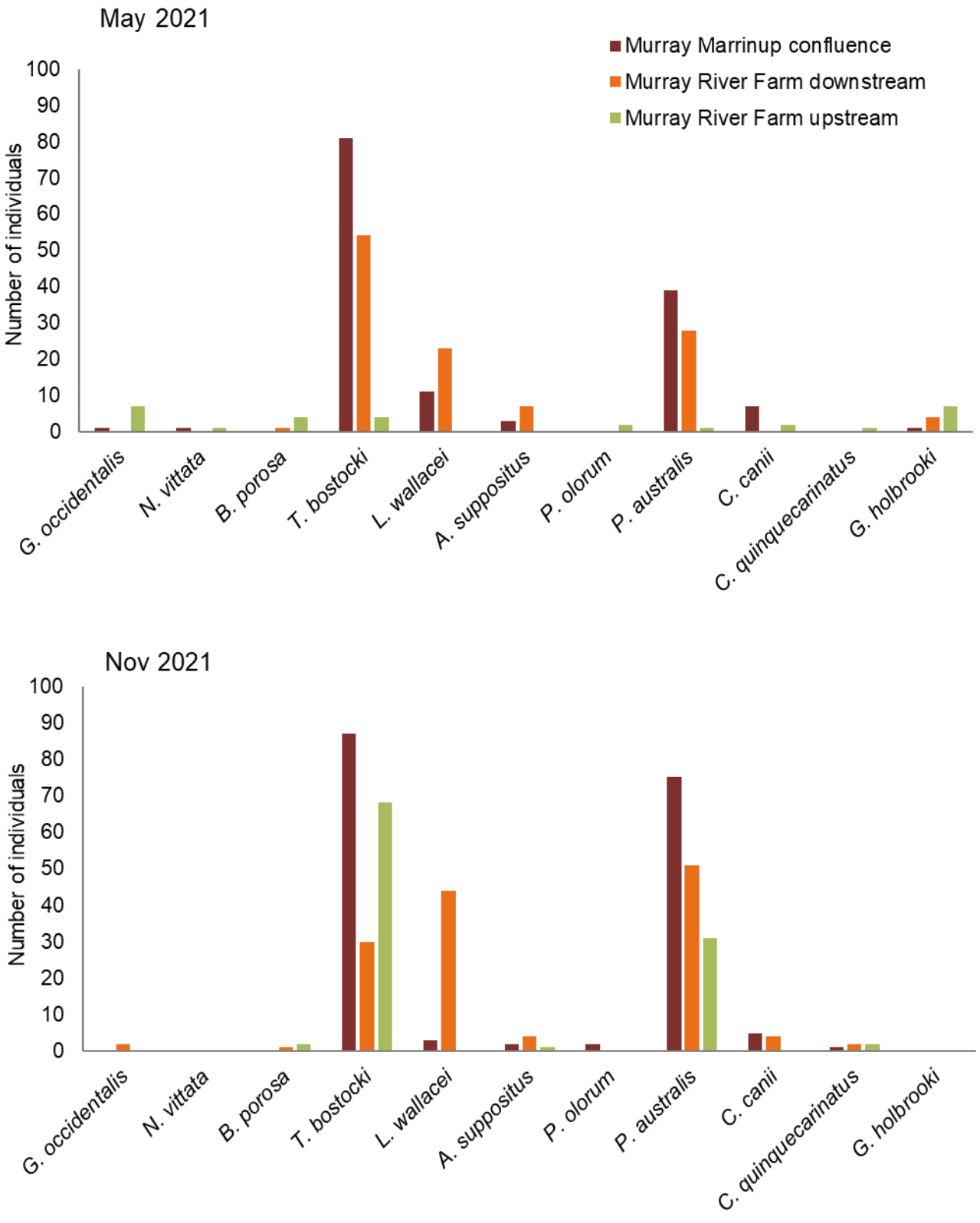

Figure 8 Number of each species captured at each site in May and November 2021.

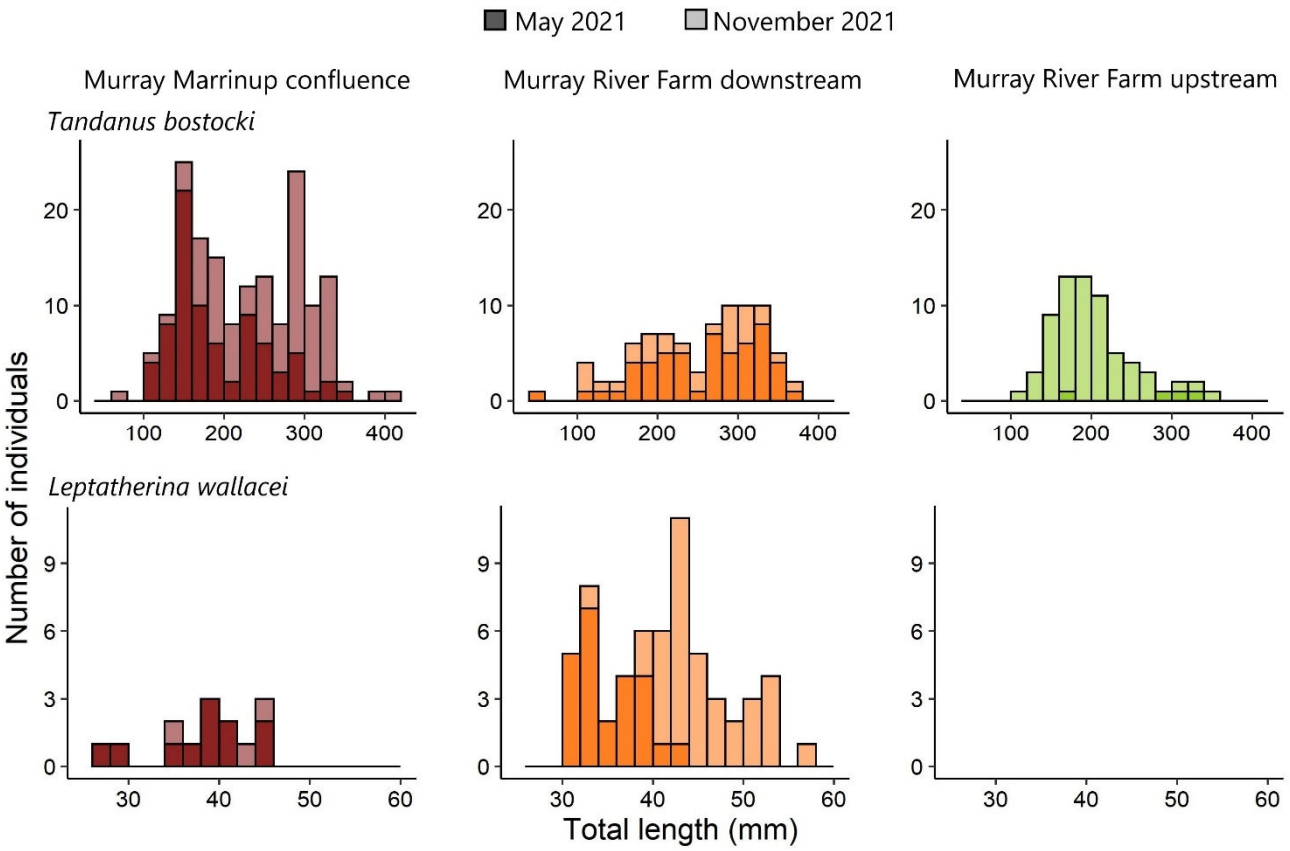

*Figure 9 Length-frequencies of Freshwater Cobbler (*T. bostocki*) and Western Hardyhead (*L. wallacei*) at the three sites in May and November 2021.*

Figure 10 (top to bottom): Juvenile Freshwater Cobbler at Marrinup Brook confluence in May 2021, eggs released from an adult Freshwater at Murray River Farm upstream in November 2021, and an Oblong Turtle being released at Marrinup Brook confluence.

Discharge trends and its influence on fauna

Streamflow data sourced from the DWER monitoring station at Baden Powell (station 614006) revealed that July and August streamflow in 2021 was well above the long term (1952-2021) average (Figure 11). This mostly contributed to a much greater annual discharge during 2021 compared to average (i.e. 408000 ML compared to a mean long term of ~251000 ML). By comparison, 2020 and 2019 were well below long term averages (Figure 11). While 2021 was unusually above average, there is an overall significant negative decline in annual discharge in the Murray River (Figure 12). Long-term projections for rainfall and streamflow are for ongoing declines throughout south-western Australia (Hope et al. 2015).

These ongoing flow declines will likely result in further reductions in recruitment to fish populations. This prediction is based on previous modelling that has demonstrated that the strength of spawning migrations of endemic freshwater fishes is positively associated with winter-spring discharge (Beatty et al. 2014). Rainfall decline projections due to climate change are projected to be most severe during the winter-spring periods in south-western Australia (Hope et al. 2015). Rainfall decline is also severely impacting the survival of stream invertebrates in this region (see Macroinvertebrate section) with many systems losing permanency causing the loss of populations (Carey et al. 2021). The long-term effects and interactions between declines in rainfall and discharge and secondary salinisation may be variable among south-western Australian catchments but will also likely be important in determining the long-term population viability of fish, crayfish and macroinvertebrates in the Murray River.

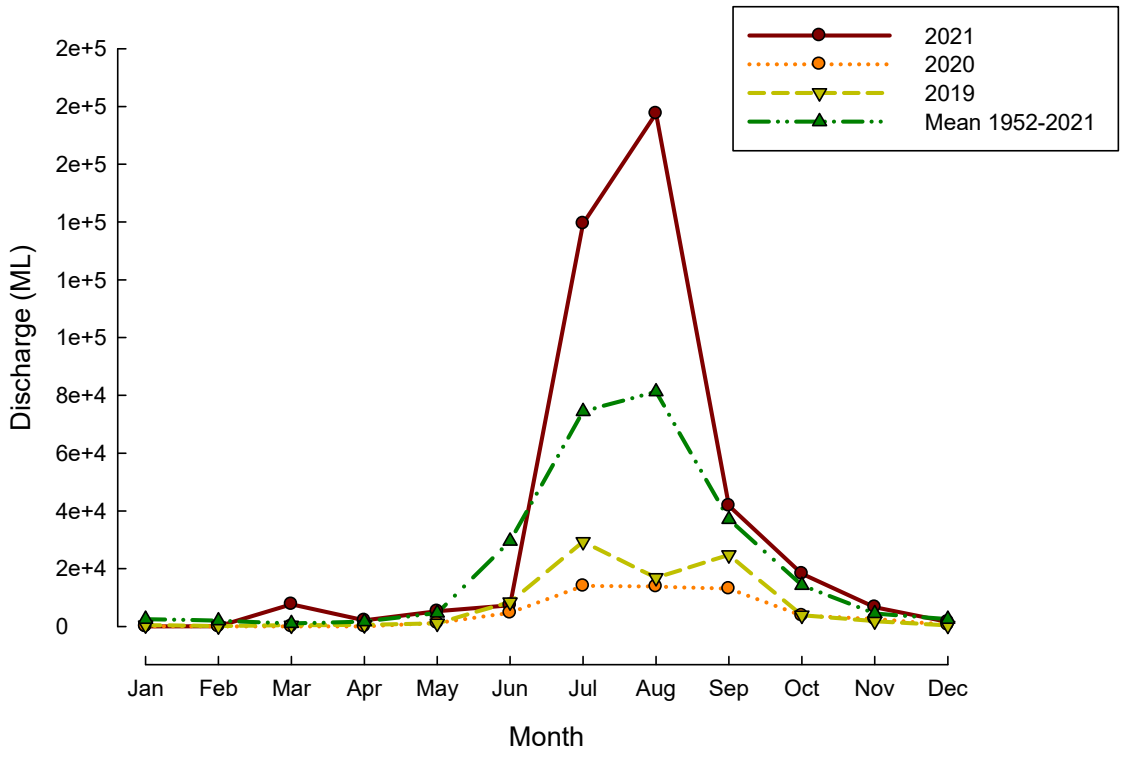

Figure 11 Total monthly discharge in 2021, 2020 and 2019 along with the long term mean monthly discharge in the Murray River (at Baden Powell). Data source DWER.

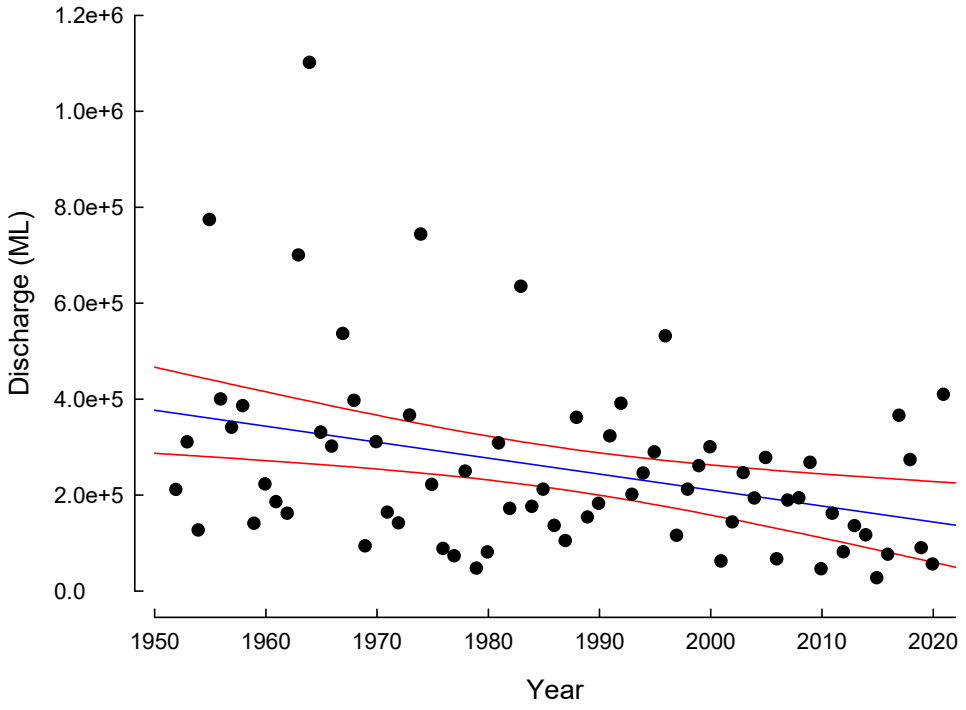

Figure 12 Long-term annual discharge in the Murray River (Baden Powell). N.B. Regression lines and 95% Cis are shown. Data source DWER.

Water quality and its influence on fauna

All sites were predictably warmer in November compared to May 2021 (Figure 13). Temperatures at Marrinup Confluence had the least amount of diurnal fluctuation of all sites, particularly in November (Figure 13). All sites were classified as saline (i.e. within the category 2-10 ppt, as defined by Mayer et al. 2005), however, all had reduced in salinity and conductivity by between ~20-30% in November compared with May 2021 (Figures 14, 15). This is typical of secondarily salinized rivers in south-western Australia due to the effects of flushing of salts that occur from the landscape over the winter-spring flow period.

The Murray River was undergoing a significantly positive increase in its long-term salinity based on the study by Mayer et al. (2005). This trend is likely having a major impact on the fish populations by favouring those more salt tolerant species over more sensitive freshwater fishes. It is likely that the elevated salinity is having a major impact on the survival, but more significantly, recruitment of juveniles of most freshwater fishes detected within the river. The Western Minnow *Galaxias occidentalis*, Western Pygmy Perch *Nannoperca vittata* and Nightfish *Bostockia porosa* were present in very low abundances (see Faunal Results). The acute salinity tolerances of the former two species have previously been determined in the laboratory, and the LC50 (effect concentration that causes 50% theoretical death) was ~14.6 ppt. While the salinity at the sites surveyed were much lower than this level, the effect of salinity on the eggs, larvae or juveniles of any south-western Australian fish has not yet been determined. Beatty et al. (2013) examined the conductivity ranges at sites where the various species had been recorded. It revealed the median

and 95th percentiles of conductivity for Western Minnow, Western Pygmy Perch and Nightfish were ~797 (95th = 9254), 600 (5940), and 685 (6872) µS.cm^{-1}. The Freshwater Cobbler had a higher median conductivity of ~3062 µS.cm^{-1}, and the latter species dominated the abundances of freshwater native species in the current sampling along with the typically estuarine Western Hardyhead *Leptatherina wallacei* (see Faunal Results). Conductivity at the sites in May 2021 ranged between ~7000-8500 (Figure 15), which therefore exceeded the 95th percentile values at sites where they were present for most of the freshwater species throughout their range in the south-west (Beatty et al., 2013). However, the Western Minnow is known to persist in some upstream salinized sections of rivers in the south-west, including the Hotham and Williams rivers (Morgan et al. 2003, 2005), which has been hypothesised to be due to its ability to move rapidly to more favourable habitats and/or greater tolerance of early life-history stages to salinity (Beatty et al. 2011). It was also recorded in high abundance in early spring downstream of the Pinjarra Weir (Beatty and Morgan, 2008). No evidence of juvenile fish recruitment was recorded for this species during the current study (only a single 0+ fish was recorded in May 2021 with a length of 58 mm TL)). This lack of recruitment and very low abundances of the species in the current study is thus somewhat surprising, and warrants additional investigation. Nightfish, while also in low abundance, did have slightly stronger evidence of some recruitment with at least three size-age cohorts being present including three juvenile fish in May 2021. Only two Western Pygmy Perch were recorded.

The water was well oxygenated at all sites in May 2021 (Figure 16), and while sensor malfunction precluded logging oxygen in November 2021, the oxygen levels would have likely have been similar given the increased flow rates during the times of sampling in November and lack of stratification in water column at all sites (pers observation). Thus, dissolved oxygen is not limiting the aquatic fauna at the sites being adequate to maintain the fishes and crayfishes present as they were well within the known field-based preferences of native fishes (Beatty et al. 2013).

The pH at all sites was slightly basic in May 2021 (being the lowest at ~7.5 at the Marrinup Brook Confluence). The pH had reduced to between 7.7-8.0 at the Murray Farm upstream site in November 2021 (Figure 17). These pH levels were at the upper levels of known field-based preferences of the native freshwater fishes (median values of 6.90—7.16), however, were still generally within the 95th percentiles of pH at their presence sites throughout the south-west (which ranged from 8.08 for Nightfish to 8.46 for Western Minnow) (Beatty et al., 2013). It is unlikely that elevated pH is significantly affecting the recruitment rates of the native fishes, however, the acute and sublethal effects of elevated pH native fishes requires further investigation.

In May and November 2021, the total N values were relatively consistent among the sites ranging between 0.53 mg/L at the Murray River Farm downstream site in November, up to 0.71 at the Marrinup Confluence site in that month (Table 3)). While the total Phosphorous was at undetectable levels in May 2021, it rose considerably at all sites in November, although was still well within the ANZECC (2000) guidelines for south-western Australian lowland rivers. In May 2021, no metals were at detectable levels at the Marrinup confluence site aside from total Iron (0.16 gm/L) (Table 4).

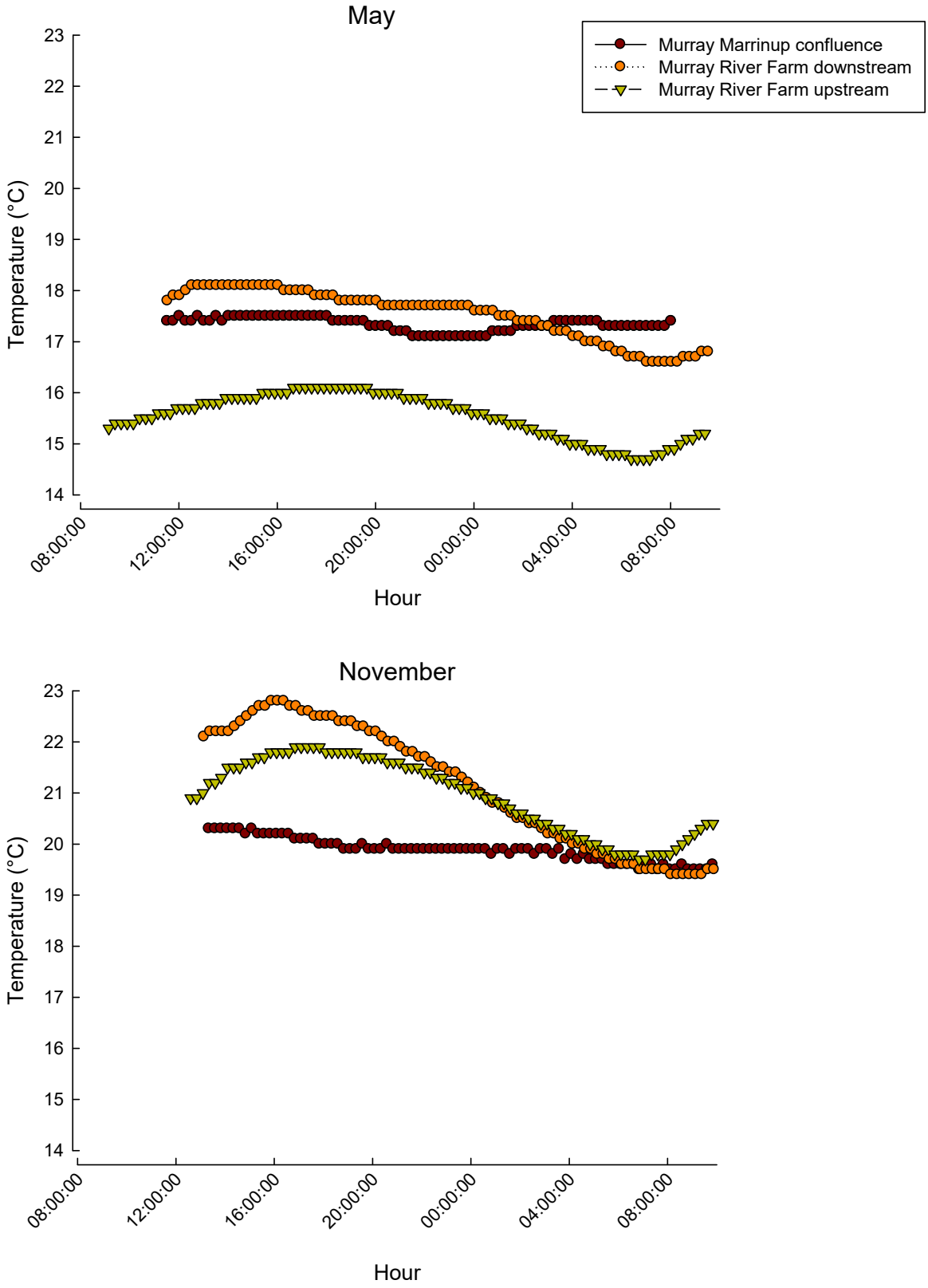

Figure 13 Temperatures logged every 15 minutes at each site in May 2021 (top) and November (bottom).

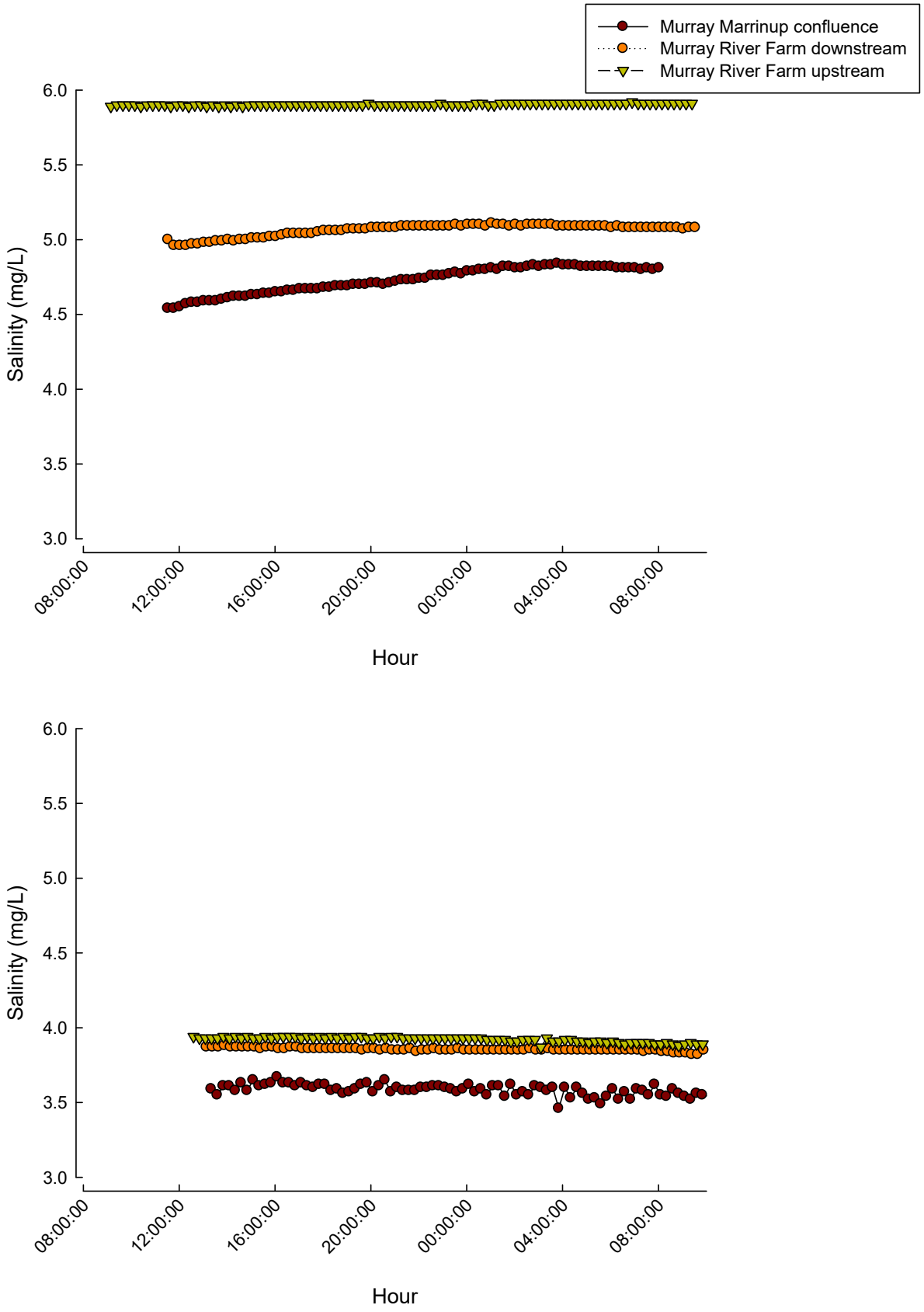

Figure 14 Salinity logged every 15 minutes at each site in May 2021 (top) and November (2022).

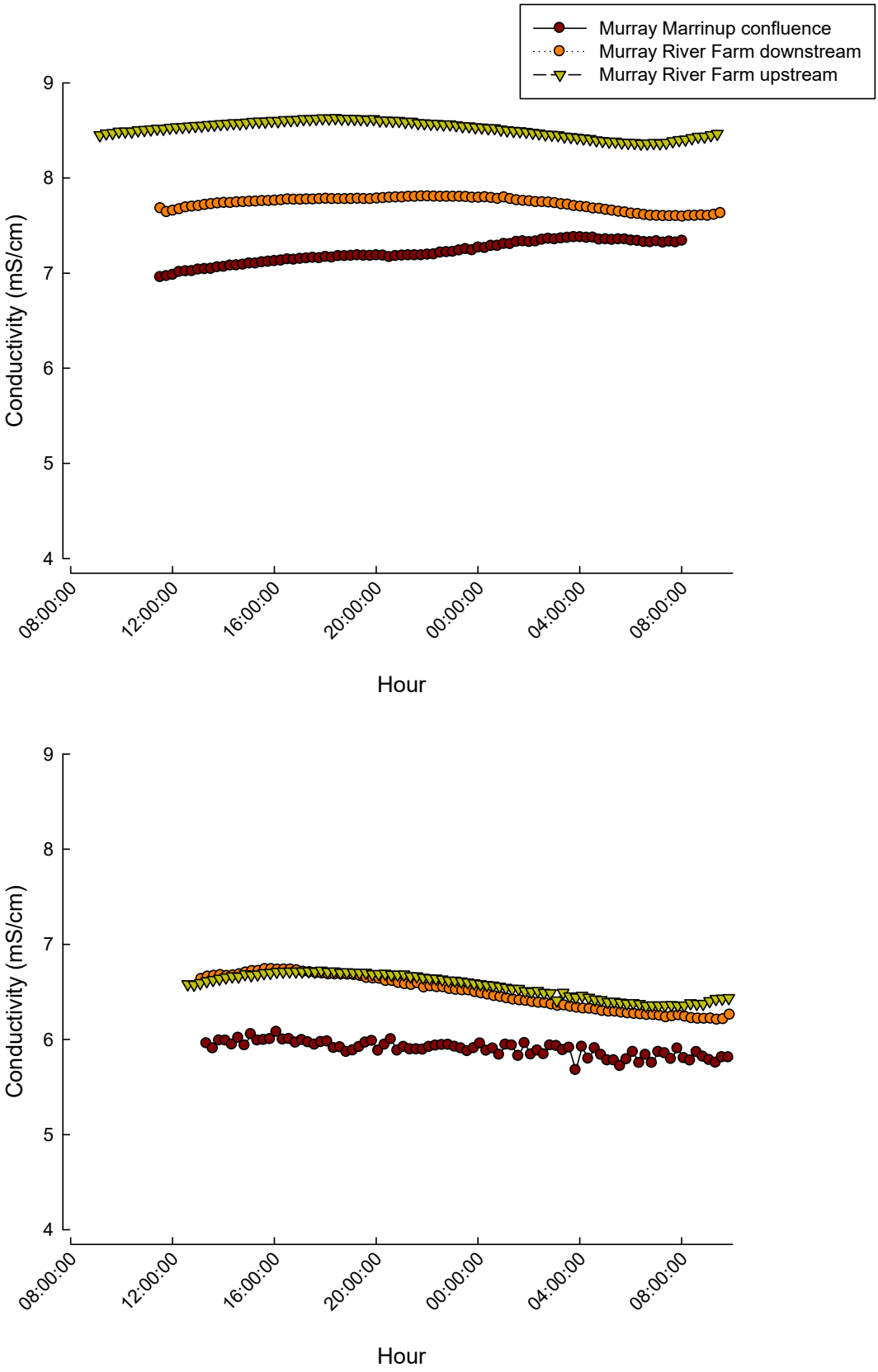

Figure 15 Conductivity logged every 15 minutes at each site in May 2021 (top) and November (2022).

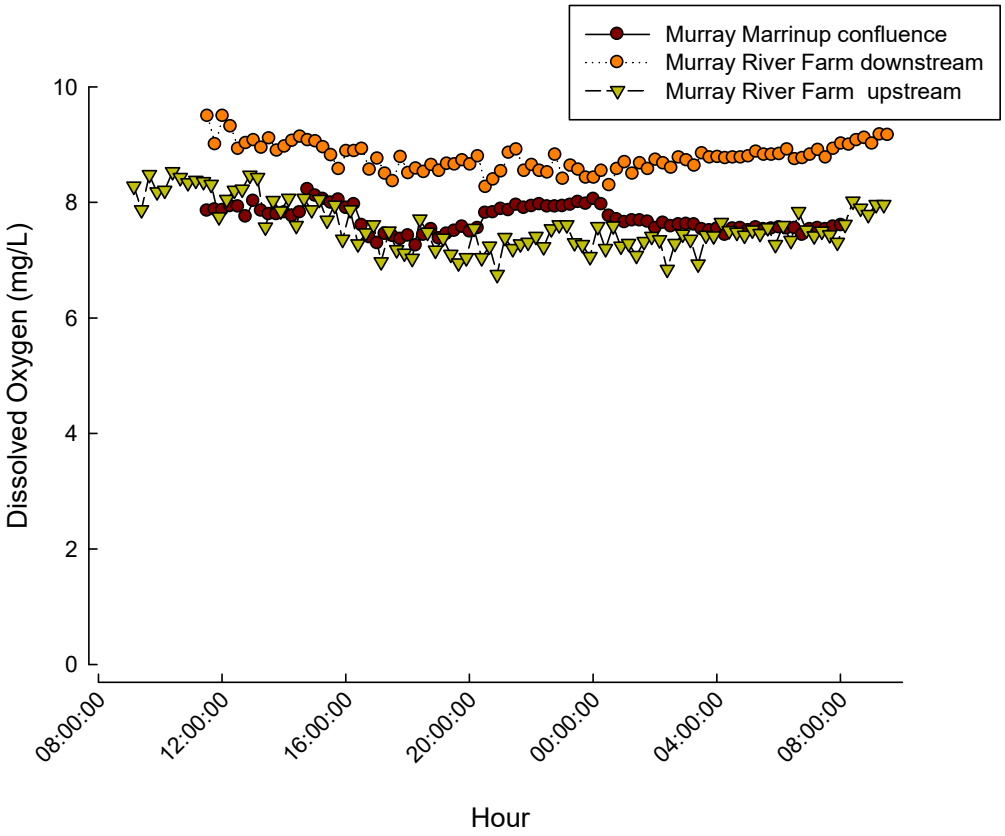

Figure 16 Dissolved oxygen logged every 15 minutes at each site in May 2021. N.B. sensor failure in November precluded presenting the dissolved oxygen from the sites during that month.

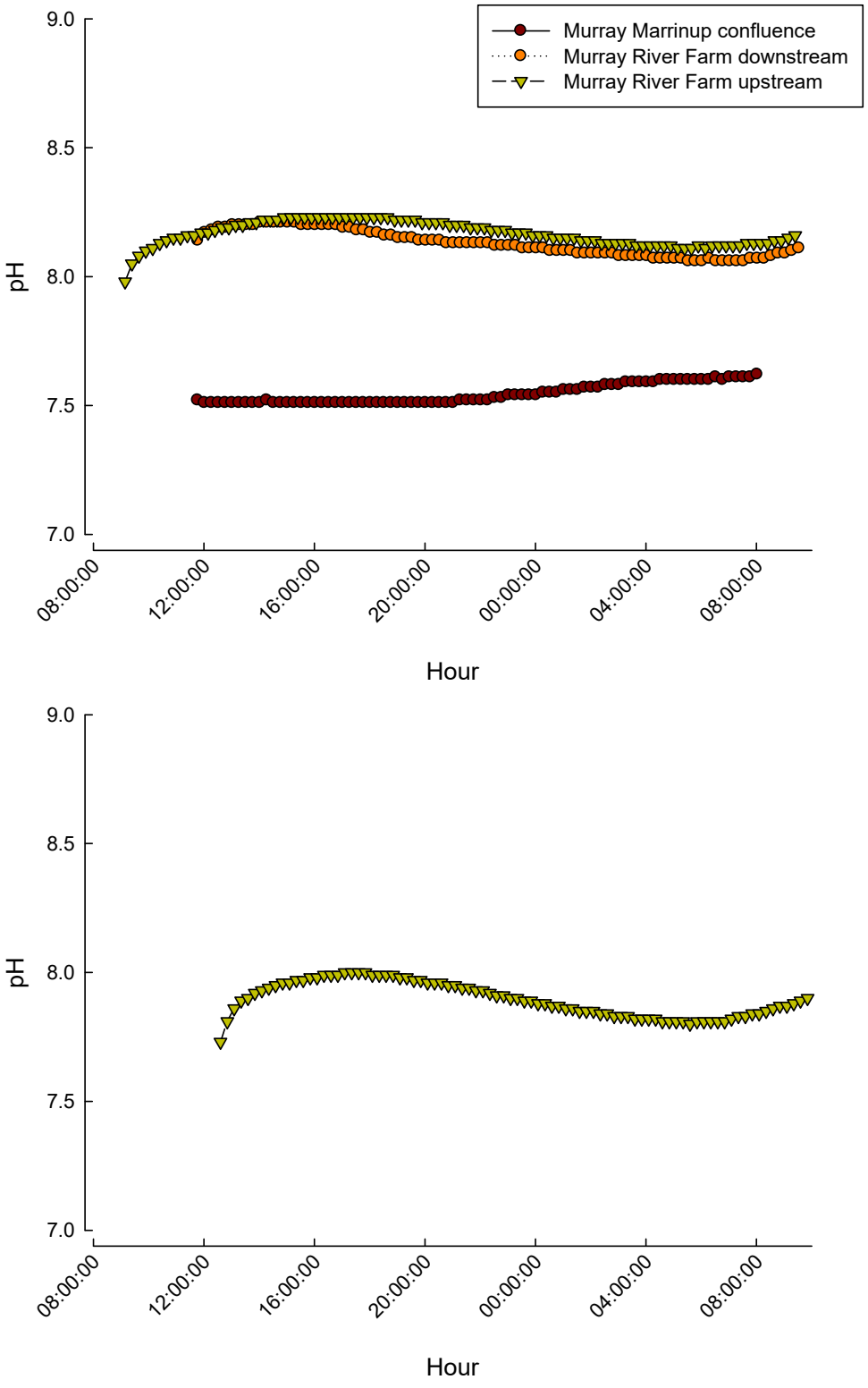

Figure 17 pH logged every 15 minutes at each site in May 2021 (top) and November (bottom). N.B. sensor failure in November precluded presenting Marrinup and Murray Farm downstream during that month.

Table 3 Water quality analysis from sites sampled in the Murray River in May and November 2021 with 95% species protection also provided (ANZG, 2018). N.B. those guidelines are for the dissolved fraction of nutrients and the reported values below are the total

	Limits of reporting (mg/L)	Murray Marrinup Brook confluence	Murray River Farm downstream	Murray River Farm upstream	ANZG (2018) 95%
May 2021					
N_total mg/l	*0.025/0.01*	0.6	0.58	0.6	1.2*
P_total mg/l	*0.005*	<0.005	<0.005	<0.005	0.06*
Turbidity NTU	*0.5*	0.8	<0.5	1	
November 2021					
N_total mg/l	*0.025/0.01*	0.71	0.53	0.55	1.2*
P_total mg/l	*0.005*	0.018	0.018	0.016	0.06*

Table 4 Heavy metal analyses for sites sampled in the Marrinup Brook confluence site in May 2021 with 95% species protection also provided (ANZG, 2018). N.B. those guidelines are for the dissolved fraction of metals and the reported values below are the total a

	Limits of reporting (mg/L)	Murray Marrinup Brook confluence	ANZG (2018) 95%
As_total mg/l	*0.001*	<0.001	0.0024 (95%)
Cd_total mg/l	*0.0001*	<0.0001	0.0002 (95%)
Cr_total mg/l	*0.001*	<0.001	0.001 (95%)
Cu_total mg/l	*0.001*	<0.001	0.0014 (95%)
Fe_total mg/l	*0.01*	0.16	-
Hg_total mg/l	*0.0001*	<0.0001	0.0006 (95%)
Ni_total mg/l	*0.001*	<0.001	0.011 (95%)
Pb_total mg/l	*0.0005*	<0.0005	0.0034 (95%)
Se_total mg/l	*0.001*	<0.001	-
Zn_total mg/l	*0.005*	<0.005	0.008 (95%)

Macroinvertebrates

Thirty-four macroinvertebrate taxa were recorded across May and November 2021 (Table 5). Total richness per site (combined across the two sweeps conducted on each occasion at each site) ranged from three taxa at the Murray River Farm in May 21 to 23 at the Marrinup Brook confluence in November 2021 (Table 5). Predictably for a south-western Australian aquatic system, overall richness in November (Spring) was significantly ($p<0.05$) higher than in May (autumn) 2021.

The most common and abundant family was the Palaemonidae due to the high abundance of *Palaemon australis* (South-western Glass Shrimp) with Chironomidae (midges), Caenidae (mayflies), and several families (i.e. Hydropsychidae, Leptoceridae, and Lymnaeidae) of Trichopterans (caddisflies) also common and abundant particularly in spring.

While relatively depauperate in terms of overall richness, particularly in May, two of the three pollution sensitive EPT Orders (Ephemeroptera (mayflies) and Trichoptera (caddisflies)) were present at all sites with Cainidae recorded in both seasons (aside from Marrinup confluence in May) and a total of eight trichopteran families present across the sites and seasons.

AUSRIVAS scores calculated for the November 2021 survey (in line with SWIRC protocols that use the Western Australia Spring Channel model) suggested that the sites were considerably impaired with OE50 (observed to expected ratios being <0.5 for all sites corresponding to Bands C or D, representing Severely Impaired or Extremely Impaired, respectively) (Table 6).

In south-western Australia, the climatic drying is having a severe impact on macroinvertebrates within lotic systems, with many that were permanent now seasonally drying, previously seasonally flowing systems permanently dry; causing the loss of invertebrate populations (Carey et al. 2021). Moreover, the interaction of drying and salinity in lakes is also causing declines in diversity with the effect of salinity on diversity caused by crossing (tolerance) thresholds rather than having a linear relationship (Pinder et al., 2005; Atkinson et al. 2021). It is likely that past increases salinity in the Murray River would have had a negative effect on the diversity of macroinvertebrates. The AUSRIVAS Bands from the O/E scores were generally lower than were that was recorded by Beatty et al. (2021) in the fresh lower Serpentine River. Ongoing flow declines will exacerbate these effects and thus protection and restoration of riparian habitats, to create diverse aquatic habitats, is recommended to help offset some of this loss of diversity.

Table 5 Macroinvertebrate abundances in the Murray River in May 2021 and November 2021.

		May 2021			Nov 2021		
		Marrinup conf.	Murray D/S	Murray U/S	Marrinup conf.	Murray D/S	Murray U/S
Order	**Family**						
Amphipoda	Ceinidae	1			7	84	25
Anthomedusae	Hydridae				1		
Araneae	Pisauridae				2	1	
Coleoptera	Curculionidae					4	2
	Dytiscidae					3	1
	Gyrinidae				1	1	1
	Hydraenidae						1
	Hydrophilidae				2	3	3
Decapoda	Palaemonidae	64	8	8	51	133	9
	Parastacidae					2	
Diptera	Ceratopogionidae				2	1	
	Chironomidae	5		5	257	62	471
	Culicidae				3	3	24
	Ephydridae						1
	Psychodidae	1					
	Simulidae				4	156	8
Ephemeroptera	Caenidae		3	14	26	28	73
Haplotaxida	Naididae				1	2	2
	Tubificidae				3	2	
Hemiptera	Corixidae						33
Lepidoptera	Crambidae	1					
Odonata	Aeshnidae			2	1	2	
Podocopida	Cyprididae				1	2	52
Symphypleona	Sminthurididae	1			3	1	
Trichoptera	Ecnomidae			2	1		
	Hydrophilidae	2					

	Hydropsychidae				9	556	7
	Hydroptilidae				1	16	
	Leptoceridae	1		5	11	24	24
	Lymnaeidae				55	16	11
	Physidae				1		27
	Planorbidae		1	1			
Nymph (Un-ID)					6		3
TOTAL RICHNESS	**34**	**8**	**3**	**7**	**23**	**22**	**20**

Table 6 AUSRIVAS macroinvertebrate modelling (W.A. spring channel model). N.B. NTE50=sum of the probabilities of all the families predicted with >50% change of occurrence, NTP50=count of number of families predicted with >50% probability of occurrence, NTC50=number of families that were predicted (above probability of 50%) that were also collected, OE50= observed to expected ratio (i.e. NTC50/NTE50), E50Signal=expected signal score for taxa having probability of occurrence >50%, O50Signal=average signal score for observed taxa that had a probability of occurrence >50%, OE50=observed to expected signal ratio (i.e. O50Signal/E50Signal), E0Signal=same as E50Signal but all taxa with probability >0% included in calculation, O0Signal=average signal score for all observed taxa, OE0Signal=observed to expected Signal ratio (i.e. O0Signal/E0Signal).

Site	NTE50	NTP50	NTC50	OE50		E50Signal	O50Signal	OE50Signal	E0Signal	O0Signal	OE0Signal	Band
Marrinup Confluence	9.93	12	2	0.2		4.56	4.5	0.99	4.37	3.53	0.81	D
Murray River Farm Downstream	12.55	16	6	0.48		4.58	3.83	0.84	4.48	3.47	0.78	C
Murray River Farm Upstream	12.03	15	3	0.25		4.62	3.67	0.79	4.49	3.13	0.7	C

Vegetation assessment

The vegetation assessment was undertaken at each site in line with the RHAs protocols with additional more comprehensive mapping of species undertaken. This was conducted by Heather Adamson and the report and vegetation maps are provided in Appendix 1.

Summary and recommendations

There was generally a diverse range of aquatic habitats at the sites that are favoured by aquatic fauna. Riparian vegetation generally showed a good representation of native flora that was in relatively good health; however, several species of weeds were present at all sites. The fencing from stock at the downstream two sites would be having a positive effect on the riparian zone, with the rocky geomorphology of the Murray River Farm upstream site likely partially mitigating the impacts of stock access.

The secondary salinisation of the main channel of the Murray River has undoubtedly had a negative impact on the aquatic fauna. The system continues to support self-maintaining populations of Freshwater Cobbler and Western Hardyhead. No obvious changes in fish and crayfish fauna had occurred at the Marrinup Brook site between the December 2017 (Heald et al. 2018a) survey and the current 2021 surveys.

The lethal tolerances of adults of three endemic south-western Australian freshwater fishes have been determined in the laboratory (see Beatty et al. 2011), however, the sub-lethal effects salinity on these species have not been determined nor have the tolerances of early life-history stages such as eggs and larvae. These are likely to be much more sensitive to elevated salinity explaining the lack of recruitment in the main channel of salinised rivers (see Beatty et al. 2011). However, the very low abundance of the Western Minnow was particularly surprising in the sites surveyed. The species is prevalent in the upper reaches of the Murray River catchment being recorded in salinities up to 24.1 ppt (well above those in the current survey sites) (Morgan and Beatty, 2003). The very low abundance of the species in the lower Murray River requires additional investigation.

The very low abundances of Eastern Gambusia during the survey was also unusual. The species is highly tolerant of elevated salinity and is found in very high abundances in the upper catchment (Morgan and Beatty, 2004). Low abundances may be associated with the timing of the surveys being outside of its peak abundance period (i.e. late summer/early autumn), however, it would still have been expected to be found in higher abundances than were detected; noting too that the species was not detected in December 2017 at the Marrinup Brook Confluence site.

The macroinvertebrate fauna was also largely indicative of an impaired system; although continued to house a range of sensitive families; particularly caddisflies.

The effect of salinisation in the Murray is similar to that in other salinized rivers such as the Blackwood, which is generally dominated by the same fish species as the Murray River (Morgan et al., 2003; Beatty et al. 2014). In the Blackwood, it is the freshwater tributaries that are crucial in maintaining the salt-sensitive species such as Western Pygmy Perch, Nightfish and threatened Western Mud Minnow (*Galaxiella munda*) and Balston's Pygmy Perch (*Nannotherina balstoni*). The

marginal-brackish Buchanan's Drain Wetland (MR261BUCH1) was surveyed in 2017 by DWER who only recorded Western Pygmy Perch, Bluespot Goby and Gilgies and found the site to be dominated by introduced Goldfish, Eastern Gambusia and One-spot Livebearer (Heald et al., 2018b). However, that system is highly modified and seasonally dries to a series of small pools. It likely that larger fresh tributaries, particularly the Dandalup River, would house the greatest abundances of small-bodied native fishes and thus be critical in maintaining populations in the lower Murray River.

While the annual discharge in 2021 was well above the long-term average in the Murray River, the preceding two years were well below average. As the spawning migration of native freshwater fishes is positively associated with the amount of discharge during the winter-spring period (Beatty et al. 2014), this may have also contributed to the very low abundances of freshwater fishes aside from the Freshwater Cobbler.

The compounding effects of salinisation and flow declines along with riparian degradation are the largest threats to the aquatic ecosystems in the Murray River. Continuing to support programs that help address these are critical. Ongoing revegetation programs in the upper catchment of the Murray River to help address secondary salinisation is recommended in order to help reduce the long-term increase in salinity. Riparian restoration and protection programs throughout the river system will also enhance the aquatic habitats and could help to offset the impact of salinisation, temperature increases and flow declines. It is also recommended that distributional surveys for fish, crayfish and macroinvertebrates occur in the fresh tributaries of the Murray River to help prioritise restoration activities. Indeed, the first documented project to reintroduce large woody debris in south-western Australian rivers was conducted in the Dandalup River (Davies, 1999). This demonstrated an increase in both fish and macroinvertebrate richness at those sites after wood was introduced. This demonstrates that the active restoration activities can prove beneficial to these aquatic ecosystems.

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Appendix 1

Vegetation Assessment of the Murray River sites

Data compiled by Heather H Adamson (Ex *Land For Wildlife* Field Officer 17yrs DBCA, now on contract with PHCC).

Scope

Survey all existing vegetation at the River Health Assessment sites: two sites on the Murray River Farm (Wyllie Group) property and the Marrinup Brook Confluence site. Murray River Farm upstream site surveyed 1/6/21.

Methods

Walking and noting species within a 100mt stretch following the river verge and up-land of around 50mts wide or less, before merging into grazing land (not included). Native and Introduced species were recorded including Fungi species. Incorporated this data onto a Mud Map as they appeared, during the survey. Total time at each site ~3 hours.

Results

Marrinup Brook confluence

May 2021

21+ *Introduced Species

7 Native Species including a **TF** species

TF (Threatened Flora) *Grevillea manglesii ssp ornithopoda* **P2 (Priority 2)** Two plants noticed est. height 2mts, very healthy, near fenceline

Native Vegetation: *Eucalyptus rudis* and *Melaleuca rhaphiophylla* dominant. Healthy, regeneration moderate, seed supply good, pollinators present, Logs and dead trees providing hollows/habitat. Canopies touching providing permanent shade for the river below. Lacking rushes and sedges only a plant of *Juncus kraussii* noticed.

Weed Species: 8+ Pastoral grasses recorded, several dense and preventing bank erosion.

My Priority for removal would be - **Dysphania ambrosioides, *Gomphocarpus fruticosus, *Cypreus tenuiflorus, *Conyza parva, *Oxalis sp *O. glabra, *O. pes-caprae, *Watsonia*

November 2021

Good reduction in most weed species since spraying although a few **Dysphania ambrosioides* (Mexican tea) are emerging in floodway. No sign of *Cottonbush

Dominant weed species: * Kikuyu and *Veldgrass

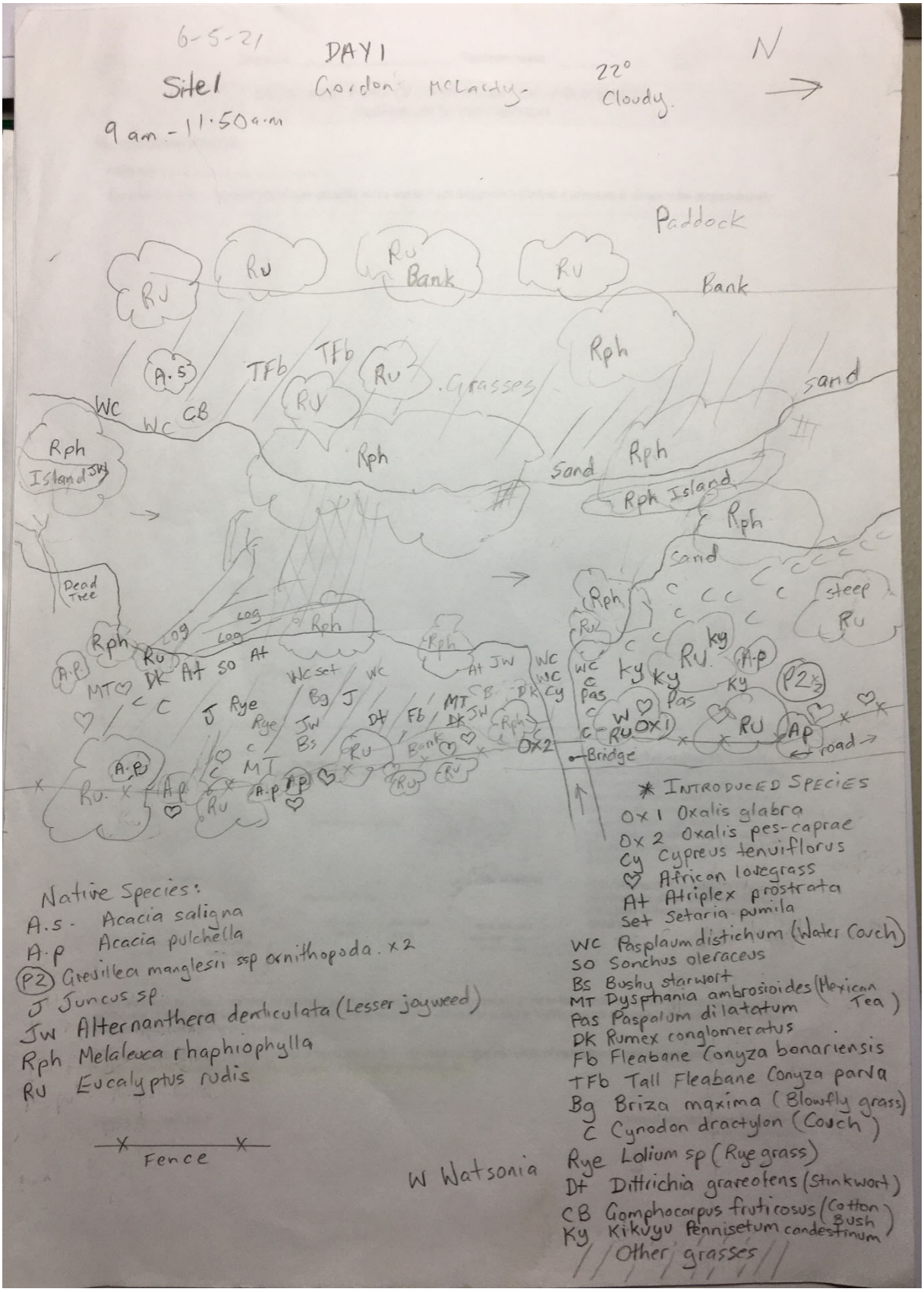
Native Species:

Juncus kraussii didn't survive the weed control

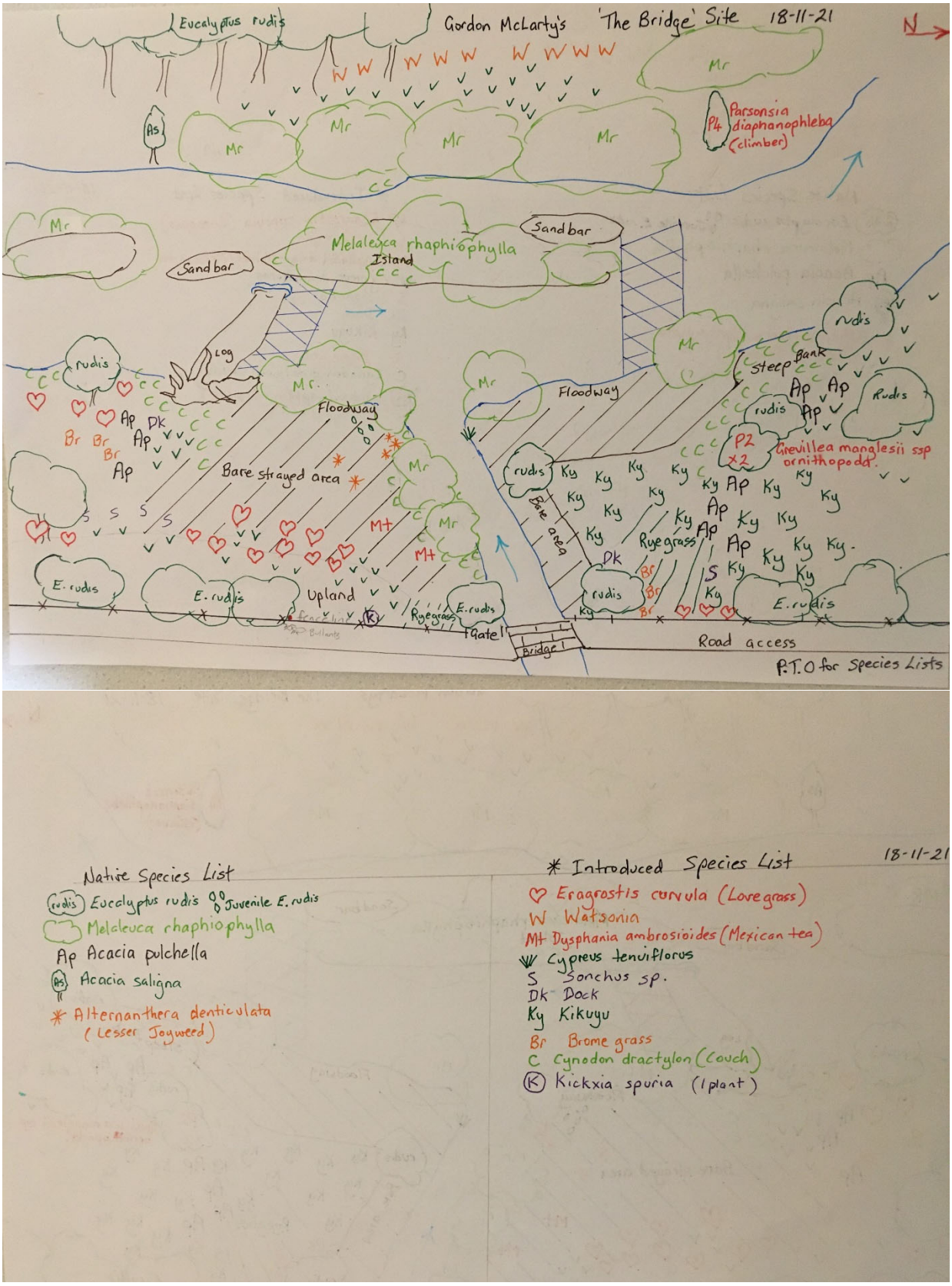
***Grevillea manglesii ssp ornithopoda* P2** two large shrubs are very healthy and in full flower

***Parsonsia diaphanophleba* P4** One plant recorded on the opposite bank – very healthy

Refer to Mud Map



Marrinup Brook Confluence site vegetation map in May 2021.



Marrinup Brook Confluence site vegetation map in November 2021.

Murray River Farm downstream

May 2021

13 *Introduced Species

11 Native species including a **TF** species

TF (Threatened Flora) *Parsonsia diaphanophleba* **P4** Three climbing plants in full flower on the opposite bank very healthy and attracting numerous butterfly species.

Native Vegetation: Fairly open area with *Eucalyptus rudis* and mixed *Myrtaceae* shrubs dominant. Generally vegetation is healthy, some regen, seed supply ok, providing some habitat and shade, numerous small birds heard.

Weed Species: Dominant areas of sprayed dead grasses – (possibly *Wildoats & *Veldt grass) and *Cotton bush, right to the water edge, emergent grass weeds present *Blackberry and Arum lily on the increase.

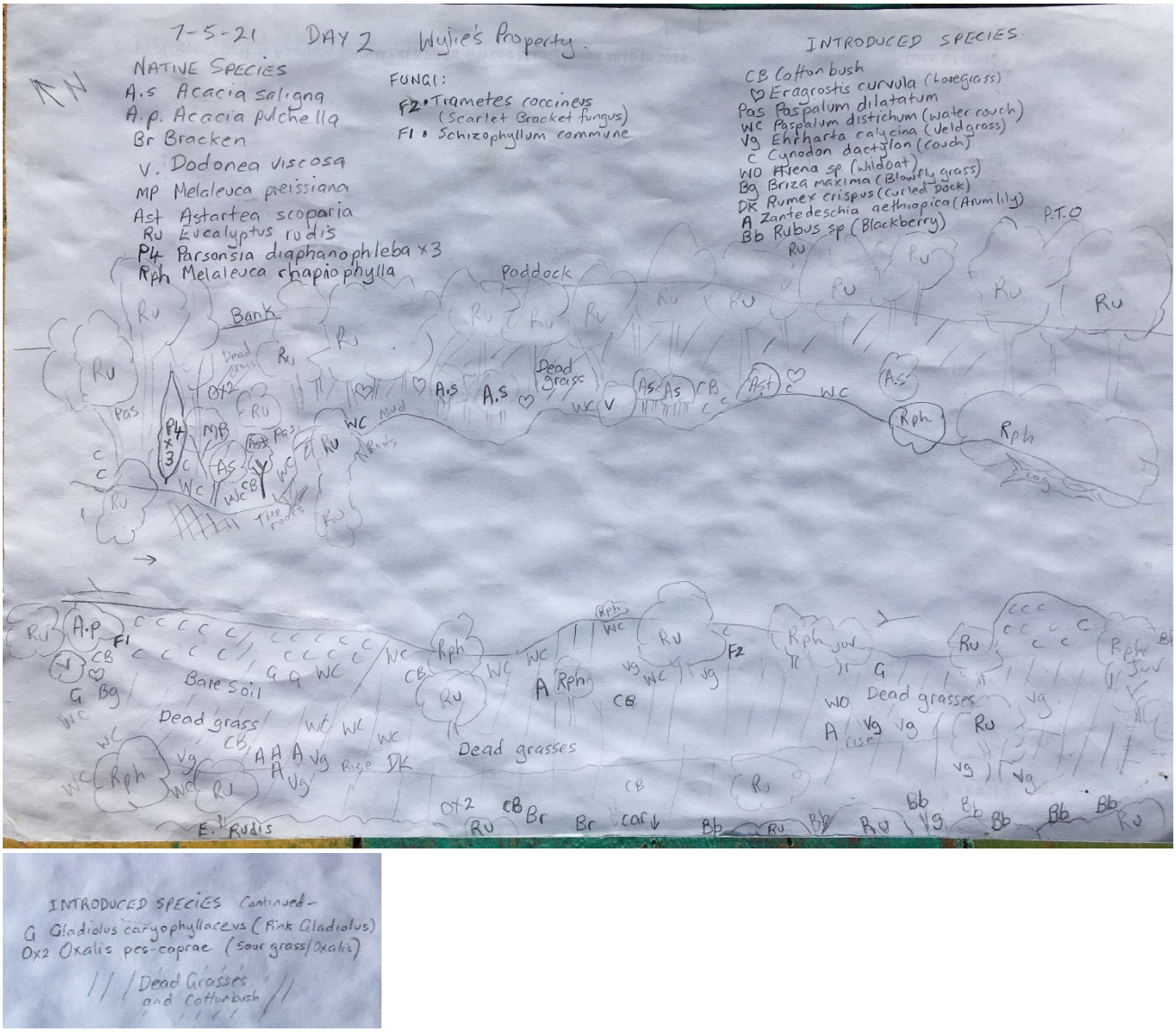
November 2021

Large bare patchy areas baring patches of grassy weeds mostly * *Ehrharta longiflora* (Annual veldgrass), **Lysimachia arvensis* (Pimpernel) and **emerging *Cottonbush**. Scattered plants of ***Arum lily** in flower – (less than 20 plants present)

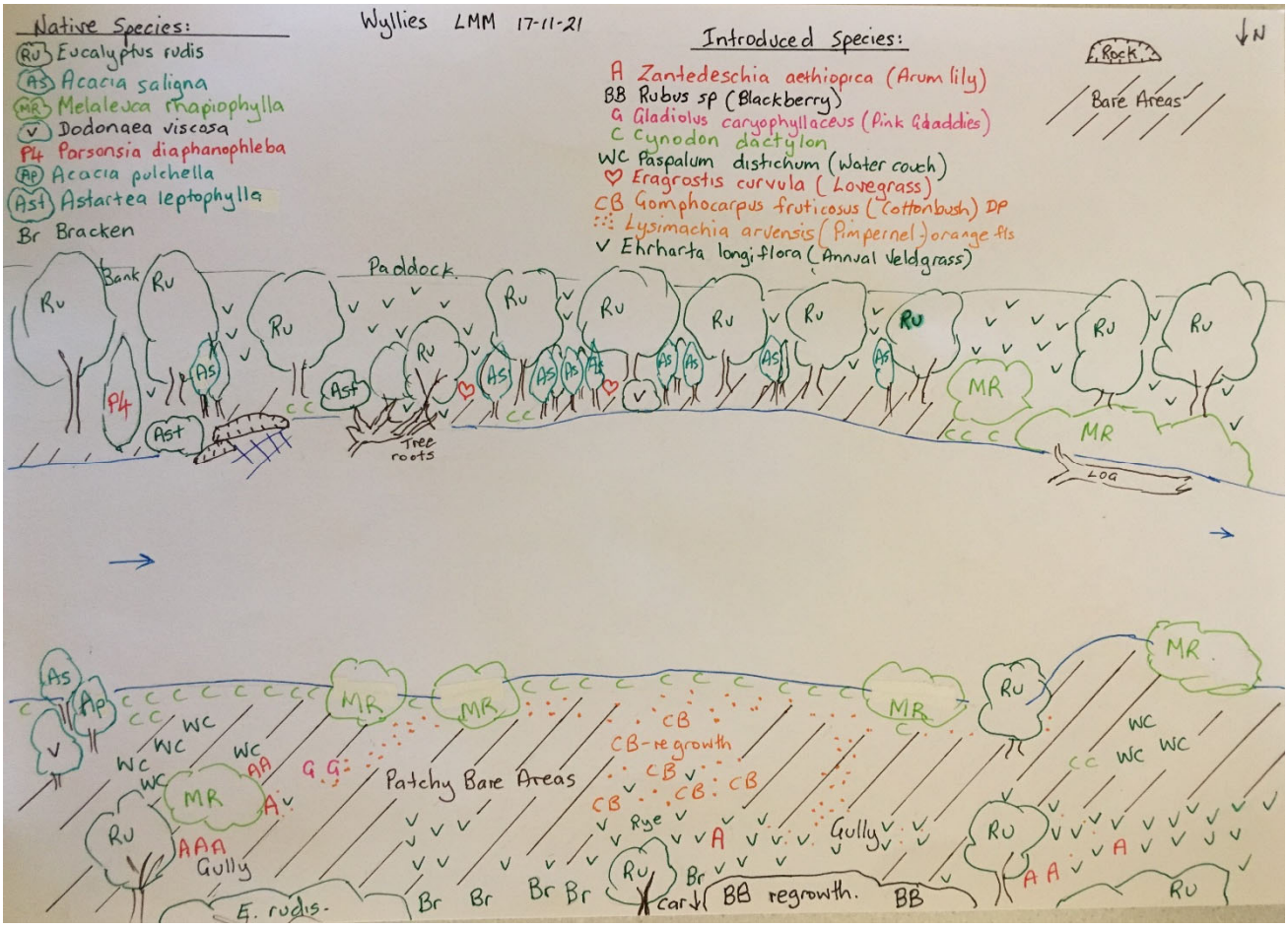
Blackberries have put on a healthy growth rate along upland slopes as the river flooded to their level this year. Recommend re-spraying the site this summer

Native Species: On the opposite bank, ***Parsonsia diaphanophleba* P4 Priority 4 species –** has climbed robustly up its support species, looks very healthy and is spreading along the ground in need of somewhere to climb next, almost reaching the waters edge. Possibly 2 or 3 plants here together. Main threat would be Blackberry infestation.

One *Dodonaea viscosa* and 2 or 3 *Astartea leptophylla* have died along the riparian zone, not sure if they were sprayed or if it was water inundation due to flooding



Murray River Farm downstream site vegetation map in May 2021.



Murray River Farm downstream site vegetation map in November 2021.

Murray River Farm upstream

May 2021

22 *Introduced Species

15 Native Species

Good representation of **native flora** *Eucalyptus rudis*, *Melaleuca rhaphiophylla* and *M. lateritia* dominant. All vegetation looks healthy, some flowering, seed production good, pollinators present, Rock fern and *Stypandra glauca* present. Lots of moss and lichen on the larger rocks. Good habitat area.

Weed Species: *Arum lily and *Bridal creeper moderate to heavy regrowth - cause for concern.

1 Fig tree & 2 Olive trees control while still young. **Stachys arvevsis* (Stagger weed) toxic to horses just starting to flower. Gladiolus bulbs sparsely spreading. 1 plant of Apple of Sodom **DP**

November 2021

Spraying that had been applied to control Arum lilies, Cottonbush, Apple of Sodom and Blackberry would estimate 85% successful with a few Blackberry plants re- appearing in the same location and 12+ Arum lily plants noticed some in flower and not all in the sprayed area. Recommend re-spraying surviving Arums and Blackberries. No Cottonbush or Apple of Sodom plants were recorded

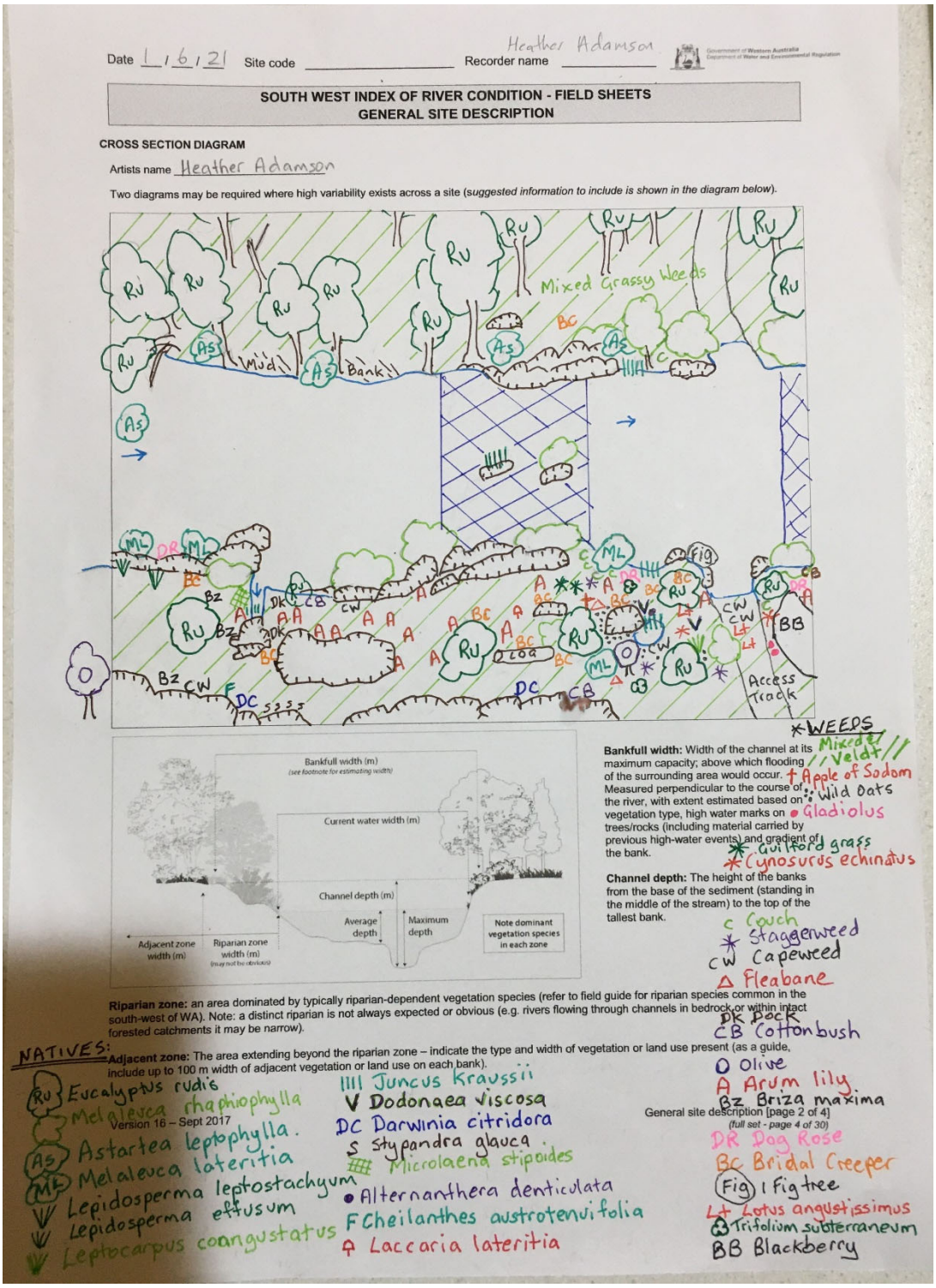
Sprayed area – looking upstream

* Fig tree at the River crossing

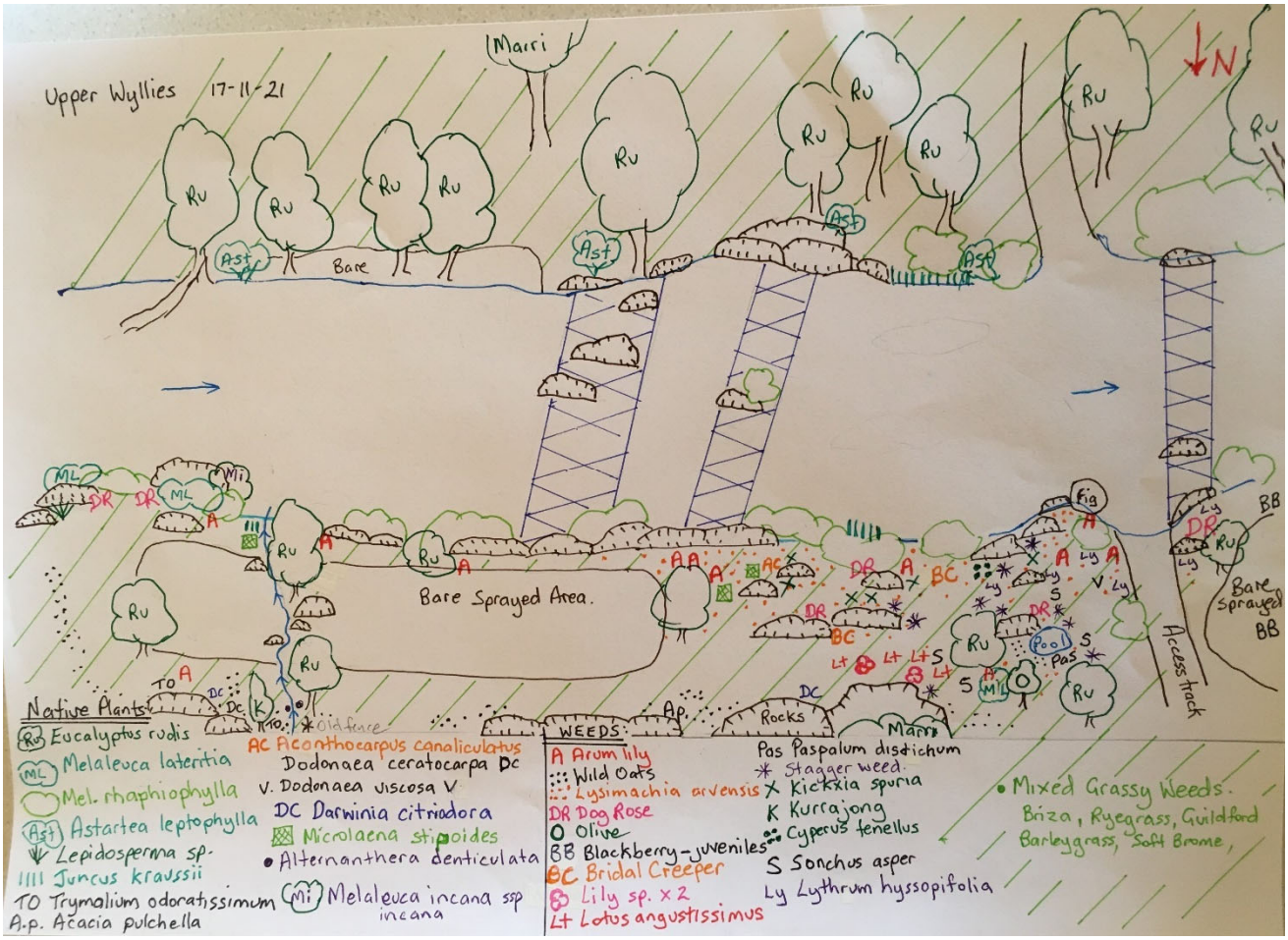
New weed species to the site are **Kickxia spuria* and **Lysimachia arvensis.* Dominant weed species is **Lolium perenne* (Perennial ryegrass) **Other Weeds of Concern:** Bridal Creeper several juvenile plants noticed, the **Rosa canina* (Dog Rose) numerous large established shrubs, the young Fig tree and two Olive trees

Native species: New to the site is *Acanthocarpus canaliculatus*. Three that I didn't record last time are *Trymalium odoratissimum, Melaleuca incana ssp incana*, *Dodonaea ceratocarpa* and a correction *Astartea scoparia* should read *Astartea leptophylla.* The native grass *Microlaena stipoides* has increased

Refer to my: Upper Murray **Mud Map** for more details



Murray River Farm upstream site vegetation map in May 2021.



Murray River Farm upstream site vegetation map in November 2021.