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Flooding regimes for frogs in lowland rivers of the Murray-Darling Basin

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Abstract

The Murray-Darling Basin supports 31 frog species, three of which, *Litoria raniformis, Litoria booroolongensis* and *Crinia sloanei,* are listed under the Environment Protection Biodiversity Conservation Act 1999 and a number of others are in serious decline. Frogs occur in nearly all freshwater habitats within the basin, from rain fed ephemeral pools to permanent lakes and rivers. The response of frog populations to the flooding is comparably easy to predict, but must consider large scale factors such as the spatial arrangement of waterbodies along with finer scale parameters such as wetland hydrology, vegetation and predator abundances. Combinations of these parameters have been used with success to predict the status of *Litoria raniformis* populations and their response to flooding. However, our results indicate that the relative importance of these parameters vary between different types of wetlands. A detailed understanding of the interactions between multiple parameters is essential when modelling how frog populations will respond to flooding management.

Introduction

The Murray-Darling Basin supports 31 frog species, three of which, *Litoria raniformis, Litoria booroolongensis* and *Crinia sloanei,* are listed nationally as vulnerable or endangered under the Environment protection Biodiversity Conservation Act 1999 (EPBC Act). Frogs occur in nearly all freshwater habitats within the basin, from ephemeral rain-fed pools in semi-arid regions to permanent lakes and streams across the Great Dividing Range. Frogs are biphasic (have a distinct tadpole and adult frog stage) and the species present in the Murray-Darling Basin all require standing water for reproduction and tadpole development. These species also exhibit a range of behavioural and physiological adaptations which allow them to persist in landscapes where water resources are often variable over space and time. Around half of the Murray-Darling Basins frogs are classed as burrowing species. The ability to burrow, coupled with an ability to slow down their metabolism to minimise energy and water use, allows these species to survive underground for extended periods (Withers and Thompson 2000). Burrowing species are common in wetlands within the drier areas of the Murray-Darling Basin, such as the Darling River system, where water resources are most variable. Non- burrowing species are common in areas with more persistent waterbodies and reliable flooding. Although they do not have specific adaptations for burrowing, this group can survive for short periods by sheltering in moist locations such as logs, mats of vegetation and in deep clay cracks. Non-burrowing species may also abandon wetlands as they dry in favour of nearby permanent waterbodies, as is the case for *Litoria raniformis* (Wassens *et al.* 2008b). This chapter will focus on non-burrowing species as this group is most likely to be impacted by flow regulation and environmental watering.

The response of frogs to flooding is rarely considered when planning environmental flow strategies. This may be due to the misconception that frogs are poorly understood and difficult to predict or that their requirements are catered for when targeting other taxonomic groups. This chapter outlines the key parameters that drive the response of frog communities following wetland flooding and presents a case study of flooding management to maintain populations of a threatened frog species. The chapter starts out describing how broad scale parameters such as the spatial distribution of waterbodies and connectivity influences frog community structure and their response to flooding. Following this, the key factors that influence frog occupancy patterns and recruitment success at individual wetlands are described.

Landscapes and Mosaics

Many frog species can move reasonable distances overland in order to access resources (Harrison and Taylor 1997; Marsh *et al.* 1999; Marsh *et al.* 2000; Marsh and Trenham 2001; Trenham *et al.* 2001; Smith and Green 2005). This movement between waterbodies, whether a one-off dispersal movement or when moving regularly in response to changes to the distribution of waterbodies, plays an important role in determining the persistence of frog populations and how they respond to flooding.

Movement between waterbodies is important at two different spatial and temporal scales. At large scales the proximity and degree of connectivity between waterbodies determines the potential for recolonisation of waterbodies following local extinctions (Smith and Green 2005). This can be an important consideration when predicting and monitoring the outcomes of environmental watering at wetlands that have been dry for an extended period (more than three years). If the area targeted for watering is isolated and potential movement corridors, such as flood runners or canals, are limited, than the ability of frogs to recolonise the wetland will also be limited. As a result the response of frogs (in terms of increases in diversity and abundance) may be limited when compared to the response of more mobile species such as waterbirds.

At smaller scales, floodplain wetlands typically occur within a mosaic of water waterbodies with differing hydrological regimes, for example a permanent river or stream which is associated with seasonally flooded ox-bow lagoons and temporary rain-fed depressions. Individuals of many frog species regularly move around the “wetland mosaic” in response to wetting and drying patterns (Marsh *et al.* 2000; Wassens *et al.* 2007b; Wassens *et al.* 2008b). For example, *Litoria raniformis* occupies permanent waterbodies during dry periods but will immediately abandon these sites in favour of newly flooded areas even though the habitat characteristics of permanent waterbodies remain unchanged (Wassens *et al.* 2008b). Breeding is more likely to occur in newly flooded areas than in permanent waterbodies and adults along with the new generation can move quite long distances to return to permanent waterbodies during dry periods (Schwarzkopf and Alford 2002; Wassens *et al.* 2008b). A very simplified example of this processes is shown in Figure 1, here frogs occupy permanent waterbodies during dry periods, move into temporary waterbodies to breed and then retreat back to permanent waterbodies along with the new recruits. One of the most important consequences of this opportunistic habitat use is that past flooding history across the mosaic can play the same or even greater role in driving abundance and persistence than habitat features at a particular point in time (especially during dry periods). That is, frogs congregate within permanent waterbodies during dry periods and can appear to be very abundant, but this is often due to past flooding of surrounding areas. The second important consideration when planning environmental flooding is that the proximity and condition of permanent waterbodies in the area will influence how frogs respond to flooding. From a manager's perspective simply asking the question *"where is the nearest permanent waterbody?"* and *"does it look OK?"* when targeting environmental water can give a good indication of which frog species will be present and how they will respond to flooding.

Local habitat features

In addition to the mosaic structure, a number of wetland parameters can be important in predicting which frog species will be present and how they will respond to a specific flooding event. Wetland hydroperiod, flooding frequency, the timing of inundation, vegetation structure, predator abundance and inter and intraspecific competition can also influence recruitment outcomes and community composition (Babbitt and Tanner 2000; Semlitsch 2000; Snodgrass *et al.* 2000; Hazell 2003).

Hydroperiod

Tadpole lifespan (time from egg to complete metamorphosis) can range from as little as 3 weeks for burrowing species such as *Litoria rubella* to six months for some larger species (Anstis 2002). Hydroperiod therefore determines the length of time available for breeding activity and tadpole development and hence which species are able to complete their development. Chronic reductions in wetland hydroperiod will exclude species with longer development times. However, the reverse is also true; increasing hydroperiod can lead to higher predator densities and can exclude species that are sensitive to predation (Adams 2000). Increasing water permanence can also lead to reduced vegetation complexity (Casanova and Brock 2000; Warwick and Brock 2003), which may exacerbate predator effects by reducing the availability of cover. In the Murrumbidgee catchment the conversion of seasonally flooded wetlands such as Barren Box Swamp into permanent water storages coincided with the extinction of resident Southern Bell Frog (*Litoria raniformis*) populations, probably because it led to increases in fish densities and reductions in vegetation cover (Wassens 2008).

Given the above factors, wetland hydrology can exert a strong influence on community composition and waterbodies with differing hydroperiods typically support distinctly different frog communities. For example, a comparison of frog communities within minor stream systems in the Lachlan catchment showed that while permanent and temporary waterbodies had similar numbers of species, the types of species present were significantly different. Of the species recorded *Litoria latopalmata, Litoria rubella* and *Crinia parinsignifera* were more likely to occur in temporary waterbodies, while *L. peronii* favoured permanent sites (Wassens *et al.* 2007a).

Hydroperiod is important when managing environmental flooding and when attempting to predict the impacts of flow regulation. Understanding the relationship between tadpole development times and hydroperiod can be useful when deciding how much water should be applied to a wetland and for what duration. However extreme care needs to be taken if setting lower limits for wetland hydroperiods because the resulting juvenile frogs often need to stay close to the waterbody for some time in order to gain condition. For example *Litoria raniformis* juveniles will often stay close to their natal site for months after adults have abandoned the area (Wassens unpublished data). Similarly, tadpoles that accelerate their development as a result of decreasing water levels metamorphose at a smaller size and which can reduce their fitness as adults (Scott 1994).

Frequency of inundation

The frequency that a wetland is inundated influences both the structure of frog communities and population persistence (Vignoli *et al.* 2007). There have been no specific studies on the impacts of altered flooding frequency on Australian frog species, however the reductions in flooding frequency along the Murrumbidgee River since 1980 (Page *et al.* 2005), has coincided with local extinctions of *Litoria raniformis* and *Litoria caerulea* both of which require regular flooding (Wassens 2008). The alteration of flooding frequency can lead to reduced recruitment opportunities for frogs or may force frogs into more permanent waterbodies which have higher predator densities, thus reducing recruitment outcomes (Vignoli *et al.* 2007). Direct mortality of resident frogs can also occur in cases where wetlands dry out completely for extended periods and no alternative waterbodies are available.

In principle, the maintenance of high quality refuge habitats should mediate the impacts of reduced flooding frequency, although this has never been empirically tested. Maintaining high quality refuge habitats might assist frogs in several ways; it can lower mortality by ensuring sufficient cover from predators, it can provide shelter sites, and it can provide more constant food resources. High quality refuge habitats may also allow for low levels of recruitment to occur during drought periods. As an example, during the drought conditions experienced on the Murray River in 2007 and 2008 small numbers of recently metamorphosed *Litoria peronii* and *Limnodynastes tasmaniensis* were observed around well vegetated permanent waterbodies (Wassens unpublished data). These permanent habitats were not used for breeding at times when temporary waterbodies were available.

Timing of inundation

Many frogs have specific activity periods and as a result the timing of inundation can influence which species are able to respond. *Crinia signifera* and *Crinia parinsignera* for example, can breed at just about any time of year including mid-winter. Both species respond well to winter flooding and are often the dominant frog species in wetlands during late autumn, winter and early spring. In contrast *Litoria peronii* prefers higher temperatures, it is unlikely to respond during flooding in cooler months, but is often the dominant species in summer (Wassens unpublished data).

Vegetation

Both aquatic and terrestrial vegetation can influence frog community composition and response to flooding. Aquatic vegetation is used as an anchor point to attach egg masses (Anstis 2002) , shelter from predators (Adams 1999) and a substrate for biofilms on which many tadpoles feed (Anstis 2002). Terrestrial and fringing vegetation is important for winter hibernation and shelter during dry conditions (Hamer *et al.* 2003). Some of the tree frogs, for example *Litoria peronii*, utilise hollows in standing timber for shelter and for foraging and they may be absent from sites without trees. Loss of wetland vegetation is a common problem in areas affected by livestock grazing or hoofed feral animals and these factors can contribute to declines of frogs and poor breeding responses following flooding (Jansen and Robertson 2001; Jansen and Healey 2003).

Interactions with other species

Many frog species preferentially breed in waterbodies that are either temporary or periodically dry out because those wetlands have lower densities of fish than permanently inundated ones (Adams 2000). The presence of predatory fish can reduce frog recruitment via direct predation of eggs and tadpoles (Holomuzki 1995; Hamer *et al.* 2002; Teplitsky *et al.* 2003), refusal of females to deposit eggs (Holomuzki 1995), and changes in tadpole behaviour and fitness (Teplitsky et al. 2003). While many frog species use water bodies that are almost exclusively fish free, the species that utilise inland wetland systems are assumed to be relatively tolerant to the presence of fish because these larger wetland systems also support native fish populations. However, introduced fish species such as *Gambusia sp*, and European Carp appear to have a far greater impact on tadpole behaviour and recruitment success than native fish species, potentially because they can occur at higher densities and are faster to colonise wetlands during flooding. European Carp which are common in many inland wetland systems also reduce water quality and damage vegetation (Roberts *et al.* 1995; Pinto *et al.* 2005) which has the potential to impact on tadpole survival.

Case study: flood management for species conservation

The Southern Bell Frog *(Litoria raniformis*) is an endangered (EPBC Act 1999) wetland species, formally common and abundant throughout the southern section of the Murray Darling-Basin. This species is now restricted to a few key floodplain habitats in the Lower Murrumbidgee and Murray River systems. Typical of non-burrowing frog species in the Murray-Darling Basin, *L. raniformis* generally utilises seasonally flooded wetlands as breeding sites and moves to permanent waterbodies when flooded habitats are not available (Wassens *et al.* 2008b). Consequently, the quality and proximity of permanent waterbodies can play a significant role in determining the occupancy patterns of *L. raniformis* and its response to wetland flooding.

The Lowbidgee region is an inland delta system fed by the Murrumbidgee River. This region contains many of the New South Wales's most significant populations of the *Litoria raniformis* (Wassens, 2005). During surveys in 2001 and 2002 it was the dominant frog species in River Red Gum Forest (*Eucalyptus camaldulensis*) wetlands and Black Box (*E. largiflorens*)/Lignum (*Muelenbeckia florulenta*) wetlands (Wassens, 2005). Since 2000 the volume of water entering the Lowbidgee floodplain has declined substantially, by 2004 *L. raniformis* was rare in the majority of its former habitats. The reductions in the volume of water entering the Lowbidgee floodplain has probably impacted on populations in two ways; 1) direct loss of habitat leading to reduced recruitment and mortality, and 2) loss of connectivity between wetlands which occurs when the landscape becomes drier and the distances between waterbodies increases due to reductions in the area flooded. Some former habitats have dried out completely; others are flooded less frequently while other sites have been reduced to small areas of permanent water which are maintained for stock and domestic purposes.

Emergency wetland watering 2007/2008

In September 2007, lack of flooding and the drying of key wetlands formally occupied by *L. raniformis* raised the real concern that the species could be lost from the region unless there was intervention. Preliminary surveys of 21 sites during September 2007 failed to locate *L. raniformis* or wetlands in suitable condition to support a recruitment event (Wassens *et al.* 2008a). On this basis the NSW Minister for Climate Change, Environment and Water made available up to 10GL of environmental water, (initially 3GL with the addition water available depending on surpluses and tributary inflows), which had been set aside in the Water Sharing Plan for the Murrumbidgee Regulated River, for watering wetlands in the region (Wassens *et al.* 2008a). The aim of these environmental diversions was to inundate targeted wetlands within the Lowbidgee Floodplain to create Southern Bell Frog habitat.

Site selection

Dry conditions at the time when wetlands were being selected for watering meant that *L. raniformis* individuals were not active and were therefore difficult to detect. Fortunately, comprehensive surveys of wetlands across the Lowbidgee floodplain had been conducted following the last large flood event to occur across the Lowbidgee floodplain in 2000 (surveys were conducted in October 2000 and January 2001) with follow up surveys in January 2004 (Wassens 2005). These survey results were used as a guide to where *L. raniformis* had previously occurred and to define the key habitat characteristics of wetlands that supported *L. raniformis.* This information was used to generate a list of wetlands that were known to have supported *L. raniformis* populations in 2000 and 2004 or where likely to have supported *L. raniformis* based on their habitat characteristics and proximity to known populations.

The challenge was then to predict which of these wetlands were most likely to have maintained a viable population since 2004. Using the principles described in the first section of this paper we developed a “decision making framework” to prioritise sites for watering (Box 1). As *L. raniformis* is known to utilise permanent waterbodies during dry periods, the proximity and quality of drought refuge habitats was a major consideration. Wetlands with no permanent water nearby (less than 2km) were excluded from further consideration even if they were known to have supported *L. raniformis* in 2001. Wetland hydrology was considered both as a means of predicting whether *L. raniformis* were likely to have persisted since 2004 as well as a means of determining the suitability of wetlands that had not been previously surveyed. Technical considerations, particularly transfer losses and the volume of water required to pool water in the wetland for extended periods were also considered.

The framework also attempted to assess the long-term viability of watering sites and their importance in maintaining the species across the whole floodplain. With the initial allocation of just 3000ML only two or three populations could be saved, it was therefore important to ensure that these populations were well connected to former habitats so that recolonisation could occur during the next large flood event.

Box 1. Decision making framework for selection of sites for watering to maintain viable *L. raniformis* populations in the Lowbidgee region of NSW

1. **The likelihood of that *L. raniformis* previously occurred at the wetland (positive identification will be weighted higher than anecdotal sightings)**
    a. Date *L. raniformis* last recorded
    b. If not recorded at the site- distance to nearest known site
2. **Drought refuge**
    a. Proximity of the site to drought refuge habitats (waterbodies that have held water consistently since late 2005)
    b. Quality of drought refuge habitats if present
        i. aquatic and fringing vegetation cover
        ii. predator density
    c. Probability of individuals being able to access and persist in drought refuge habitats after the wetland dries
    d. Presence of mortality sinks (for example regulators with an enclosed box base are known to trap frogs, snakes and turtles). *L. raniformis* is particularly vulnerable because they often move into the regulators because they hold water but are unable to climb out when the water levels go down.
3. **Target wetlands (habitat suitability)**
    a. Quality and condition of target wetlands as breeding sites (estimate vegetation cover and complexity if possible)
    b. Time since last flooded
    c. Frequency of inundation
    d. Estimated wetland hydroperiod
    e. Wetland management- heavy grazing, cattle wallowing, water extraction or burning
    f. Landholder support (if applicable)
    g. Representativeness of wetland plant communities (River Red Gum/Black Box -Lignum)
4. **Technical considerations**
    a. Estimate transfers losses
    b. Volume of water required
    c. Presence of water control structures (regulators, pipes, canals)
5. **Landscape considerations - Capability of the target wetland to act as a source population to allow for future recolonisation as of other *L. raniformis* habitats in the region**
    a. Distance of wetland to other known populations
    b. Position of wetland within the context of the known range of the species (Edge, middle, centre of known range)
    c. Dispersal pathways between wetlands

Framework implementation

Technical considerations were used for the first cull, and any water body that could not be fully flooded with the volume of water available was excluded. As a result, River Red Gum and Black Box wetlands on the northern and southern sides of the Murrumbidgee River which were more than 2km from the Red Bank Weir or a suitable regular structure were excluded because they would have required more than the available 3GL to fill. Likewise, waterbodies at the bottom of the Nimmie-Caria systems were not considered because of unacceptable transfer losses.

Of the remaining sites, three wetlands where *L. raniformis* had been recorded in 2001 were excluded because there was no longer any permanent waterbodies within more than 2 km of the target wetland and hence there was a high probability that *L. raniformis* was already extinct from those sites.

This left just nine wetlands that fulfilled the selection criteria: they were known or were predicted to have supported *L. raniformis*, they were near permanent water, could be filled with minimal transfer losses, and would be connected to former *L. raniformis* habitats during a larger flood event. As the volume of water was limited, these nine sites were ranked according to the selection criteria and the best six sites were selected for watering, three within Black Box/Lignum wetlands within the Nimmie-Caira System (Avalon, Eulimbah and Warwaegae swamps) and three within River Red Gum wetlands of Yanga National Park (Mercedes, Pococks and Two Bridges Swamp) (Table 1). In addition to the decision making framework, we aimed to water "clusters" of wetlands, which were in close proximity to each other and water supply infrastructure which ensured that there was some connectivity between watering sites in each system and minimised transfer losses.

Additional environmental water allocations were made available in early January and after topping up the six initial watering sites, the remaining three wetlands were flooded. Of these Paul Coates Swamp was in very close proximity to Mercedes Swamp and was known to have supported *L. raniformis* up until 2004, but was prioritised below Mercedes Swamp because its large area made it difficult to flood to a sufficient depth with the volume of water initially available. Southern Bell Frogs were recorded at South Eulimbah Stock Dam, which is part of the larger Eulimbah Swamp complex but was initially not considered because it already received Stock and Domestic water. This site was topped up in March after Southern Bell Frogs were found there to ensure that resident individuals would survive through to the 2008/2009. The third site Shaw's Swamp was not predicted to support *L. raniformis* because it did not flood frequently enough, this site filled via a leaking regulator and was later topped up to maintain the aquatic vegetation.

Outcomes

Initial response

Litoria raniformis responded to flooding at six of the nine sites watered. It was absent from Avalon Swamp where it had previously been recorded in 2004 and Pocock's Swamp which had not been surveyed previously. It was also absent from Shaw's Swamp in Yanga National Park as was predicted. Overall the abundance was very low, less than 20 individuals were recorded at each of the sites during six days of searches. In comparison, 92 *L. raniformis* individuals were collected in a single night at Paul Coates Swamp in January 2001 (Wassens 2005).

As noted earlier, it may be possible to extend the length of time that populations persist between floods by providing persistent refuges of high quality and with low predator densities. Poor quality refuge habitats and chronic isolation may have contributed to the loss of the Avalon Swamp population. Avalon Swamp did contain a permanent water body but it was in poor quality with no aquatic or fringing vegetation. It was also later revealed to have dried out for a short period in 2006 and contained very high densities of Common Carp (Jennifer Spencer Department of Environment and Climate Change unpublished data). The loss of the Avalon Swamp population highlights the sensitivity of *L. raniformis* to wetland drying and also the importance of maintaining high quality permanent waterbodies during droughts.

Recruitment outcomes

Calling activity commenced immediately after the waterbodies were flooded at all six sites where *L. raniformis* was present. Successful recruitment as evidenced by the presence of tadpoles and metamorphs (recently metamorphosed tadpoles) occurred at three sites; Mercedes Swamp, Two Bridges Swamp and South Eulimbah Stock Dam (Paul Coates Swamp was not resurveyed) (Figure 3). Evidence of recruitment by *L. raniformis* was not observed at Eulimbah or Warwaegae Swamps despite strong calling activity. These two sites also had comparatively low levels of recruitment by other frog species indicating that that these sites had lower suitability for frog breeding overall.

Differences in vegetation structure and high densities of juvenile Carp, particularly at Warwaegae and Eulimbah Swamp are likely to have contributed to the poor breeding response at these wetlands. While all sites except South Eulimbah Stock Dam contained Carp, their impact on *L. raniformis* recruitment appears to have far more significant within the Black Box/Lignum wetlands, probably due to differences in fish densities and also aquatic vegetation communities. The structure of vegetation can reduce fish predation on tadpoles by supplying predator refuges (Lawler *et al.* 1999), and it is likely that the dense emergent vegetation cover at Mercedes and Two Bridges Swamps provided better cover and protection from European Carp than the softer submerged and floating aquatic vegetation that dominated Eulimbah and Warwaegae Swamps. The presence of large number of metamorphs at the South Eulimbah Stock Dam which had similar habitat structure to Eulimbah and Warwaegae Swamps but was free of Carp also provides evidence for a potential link between Carp and poor breeding outcomes.

Relationships with other frog species

Wetlands that supported successful recruitment of *L. raniformis* also contained the highest abundances and diversity of tadpoles and metamorphs of the other resident frog species: *Limnodynastes interioris, L. fletcheri, L. tasmaniensis, Litoria peronii,* and *Crinia parinsignifera* (Figure 2). This suggests that flooding to maintain the *Litoria raniformis* will also have positive benefits for other frog species. Subsequent fish surveys have also shown Two Bridges Swamp, the site with the highest frog diversity and tadpole abundances, to have a high diversity of native fish (Jennifer Spencer, Department of Environment and Climate Change unpublished data).

Lessons learnt

Predicting outcomes to flooding

This case study represents the first time that flooding management had been used as an emergency measure to prevent the extinction of local populations of a threatened frog species. Success was influenced by (i) our ability to predict which sites would still be occupied and (ii) our ability to forecast recruitment outcomes. Overall the decision making framework was quite successful in predicting the persistence of *L. raniformis*. However, not all of the selection criteria proved useful when making these predictions for example, it was difficult to describe aquatic vegetation communities at sites that had not been surveyed in 2001 and 2004. It was also difficult to predict wetland hydroperiod because this largely depends on the volume of water entering the wetland and we relied heavily on the expert knowledge of landholders and State Water staff. Expert knowledge also played a key role in weighting the relative importance of the different criteria. For example Shaw's Swamp conformed to the majority of selection criteria, except flooding frequency, in this case expert knowledge was required to assess how important this factor was likely to be in relation to the others.

Frog populations are influenced by multiple factors occurring at a range of spatial and temporal scales. In this instance, the relative importance of these factors also appeared to differ between wetland systems. This presented further complications when applying the decision making framework across different wetland types. The habitat requirements and ecology of *L. raniformis* within River Red Gum wetlands had been the focus of earlier research (Wassens 2005). This study formed the basis for the site selection strategy and made it easier to predict which wetlands would be occupied and would sustain recruitment. The response of populations to flooding within Black Box - Lignum wetlands was harder to predict particularly in terms of recruitment outcomes. The presence of Carp appears to be far more important in Black Box -Lignum wetlands than in River Red Gum wetlands and as a result the relative importance of this (and probably other) factor needs to be weighted differently in different types of wetlands.

Limited knowledge of past flooding frequencies presented a problem in some instances. For example, Pocock's Swamp was initially believed to have a similar flooding frequency to Mercedes Swamp to which it is connected, but on further investigation it was found to flood less frequency (every three to four years).

Monitoring outcomes

Surveys of calling activity are commonly used to assess frog populations and breeding response. While this technique has an advantage in that it is quick and inexpensive, calling activity frequently has little relationship with actual recruitment outcomes, as this case study highlights. This potential lag between the first failed recruitment event and the eventual disappearance of a population needs to be taken into account when planning monitoring. Focusing on outcomes such as recruitment and measuring a wide range of environmental parameters which may give a clue to the causes of recruitment failures is essential if intervention is to be employed.

Managing for stability in variable systems

Wetland frogs, *Litoria raniformis* in particular, typically exhibit boom and bust population dynamics. They are adapted to large scale flooding which allows for high levels of recruitment and high abundances during good periods, and these high abundances help to sustain populations during periods of high mortality such as droughts. Population crashes and local extinctions are comparably common but these are compensated by recolonisation and recovery (Alford and Richards 1999; Skelly *et al.* 1999; Richter *et al.* 2003). Our current flooding strategy is conservative and focuses on maintaining comparatively small areas of habitats in a stable state. Whether this type of conservative management can successfully maintain viable populations in the long-term is open to question.

Conclusions

The response of frogs to flooding is rarely considered when planning environmental flow strategies. This may be due to the misconception that frogs are poorly understood and difficult to predict, or that their requirements are catered for when targeting other taxonomic groups. The continual decline of frog populations across the Murray-Darling Basin and the loss of species from wetland systems under active flooding management highlight the importance of considering frogs when targeting environmental water along with other wetland taxa.

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References

Adams, M. J. (1999). Correlated factors in amphibian decline: exotic species and habitat change in western Washington. *Journal of Wildlife Management* **63**, 1162-1171.

Adams, M. J. (2000). Pond permanence and the effects of exotic vertebrates on anurans. *Ecological Applications* **10**, 559-568.

Alford, R. A., and Richards, S. J. (1999). Global amphibian declines: a problem in applied ecology. *Annual Review of Ecology & Systematics* **30**, 133-165.

Anstis, M. (2002). 'Tadpoles of South-eastern Australia: a guide with keys.' (Reed New Holland: Sydney.)

Babbitt, K. J., and Tanner, G. W. (2000). Use of temporary wetlands by anurans in a hydrologically modified landscape. *Wetlands* **20**, 313-322.

Casanova, M. T., and Brock, M. A. (2000). How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology* **147**, 237-250.

Hamer, A. J., Lane, S. J., and Mahony, M. J. (2002). The role of introduced Mosquitofish (*Gambusia Holbrooki*) in excluding the native Green and Golden Bell Frog (*Litoria aurea*) from original habitats in south-eastern Australia. *Oecologia* **132**, 445-452.

Hamer, A. J., Lane, S. J., and Mahony, M. J. (2003). Retreat site selection during winter in the Green and Golden Bell Frog, Litoria Aurea Lesson. *Journal of Herpetology* **37**, 541-545.

Harrison, S., and Taylor, A. D. (1997). Empirical evidence for metapopulation dynamics. In 'Metapopulation biology: ecology, genetics and evolution'. (Eds I. Hanski and M. E. Gilpin.) pp. 27-39. (Academic press: San Diego.)

Hazell, D. (2003). Frog ecology in modified Australian Landscapes: a review. *Wildlife Research* **30**, 193-205.

Holomuzki, J. R. (1995). Oviposition sites and fish-deterrent mechanisms of two stream anurans. *Copeia*, 607-613.

Jansen, A., and Healey, M. (2003). Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. *Biological Conservation* **109**, 207-219.

Jansen, A., and Robertson, A. I. (2001). Relationships between livestock management and the ecological condition riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* **38**, 63-75.

Lawler, S. P., Dritz, D., Strange, T., and Holyoak, M. (1999). Effects of introduced mosquitofish and bullfrogs on the threatened California Red-Legged Frog. *Conservation Biology* **13**, 613-622.

Marsh, D. M., Fegraus, E., and Harrison, S. (1999). Effects of breeding pond isolation on the spatial and temporal dynamics of pond use by the Tungara Frog, *Physalaemus pustulosus*. *Journal of Animal Ecology* **68**, 804-814.

Marsh, D. M., Rand, A. S., and Ryan, M. J. (2000). Effects of inter-pond distance on the breeding ecology of tungara frogs. *Oecologia* **122**, 505-513.

Marsh, D. M., and Trenham, P. C. (2001). Metapopulation dynamics and amphibian conservation. *Conservation Biology* **15**, 40-49.

Page, K., Read, A., Frazier, P., and Mount, N. (2005). The effect of altered flow regime on the frequency and duration of bankfull discharge: Murrumbidgee River, Australia. *River Research and Applications* **21**, 567-578.

Pinto, L., Chandrasena, N., Pera, J., Hawkins, P., Eccles, D., and Sim, R. (2005). Managing invasive carp (*Cyprinus carpio* L.) for habitat enhancement at Botany Wetlands, Australia. *Aquatic Conservation-Marine and Freshwater Ecosystems* **15**, 447-462. doi:10.1002/aqc.684|ISSN 1052-7613

Richter, S. C., Young, J. E., Johnson, G. N., and Seigel, R. A. (2003). Stochastic variation in reproductive success of a rare frog, Rana sevosa: Implications for conservation and for monitoring amphibian populations. *Biological Conservation* **111**, 171-177.

Roberts, J., Chick, A., Oswald, L., and Thompson, P. (1995). Effect of carp, *Cyprinus carpio* L, an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. *Marine and Freshwater Research* **46**, 1171-1180.

Schwarzkopf, L., and Alford, R. A. (2002). Nomadic movements in tropical toads. *OIKOS* **96**, 492-506.

Scott, D. E. (1994). The effect of larval density on adult demographic traits in *Ambystoma opacum*. *Ecology* **75**, 1383-1396.

Semlitsch, R. D. (2000). Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management* **64**, 615-631.

Skelly, D. K., Werner, E. E., and Cortwright, S. A. (1999). Long-term distributional dynamics of a Michigan amphibian assemblage. *Ecology* **80**, 2326-2337.

Smith, M. A., and Green, D. M. (2005). Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? *Ecography* **28**, 110-128.

Snodgrass, J. W., Komoroski, M. J., Bryan, A. L., and Burger, J. (2000). Relationships among isolated wetland size, hydroperiod, and amphibian species richness: implications for wetland regulations. *Conservation Biology* **14**, 414-419.

Teplitsky, C., Plenet, S., and Joly, P. (2003). Tadpoles' responses to risk of fish introduction. *Oecologia* **134**, 270-277.

Trenham, P. C., Koenig, W. D., and Shaffer, H. B. (2001). Spatially autocorrelated demography and interpond dispersal in the salamander *Ambystoma californiense*. *Ecology* **82**, 3519-3530.

Vignoli, L., Bologna, M. A., and Luiselli, L. (2007). Seasonal patterns of activity and community structure in an amphibian assemblage at a pond network with variable hydrology. *Acta Oecologica-International Journal of Ecology* **31**, 185-192.

Warwick, N. W., and Brock, M. A. (2003). Plant reproduction in temporary wetlands: the effects of seasonal timing, depth, and duration of flooding. *Aquatic Botany* **77**, 153-167.

Wassens, S. (2005). The use of space by the endangered Southern Bell Frog (*Litoria raniformis*) in the semi-arid region of New South Wales, Australia. PhD Thesis, Charles Sturt University.

Wassens, S. (2008). Review of the past distribution and decline of the southern bell frog *Litoria raniformis* in New South Wales. *Australian Zoologist* **34**, 446-452.

Wassens, S., Arnaiz, O. L., Healy, S., Watts, R. J., and Maguire, J. (2008a). 'Hydrological and habitat requirements to maintain viable Southern Bell Frog (Litoria raniformis) populations on the Lowbidgee floodplain- Phase 1.' (Department of Environment and Climate Change.: Queanbeyan.)

Wassens, S., Arnaiz, O. L., and Watts, R. J. (2007a). '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.' (Department of Environment and Climate Change: Queanbeyan.)

Wassens, S., Roshier, D. A., Watts, R. J., and Robertson, A. I. (2007b). Spatial patterns of a Southern Bell Frog (*Litoria raniformis)* population in an agricultural landscape. *Pacific Conservation Biology* **13**, 104-110.

Wassens, S., Watts, R. J., Jansen, A., and Roshier, D. (2008b). Movement patterns of Southern Bell Frogs (*Litoria raniformis*) in response to flooding. *Wildlife Research* **35**, 50 - 58.

Withers, P. C., and Thompson, G. G. (2000). Cocoon formation and metabolic depression by the aestivating hylid frogs *Cyclorana australis* and *Cyclorana cultripes* (Amphibia: Hylidae). *Journal of the Royal Society of Western Australia* **83**, 39-40.

Figures

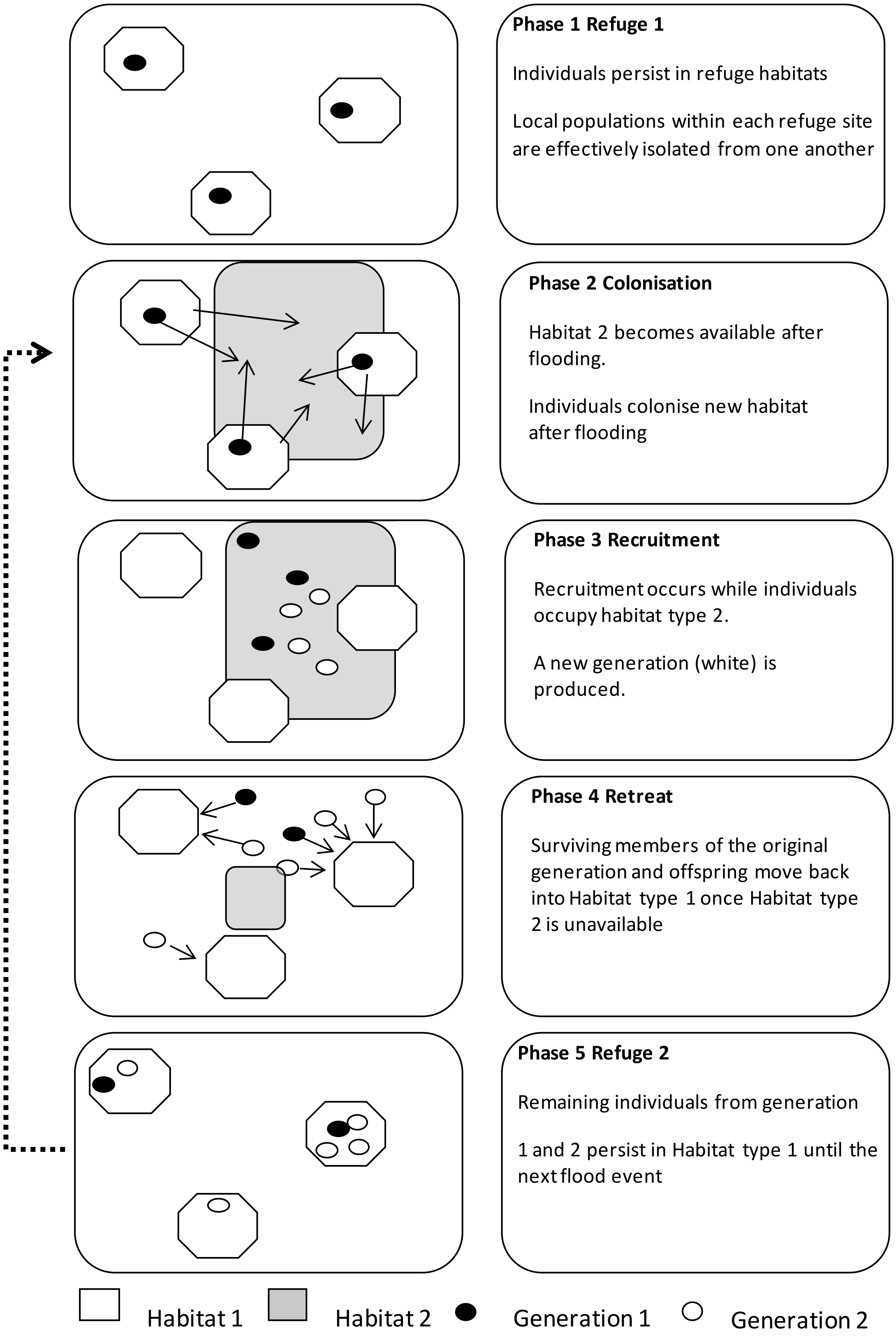
Figure 1 Simplified model of the response of non-burrowing wetland frog species to wetting and drying within a wetland mosaic

Figure 2. Location of wetland watering sites and previous records of *L. raniformis* within the Lowbidgee region of NSW. Flood extent and floodway layers supplied by State Water, extent of flooded wetlands by DECC; previous records from Wassens 2005. From (Wassens *et al.* 2008a)

Figure 3. Mean (±SE) abundance of tadpoles and metamorphs at each wetland. *L. tasmaniensis* and *L. fletcheri* have been combined into a single group "*Limnodynastes*" because it is not possible to separate these two species as tadpoles. Redbank Weir has been excluded because no tadpoles were collected. From Wassens et al 2008a.

Tables

Table 1. General characteristics of wetlands targeted for Environmental Watering in 2007



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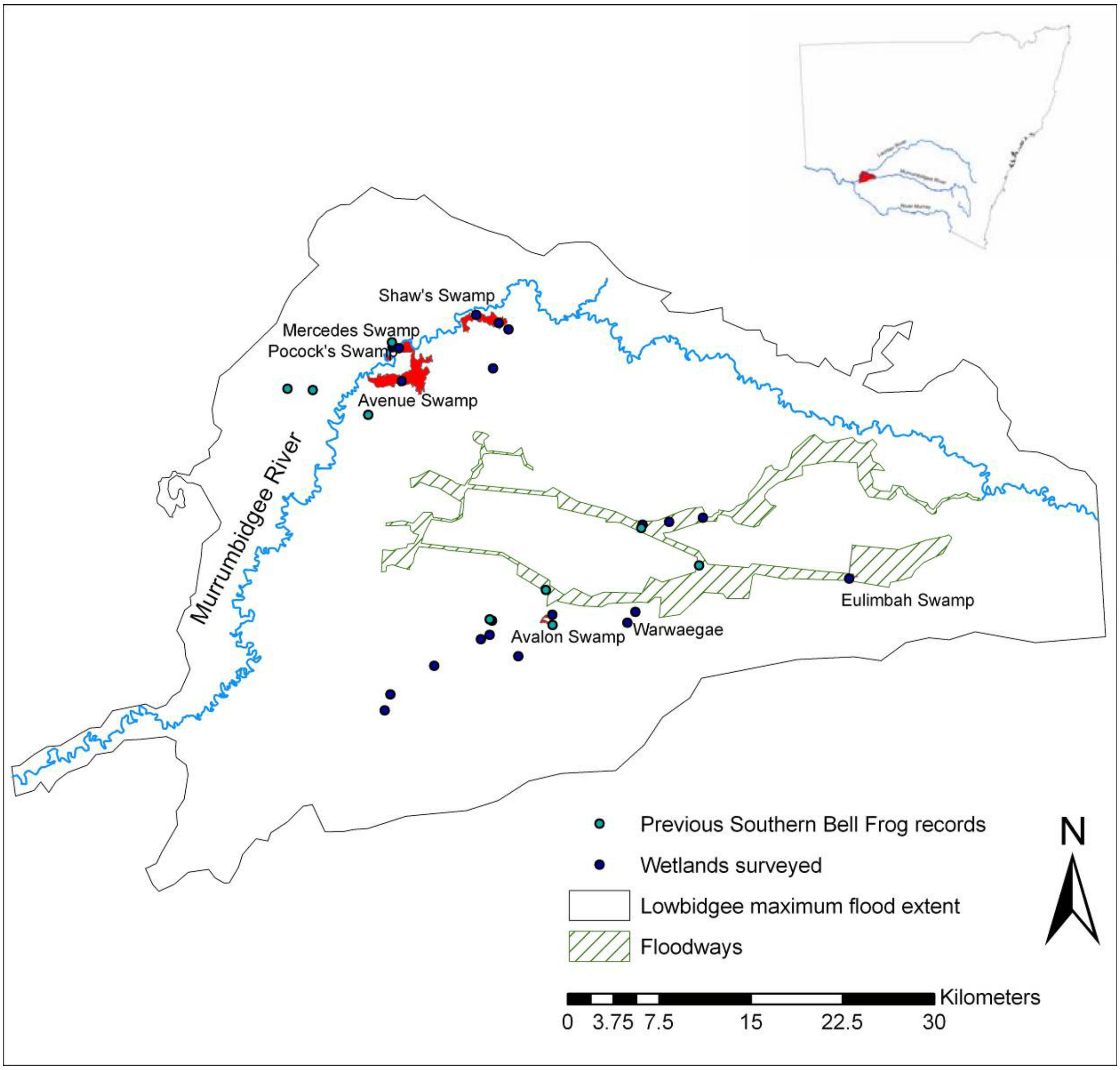

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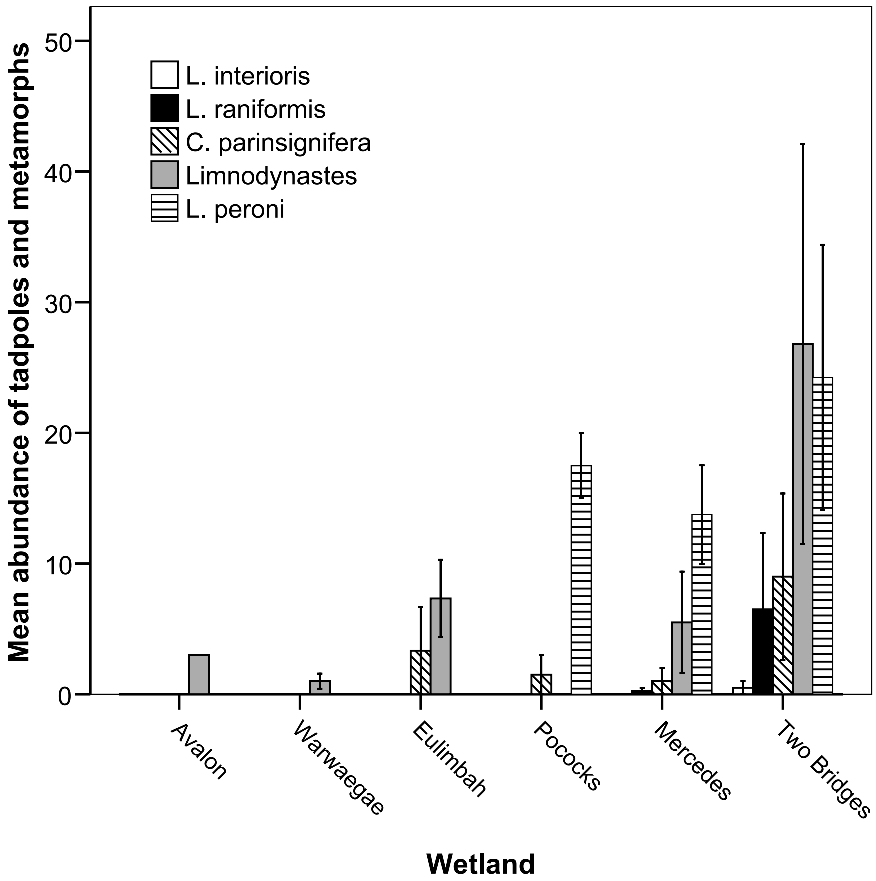

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Site	Description	The date L. raniformis last recorded	Time dry (months)	Distance of water body to other known populations	Frequency of connection between target wetlands nearest population	Area flooded (ha)	*L. raniformis* present 2008
Eulimbah swamp	Large Lignum wetland with deep canal on one side.	Dec. 2007	8	<2km Eulimbah Stock Dam	1-2 years via canal	<50 ha (2005 flooding extent 3000 ha)	Yes
South Eulimbah Stock Dam	S&D dam feed via lignum flood runner. Southern Edge of Eulimbah Swamp.	March 2008	0	<2km Eulimbah	yearly S &D via lignum flood runner	20	Yes
Warwaegae	Lignum /Cumbungi Permanent S&D dam and overflow into lignum	Never surveyed	5	6km to Avalon	yearly S &D via canal	6	Yes
Mercedes Swamp	Tall Spike Rush/ River Red Gum wetland. Currently dry but flooded annually every year until 2006	Jan 2001	6	<1km Paul Coates	yearly via weir (except 2006)	95	Yes
Two Bridges Swamp	Tall Spike Rush/ River Red Gum on the flood runner to Piggery Swamp. Patches of damp soil remaining.	Never surveyed	2	<2km Mercedes	yearly via weir (except 2006)	180	Yes
Paul Coates Swamp	Complex of open tall spike rush and forested short spike rush wetlands. Subject to forestry and some grazing	Jan 2004	12	<1km Mercedes	yearly via weir (except 2006)	100	Yes
Avalon swamp	Black Box/lignum. Main section of waterbody permanent until 2006	Jan 2004	8	25km to Eulimbah	1-2 years via canal	34	No
Shaw's Swamp	Shallow forested, short spike rush wetland off Wagorah Creek on Yanga NP.	Never surveyed	36	>5km Two bridges	>2 years?	100	No
Pococks Swamp	Grassy/River Red Gum wetland connected to Mercedes Swamp during high flows.	Never surveyed	36	<0.5km Mercedes	>2 years?	65	No

S&D = Stock and domestic