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Optimising frog breeding responses to flooding in managed wetlands (ii) *frog distributions through the Murray Floodplain*

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Optimising frog breeding responses to flooding in managed wetlands *(ii) frog distributions through the Murray Floodplain*

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Barking Marsh Frog (*Limnodynastes fletcheri*) metamorph, Euston.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Frog communities were surveyed along the Murray River corridor from the Hume Dam to the New South Wales/South Australia border between August 2008 and January 2010. The aim of the study is to investigate species occupancy patterns with respect to variation in wetland biophysical conditions and hydrology. A total of ten frog species were recorded, two of these, *Litoria raniformis* and *Crinia Sloanei* are listed under the Environment Protection and Biodiversity Conservation Act 1999.

Wetland habitats were grouped into three broad hydrological classes,; permanent, long hydroperiod (5-9 months) and temporary waterbodies (2-3 months). Frog communities differed significantly between the three hydrological classes - long hydroperiod waters contained the highest species richness and were more likely to support listed species than either permanent or temporary wetlands. Occupancy patterns were modeled in relation to the measured biophysical habitat parameters (water quality, vegetation and hydrology) for seven species using logistic regression. Individual species differed in their sensitivity to the measured habitat parameters and overall measures of physical habitat such as vegetation complexity and hydrology were better predictors of occupancy than water quality. The interaction between wetland hydrology and aquatic vegetation diversity was also important for many species. Importantly maintaining a higher diversity of aquatic vegetation increased the probability of occupancy within permanent waterbodies, but was less important within long hydroperiod and temporary wetlands.

Despite the prolonged dry period, wetlands of the Murray River Floodplain still have the potential to support a high diversity of frog species, however much of this diversity is confined to seasonally flooded wetlands with a long hydroperiod, which typically received environmental flooding

1.0 INTRODUCTION

The Murray catchment management area supports 24 frog species, 14 of which occur downstream of the Hume Dam. However records of individual species are sparse and are underrepresented compared to other regions, for example there are 2635 individual records for frog species in the Murrumbidgee CMA region and just 734 in the larger Murray CMA region (NSW ALTAS database, 2010). The occupancy patterns of frogs within floodplain wetlands along the Murray River is also poorly described, with the exception being the Barmah-Milawa forest which was monitored between 2000 and 2004 (Ward 2004). This lack of information on species distributions has made it difficult to predict the impacts of altered wetland flooding regimes on frog communities, assess the extent of change in frog communities across the catchment or to predict outcomes of environmental flooding in terms of frog responses.

The distribution of frogs across wetland systems can be influenced by a range of environmental factors, most notably hydrological regime (Babbitt, Baber *et al.* 2009; Egan and Paton 2004; Gomez-Rodriguez, Diaz-Paniagua *et al.* 2009), aquatic and fringing vegetation (Hazell, Cunnningham *et al.* 2001; Mac Nally, Horrocks *et al.* 2009), the distribution of predators and exotic fish (Baber and Babbitt 2003; Denoel, Dzukic *et al.* 2005; Pearl, Adams *et al.* 2005). Wetland hydroperiod, in particular can be a key driver of frog distributions, both directly by determining the length of time that tadpoles have to reach metamorphoses and indirectly by influencing aquatic vegetation communities (Casanova and Brock 2000; Warwick and Brock 2003), and fish densities (Adams 2000; Pearl, Adams *et al.* 2005).

Many frogs are relatively mobile during flood periods (Smith and Green 2006). In floodplain wetland systems some species will move between wetlands to take advantage of newly created habitats or to refuge during dry periods (Wassens 2010). Permanent waterbodies may be used as refuge habitats during dry periods, but may not necessarily support frog breeding due to their high predator densities (Wassens and Maher 2010). Rain-fed wetlands can support breeding by species with short developmental durations (Bulger, Scott *et al.* 2003) while seasonally or intermittently flooded, large wetland systems often have longer hydroperiods and may therefore be critical for breeding by species with longer development times (Wassens, Hall *et al.* 2010; Wassens and Maher 2010).

Regulation of the Murray River system has lead to significant changes in wetland hydrology and subsequent changes in the patterns of habitat use and occupancy is likely to have occurred. River regulation has led to decreases in the frequency of large flood events, reduced seasonal flooding and in other cases increased wetland permanence due to high flows during irrigation season (Walker and Thoms 1993). More recently, extended drought has led to extensive drying of riverine wetlands within the Murray River (Ganf, White *et al.*

2010). Over the last decade the hydrological regimes of wetlands have become more dichotomous, where; permanent and temporary rain-fed wetlands remain relatively widespread while seasonally flooded habitats are restricted to locations under environmental flooding management.

The extent to which these hydrological changes have contributed to shifts in associated frog communities and the current distribution of frogs relative to wetland characteristic such as hydrology and vegetation complexity is not known. The aims of this study are to describe frog communities of the Murray River Floodplain and their habitats and to identify relationships between habitat parameters and the probability of occurrence by each of the frog species present

2.0 METHODOLOGY

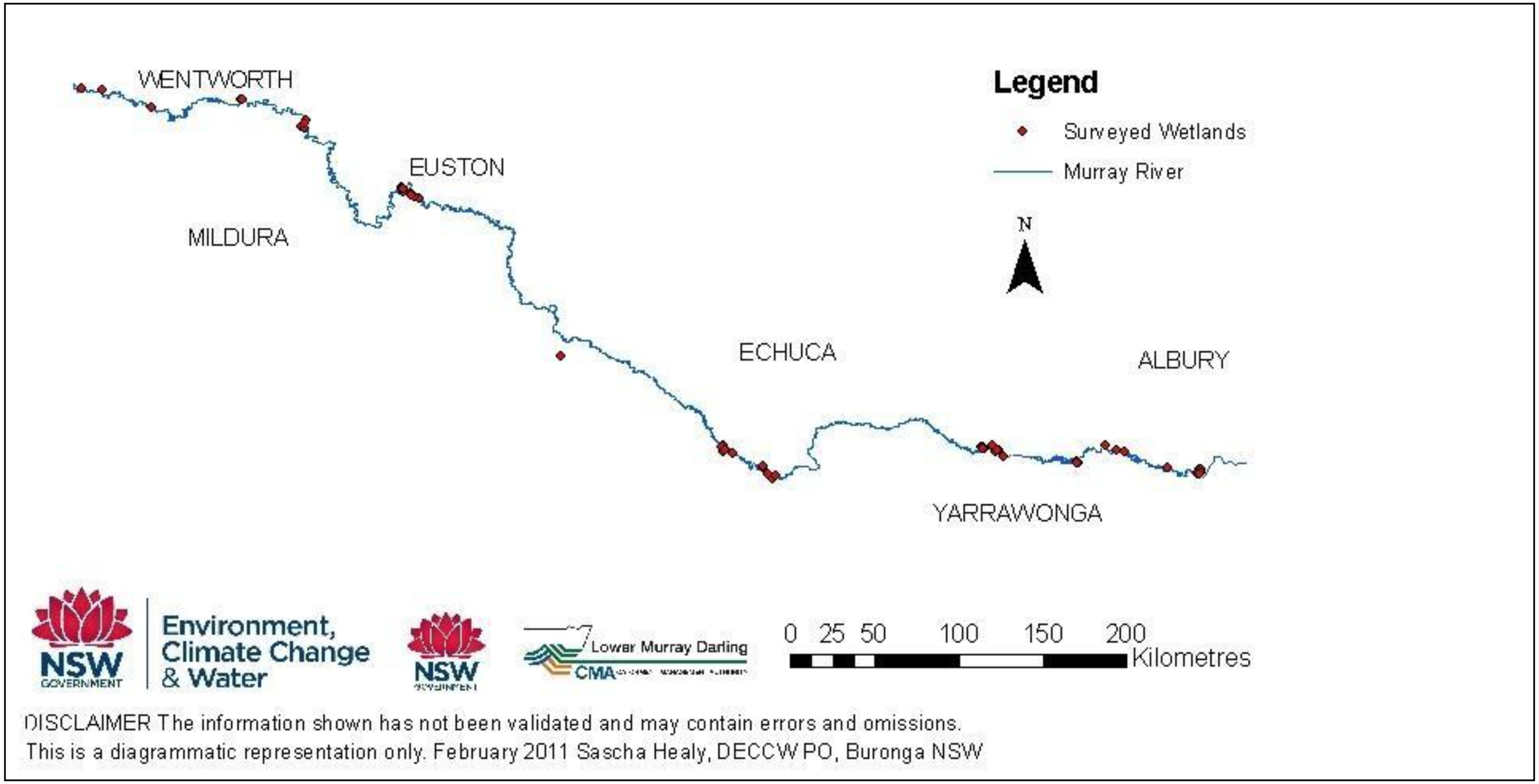
2.1 Site selection and study region

Wetlands were selected from the Murray River floodplain between Hume Dam and the South Australian Border. We aimed to identify and survey as many wetlands as possible from within the study region, however, very dry conditions experienced between 2007 and 2009 limited the availability of some wetland types. Given the large distances covered during field surveys, we limited the selection of wetlands to within 50km of seven key regions (100km for Wentworth) (TABLE 1; Figure 1). Larger water bodies within a suitable radius of these regions were identified using the Murray River Wetlands Database (2006) with smaller rain fed depressions and back-waters identified during field inspections. A total of 77 discrete waterbodies were identified from along the Murray floodplain. As expected, the distribution of wetland types was not evenly distributed across the regions (TABLE 1; Figure 1) with rain -fed depressions more common in the higher rainfall regions in the east and backwaters more common in the western section of the floodplain. All wetlands were surveyed on three occasions (August 2008, October 2008 and December 2009,) with additional surveys in January 2010 following managed flooding of wetlands around Wentworth.

A simple hydrological classification that was relatively easy to apply across the range of wetland types present and that was biologically meaningful was created. The hydrological regime of larger wetlands was classified according to the commence-to-fill values given in the River Murray Floodplain Inundation Model (RiMFIM), while the hydrology of smaller wetlands was assessed in the field. We aimed to describe wetland hydrology in a manner that would be ecologically meaningful as a predictor of habitat use by frogs, but that was also relatively simple to apply without the aid of detailed hydrological models. During the course of the study, three key hydrological regimes were recognised, permanent wetlands were those with a low commence to flow, frequently connected to the river that had contained water for an extended period prior to the surveys and were highly unlikely to dry out completely. Long (hydroperiod 5 - 9 months) underwent fairly regular or seasonal flooding via a connection to the river, but with a drying phase, these were typically subject to active, water management. Short (hydroperiod 2-3 months) were dominantly rain fed with less regular flooding frequencies and with no direct connection to the river during the study period, although these sites might be connected to the river during larger flood events. As these surveys were conducted during very dry conditions it was relatively easy to fit wetlands into this simple classification system, in wetter years such as simple classification systems may not fully capture the range of hydrological regimes.

TABLE 1. Summary of number of waterbody types surveyed for frogs within each region

	Region (mean annual rainfall mm)						
	Albury (701mm)	Corowa (536mm)	Yarrawonga (516mm)	Echuca (424mm)	Euston (311mm)	Mildura (281mm)	Wentworth (283mm)
Wetland type							
Backwater (n=8)	0	0	1	0	5	1	1
Rain fed depression (n=21)	6	6	5	2	1	0	1
Creeks & canals (n=11)	0	0	2	6	3	0	0
Oxbow (n=32)	6	4	6	4	1	6	5
Open wetlands (n=5)	0	1	0	4	0	0	0
Hydrological regime							
Short (n=16)	6	1	5	2	2	0	0
Long (n=32)	0	6	2	10	6	1	7
Permanent (n=29)	6	4	7	4	2	6	0



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This is a diagrammatic representation only. February 2011 Sascha Healy, DECCW PO, Buronga NSW

FIGURE 1. Wetlands surveyed for frogs along the Murray River floodplain during August 2008, October 2008, December 2009 and January 2010

a) Backwater (Euston) b) Rain fed depression (Euston)

c) Canal (Euston) d) Oxbow (Euston)

e) Open Wetland (Echuca)

PLATE 1(a-e) Examples of wetland types identified from the Murray River floodplain between August 2008 and December 2009

2.2 Frog surveys

Visual encounter surveys were conducted after dark along 25m transects around the edge of each wetland for 30 person minutes on each of the three survey occasions. A 30 watt spotlight was used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. Although the number of frogs recorded was counted, these data were converted to presence/absence data for each month for all further analyses. Aural surveys were conducted concurrently with visual encounter surveys.

2.3 Vegetation, water quality and hydrology

Wetland characteristics that were not expected to change during the survey period were recorded once at the start of the survey period these included general assessments of the surrounding vegetation communities, soil type, and percent of dead standing timber and course woody debris and continuity of fringing vegetation. Wetland characteristics that are variable over time such as the proportion of open water, aquatic vegetation and inundated fringing vegetation were measured at each of the three survey occasions. Within each wetland three replicate quadrats were also established to monitor fine scale changes in aquatic vegetation communities and water chemistry over time. Within each quadrat aquatic vegetation was classed as being either tall emergent macrophytes, short emergent macrophytes, submerged macrophytes, floating macrophytes and the percent cover of each was recorded. Water physico-chemical data was collected at each of the three quadrats in each wetland. Turbidity (NTU), conductivity(μS cm^{-1}) and pH, temperature, dissolved oxygen (mg/L) and water depth (cm) were collected using a hand held YSI multi-sonde. The mean of values for the three replicates was used in all analyses.

2.3 Data analysis

Data was checked for normality using Levene's Test of Equality of error variances prior to analysis. In this instance the habitat and water chemistry data did not conform to a normal distribution and the Kruskal–Wallis test was used as a nonparametric alternative to one-way analysis of variance (ANOVA) to compare habitat characteristics and tadpole abundances between seasons and wetland types.

Differences in the composition of frog communities between the five wetland types (Backwaters, canals, oxbow lagoons, depressions and open wetlands) and the three hydrological classes (permanent, Long and short) were assessed using Analysis of Similarities (ANOSIM) (Primer version 5). The relative contribution of each frog species to differences between the three hydrological classes was assessed using SIMPER (Primer version 5).

The distribution of frog species in relation to the measured habitat variables was accessed using logistic regression. Individual logistic regression models were developed for each species and each of the measured habitat variables. The fit of each model was assessed using the Log-likelihood statistic, the adjusted r^2 and the statistic chi-square (Hosmer and Lemeshow 2000). The modeled probability for each was generated and used to visualize the probability of occupancy with respect to the measured habitat and hydrological variables.

3.0 RESULTS

3.1 Distribution patterns

A total of 10 frog species were recorded over the three survey periods.. The most common species were *Crinia signifera* (64% of wetlands), *Crinia parinsignifera* (64% of wetlands) and *Limnodynastes tasmaniensis* (55% of wetlands) (TABLE 2). Two species listed as Vulnerable under the Environment Protection and Biodiversity Conservation Act 1999 were recorded *Litoria raniformis* was identified from larger wetlands west of Mildura (0.08% of wetlands), while *Crinia sloanei* was located from a small number of wetlands between Albury and Euston (0.08% of wetlands). Eight of the ten species have a historical range that extends across the entire study area, the exceptions are *Litoria ewingii* which is restricted to the far eastern end of the Murray River and *Crinia signifera* which is absent from the far western section of the Murray River (west of Mildura). Despite this, species richness increased in a westerly direction. Water bodies in the east, Albury to Yarrawonga, typically contained three or fewer species while wetlands in the west, Euston to Wentworth, contained greater than four species (Figure 2).

TABLE 2. Summary of the number of waterbodies occupied by each species during the study period within each region.

	Albury (n=12)	Corowa (n=11)	Yarrawonga (n=14)	Echuca (n=16)	Euston (n=10)	Mildura (n=7)	Wentworth (n=7)	% of sites
Crinia signifera	12	8	9	12	8	0	0	64
Crinia parinsignifera	8	8	5	8	7	6	7	64
Limnodynastes tasmaniensis	5	9	1	7	7	6	7	55
Litoria peronii	3	7	3	7	6	7	6	51
Limnodynastes fletcheri	0	0	0	5	7	5	7	31
Limnodynastes dumerilii	0	0	1	8	2	4	7	29
Neobatrachus sudelli	3	0	0	1	5	2	5	21
Crinia sloanei	0	0	0	3	1	0	1	0.08
Litoria raniformis	0	0	0	0	0	3	3	0.08
Litoria ewingii	1	0	0	0	0	0	0	0.01

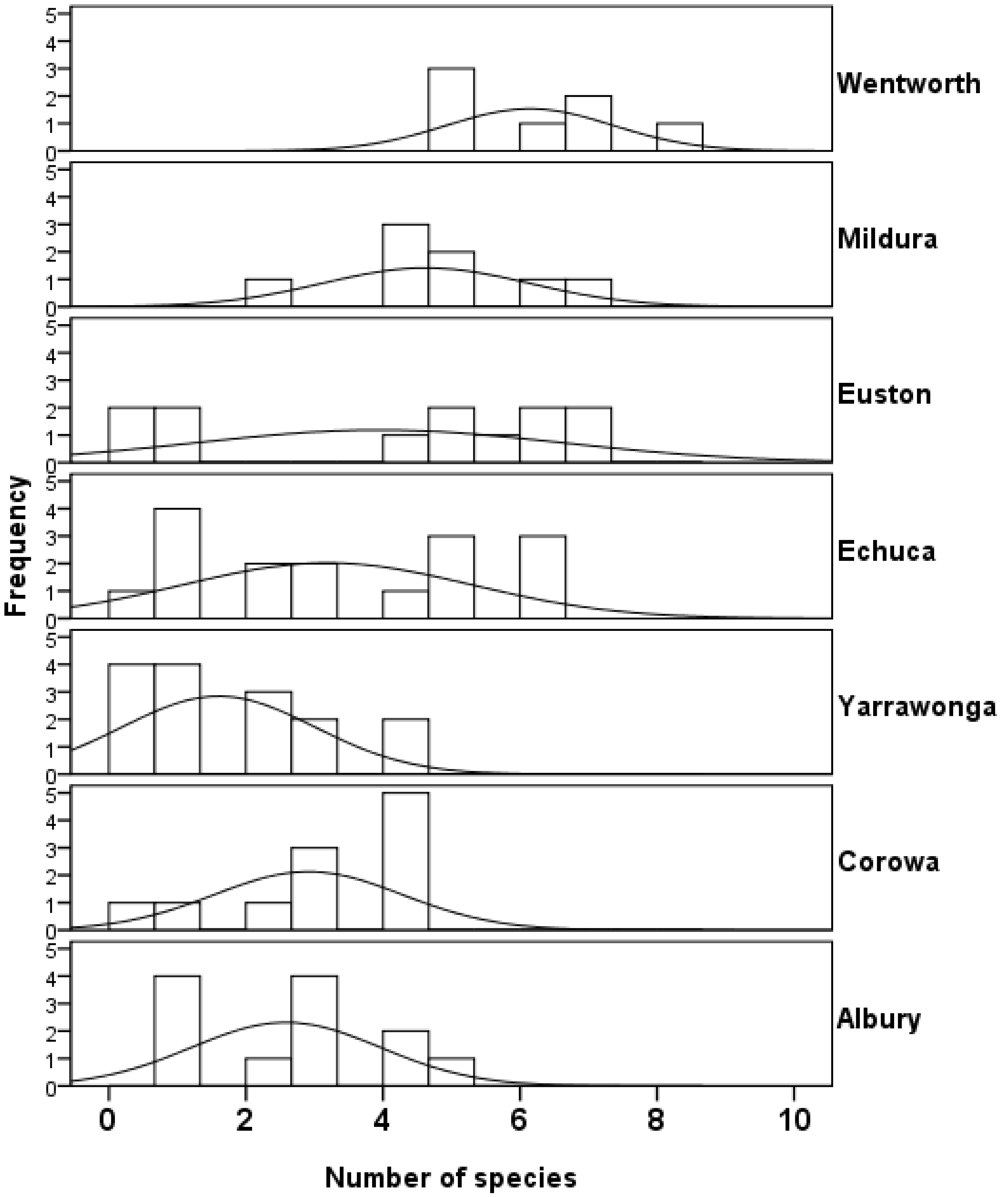

FIGURE 2. Frequency distribution of species richness in wetlands across the study region.

3.2 Community composition

Frog communities did not differ significantly between the wetland types (ANOSIM Global R = 0.024, p = 0.303). However, there were significant differences in the composition of frog communities between the three hydrological classes (ANOSIM Global R = 0.114, P = 0.02). Two species, *Crinia signifera* and *Neobatrachus sudelli* were evenly distributed across the three hydrological classes while five species exhibited a preference for seasonally flooded wetlands and were rarely encountered in waterbodies with short hydroperiods (TABLE 3). The long hydroperiod wetlands had a more even distribution of species, with no single species contributing more than 30% to the community, while the permanent and short hydroperiod wetlands were dominated *Crinia signifera* which contributed greater than 50% to permanent waterbodies and 82% to the short hydrology (Figure 3). The long hydroperiod wetlands had significantly higher frog species richness than short or permanent sites (GLM, f = 9.743, p<0.001). This occurred because permanent sites were often dominated by a few common species, while long hydroperiod sites were more likely to contain rarer species.

TABLE 3. The number of wetland sites occupied by each species over the three survey periods and their association with wetlands of the three hydrological classes.

	Permanent (n =29)	Long (n=33)	Short (n=15)	Total (n= 77)	% of sites	Pearson Chi-Square	Asymp. Sig. (2-sided)
Crinia signifera	18	19	12	49	64	2.290	0.318
Crinia parinsignifera	18	25	6	49	64	5.747	0.056
Limnodynastes tasmaniensis	12	27	3	42	55	**19.148**	**<0.001***
Litoria peronii	14	23	3	39	51	**13.212**	**0.001***
Limnodynastes fletcheri	5	18	1	24	31	**15.225**	**<0.001***
Limnodynastes dumerilii	5	17	0	22	29	**16.336**	**<0.001***
Neobatrachus sudelli	4	9	3	16	21	1.711	0.425
Crinia sloanei	0	3	3	6	0.08	NA	NA
Litoria raniformis	3	3	0	6	0.08	NA	NA
Litoria ewingii	0	1	0	1	0.01	NA	NA

* indicates that that species is not distributed evenly across the three hydrological classes

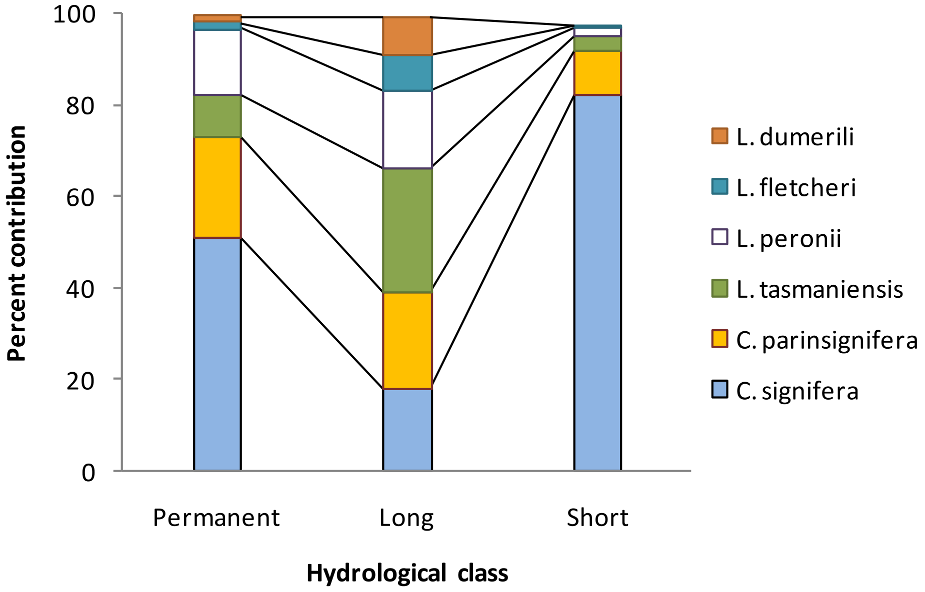

FIGURE 3 Community composition of the three hydrological classification, based on their relative SIMPER contribution (species with a contribution of less than five percent contribution (rare species) are excluded)

3.4 Habitat associations

The complexity of aquatic vegetation, fringing vegetation cover and the interaction between aquatic vegetation diversity and wetland hydrology were useful predictors of the probability of occupancy by resident species (TABLE 4). Sensitivity to these variables varied between species. For example the probability of occupancy by *Crinia signifera* did not change in response to changes in aquatic vegetation diversity, but increased significantly with increasing percentage cover of fringing vegetation (Figure 4). *Limnodynastes fletcheri* was the most sensitive to the complexity of aquatic vegetation, as were *Limnodynastes tasmaniensis, Limnodynastes dumerilii, Litoria peronii* and *Neobatrachus sudelli,* which were also likely to occupy waterbodies with more complex vegetation (Figure 4). The occupancy of wetlands by *Crinia signifera* and *C. parinsignifera* could not be predicted using aquatic vegetation diversity or vegetation complexity, however fringing vegetation cover was a good predictor for *C. signifera* (Figure 4). With the exception of *Crinia signifera* and *Neobatrachus sudelli*, the probability of occupancy by most frog species declined when fringing vegetation cover was very high. None of the measured water chemistry variables were useful predictors of occupancy (TABLE 5).

The interaction between wetland hydrology and aquatic vegetation complexity provides an interesting insight into the relative importance of aquatic vegetation complexity under differing hydrological regimes to frog community composition. This interaction was particularly important for four species *Limnodynastes fletcheri,* *Limnodynastes tasmaniensis*, *Limnodynastes dumerilii and Litoria peronii*. In general, vegetation complexity was more important in permanent wetlands, where increasing vegetation complexity lead to an increase in the probability of occupancy, than in wetlands with either a short or long hydroperiod (Figure 4). The four species were not likely to occupy short hydroperiod wetlands, regardless of their vegetation complexity, while long hydroperiod wetlands had a high probability of occupancy regardless of vegetation complexity (Figure 4).

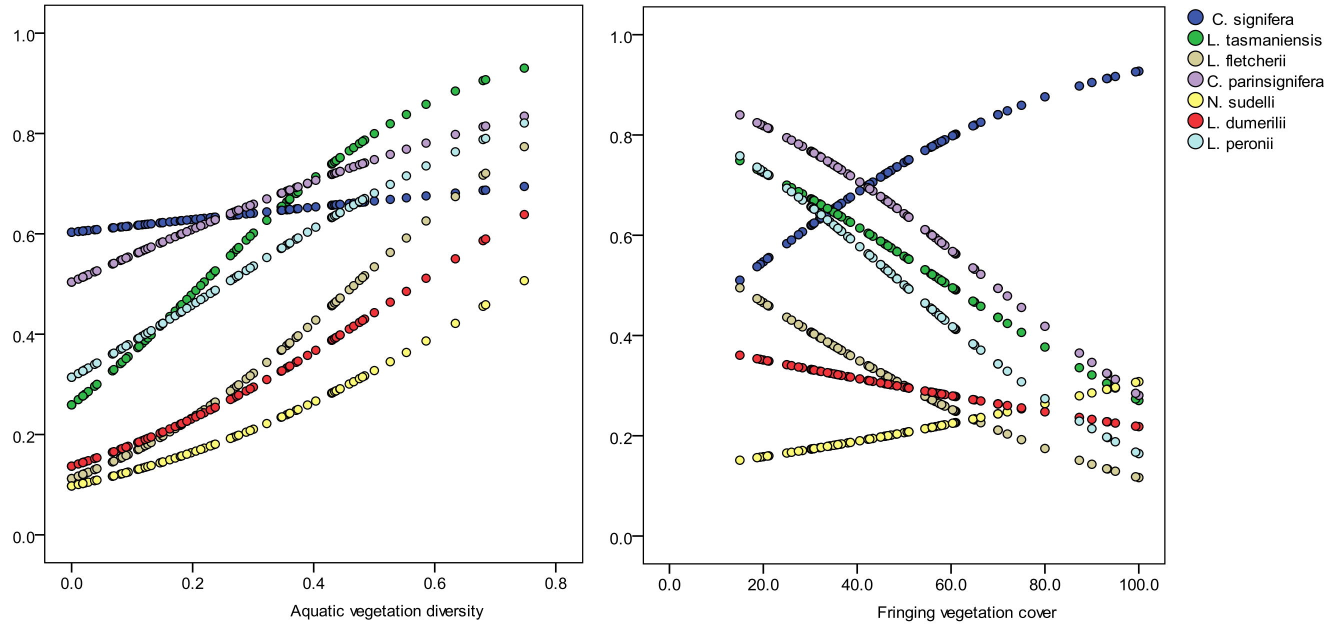

FIGURE 4 Comparison of the probability of occupancy by wetland frog species given differing levels of aquatic vegetation diversity and fringing vegetation cover. Note that it is not possible to model the distribution of rare species using logistic regression.

PLATE 2. *Limnodynastes fletcheri* is more likely to occupy wetlands that have a high diversity of aquatic vegetation.

PLATE 3. Diverse aquatic vegetation greatly increases the likelihood that permanent wetlands will be occupied by many frog species

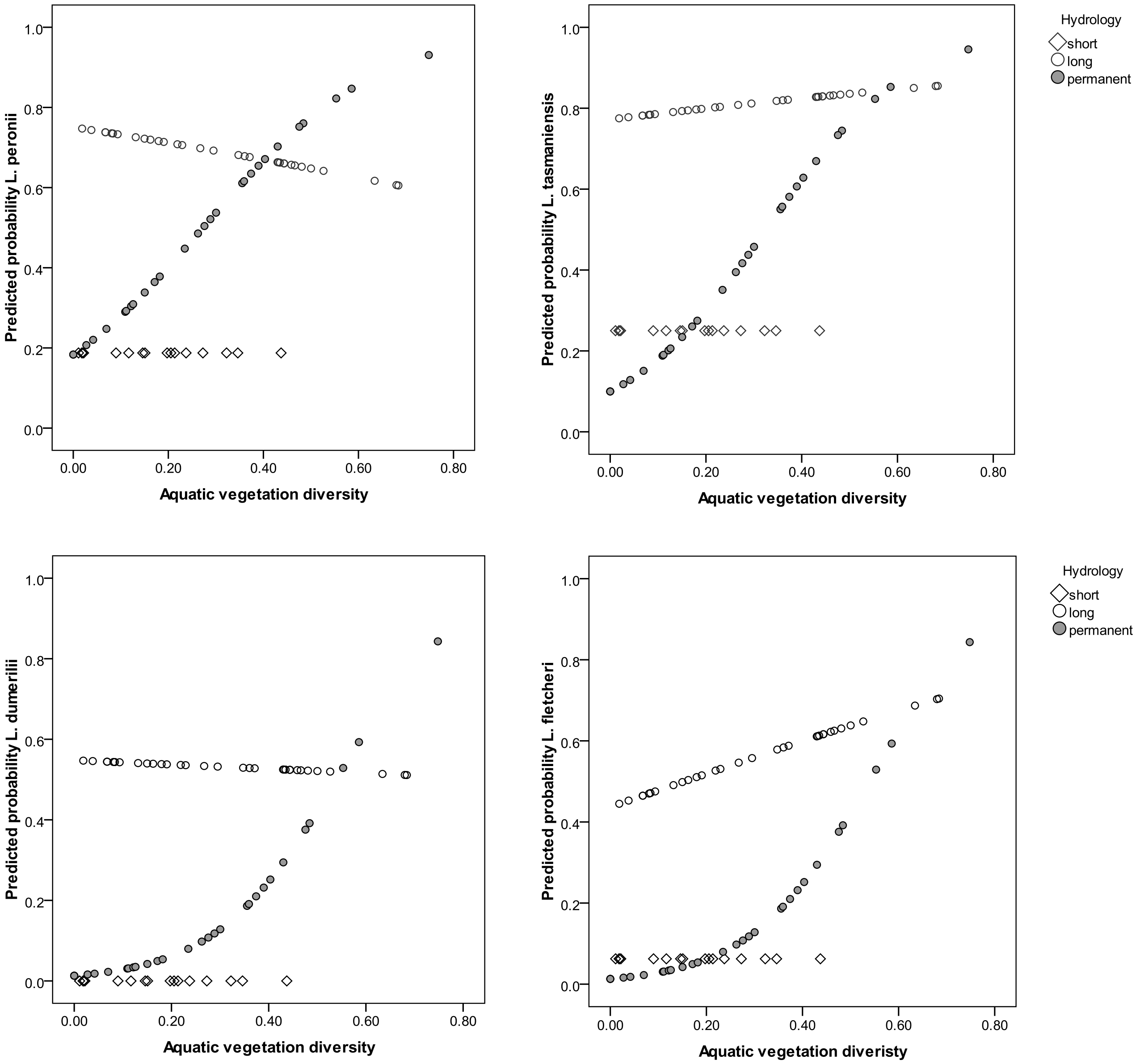

FIGURE 5. The probability of occupancy by *L. peronii, L. fletcheri, L. tasmaniensis* and *L. dumerillii in response to* interaction between hydrological regime and aquatic vegetation diversity. Aquatic vegetation diversity is a better predictor of occupancy within permanent water bodies.

TABLE 4. Logistic regression summaries of the relationship between the presence and absence of each species and a subset of the measured habitat variables. Only habitat variables with at least one significant relationship and that are not highly correlated with other variables have been included in this table. Significant relationships are highlighted in bold a, significant value indicates that the probability of occupancy is significantly related to that variable (that is the variables is a good predictor of occupancy). The Hosmer-Lemeshow test is a measure of the goodness of fit the model, significance values above 0.05 indicates that the observed occupancy pattern is not significantly different from those predicted in the model, a high significance value indicates a better level of fit.

		Hosmer- Lemeshow test		Model summary		Confidence interval and significance	
variable	species	Chi-square	Sig.	-2 Log likelihood	Nagelkerke R Square	Wald	Sig.
Aquatic vegetation diversity	*C. parinsignifera*	4.59	0.80	98.287	0.05	2.50	0.11
	C. signifera	6.91	0.55	100.765	0.00	0.18	0.67
	L. dumerilii	5.44	0.71	86.546	0.10	5.23	**0.02**
	L. fletcheri	1.40	0.99	85.303	0.18	8.88	**0.00**
	L. peronii	5.02	0.76	100.901	0.10	5.32	**0.02**
	L. tasmaniensis	6.93	0.54	93.470	0.20	10.32	**0.00**
	N. sudelli	7.39	0.50	74.603	0.08	3.93	**0.05**
Aquatic vegetation cover	*C. parinsignifera*	6.60	0.58	100.725	0.00	0.22	0.64
	C. signifera	7.81	0.45	87.239	0.06	2.77	0.10
	L. dumerilii	6.08	0.64	92.524	0.03	1.37	0.24
	L. fletcheri	8.53	0.38	89.138	0.11	6.03	**0.01**
	L. peronii	14.00	0.08	105.259	0.03	1.45	0.23
	L. tasmaniensis	11.85	0.16	101.276	0.07	4.15	**0.04**
	N. sudelli	6.04	0.64	75.733	0.06	2.90	0.09
Fringing vegetation cover	*C. parinsignifera*	9.02	0.25	94.457	0.11	5.89	**0.02**
	C. signifera	7.32	0.50	85.797	0.08	3.84	**0.05**
	L. dumerilii	2.66	0.91	93.464	0.01	0.43	0.51
	L. fletcheri	3.42	0.84	92.261	0.06	2.96	0.09
	L. peronii	9.71	0.29	99.416	0.12	6.35	**0.01**
	L. tasmaniensis	5.81	0.56	101.255	0.07	4.12	**0.04**
	N. sudelli	10.72	0.22	78.063	0.01	0.64	0.42
Hydrology	*C. parinsignifera*			93.287	0.13	7.09	**0.03**
	C. signifera			89.908	0.01	0.33	0.85
	L. dumerilii			73.806	0.33	6.43	**0.04**
	L. fletcheri			78.004	0.29	13.72	**0.00**
	L. peronii			95.360	0.18	9.44	**0.01**
	L. tasmaniensis			88.771	0.26	14.04	**0.00**
	N. sudelli			57.735	0.04	1.52	0.47
Hydrology * aquatic vegetation diversity	*C. parinsignifera*	4.95	0.55	96.116	0.08	4.36	0.11
	C. signifera	10.28	0.17	86.802	0.06	2.84	0.24
	L. dumerilii	7.65	0.27	82.515	0.20	9.90	**0.01**
	L. fletcheri	7.18	0.30	79.848	0.26	12.64	**0.00**
	L. peronii	6.28	0.39	98.300	0.14	7.48	**0.02**
	L. tasmaniensis	4.68	0.59	89.019	0.26	11.90	**0.00**
	N. sudelli	3.81	0.70	76.094	0.05	2.58	0.28

Note that it is not possible to model the distribution of rare species using logistic regression)

TABLE 5. Logistic regression summaries of the relationship between the presence and absence of each species and a subset of the measured water chemistry variables. Significant relationships are highlighted in boldand a, significant value indicates that the probability of occupancy is significantly related to that variable (that is the variables is a good predictor of occupancy). The Hosmer- Lemeshow test is a measure of the goodness of fit the model, significance values above 0.05 indicates that the observed occupancy pattern is not significantly different from those predicted in the model, a high significance value indicates a better level of fit.

		Hosmer- Lemeshow test		Model summary		Significance	
variable	species	Chi-square	Sig.	-2 Log likelihood	Nagelkerke R Square	Wald	Sig.
Turbidity (NTU)	*C. parinsignifera*	7.52	0.38	99.414	0.01	0.61	0.43
	C. signifera	7.31	0.50	89.284	0.01	0.28	0.60
	L. dumerilii	7.02	0.43	89.089	0.04	1.47	0.23
	L. fletcheri	10.67	0.15	88.975	0.08	2.10	0.15
	L. peronii	2.60	0.92	98.152	0.12	3.80	**0.05**
	L. tasmaniensis	7.00	0.43	100.434	0.07	2.92	0.09
	N. sudelli	8.06	0.33	59.122	0.00	0.06	0.81
pH	*C. parinsignifera*	7.16	0.52	99.659	0.01	0.37	0.54
	C. signifera	4.08	0.85	89.537	0.00	0.06	0.81
	L. dumerilii	9.82	0.28	91.022	0.01	0.42	0.52
	L. fletcheri	4.06	0.85	92.571	0.01	0.62	0.43
	L. peronii	6.15	0.63	105.119	0.00	0.19	0.67
	L. tasmaniensis	7.27	0.51	103.439	0.02	1.04	0.31
	N. sudelli	10.56	0.23	56.929	0.05	2.03	0.15
Conductivity ($\mu S\ cm^{-1}$)	*C. parinsignifera*	7.10	0.42	96.718	0.06	2.00	0.16
	C. signifera	10.23	0.18	86.755	0.05	2.22	0.14
	L. dumerilii	8.73	0.27	90.763	0.01	0.50	0.48
	L. fletcheri	17.31	0.02	92.269	0.02	0.62	0.43
	L. peronii	10.43	0.17	102.699	0.04	1.49	0.22
	L. tasmaniensis	9.71	0.21	101.299	0.06	1.71	0.19
	N. sudelli	5.69	0.58	59.121	0.00	0.06	0.81

4.0 DISCUSSION

4.1 Frog communities in the Murray Floodplain

We aimed to survey as many wetlands as possible within the Murray River floodplain; however our choice of wetlands was limited by prolonged dry conditions in the years preceding these surveys. Despite this, ten frog species were recorded during this study. Two species of these are listed under state and federal legalisation. *Litoria raniformis* (Endangered TSC Act 1995 and Vulnerable EPBC Act 1999) was formally widespread in wetlands along the Murray River (Wassens 2008) but is now restricted to seasonally flooded and permanent wetlands in the far western section of the Murray River. *Crinia sloanei* (Vulnerable EPBC Act 1999) was also rare within the study sites; this species is restricted to the eastern section of the study area and is relatively common in rain fed wetlands further from the river which were not included in this study (S. Wassens pers. obs). The remaining species are common and widespread throughout the Murray floodplain and its tributaries.

The diversity of frogs within wetlands increased in a westerly direction, with the wetlands west of Mildura supporting the highest diversity of species. This pattern may reflect the relative distribution of wetland types. Seasonally flooded oxbow lagoons and well vegetated backwaters were the more common in the western section of the study area than in the east. The western section of the floodplain also had a greater number of wetlands under active management and these were critically important habitats for *Litoria raniformis.*

4.2 Habitat associations

We opted for a simple classification system based on wetland hydrology and type because these broad classifications were relatively insensitive to differences in climate and did not require detailed hydrological information, and as such could be applied along the full length of the Murray River. These classifications were also considered to be ecologically meaningful in terms of the known habitat requirements of wetland frogs (Spencer and Wassens 2009; Wassens 2010; Wassens, Hall *et al.* 2010). Frog communities differed significantly between the three different hydroperiod classes. Permanent and short hydroperiod wetlands were dominated by widespread and common species, mainly *Limnodynastes tasmaniensis, Crinia parinsignifera and C. signifera.* Less common and rare species generally occurred in long hydroperiod wetlands, most of which were under active environmental flooding management by Murray Wetlands Working Group on behalf of the Department of Environmental, Climate Change and Water. This highlights the importance of environmental flooding as tool to maintaining populations of rare and endangered frog species across the Murray Floodplain.

TABLE 6 Comparison of the suitability of habitat variables as predictors of occupancy for each species (see Table 4 for full details)

	Aquatic vegetation diversity	Aquatic vegetation cover	Fringing vegetation cover	Hydrology	Hydrology * aquatic vegetation diversity
C. parinsignifera	Low	Low	High	High	Moderate
C. signifera	Low	Moderate	High	Low	Low
L. dumerilii	High	Low	Low	High	High
L. fletcheri	High	High	Moderate	High	High
L. peronii	High	Low	High	High	High
L. tasmaniensis	High	High	High	High	High
N. sudelli	High	Moderate	Low	Low	Low

The measured habitat variables differed in their suitability as predictors of occupancy for each of the frog species modelled (Table 6). Aquatic vegetation diversity could discriminate between occupied and vacant sites for five of the seven species, but not for *Crinia parinsignifera* or *Crinia signifera* and was more useful when predictor occupancy than aquatic vegetation cover. This agrees with the studies frogs in oxbow lagoons on the Murrumbidgee River (Jansen and Healey 2003) and for *L. raniformis* populations in inland New South Wales (Wassens, Hall *et al.* 2010), while (Hazell, Cunnningham *et al.* 2001) found that occupancy was related to the percent cover of emergent vegetation rather than total cover of aquatic vegetation. However, the interaction between wetland hydrology and aquatic vegetation diversity was more significant (typically explained a greater percentage of variability in the model) than aquatic diversity alone. In general aquatic vegetation complexity was less important in seasonally flooded wetlands than in permanent ones. Seasonally flooded wetlands had a similar probability of occupancy regardless of their vegetation complexity as did short hydroperiod wetlands. In permanent wetlands where predator densities are higher, the availability of aquatic vegetation may influence recruitment success by providing protection and feeding substrates for tadpoles (Kats and Ferrer 2003). It should be noted that vegetation complexity my also reflect a range of hydrological conditions, such as water depth and stability of water levels as well as productivity (Casanova and Brock 2000), which may also influence frog occupancy patterns.

As expected the distribution of the two most commonly recorded species, *Crinia parinsignifera* and *Crinia signifera*, was not linked to hydrology, aquatic vegetation, or water chemistry. However occupancy by both species increased with increasing cover of fringing vegetation. *Crinia parinsignifera* and *C. signifera* are very small frogs and typically call from patches of fringing vegetation which provides some protection from predators. In contrast, the majority of larger frog species were negatively associated with fringing vegetation. The distribution of fringing vegetation around many larger wetlands is clumped, and a large number of frogs can congregate within this vegetation, however open areas are still important because frogs are visual hunters and open areas give them a clear view of potential prey.

Water quality was not a useful predictor of frog occupancy patterns. Similar results have been shown for frog communities elsewhere for example (Hamer, Lane *et al.* 2002; Healey, Thompson *et al.* 1997) all showed that aquatic vegetation to be a better predictor than water quality. However, extreme declines in poor water quality as a result of acid sulphate and increasing salinity can have a negative impact on frog populations, with conductivities under 3000μS cm^{-1} generally considered to be within the tolerance range for tadpoles of most common species, while 6000μS cm^{-1}will exclude tadpoles (Smith, Schreiber *et al.* 2007). None of the wetlands included in this study had conductivities grater then 3000μS cm^{-1} or exhibited acid sulphate symptoms.

4.3 Other species

Litoria raniformis was recorded in wetlands west of Mildura and appears to have declined from its former range in the east. Of the species identified in this study, *L. raniformis* is the most sensitive species to altered wetland hydrology (Wassens, Hall *et al.* 2010); increasing permanence of wetlands and reduced vegetation cover, as well as reduced flooding frequency can result in local extinctions of this species (Wassens, Hall *et al.* 2010). Recruitment outcomes of *L. raniformis* can be seriously impacted by European carp (*Cyprinus carpio*) (Spencer & Wassens 2009). Three of the wetlands which contained *L. raniformis* were filled via pump which greatly reduces carp densities. This watering method, along with the installation of carp screens may improve recruitment outcomes for *L .raniformis* during managed environmental flood events.

4.4 Management Implications

Wetlands across the Murray River floodplain support a relatively high diversity of frog species, however much of this diversity is confined to seasonally flooded wetlands with a long hydroperiod, which were typically under active management. Maintaining seasonal flooding regimes, with a draw down between years is one of the most effective ways of maintaining frog diversity within the Murray Floodplain and is critically important for the *Litoria raniformis.* We did not consider flooding history in this study, although the majority of long hydroperiod wetlands considered were subject to relatively regular flooding. Studies of frog population in the Lowbidgee floodplain have shown that diversity declines significantly once flooding frequency is less than one in four years (Spencer and Wassens 2009), likewise diversity also declines when wetlands become permanent.

Maintaining vegetation within wetlands is important and even small patches of aquatic and fringing vegetation can support high densities of frogs. While this study was conducted at the wetland scale, frog activity was often linked to specific areas within the wetlands, which were typically shallow and well vegetated (Plate 4). Identification of these vegetated “mesohabitats” with in large wetlands may be a good predictor of frog occupancy and abundance. Smaller scale assessment of the distribution of frogs within a wetland would make a useful contribution to our understanding of frog occupancy patterns and the development of decision support tools based on LIDAR and remote sensing data such as mesohabitat distribution is likely to be more easily measured using remote sensing than smaller scale variables such as vegetation complexity.

(a) Horseshoe Lagoon- Temporary

(b) Horseshoe Lagoon

PLATE 4. (a) Horseshoe lagoon- temporary, a small vegetated backwater associated with Horseshoe lagoon (b) supported three frog species in high abundances; no frogs were found in the permanent section of Horseshoe lagoon

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APPENDIX 1 SUMMARY OF WETLAND CHARACTERISTICS

CODE	Wetland	region	lat	long	hydroperio	type	landuse
P_ALBURYP01	8261 (ALP1)	Albury	-36.07804	147.025813	Long	oxbow	pasture/livestock
P_ALBURYP02	8269 (ALP2)	Albury	-36.078047	147.02579	Long	oxbow	pasture/livestock
P_ALBURYP03	ALP3	Albury	-36.096106	147.026691	Long	oxbow	pasture/livestock
P_ALBURYP04	ALP4	Albury	-36.102973	147.013629	Long	oxbow	pasture/livestock
P_ALBURYP05	ALP5	Albury	-36.098227	147.009311	Long	oxbow	pasture/livestock
P_ALBURYP06	Bagnalls	Albury	-36.06935	146.854621	Long	oxbow	urban
T_ALBURY01	ALT01	Albury	-36.079997	147.028943	Short	depression	pasture/livestock
T_ALBURY02	ALT02	Albury	-36.093278	147.0277	Short	depression	pasture/livestock
T_ALBURY03	ALT03	Albury	-36.092392	147.027909	Short	depression	pasture/livestock
T_ALBURY04	ALT04	Albury	-36.091642	147.027902	Short	depression	pasture/livestock
T_ALBURY05	ALT05	Albury	-36.107005	147.019334	Short	depression	pasture/livestock
T_ALBURY06	ALT06	Albury	-36.107242	147.020528	Short	depression	grazed RRG forest
P_COROWA01	7992	Corowa	-36.033026	146.364135	Long	oxbow	grazed RRG forest
P_COROWA03	8070 Lower	Corowa	-36.045165	146.370438	Long	oxbow	grazed RRG forest
P_COROWA04	7413	Corowa	-35.974254	146.578224	Long	oxbow	grazed RRG forest
P_COROWA05	7312	Corowa	-35.953132	146.520601	Long	oxbow	grazed RRG forest
P_COROWA06	8070 Upper	Corowa	-36.045511	146.370067	Long	oxbow	grazed RRG forest
T_COROWA01	NMW	Corowa	-35.979847	146.581288	Short	depression	grazed RRG forest
T_COROWA02	Pebble	Corowa	-36.048254	146.367888	Short	depression	grazed RRG forest
T_COROWA03	Quatta SF	Corowa	-35.976414	146.580277	Short	depression	grazed RRG forest
T_COROWA04	River	Corowa	-36.048406	146.369064	Short	depression	grazed RRG forest
T_COROWA05	Sandy	Corowa	-36.047053	146.366856	Short	depression	grazed RRG forest
T_COROWA09	7582	Corowa	-35.984918	146.624522	Seasonal	canal	grazed RRG forest
P_ECHOCA08	7703	Echuca	-35.996203	144.527385	Long	oxbow	ungrazed RRG forest
P_ECHUCA01	8535	Echuca	-36.116578	144.756373	Long	oxbow	urban RRG forest
P_ECHUCA02	7568	Echuca	-35.986867	144.472499	Long	canal	cropping
P_ECHUCA04	8543	Echuca	-36.127328	144.74259	Long	river	urban RRG forest
P_ECHUCA05	7485	Echuca	-35.949166	144.476898	Seasonal	backwater	ungrazed RRG forest
P_ECHUCA06	7455	Echuca	-35.947884	144.476622	Seasonal	backwater	ungrazed RRG forest
P_ECHUCA07	7488	Echuca	-35.947306	144.476593	Seasonal	backwater	ungrazed RRG forest
T_ECHUCA01	8499	Echuca	-36.10034	144.715897	Seasonal	backwater	urban
T_ECHUCA03	8535	Echuca	-36.116578	144.756373	Seasonal	oxbow	urban
T_ECHUCA04	ET02	Echuca	-36.065951	144.692066	Short	depression	grazed RRG forest
T_ECHUCA05	ET03	Echuca	-36.065172	144.691421	Short	depression	grazed RRG forest
T_ECHUCA06	164	Echuca			Short	canal	grazed RRG forest
T_ECHUCA07	Canal	Echuca	-35.959665	144.464807	Short	canal	grazed RRG forest
P_MILDURA01	1082	Mildura	-34.212519	142.240329	Long	oxbow	ungrazed RRG forest
P_MILDURA03	1084	Mildura	-34.562187	143.821093	Long	oxbow	ungrazed RRG forest
P_MILDURA04	1087	Mildura			Long	oxbow	ungrazed RRG forest
P_MILDURA05	1106	Mildura	-34.248425	142.222878	Long	oxbow	ungrazed RRG forest
P_MILDURA06	1113	Mildura	-34.258363	142.237599	Seasonal	backwater	ungrazed RRG forest
P_MILDURA07	1097	Mildura	-34.227019	142.23748	Long	oxbow	ungrazed RRG forest
P_MILDURA08	393	Mildura	-35.477178	143.609987	Long	oxbow	ungrazed RRG forest
P_ROBINVA01	1518	Euston	-34.574949	142.757543	Long	oxbow	ungrazed RRG forest
P_ROBINVA02	1585	Euston	-34.607187	142.80349	Long	river	ungrazed RRG forest
T_ROBINVAL01	1585b	Euston	-35.979611	144.480246	Short	river	ungrazed RRG forest
T_ROBINVAL02	1668	Euston	-34.632262	142.847729	Seasonal	oxbow	ungrazed RRG forest
T_ROBINVAL03	RT01	Euston	-34.59481	142.763837	Short	depression	ungrazed RRG forest
T_ROBINVAL04	RT02	Euston	-34.624481	142.820759	Short	canal	cropping
T_ROBINVAL05	RT04	Euston	-34.57827	142.764646	Short	backwater	ungrazed RRG forest
T_ROBINVAL06	RT05	Euston	-34.577366	142.755885	Seasonal	backwater	ungrazed RRG forest
T_ROBINVAL07	RT06	Euston	-35.968633	145.863136	Seasonal	backwater	ungrazed RRG forest
T_ROBINVAL08	RT03	Euston	-34.57904	142.763364	Seasonal	backwater	ungrazed RRG forest
P_WENTWOR01	442	Wentworth	-34.104861	141.893233	Long	river	Urban RRG forest
P_WENTWOR02	128	Wentworth	-34.045519	141.045033	Seasonal	oxbow	grazed RRG forest
T_WENTWOR03	152	Wentworth	-34.055309	141.158187	Seasonal	oxbow	grazed RRG forest
T_WENTWOR04	164	Wentworth	-34.055309	141.158187	Seasonal	oxbow	grazed RRG forest
T_WENTWOR05	367	Wentworth	-34.10003	141.907432	Seasonal	oxbow	ungrazed forest/urban
T_WENTWOR06	3938	Wentworth	-34.614775	142.803298	Seasonal	oxbow	grazed RRG forest

Appendix 1 Summary of wetland characteristics (continued)

CODE	**Wetland**	**region**	**lat**	**long**	**hydroperio**	**type**	**landuse**
T_WENTWOR07	793	Wentworth	-34.142282	141.419481	Seasonal	oxbow	grazed RRG forest
P_YARRAWONG01	7634	Yarrawonga	-35.957124	145.857837	Long	oxbow	grazed RRG forest
P_YARRAWONG02	7484	Yarrawonga	-35.968376	145.872615	Long	oxbow	ungrazed RRG forest
P_YARRAWONG03	7351	Yarrawonga	-35.95084	145.912947	Long	oxbow	ungrazed RRG forest
P_YARRAWONG04	7511 pool 1	Yarrawonga	-35.972653	145.946741	Long	depression	ungrazed RRG forest
P_YARRAWONG05	7511 pool 2	Yarrawonga	-35.9731	145.946092	Long	depression	ungrazed RRG forest
P_YARRAWONG06	7773	Yarrawonga	-36.014503	145.974909	Long	oxbow	ungrazed RRG forest
T_YARAWONG01	7293	Yarrawonga	-35.955227	145.861722	Seasonal	oxbow	grazed RRG forest
T_YARAWONG02	MT01	Yarrawonga	-35.9688	145.863065	Short	depression	ungrazed RRG forest
T_YARAWONG03	MT02	Yarrawonga	-35.983564	145.931084	Short	depression	ungrazed RRG forest
T_YARAWONG04	MT03	Yarrawonga	-35.97261	145.936217	Short	depression	ungrazed RRG forest
T_YARAWONG05	MT04	Yarrawonga	-35.967755	145.863021	Short	depression	ungrazed RRG forest

APPENDIX 2 FROG SPECIES PRESENCE (1) AND ABSENCE (0) IN EACH WETLAND

Code	Wetland	*L. peronii*	*L. raniformis*	*L. dumerili*	*C. sloanei*	*C. parinsignifera*	*L. fletcheri*	*C. signifera*	*L. tasmaniensis*
P_ALBURYP01	8261 (ALP1)	0	0	0	0	1	0	1	1
P_ALBURYP02	8269 (ALP2)	0	0	0	0	1	0	1	1
P_ALBURYP03	ALP3	0	0	0	0	1	0	1	1
P_ALBURYP04	ALP4	1	0	0	0	1	0	1	1
P_ALBURYP05	ALP5	0	0	0	0	1	0	1	0
P_ALBURYP06	Bagnalls	1	0	1	0	1	0	1	1
P_COROWA01	7992	0	0	0	0	0	0	0	0
P_COROWA03	8070 Lower	1	0	0	0	1	0	1	1
P_COROWA04	7413	1	0	0	0	1	0	1	1
P_COROWA05	7312	0	0	0	0	0	0	1	0
P_COROWA06	8070 Upper	1	0	0	0	1	0	1	1
P_ECHOCA08	7703	1	0	1	1	0	1	1	1
P_ECHUCA01	7703	0	0	0	0	0	0	1	0
P_ECHUCA02	8535	0	0	0	0	0	0	1	0
P_ECHUCA04	7568	0	0	0	0	0	0	0	0
P_ECHUCA05	8543	1	0	1	0	1	1	1	1
P_ECHUCA06	7485	0	0	1	0	1	1	1	1
P_ECHUCA07	7455	0	0	1	0	0	0	1	0
P_ECHUCA08	7488	1	0	0	0	0	0	0	0
P_MILDURA01	1082	1	1	0	0	1	1	0	1
P_MILDURA03	1084	1	0	0	0	1	1	0	1
P_MILDURA04	1087	1	1	1	0	1	1	1	1
P_MILDURA05	1106	1	0	0	0	0	0	1	0
P_MILDURA06	1113	1	0	1	0	1	1	0	1
P_MILDURA07	1097	1	1	1	0	1	1	0	1
P_MILDURA08	393	1	0	1	0	1	0	0	1
P_ROBINVA01	1518	1	0	1	0	1	1	1	1
P_ROBINVA02	1585	0	0	0	0	0	0	0	0
P_WENTWOR01	442	0	0	1	0	1	1	1	1
P_YARRAWONG01	7634	0	0	0	0	0	0	1	0
P_YARRAWONG02	7484	1	0	0	0	1	0	1	0
P_YARRAWONG03	7351	1	0	1	0	1	0	1	0
P_YARRAWONG04	7511 pool 1	0	0	0	0	0	0	0	0
P_YARRAWONG05	7511 pool 2	0	0	0	0	0	0	1	0
P_YARRAWONG06	7773	0	0	0	0	1	0	1	0
P_YARRAWONGA07	7328	0	0	0	0	0	0	0	0
T_ALBURY01	ALT01	0	0	0	0	0	0	1	0
T_ALBURY02	ALT02	0	0	0	0	0	0	1	0
T_ALBURY03	ALT03	0	0	0	0	0	0	1	0
T_ALBURY04	ALT04	0	0	0	0	0	0	1	0
T_ALBURY05	ALT05	0	0	0	0	1	0	1	0
T_ALBURY06	ALT06	1	0	0	0	1	0	1	1
T_COROWA01	NMW	0	0	0	0	0	0	1	1
T_COROWA02	Pebble	1	0	0	0	1	0	1	1

Appendix 2 frog species presence (1) and Absence (0) in each wetland (continued)

Code	**Wetland**	***L. peronii***	***L. raniformis***	***L. dumerili***	***C. sloanei***	***C. parinsignifera***	***L. fletcheri***	***C. signifera***	***L. tasmaniensis***
T_COROWA03	Quatta SF	1	0	0	0	1	0	1	1
T_COROWA04	River	1	0	0	0	1	0	0	1
T_COROWA05	Sandy	1	0	0	0	1	0	0	1
T_COROWA09	7582	0	0	0	0	1	0	1	1
T_ECHUCA01	8499	1	0	1	0	1	1	1	0
T_ECHUCA03	8535	1	0	1	0	1	0	1	1
T_ECHUCA04	ET02	0	0	0	1	1	0	1	0
T_ECHUCA05	ET03	0	0	0	1	1	0	1	0
T_ECHUCA06	164	0	0	1	0	1	0	1	1
T_ECHUCA07	Canal	0	0	0	0	0	0	1	0
T_ECHUCA08	Moira Lake	1	0	1	0	1	1	0	1
T_ROBINVAL01	1585b	0	0	0	0	0	0	1	0
T_ROBINVAL02	1668	1	0	1	0	1	1	1	1
T_ROBINVAL03	RT01	0	0	0	1	1	1	1	1
T_ROBINVAL04	RT02	0	0	0	0	0	0	0	0
T_ROBINVAL05	RT04	1	0	0	0	1	1	1	1
T_ROBINVAL06	RT05	1	0	0	0	1	1	1	1
T_ROBINVAL07	RT06	1	0	0	1	1	1	1	1
T_ROBINVAL08	RT03	1	0	0	0	1	1	1	1
T_WENTWOR02	128	1	1	1	0	1	1	1	1
T_WENTWOR03	152	1	0	1	0	1	1	1	1
T_WENTWOR04	164	1	1	1	1	1	1	1	1
T_WENTWOR05	367	1	0	1	0	1	1	0	1
T_WENTWOR06	3938	1	1	1	0	1	1	1	1
T_WENTWOR07	793	1	0	1	0	1	1	0	1
T_YARAWONG01	7293	0	0	0	0	1	0	1	0
T_YARAWONG02	MT01	0	0	0	0	0	0	1	0
T_YARAWONG03	MT02	0	0	0	0	0	0	0	0
T_YARAWONG04	MT03	0	0	0	0	0	0	0	0
T_YARAWONG05	MT04	0	0	0	0	0	0	1	0