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Assessing the diversity, abundance and hydrological requirements of frog populations at 'Burrawang West' and 'Yarnel' Lagoons, two small wetlands on anabranch creeks of the mid-Lachlan River

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Disclaimer

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Executive summary

Frogs make up an important part of wetland biodiversity and are a major component of wetland food chains. However, very little is known about the factors influencing frog distributions and their requirements in terms of vegetation, water chemistry and water regime. This lack of knowledge restricts our ability to make sound management decisions, particularly with regard to flooding regimes.

This study was conducted in the mid Lachlan catchment near Condobolin in central western New South Wales. Frog communities were surveyed at 23 locations along creek lines and depressions within the properties Yarnel and Burrawang West. Surveys for frogs and tadpoles were conducted over three sample periods between January 15th and March 8th. At each site we also recorded a range of habitat parameters, associated with aquatic and terrestrial vegetation, water regime and water chemistry.

A total of seven frog species was recorded. Frog communities on both properties were similar in terms of diversity and species composition. However, frog community composition and diversity were significantly different at sites with temporary and permanent water regimes. Temporary waterbodies supported a higher diversity of species and were more likely to contain tadpoles than permanent ones. Permanent sites tended to be dominated by commonly occurring species and were unlikely to contain tadpoles.

Individual species differed in terms of their sensitivity to vegetation parameters, water depth and water chemistry. For example, sites occupied by the Peron's tree frog (*Litoria peronii*) were, on average deeper, with a higher proportion of dead standing timber and larger areas of open water than vacant ones. In contrast, the broad–palmed frog (*Litoria latopalmata*) occupied sites that were shallow with only small areas of open water.

In addition to these surveys, we reviewed the literature to determine the normal tadpole life span, timing of breeding and preferred breeding habitat of frogs occurring or likely to occur on the two properties. These data were than combined with our survey data to generate hypotheses predicting frog responses under water regimes that varied in terms

of (1) timing of flooding, (2) type of habitat flooded (semi-permanent or temporary waterbodies), (3) time that water remained on flooded areas (hydroperiod), and (4) the vegetation and water depth of flooded areas.

The requirements of many species encountered in this study differed in terms of one or more of these factors. This suggests that flooding management should focus on creating a mosaic of wetland habitats, incorporating both temporary water bodies with short hydroperiods and semi-permanent waterbodies with longer hydroperiod. Variability in the timing of inundation is also recommended to ensure that both spring and summer breeding species are catered for.

1.0 Introduction

Riverine wetland systems are dynamic across space and time as a result of variation in river discharge, over bank flows and rainfall (Boulton and Brock 1999) The cycles of wetland flooding and drying drive breeding, recruitment and movement patterns of a range of aquatic and semi-aquatic organisms, including water birds (Dorfman and Kingsford 2001; Roshier, Robertson and Kingsford 2002), fish (Young et al. 2001) and invertebrates (Sheldon, Boulton and Puckridge 2002; Jenkins and Boulton 2003).

Faunal responses to wetland flooding and drying are complex because they are typically driven by factors at a range of different spatial and temporal scales. At broader spatial and temporal scales, colonisation and movements can be influenced by the availability of alternate wetland patches (Roshier et al. 2001), the spatial arrangement of resource patches (Hanski 1999), characteristics of the surrounding landscape (Mazerolle and Villard 1999) and connectivity to the river (Jenkins and Boulton 2003). Once an organism has reached a newly flooded wetland, its survival, breeding activities, the recruitment success of offspring and subsequent emigration from the wetland will be driven by a host of local conditions. These include wetland water regime (hydro-period, frequency and timing of inundation) (Snodgrass et al. 2000), water depth (Casanova and Brock 2000), aquatic and riparian vegetation cover and composition (Vasconcelos and Calhoun 2006), and water quality (Della Bella, Bazzanti and Chiarotti 2005).

The importance of these biophysical factors and the scale of interaction are largely defined by the movement capabilities and habitat requirements of the individual species or taxonomic group. For example, water birds interact with their environment at large spatial and temporal scales and are able to take advantage of water resources which are highly variable across space and time (Roshier and Reid 2003). In contrast, semi-aquatic and aquatic organisms often have poor dispersal capability and their ability to colonise newly flooded wetlands is dependant on a direct connection via water flow (Galat et al. 1998; Jenkins and Boulton 2003; Balcombe et al. 2006) or on the proximity to other water bodies within the surrounding landscape (Hanski 1999).

1.1 Factors influencing frog responses to flooding

While the relationship between frog abundance and community composition and wetland flooding regime has not been tested directly, specific components of these relationships have been investigated for frogs in the Northern Hemisphere. Based on these studies, wetland flooding regime is likely to be important in driving frog occupancy patterns and abundance both directly through its influence on connectivity, wetland hydroperiod, flooding frequency and the timing of inundation, and indirectly through its influence of vegetation structure, water quality and fish abundances.

Of these factors, local scale and wetland scale factors have received the most attention. The occurrence of many species is driven by the spatial distribution and availability of resources patches, such as over winter sites, foraging and refuge habitats (Schabetsberger et al. 2004; Regosin et al. 2005; Wassens 2006a). At the wetland scale, many frog species also have specific habitat requirements in terms of vegetation (Jansen and Healey 2003), hydrological regime (Snodgrass et al. 1999; Snodgrass et al. 2000), water quality (Skelly 2001) and predator occurrence (Adams 2000).

The term hydrological regime incorporates wetland hydroperiod, flooding frequency and timing of inundation. Wetland hydroperiod is the length of time that the wetland holds surface water, flooding frequency is the number of times a wetland receives flood water over a given time period and timing of inundation relates to the seasonality of flow. Wetland hydroperiod influences how long tadpoles have to reach metamorphosis, shortened hydroperiod can result in mass mortality of tadpoles and over time, will exclude species with longer larval life spans (Rowe and Dunson 1995; Ryan and Winne 2001; Baber et al. 2004). Extending hydroperiods increases the abundance of predators such as fish (Adams 2000) and reduces vegetation cover (Warwick and Brock 2003), both of which have the capacity to exclude species which have tadpole stages that are sensitive to predation or loss of cover.

Flooding frequency is likely to influence the long-term persistence of amphibian species. Surprisingly, studies investigating this relationship are limited, probably because the wetlands in the northern hemisphere tend to have more regular flooding patterns.

Flooding frequency determines the length of time between breeding events for species that breed in temporary waterbodies and may restrict the occurrence of species with shorter life spans.

The timing of inundation is also an important factor in driving breeding responses (Rowe and Dunson 1993). While some species will breed opportunistically throughout the year, breeding activity of others may be restricted to a particular season, e.g spring, summer or autumn. Species with a restricted breeding season may not respond to flood events which do not coincide with their normal activity cycles (Jakob et al. 2003).

From this short review we see that the response of frogs to flooding can be driven by a number of factors occurring across a range of spatial and temporal scales. Understanding these factors is essential for the long-term management of frogs within riverine wetland systems. The aims of this study are to (1) describe the frog species communities present within the landscape, (2) describe the environmental factors driving their distribution and (3) identify groupings of species based on their environmental requirements and (4) predict the responses of these groups of species to wetland flooding.

1.2 Terms of reference

- A benchmark assessment of the diversity and abundance of frog populations at "Burrawang West" and "Yarnel" Lagoons prior to the application of RiverBank water.

- A description of current and potential habitats for frogs at Burrawang West and Yarnel Lagoons and the recommended management interventions to achieve the potential.

- Development of a recommended long-term monitoring strategy to test hypotheses on future status of frog populations at both sites. The hypotheses should account for achievable management interventions such as but not restricted to: manipulation of water levels through use of RiverBank water; protection and / or restoration of littoral vegetation; and inclusion of additional substrate / woody debris.

- Recommendations on an appropriate watering regime to maximise the diversity of frog populations at both sites.

2.0 Methods

2.1 Study area

The Lachlan River originates near Gunning in Northern inland NSW and flows west over 1500km terminating in the Great Cumbung Swamp in south west New South Wales. The area of the Lachlan catchment is approximately 84700km^2 and is responsible for 14% of NSW agricultural production (Hillman and Brierly 2002). Natural river flow of the Lachlan system was characterised by high annual variability with relatively regular flooding interspersed with prolonged periods of low to no flow (Kemp 2004). However, the river is regulated by the Wyangala Dam (1220GL) on the main channel and Carcoar Dam (36GL) on the Belubula River tributary as well as by numerous weirs resulting in a reduction of small to medium floods as well as low flows (<200ML/day) (Hillman and Brierly 2002).

The study was undertaken in the mid-Lachlan valley near Condobolin. Sample sites were located within approximately five kilometres of the wetlands targeted for the application of RiverBank water on two properties, Burrawang West and Yarnel (Figure 1).

Burrawang West Lagoon is near the junction of Goobang and Yarrabandai Creeks, about 20km east of Condobolin (Plate 1). The property supports a beef enterprise with associated cereal and pasture crops and an ecotourism business. Sections of the creek line and the lagoon have been fenced to exclude cattle. Water levels within the creek system and in the lagoon are maintained by a weir on the junction of Goobang and Yarrabandai Creek. Water flow over the weir creates a series of shallow, temporary pools within the channel. Water levels within the main channel behind the weir remained relatively constant during the study period. However, high flows in September 2006 caused water from the main channel to break out into low lying areas.

“Yarnel” Lagoon is on Wallaroi Creek about 15 km south of Condobolin. The lagoon is a shallow depression off the main creek line (Plate 2). When flooded it can cover an area of 40 ha and attracts a large number of waterbird species, including the threatened brolga. There is currently no restriction on grazing access. A small weir regulates water levels within the Wallaroi Creek. Water levels within the creek were low prior to these surveys, but a water release in early January caused an increase in water levels, flooding Yarnel lagoon and over topping the weir to create small areas of temporary water.

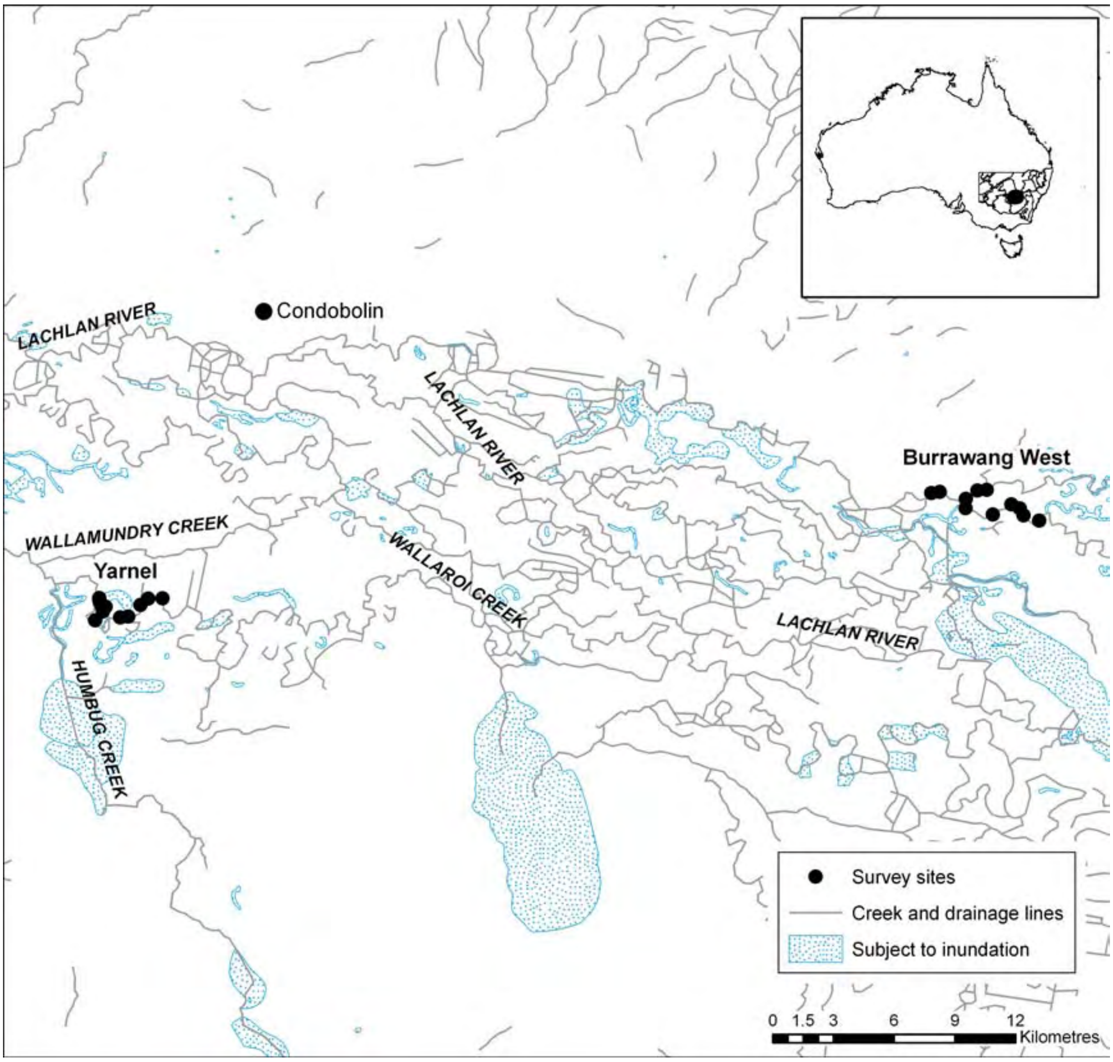


Figure 1. Location of sample sites in the Lachlan catchment

Plate 1. Burrawang West Lagoon at the junction of Goobang and Yarrabandai Creeks

Plate 2. Yarnel Lagoon off Wallaroi Creek

2.2 Study species

There have been very few studies of frog communities within the Lachlan catchment and both museum and National Parks and Wildlife records of frogs in this region are scarce. Frog calling activity was monitored by community groups in 2000 and 2001 within the Lachlan catchment (Magarey and White 2003). This project identified eight frog species but did not describe their habitats. Based on existing records, a total of 13 species is likely to occur in the region.

2.3 Sample site selection

A stratified random approach was used to select sample sites from along creek lines and wetland depressions at both properties. A total of 23 sample sites were surveyed on Burrawang West and Yarnel (Figure 2 and 3). Surveys of habitats, adult frogs and tadpoles were conducted at all sample sites on three separate occasions, January 16th and 17th, January 30th and 31st and March 8th and 9th).

2.4 Frogs surveys

At each sample site a five-minute audio and 20 minute visual survey were conducted between 9pm and 3am. Visual encounter surveys were conducted using a 30 watt spotlight along 25m transects running parallel to the waters edge and into the surrounding terrestrial habitats. Audio surveys involved listening for the distinct calls of each species. Call play back was used for the Southern Bell Frog (*Litoria raniformis*). *Litoria raniformis* had previously been recorded from the Lachlan River but is likely to be locally extinct (Wassens 2006a). All individuals sighted were classed as adult or metamorph based on the presence of vestigial tail stump.

2.5 Tadpole surveys

Searches for tadpoles and egg masses were conducted during the day. Egg masses were counted from along a 25 metre transect, starting at the waters edge and extending approximately 1.5m into the water. Egg masses were identified to species based on their distinctive shape and form according to Anstis (2002). Tadpoles were collected using five sweeps of a soft mesh net and were identified to species according to Anstis (2002).

2.6 Habitat condition

Habitat surveys were conducted during the day at the sample site. At each sample site, we recorded measures of water quality and habitat (vegetation, timber and water depth). Water chemistry parameters were measured between 8.00am and 12.00pm using a hand-held meter (Hydrolab). Two replicates each of conductivity ($mScm^{-1}$), turbidity (NTU), pH, water temperature (^{0}C), and water depth 200cm from the water edge were recorded. At each sample site the percent cover of aquatic vegetation was estimated for 2 x 10m sections across the water course or wetland. Aquatic and fringing vegetation was described in terms of the percent cover of floating vegetation, submerged vegetation, short emergent vegetation (vegetation less than 30cm above water line), tall emergent vegetation (vegetation greater than 30cm above the water line), dead standing and fallen timber (DST) and open water. The percent continuity of fringing vegetation was estimated for a 10m section on each side of the watercourse.

Sample sites were classified as being permanent if they contained water on all three survey occasions and temporary if they had completely dried, or nearly dried out (water depth less than 10cm) on any of the three survey occasions.

2.7 Data analysis

Many frog species have highly variable activity patterns which means that detection rates can change over time (Heyer et al. 1994). In order to reduce the possibility of false negatives, the presence or absence of individual species at each sample site was pooled for the three sample occasions (January 16th, January 30th and March 8th).

2.7.1 Community composition

Non-metric multidimensional scaling (MDS) was used to compare frog assemblages between Yarnel and Burrawang West and between sample sites with permanent and temporary water regimes. Non-metric multidimensional ordinations were performed using the PRIMER version 5, with Bray-Curtis similarity measures (Clarke and Warwick 1994). Analysis of similarities (ANOSIM) was used to test whether the variation in frog assemblages between treatments (site and water regime) was greater than the variation within the treatments. General Linear Models were used to determine whether frog species richness differed significantly between the two properties and water regimes or with the interaction between property and water regime.

2.7.2 Patterns of habitat occupancy

Differences in the environmental variables (vegetation, water depth and water quality) between sites where each species was present and absent were determined using t-tests. This technique essentially tests whether the mean of each habitat variable at sites where a particular species is present differs significantly from the sites where it is absent. T- tests were used instead of logistic regression because many species were either very common, occurring at the majority of sites, or very rare occurring at one or two sites. As a result of the low numbers of sites where each species were present or absent, the predictive power within the logistic regression model for these species was poor.

Because tadpoles and metamorphs were relatively rare, we were unable to identify breeding sites for each species. Consequently, data for all species were pooled when describing breeding sites. As with the occupancy patterns of adults, differences in habitat and water chemistry parameters at sites where breeding activity was present and those where it was absent were determined using t-tests.

3.0 Results

3.1 Habitat surveys

Of the 23 sample sites, nine dried out either completely or to less than 10cm (temporary) while 14 sites contained water at relatively constant levels (permanent) throughout the study period (Figure 2). The measured habitat parameters were highly variable between survey sites (Table 1) (Appendix 1). A number of permanent sample sites contained virtually no aquatic vegetation (Plate 1). The shallower temporary sites often contained abundant aquatic vegetation (Plate 2). Water depth was also very variable ranging from 8.3cm to 73.3 cm. All survey sites contained at least some dead standing timber.

Table 1. Summary of habitat parameters at the 23 survey sites over the three survey occasions

Habitat parameter	Minimum	Maximum	Mean	Std. Error
Conductivity ($mScm^{-1}$)	0.4	1.2	0.6	0.0
pH	7.0	8.7	7.6	0.1
Water temperature	22.9	36.9	28.4	0.8
Water depth (cm)	8.3	73.3	36.3	4.4
Number of microhabitats	2.8	6.2	4.3	0.2
% cover open water	3.3	90.0	54.6	5.5
% cover floating vegetation	0.0	85.0	22.2	5.6
% cover tall emergent vegetation	0.0	58.3	17.3	4.1
% cover short emergent vegetation	0.0	43.3	5.3	2.2
% cover submerged vegetation	0.0	46.7	6.3	2.5
Continuity of fringing vegetation	0.0	30.0	9.5	1.8
Dead standing timber	1.3	20.0	8.3	1.1

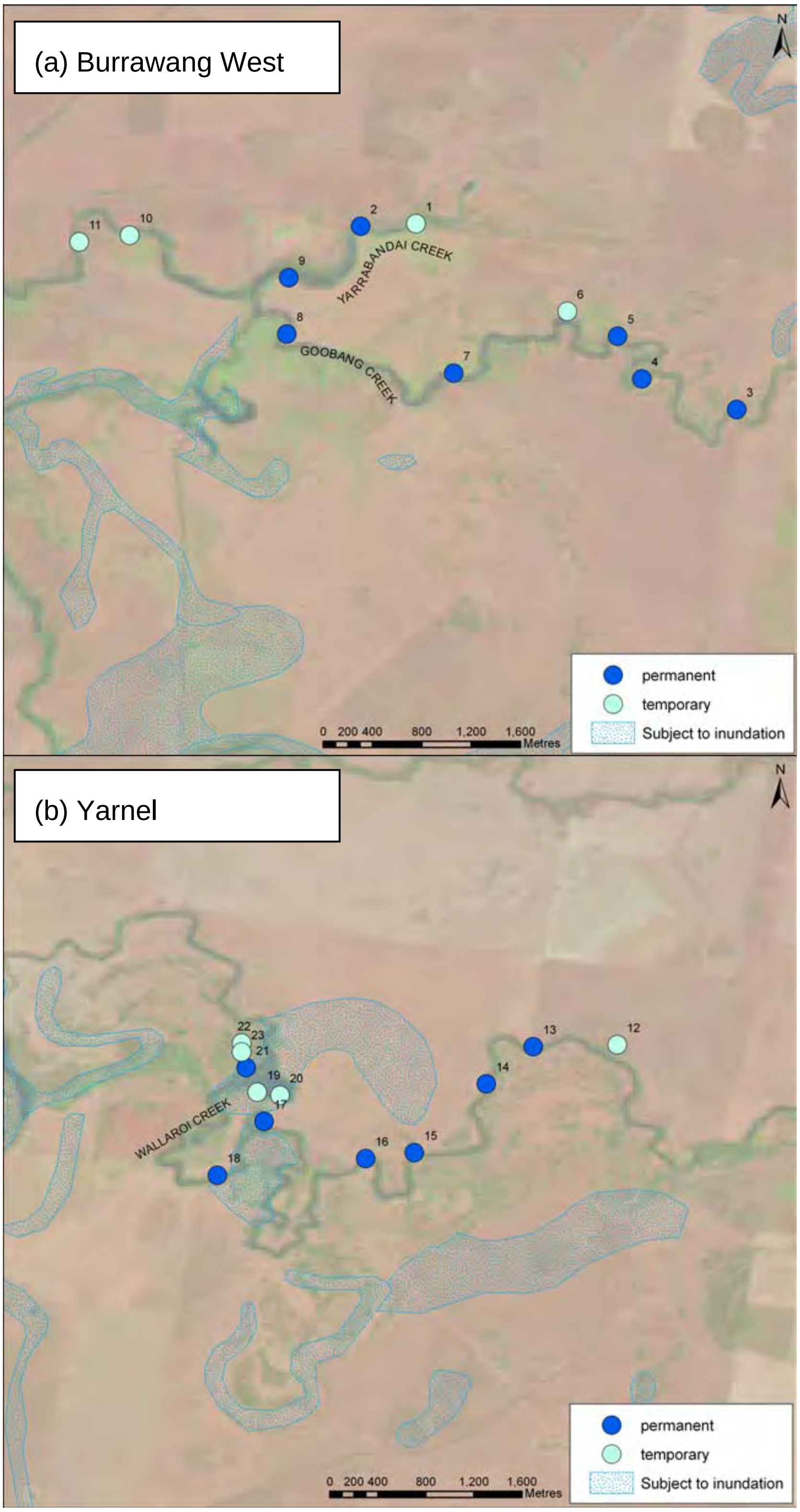


Figure 2. The distribution of temporary and permanent survey sites at (a) Burrawang West and (b) Yarnel.

Plate 3. The upper section of Goobang Creek on Burrawang West contained virtually no aquatic vegetation

Plate 4. Temporary waterbodies on the overflow from Yarnel weir contained abundant aquatic vegetation

3.2 Description of frog populations

A total of seven frog species was recorded during the study (Table 2). The Barking marsh frog (*Limnodynastes fletcheri*) was the most commonly recorded species, occurring at 20 of the 23 sample sites (Figure 3). The Peron's tree frog (*Litoria peronii*) was also widespread, occurring at 18 sample sites. A number of species were restricted to a small number of samples sites; these included The Inland banjo frog (*Lymnodynastes interioris*) which was recorded at three sample sites and the Desert tree frog (*Litoria rubella*) which was recorded at one sample site only (see Appendix 2 for a list of frog species at each site and Appendix 3 for species occurring at each site on each of the three sampling occasions).

Table 2 Number of sample sites occupied by frog species likely to occur in the region.

Common name	**Number of sites occupied**	**Frequency**	**Breeding observed***
Broad-palmed frog (*Litoria latopalmata*)	8	0.35	Yes
Peron's tree frog (*Litoria peronii*)	18	0.78	No
Desert tree frog (*Litoria rubella*)	1	0.04	Yes
Plains froglet (*Crinia parinsignifera*)	4	0.17	Yes
Barking marsh frog (*Limnodynastes fletcheri)*	20	0.87	Yes
Inland banjo frog (*Limnodynastes interioris*)	3	0.13	No
Spotted marsh frog (*Limnodynastes tasmaniensis*)	15	0.65	Yes
Painted burrowing frog (*Neobatrachus sudelli*)		Not recorded	
Wrinkled toadlet (*Uperoleia rugosa*)		Not recorded	
Common eastern froglet (*Crinia signifera*)		Not recorded	
Green tree frog (*Litoria caerulea*)		Not recorded	
Waterholding frog (*Cyclorana platycephala*)		Not recorded	

* Presence of egg masses, tadpoles or resent metamorphs

There were no significant differences in the species richness ($f = 0.649$, $p = 0.430$) or community composition (ANOSIM Global $R = 0.031$, $p = 0.315$) between the two properties (Burrawang West and Yarnel). All seven species were recorded at Burrawang West, while six were recorded at Yarnel where *Litoria rubella* was absent (see appendix 2).

The composition of frog communities differed significantly between sample sites with permanent and temporary water regimes (ANOSIM Global $R = 0.305$, $p=0.002$) (Figure 4). Of the species recorded *Litoria latopalmata, Litoria rubella, Limnodynastes tasmaniensis* and *Crinia parinsignifera* were more likely to occur in temporary waterbodies *L. peronii* favoured permanent sites and *L. fletcheri* exhibited no preference.

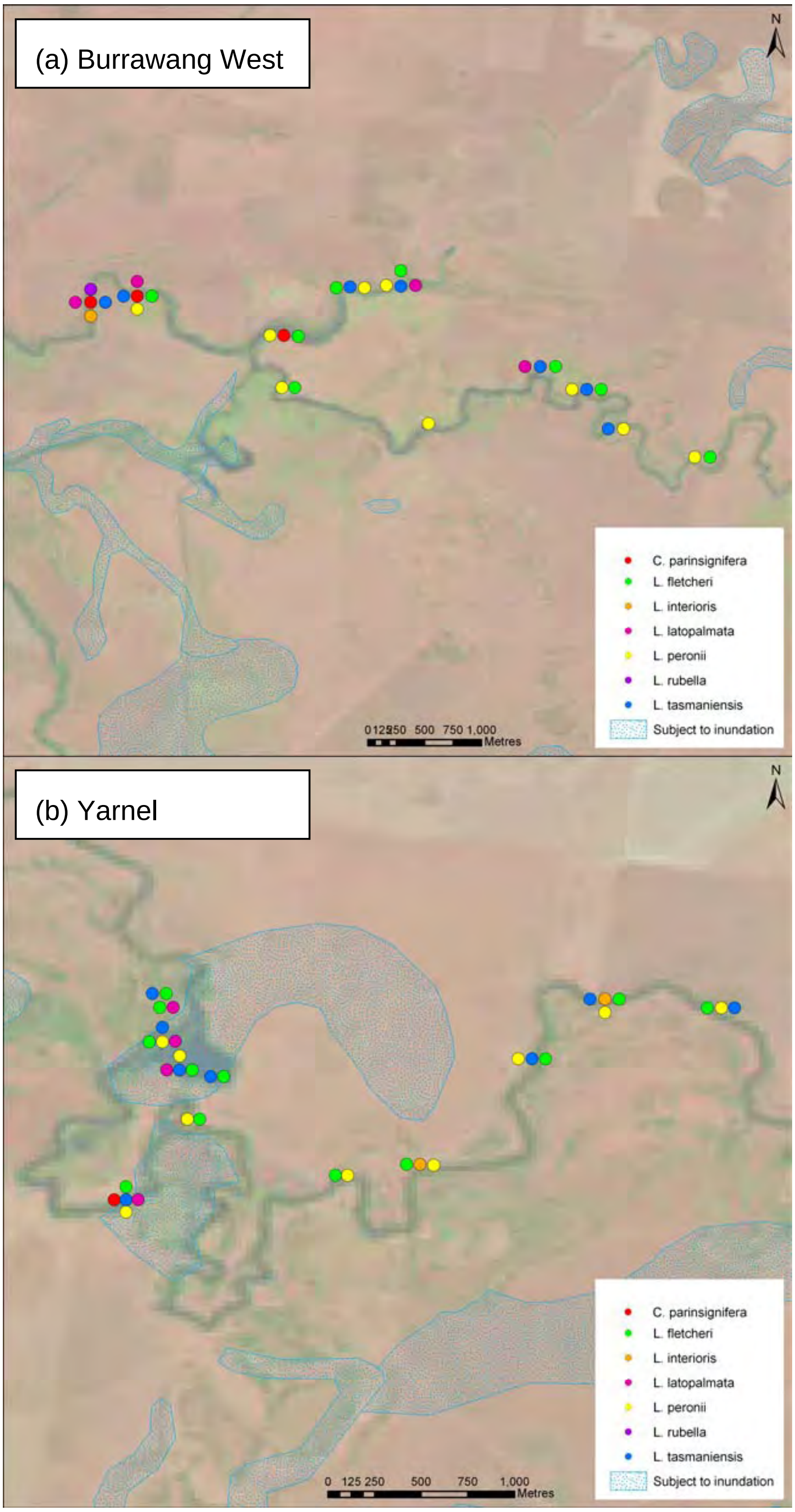


Figure 3. The distribution of frog species within each survey sites at (a) Burrawang West and (b) Yarnel.

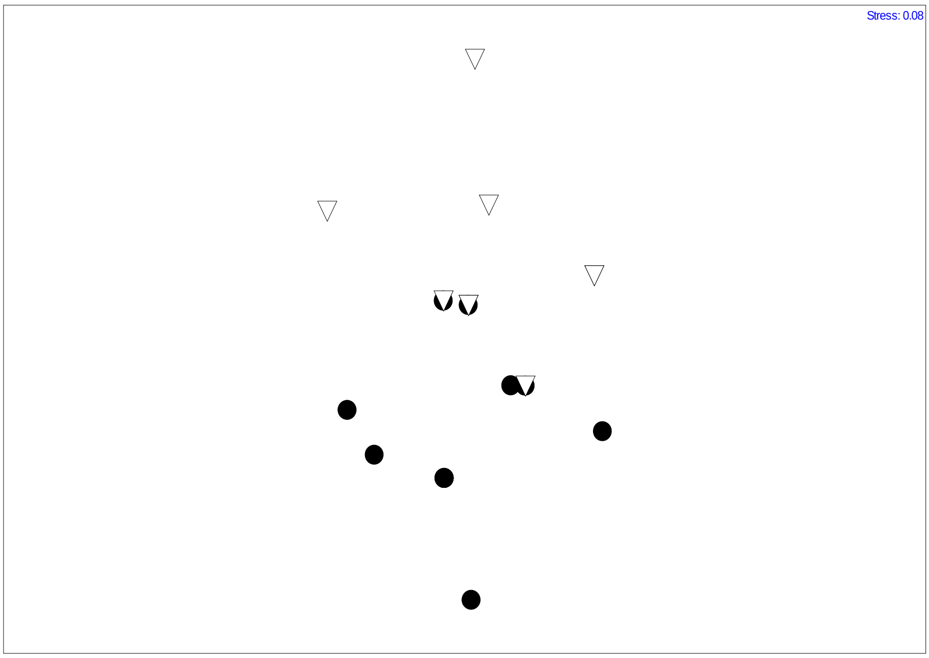


Figure 4. MDS plot of frog communities within permanent and temporary waterbodies at two properties (Burrawang west and Yarnel) in the mid Lachlan catchment. Open triangles = temporary waterbodies, closed circles = permanent waterbodies. n= 23, note that some points are super imposed.

Despite the differences in community composition, species richness did not differ significantly between permanent and temporary sites (f = 2.512, p = 0.129), however species richness did differ significantly with the interaction between property and hydroperiod (f = 10.791, p = 0.004). Temporary sample sites supported a greater number of species than permanent sample sites at Burrawang west, but this relationship was less pronounced at Yarnel (Figure 5).

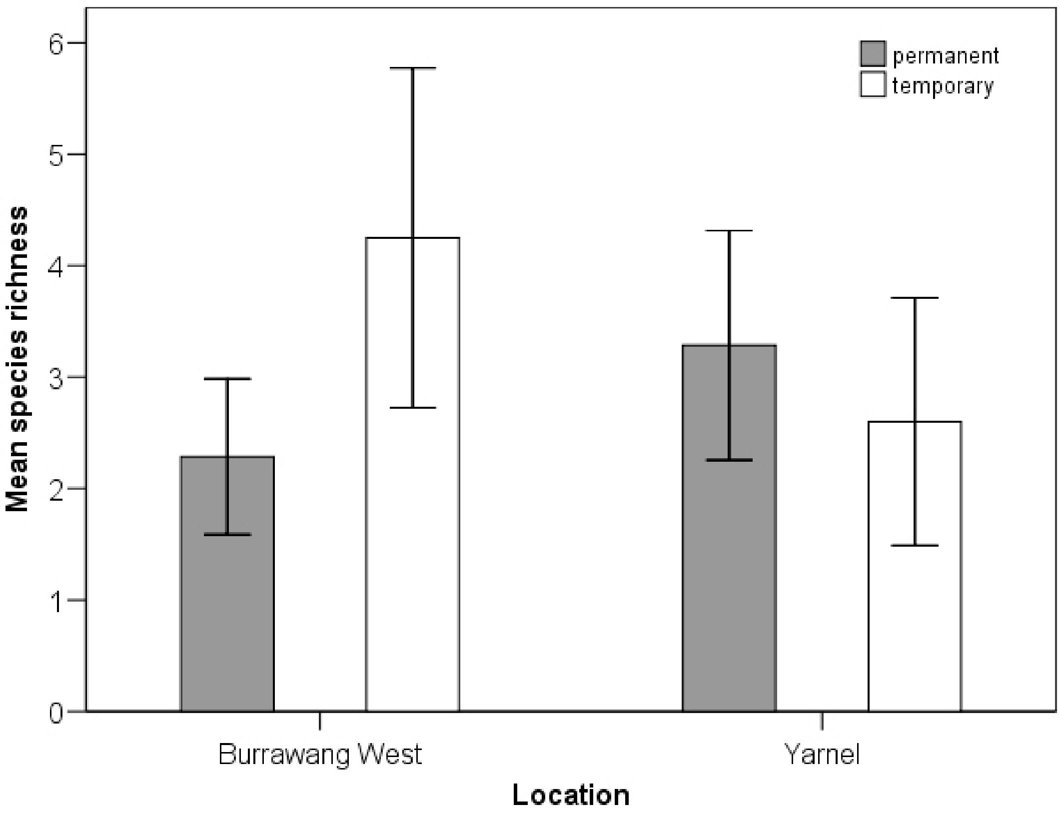


Figure 5 Mean (± Standard Error) species richness in permanent and temporary sample sites at 'Burrawang West' and 'Yarnel'.

3.3 Patterns of habitat occupancy

Patterns of habitat occupancy by individual species were linked to the habitat features at each study site. Study sites occupied by *Litoria peronii* were on average, deeper, with higher percentages of open water and greater amounts of dead standing timber (Table 3; Figure 6). The patterns of habitat occupancy of other species reflected their preference for temporary waterbodies. *Litoria latopalmata* occupied sites with shallow water and less than 40% open water (Table 3, Figure 7a). *Crinia parinsignifera* also occupied sites with shallow water and a high diversity of microhabitats (Table 3, Figure 7b). Sites occupied by *Limnodynastes fletcheri* generally had a high percentage cover of tall emergent vegetation (mainly *Typha sp.*) although the low number of sites where this species was absent means that the power of this relationship is weak (Table 3, Figure 7c).

Table 3 T-test results for the differences in water chemistry and habitat parameters at sites where each frog species was present or absent. Only variables with significant results are included in the table. Variables that have been excluded from the table are: pH, Percent cover submerged vegetation and Continuity of overhanging vegetation**.** Bold entries indicate statistically significant results.

		L. peroni	*L. latopalmata*	*C. parinsignifera*	*L. fletcheri*	*L. interioris*	*L. tasmaniensis*
Conductivity	t	1.092	-0.306,	1.444	-2.389	1.858	-1.834
	sig	0.316	0.763	0.174	0.032	0.078	0.081
Water temperature	t	2.789	-0.884	-0.450	-1.150	0.352	-1.336
	sig	**0.032**	0.389	0.658	0.316	0.732	0.196
Water depth at 200cm	t	-4.311	3.267	2.352	0.569	-1.320	1.176
	sig	**0.000**	**0.004**	**0.035**	0.603	0.293	0.261
Number of microhabitats	t	-1.260	-0.611	-3.963	0.673	0.439	0.351
	sig	0.256	0.551	**0.006**	0.561	0.687	0.732
Percent cover open water	t	-3.030	2.086	1.094	1.067	-0.915	1.678
	sig	**0.009**	**0.050**	0.299	0.361	0.429	0.109
Percent cover emergent vegetation	t	-1.711	-0.957	-0.086	-2.575	0.461	-0.966
	sig	0.121	0.361	0.936	**0.029**	0.678	0.345
Percent cover floating vegetation		0.263	0.865	-0.061	0.087	1.174	-0.236
		0.035	0.397	0.954	0.934	0.307	0.816
Dead standing timber	t	-2.327	1.366	-0.259	2.704	0.416	1.145
	sig	**0.043**	0.188	0.804	0.090	0.692	0.277

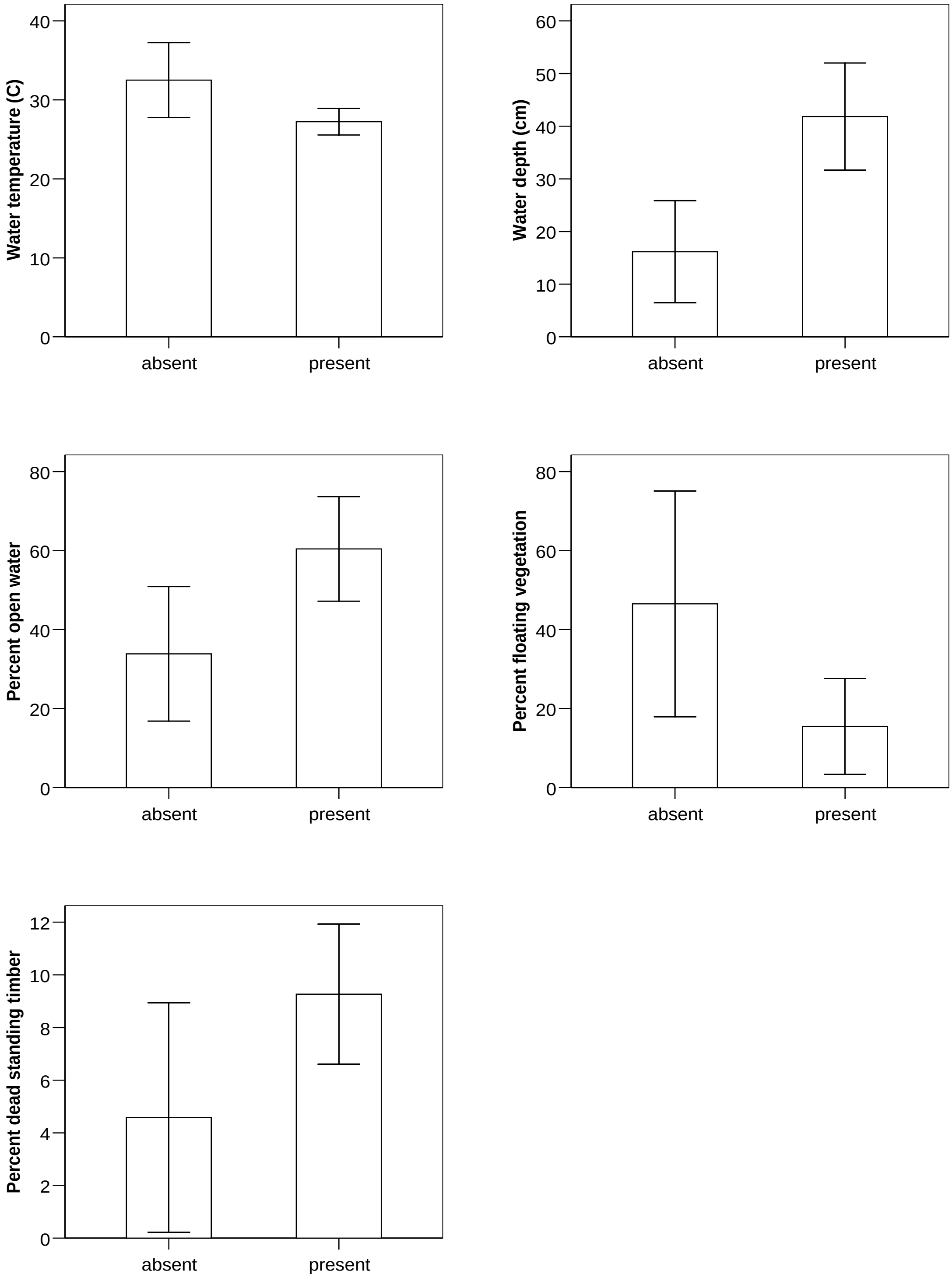
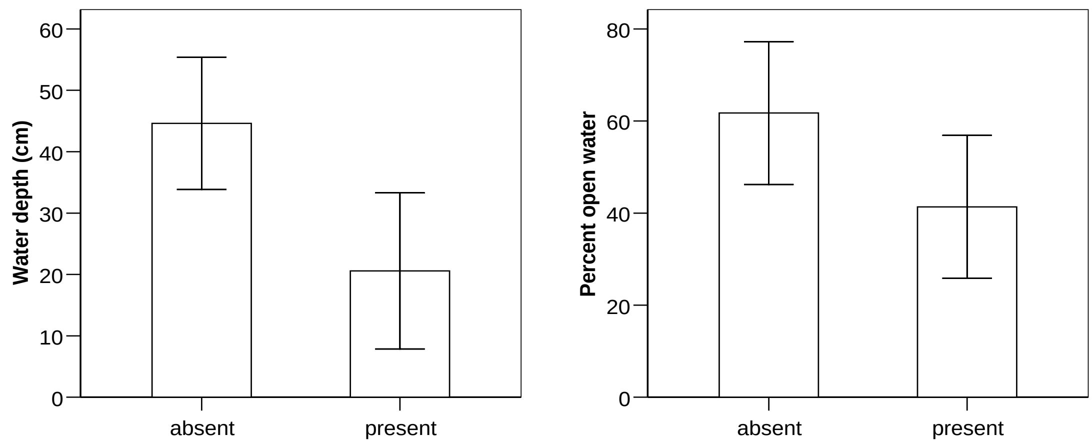
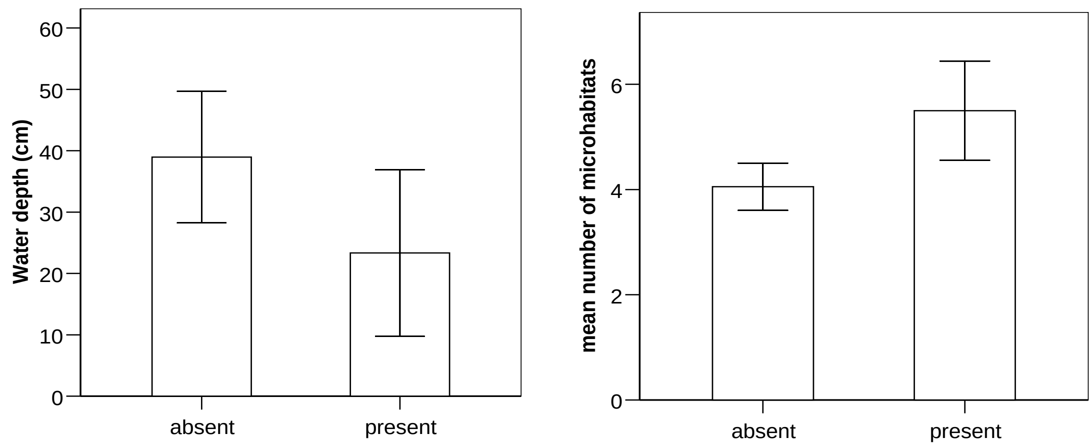


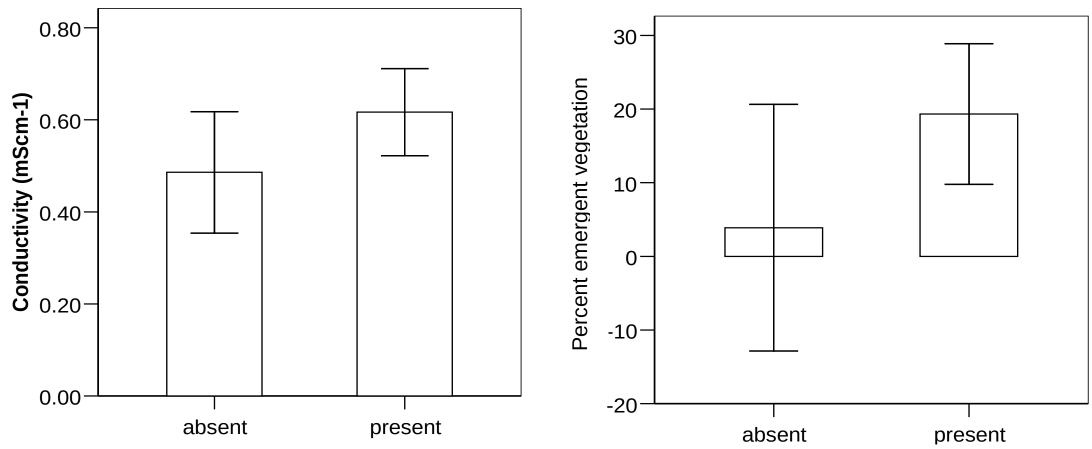
Figure 6. Mean (± Standard Error) habitat and water chemistry variables at sample sites where *L. peronii* was absent (n=5) and present (n=18). Only variables that were significantly different have been plotted.



(a) ***L. latopalmata***



(b) ***C. parinsignifera***



(c) ***L. fletcheri***

Figure 7. Mean (± Standard Error) habitat and water chemistry variables at sample sites where (a) *L. latopalmata* was absent (n=15) and present (n=8), (b) *C. parinsignifera* was absent (n=19) and present (n= 4) and (c) *L. fletcheri* was absent (n=3) and present (n= 20). Only variables that were significantly different have been plotted.

3.4 Breeding sites

Tadpoles and recent metamorphs were recorded for five of the seven species present in this study. Despite persistent calling activity we did not identify egg masses, tadpoles or metamorphs of *L. peronii* or *Limnodynastes interioris.* Of the six sites where breeding activity occurred five had temporary water regimes, while one was a well vegetated site with a permanent water regime. Breeding sites were significantly shallower than non-breeding sites ($t = 3.476$, $p = 0.002$) and had a higher percent cover of aquatic vegetation ($t = -2.344$, $p = 0.029$) (Figure 8).

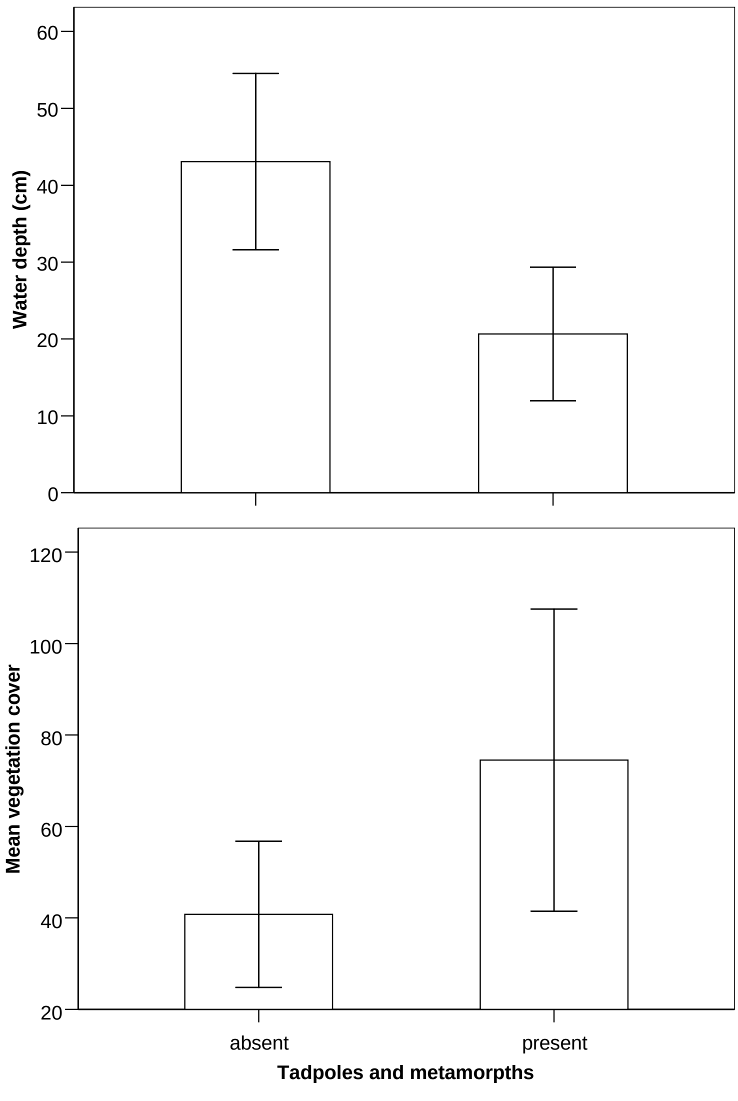


Figure 8 Mean (± Standard Error) habitat variables at sample sites where frog breeding was present (n=6) and absent (n=17). Only variables that were significantly different have been plotted.

4.0 Discussion

At total of seven frog species was identified from within the two properties. The timing of the surveys in mid and late summer meant that the winter and spring active species such as members of the *Crinia* and *Uperoleia* genus and *Neobatrachus sudelli* were either absent or under represented in this study. The timing of our surveys and the prevailing dry conditions also meant that this study focused on the identification of summer refuge habitats rather than breeding habitats. These observed patterns of occupancy are likely to change over time and in response to changing habitat availability, particularly flooding (Wassens, 2006).

The hydrology of the wetland systems on both properties has been altered by the construction of weirs. This has resulted in increased water permanence, increased water depth and a subsequent decline in vegetation diversity in some areas. During this study, the composition of frog communities separated into two distinct groups; those occurring in temporary habitats and those occurring in more permanent habitats within the channel. Temporary waterbodies are favoured by many frog species because they have lower fish densities (Baber et al. 2004) and generally more complex vegetation (Warwick and Brock 2003). Temporary sites were favoured as summer breeding habitats for the same reasons. The tendency of *Litoria latopalmata*, *Limnodynastes tasmaniensis* and *Crinia parinsignifera* to occupy sites with shallow water may reflect their preference for more temporary, better vegetated sites.

Of the more commonly occurring species, *Limnodynastes fletcheri* showed little preference for temporary or permanent sites, but tended to occupy sites with a higher percentage of emergent vegetation. *Litoria peronii* was more likely to occur in permanent sites, with deep open water and abundant dead standing timber. However, it must be noted that the patterns of habitat occupancy by *L. peronii* in particular, reflect the use of summer refuge rather then breeding habitats. *L. peronii* tends to forage and refuge around permanent water, but is most likely to breed in semi-permanent or temporary habitats (Cogger 2000).

Breeding was attempted in temporary habitats by *Litoria rubella, Litoria latopalmata, Limnodynastes tasmaniensis* and *Crinia parinsignifera* however it was not clear if these breeding attempts were successful, because the temporary sites dried up relatively quickly. Successful recruitment of *L. fletcheri* and *L. tasmaniensis* occurred in shallow, well vegetated permanent areas at Burrawang West. The distribution of both of these habitats was limited during this study, due partly to the dry conditions and partly because of increasing water permanence within the channel as a result of weir construction (historically temporary sites have become more permanent).

4.1 Response to flooding

All the species identified during this study preferentially breed in flooded habitats and are likely to respond positively to flooding. The response of individual species in terms of breeding activity and recruitment success will vary depending on the following criteria (1) the timing of inundation, (2) the length of time that flood water remains in temporary water bodies, and (3) the habitat features of flooded habitats, e.g aquatic vegetation, the presence of standing timber and water depth (Table 4). As can be seen from Table 4 some species vary in their sensitivity to these parameters. For example *Litoria caerulea* only breeds in temporary wetlands in summer and these wetlands need to hold water for at least 2 months in order for tadpoles to reach metamorphosis. In contrast, *Litoria rubella* will breed opportunistically in any temporary water body and is relatively insensitive to the timing of flooding and short hydroperiods. In theory a flooding event timed to suit *L. caerulea* would also benefit *L. rubella* and a range of other summer breeding species, assuming that no competitive exclusion occurs. Based on a combination of our field data and published information we have developed hypotheses on the response of frog species to differing flooding regimes (Table 5). We have also developed recommendations and monitoring protocols for groups of frog species that are likely to respond in a similar way to the recommended hydrological regimes (Table 6)

Table 4. Summary of the breeding habitat requirements of frogs potentially occurring in the mid-Lachlan region. Occurrence is based on the present surveys, NSW NPWS atlas data, the Australian Museum and (Magarey and White 2003). Breeding habitat is based on present surveys and information from (Cogger 2000). ? indicates insufficient data.(Barker and Grigg 1977; Robinson 1998; Anstis 2002)

	Survey results		Preferred hydrology of breeding sites[1]			Timing of breeding[1]				Tadpole lifespan (months)	
Species	**Occurrence at study sites (% of sites)**	**Preferred habitat**	**Temporary**	**Semi-perm**	**permanent**	**autumn**	**winter**	**spring**	**summer**	**lower**	**upper**
Litoria caerulea	Not recorded		*						*	2	?
Cyclorana platycephala	Not recorded		*					*	*	1	2
Litoria rubella	0.04		*				*	*	*	1	?
Crinia Sloanei	Not recorded		*				*	*		2	3
Crinia signifera	Not recorded		*	*			*	*		2	3
Crinia parinsignifera	0.17	diversity	*	*			*	*	*	3	?
Litoria peronii	0.78	Dead standing timber	*	*				*	*	3.5	?
Uperoleia rugosa	Not recorded		*	*				*	*	3.5	?
Litoria latopalmata	0.35	Aquatic cover	*	*	*			*	*	?	?
Limnodynastes tasmaniensis	0.65	No	*	*	*		*	*	*	3	?
Limnodynastes fletcheri	0.87	Emergent veg.		*	*		*	*	*	3[1]	?
Limnodynastes interioris	0.13	No		*	*		*	*	*	6	?
Neobatrachus sudelli	Not recorded			*	*	*	*	*		4	7

1. Assuming similar requirements to *L. tasmaniensis* which has very similar tadpoles

Table 5 Hypotheses of frog species responses to different flooding regimes. The number of species that have been observed at Burrawang West and Yarnel and could potentially respond to these regimes are shown. The total number of species that could respond is shown in brackets. This includes species that were not observed but that could potentially occur on these properties.

Habitat	Timing	No. species that could potentially respond	Min hydro-period for successful recruitment of all species	Hypothesis
Temporary	autumn	0 (1)	4 months	• If temporary habitats are flooded in autumn and *Neobatrachus sudelli* is present on the two properties, then it may commence calling activity. • Successful recruitment will occur if waterbodies remain flooded for four months.
	winter	3 (5)	3 months	• If temporary habitats are flooded in winter then the three species that are currently present on the two properties will respond and a further two may respond if they occur on either property. • Assuming that all species are present, successful recruitment of the five species in this group will occur if waterbodies remain flooded for 3 months.
	spring	5 (9)	3.5 months	• If temporary habitats are flooded in spring then five species that are currently present on the two properties will commence calling and a further four species may respond if they occur on either property. • Assuming that all species are present, successful recruitment may occur for four species if water remains for 2 months, and a further four species may recruit if water remains for 3 months
	summer	6 (8)	3.5 months	• If temporary habitats are flooded in summer then a breeding response will occur for six species that are currently present on the two properties and a further two species may respond if they occur on either property. • Assuming that all species are present, successful recruitment may occur for three species if water remains for 2 months, and a further 4 species will recruit if water remains for 3.5 months

Habitat	Timing	No. species that could potentially respond	Min hydro-period for successful recruitment of all species	Hypothesis
Semi-permanent and permanent	autumn	0 (1)	4 months	• If semi-permanent habitats are flooded in autumn and *Neobatrachus sudelli* is present in on the two properties, then it may commence calling activity. • Successful recruitment will occur if waterbodies remain flooded for four months.
	winter	4 (6)	6 months	• If semi-permanent habitats are flooded in winter then four species that are currently present on the two properties may respond and a further two may respond if they occur on either property. • Assuming that all species are present, successful recruitment of 4 species will occur if water remains for 3 months all species may respond if water remains for 6 months
	spring	6 (9)	6 months	• If semi-permanent habitats are flooded in spring then six species that are currently present on the two properties may respond and a further three species may respond if they occur on either property. • Assuming that all species are present, successful recruitment of 7 species will occur if water remains for 3.5 months all species may respond if water remains for 6 months
	summer	6 (7)	6 months	• If semi-permanent habitats are flooded in summer then six species that are currently present on the two properties may respond and a further one may respond if they occur on either property. • Assuming that all species are present, successful recruitment of 6 species will occur if water remains for 3.5 months, all species may respond if water remains for 6 months

4.2 Management recommendations

Recommendation 1

Competition between different tadpole species and predation of smaller species of frogs and their metamorphs by larger species such as *Litoria peronii* may be a significant factor in structuring frog communities at a single location. It is possible that some species trade off the risks associated with failed recruitment due to drying against the risk of predation and competition by frog species that occur in more persistent waterbodies. Emphasis should therefore be on creating a mosaic of waterbodies with different hydroperiods and conditions rather than attempting to manage a single area for as many species as possible. Management and monitoring recommendations to maintain a mosaic of habitats is shown in Table 7

Recommendation 2

Litoria caerulea has previously been recorded in the region and was expected to be active during the survey period. This species is believed to have declined significantly from within the Murrumbidgee catchment (Wassens 2006b) and the status of this species in the Lachlan region is uncertain. In addition the Southern Bell Frog (*Litoria raniformis*) has previously been recorded from within the Lachlan Catchment but is likely to be locally extinct. Information on the types of habitats traditionally occupied by these species in the region is limited. As a result it is not possible to make recommendations on the potential for reintroduction of either of these species to either property.

Recommendation 3

It is not necessary to flood wetlands during both spring and summer within a single year; instead the timing of flooding can be varied across years. Temporal variability in flooding regimes may benefit frog diversity because it will allow different groups to recruit across different years. This may also be more achievable when water is limited.

Recommendation 4

The main channels at both locations are presently deep with limited vegetation. Drawing down water levels in summer (but not drying the system out completely) may increase vegetation diversity, particularly at Burrawang West where the water levels appear to be relatively constant. Higher levels of aquatic vegetation have been shown to support more species of frogs (Jansen and Healey, 2003).

Recommendation 5

The weir overflow area (down stream of the weir) on Burrawang West represents high quality frog habitat, particularly for species that favour temporary water bodies. Care should be taken to ensure that the water regime in this area remains temporary, with a hydroperiod of no more than 3 months. Increasing the hydroperiod in this area is likely to result in a decline in species diversity due to loss of temporary breeding habitat. Yarnel Lagoon also has the potential to provide excellent frog habitat if flooded to its full extent. Maintenance of this site for frogs will also benefit water birds.

Recommendation 6

The current level of grazing at both properties does not appear to have an adverse impact on fringing vegetation so current or lower levels of stocking are recommended. Increasing stock density may result in reduced aquatic and fringing vegetation cover (Jansen and Robertson 2001). Declining vegetation cover and condition will have negative impacts on many of the frog species presently occurring at both properties (Jansen and Healey 2003).

Recommendation 7

Call recording is an effective way to monitor calling activity over time. Call recorders can be set out and left for extended periods and as such are useful for identifying rare or infrequently calling species. A minimum of four call recorders should be established at each site. On Yarnel recommended locations for the call recorders are the Yarnel Lagoon (sites 19), the weir pool (site 21) as well as site 18 and site 13 at the eastern end of

Wallaroi Creek. At Burrawang West call recorders should be established in the temporary waterbodies down stream of the weir (sites 10 and 11), near the junction of Goobang and Yarrabandai Creek (site 9) and the eastern end of Goobang Creek (site 6). While these sites are recommended, it is important to maintain some level of flexibility and to reassess these locations as more information on flooding patterns and habitats becomes available. Call recording should commence prior to flooding and then be monitored for as long as possible after flooding (Table 6 and 7).

Visual surveys for adults, metamorphs and tadpoles will need to be conducted on at least four occasions for each habitat type. Visual surveys should be conducted at all sites prior to flooding as this will establish which species are active and have the potential to respond to a flood event. This information can be measured against those species that actually respond to the flood event, giving an indication of the success of the flooding regime. Visual surveys should also be conducted after flooding to assess the abundance of metamorphs which provides a measure of recruitment success (see Table 6 and Table 7 for timing of surveys).

Tadpole surveys assist in monitoring breeding activity. There are two methods commonly employed to survey tadpoles, sweep netting and bait trapping. Bait trapping is recommended because it is more effective in areas of dense aquatic vegetation and provides a quantitative measure of abundance. Ideally tadpole surveys should be conducted at as many locations as possible, but at least at sites designated for call recording (sites 6, 9, 10, 11, 13, 18, 19 and 21).

Table 6 General timeline for monitoring on both properties. Timings are a guide only and may be modified depending on the timing of flooding and prevailing climatic conditions. Tad = tadpole surveys, Met = metamorph surveys, visual= pre flooding visual surveys, flood = likely flooding time.

Habitat	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Spring temporary	Visual	Flood	Tad	Met					
Spring semi-permanent		Flood		Tad		Tad	Meta		
Summer temporary				Visual	Flood		Tad		

4.3 Limitations and future directions

The surveys for this study were undertaken in summer. Consequently winter and spring breeding species were either absent or under represented in this study. As a result, the placement of these species into management groups was based solely on their tadpole lifespan and timing of breeding and does not incorporate their needs in terms of vegetation, over wintering sites or summer refuge habitats.

The habitat preferences and breeding biology of the species occurring in the Lachlan region are very poorly understood. This lack of information, particularly regrading tadpole lifespan limits our ability to make sound predictions on the water requirements of most species. Most of the data on tadpole lifespan used here is from laboratory trials conducted under ideal conditions e.g (Anstis 2002). In natural systems, tadpole lifespan is influenced by a number of factors including temperature (Anstis 2002), inter and intra specific competition (Bardsley and Beebee 1998) and water quality (Boone and Semlitsch 2002). Many species are also capable of accelerating metamorphosis in response to pond drying (Ryan and Winne 2001). Monitoring of breeding responses, tadpole development and recruitment following flooding is essential so that future flooding practices can be modified to more accurately reflect their needs.

At the broader scale, information on the faunal composition and biological characteristics of key wetland systems and in-stream channels throughout the Lachlan Catchment is presently limited. This lack of knowledge currently represents a major obstacle in terms of the allocation of environmental water. Identification of key wetlands, faunal communities and species within the region would assist in decision making regarding environmental water allocations. Similarly, better understanding of the water needs (frequency, timing and duration of inundation) of key wetland fauna such as frogs, turtles and water birds would greatly improve our capacity to make decisions for the successful recruitment of key fauna to occur. While this study greatly extends our knowledge of the water requirements of frog species within the study area, extending this research to other wetlands and potentially other taxa would allow for a more strategic approach to environmental water allocations within the catchment.

Table 7. Recommendations for flooding regimes and habitat management to maintain a mosaic of different habitats, potential species responses and monitoring regimes.

	Temporary habitats, spring	**Temporary habitats, summer**	**Permanent and semi-permanent habitats spring**
Species observed that are likely to respond	*Litoria rubella, Crinia parinsignifera, Limnodynastes tasmaniensis*	*Litoria rubella, Crinia parinsignifera, Limnodynastes tasmaniensis, Litoria latopalmata*	*Crinia parinsignifera, Litoria peronii, Limnodynastes tasmaniensis, Litoria latopalmata, Limnodynastes fletcheri, Limnodynastes interioris*
Species potentially responding	*Crinia sloanei, Crina signifera, Cyclorana platycephala*	*Litoria caerulea, Cyclorana platycephala*	*Neobatrachus sudelli, Uperoleia rugosa*
Timing of inundation	Spring	Early summer	Spring or Summer
Hydroperiod	3 months	3 months	6 months
Habitat characteristics (based on surveys data)	Maintain fringing vegetation[1]	> 50% aquatic cover	Maintain fringing vegetation[1], > 20% emergent vegetation and standing timber
Water depth (based on surveys data)	Shallow 20-30cm	Shallow 20-30cm	No preference
Monitoring regime	Record calling at the onset of flooding Monitor tadpole development at 2 months after flooding, and search for metamorphs at 3 months	Record calling at the onset of flooding Monitor tadpole development at 2 months after flooding, and search for metamorphs at 3 months	Record calling at the onset of flooding Monitor tadpole development at 3 and 5 months after flooding, and search for metamorphs at 6 months
Management interventions for each habitat type	Reduce grazing pressure or exclude stock while waterbodies are full in order to maintain fringing vegetation	Reduce grazing pressure or exclude stock while waterbodies are full in order to maintain aquatic vegetation cover	Maintain dead standing timber Avoid burning or removing tall emergent vegetation during spring and summer Draw down water in sections of the channel to encourage vegetation growth and reduce fish densities*

[1] Jansen and Healey 2003

5.0 Reference List

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Appendix 1.

Summary of habitat variables at each sample site.

Property	Sample site	Easting	Northing	Hydrology	Turbidity (NTU)	Conductivity ($mScm^{-1}$)	pH	Water temperature	Water depth (cm)	Microhabitat number	% open water	% floating vegetation	% tall emergent	% short emergent	% submerged veg.	Continuity fringing	% DST	Erosion score
Burrawang West	1	543304	6331859	temporary	38.5	0.54	7.21	22.9	20.0	4.3	3.3	1.7	53.3	43.3	38.3	0.0	5.0	0.0
	2	542927	6331839	permanent	22.7	0.52	7.30	22.8	36.6	5.3	5.0	81.7	23.3	0.0	6.7	1.7	6.7	0.0
	3	545481	6330340	permanent	37.6	0.54	7.68	23.7	41.6	3.3	70.0	23.3	0.0	0.0	0.0	13.3	16.7	0.0
	4	544837	6330592	permanent	21.3	0.49	7.81	25.4	56.6	3.3	86.7	5.0	0.0	0.0	0.0	11.7	16.7	0.0
	5	544673	6330939	permanent	25.1	1.22	7.47	24.2	28.3	4.0	86.7	53.3	0.0	0.0	6.7	13.3	13.3	0.0
	6	544331	6331141	temporary	37.6	0.45	7.50	28.0	8.3	5.0	36.7	45.0	0.0	11.7	46.7	25.0	1.7	0.0
	7	543556	6330644	permanent	34.9	0.43	7.49	24.9	39.1	6.0	70.0	34.2	11.7	5.0	2.5	6.7	20.0	0.0
	8	542420	6330966	permanent	23.4	0.41	7.40	25.9	73.3	5.0	83.3	6.7	1.7	5.0	1.7	10.0	8.3	0.0
	9	542436	6331423	permanent	32.0	0.43	7.35	27.8	33.3	6.2	40.0	55.0	12.5	13.3	4.2	4.2	4.2	0.0
	10	541355	6331773	temporary	24.4	0.49	7.69	29.6	15.8	5.8	65.0	5.0	2.5	25.0	4.2	14.2	13.3	5.0
	11	541011	6331720	temporary	22.9	0.54	7.41	29.5	27.5	5.0	45.0	30.0	0.0	11.3	6.3	5.0	10.0	5.0
Yarnel	12	509096	6326606	temporary	30.0	0.48	7.60	33.9	70.0	4.0	80.0	5.0	0.0	5.0	5.0	0.0	5.0	10.0
	13	508510	6326590	permanent	33.4	0.51	7.47	27.5	56.6	3.7	90.0	0.8	5.0	0.0	0.0	22.7	7.7	7.5
	14	508181	6326281	permanent	28.7	0.50	7.47	26.9	46.6	4.7	46.7	3.3	48.3	0.0	0.0	17.0	6.7	3.3
	15	507677	6325707	permanent	27.2	0.52	7.51	26.8	73.3	3.7	63.3	0.0	33.3	0.0	1.7	10.0	5.0	3.3
	16	507337	6325658	permanent	19.0	0.53	7.57	25.6	57.5	4.0	90.0	0.0	10.0	0.0	0.0	30.0	16.3	10.0
	17	506628	6325968	permanent	29.8	0.57	7.49	29.5	20.8	4.2	66.7	0.0	31.7	0.0	2.5	18.3	5.8	0.0
	18	506301	6325520	permanent	25.7	0.63	7.52	28.1	16.6	5.0	35.0	1.7	58.3	0.0	5.0	3.3	7.5	0.0
	19	506580	6326212	temporary	100.	0.86	8.14	35.0	11.2	2.8	47.5	0.0	42.5	0.0	10.0	0.0	1.3	0.0
	20	506739	6326187	temporary	108.	0.98	8.73	36.9	20.0	2.8	37.5	27.5	32.5	0.0	2.5	0.0	1.3	5.0
	21	506503	6326417	permanent	27.0	0.68	7.56	29.0	55.0	5.0	58.3	1.7	31.7	1.7	0.0	11.7	7.5	0.0
	22	506470	6326621	temporary	20.0	0.74	7.00	35.7	15.0	3.0	10.0	85.0	0.0	0.0	0.0	0.0	5.0	5.0
	23	506470	6326547	temporary	30.0	0.72	7.55	32.1	10.0	3.0	40.0	45.0	0.0	0.0	0.0	0.0	5.0	10.0

Appendix 2

Summary of species recorded across all three survey periods

Sample site	property	easting	northing	*L. latopalmata*	*L. peronii*	*L. rubella*	*C. parinsignifera*	*L. fletcheri*	*L. interioris*	*L. tasmaniensis*
1		543304	6331859	*	*			*		*
2		542927	6331839		*			*		*
3		545481	6330340		*			*		
4		544837	6330592		*					*
5		544673	6330939		*			*		*
6	Burrawang west	544331	6331141	*				*		*
7		543556	6330644		*					
8		542420	6330966		*			*		
9		542436	6331423		*		*	*		
10		541355	6331773	*	*		*	*		*
11		541011	6331720	*		*	*		*	*
12		509096	6326606		*			*		*
13		508510	6326590		*			*	*	*
14		508181	6326281		*			*		*
15		507677	6325707		*			*	*	
16		507337	6325658		*			*		
17	Yarnel	506628	6325968		*			*		
18		506301	6325520	*	*		*	*		*
19		506580	6326212	*	*			*		
20		506739	6326187					*		*
21		506503	6326417	*	*			*		*
22		506470	6326621					*		*
23		506470	6326547	*				*		

* indicates species presence

Appendix 3

Species occurrence at each sample site on each of the three survey periods

Survey date	Property	*Sample Site*	*C. parinsignifera*	*L. fletcheri*	*L. latopalmata*	*L. peronii*	*L. rubella*	*L. tasmaniensis*	*L.interioris*	Total species
16th of January	**Burrawang West**	1	0	1	1	1	0	1	0	**4**
		2	0	1	0	1	0	1	0	**3**
		3	0	0	0	0	0	0	0	**0**
		4	0	0	0	0	0	0	0	**0**
		5	0	0	0	0	0	0	0	**0**
		6	0	0	0	0	0	1	0	**1**
		7	0	1	0	1	0	1	0	**3**
		8	0	1	0	1	0	0	0	**2**
		9	0	1	0	1	0	0	0	**2**
		10	1	1	1	1	0	1	0	**5**
		11	1	0	1	0	1	1	0	**4**
15th January	**Yarnel**	12	0	0	0	1	0	1	0	**2**
		13	0	1	0	1	0	1	0	**3**
		14	0	1	0	1	0	1	0	**3**
		15	0	1	0	1	0	0	0	**2**
		16	0	1	0	1	0	0	0	**2**
		17	0	1	0	1	0	0	0	**2**
		18	1	1	1	1	0	1	0	**5**
		19	0	1	1	1	0	1	0	**4**
		20	0	0	0	0	0	0	0	**0**
		21	0	1	1	1	0	1	0	**4**
		22	0	1	0	0	0	1	0	**2**
		23	0	1	0	0	0	1	0	**2**
30th of January	**Burrawang West**	1	0	1	0	0	0	0	0	**1**
		2	0	1	0	1	0	1	0	**3**
		3	0	0	0	1	0	0	0	**1**
		4	0	0	0	1	0	0	0	**1**
		5	0	1	0	1	0	1	0	**3**
		6	0	0	1	0	0	1	0	**2**
		7	0	0	0	1	0	0	0	**1**
		8	0	1	0	1	0	0	0	**2**
		9	0	1	0	1	0	0	0	**2**
		10	1	1	1	1	0	1	0	**5**
		11	0	0	0	0	0	0	1	**1**
31st January	**Yarnel**	12	0	1	0	0	0	1	0	**2**
		13	0	1	0	1	0	0	1	**3**
		14	0	1	0	0	0	1	0	**2**
		15	0	1	0	0	0	0	1	**2**
		16	0	1	0	1	0	0	0	**2**
		17	0	1	0	1	0	0	0	**2**
		18	0	1	0	1	0	0	0	**2**
		19	0	0	0	1	0	0	0	**1**
		20	0	0	0	0	0	0	0	**0**
		21	0	1	1	1	0	1	0	**4**
		22	0	1	0	0	0	0	0	**1**
		23	0	1	0	0	0	0	0	**1**

Survey date	Property	Sample Site	*C. parinsignifera*	*L. fletcheri*	*L. latopalmata*	*L. peronii*	*L. rubella*	*L. tasmaniensis*	*L.interioris*	Total species
7th of March	**Burrawang West**	1	0	1	0	0	0	1	0	2
		2	0	1	0	0	0	0	0	1
		3	0	1	0	1	0	0	0	2
		4	0	1	0	0	0	0	0	1
		5	0	0	0	1	0	0	0	1
		6	0	0	0	0	0	0	0	0
		7	0	0	0	0	0	0	0	0
		8	0	1	0	0	0	0	0	1
		9	0	1	0	0	0	1	0	2
		10	0	0	0	0	0	0	0	0
		11	0	1	0	0	0	1	0	2
8th of March	**Yarnel**	12	0	1	0	0	0	1	0	2
		13	0	1	0	0	0	1	0	2
		14	0	1	0	1	0	0	0	2
		15	0	0	0	0	0	1	0	1
		16	0	1	0	1	0	0	0	2
		17	0	1	1	0	0	0	0	2
		18	0	0	0	0	0	0	0	0
		19	0	0	0	0	0	0	0	0
		20	1	0	0	0	0	0	0	1
		21	1	0	0	0	0	1	0	2
		22	0	0	0	0	0	0	0	0
		23	1	0	0	0	1	1	0	3