Author: S. Wassens, R. Watts, A. Jansen and D. Roshier

Title: Movement patterns of Southern Bell Frogs (Litoria raniformis) in response to flooding.

Journal: Wildlife Research **ISSN**: 1035-3712
Year: 2008
Volume: 35
Issue: 1
Pages: 50-58

Abstract: Within the semiarid regions of New South Wales, Australia, the endangered southern bell frog (Litoria raniformis) occupies a landscape that is characterised by unpredictable rainfall and periodic flooding. Limited knowledge of the movement and habitat-occupancy patterns of this species in response to flood events has hampered conservation efforts. We used radio-tracking to assess changes in movement patterns and habitat occupancy of L. raniformis (n = 40) over three different periods (November, January and April/May) that coincided with the flooding, full capacity and subsequent drying of waterbodies within an irrigation landscape. We assessed (1) the use of permanent and ephemeral habitats in response to flooding and drying and (2) distances moved, turning angles and dispersion of frogs during wetland flooding, full capacity and drying. Individuals remained in permanent waterbodies in November but had abandoned these areas in favour of flooded ephemeral waterbodies by January. As the ephemeral waterbodies dried, radio-tracked individuals moved back into permanent waterbodies. The movement patterns of radio-tracked individuals were significantly different in the three radio-tracking periods, but did not differ significantly between sexes. Individuals moved significantly greater distances over 24 h, in straighter lines and movements were more dispersed while they occupied ephemeral waterbodies during January than when they occupied permanent waterbodies during November and April/May. Local weather conditions did not influence movement patterns when all three tracking periods were modelled together using a single linear stepwise regression. The dynamic distribution of habitat patches over space and time, combined with changing patterns of resource utilisation and movement of L. raniformis, highlights the importance of incorporating both permanent and ephemeral habitat patches into conservation plans. Reductions in flood frequency and extent of ephemeral

Author Address: swassens@csu.edu.au
rwatts@csu.edu.au
ajansen@csu.edu.au
droshier@csu.edu.au

URL: http://dx.doi.org/10.1071/WR07095

http://www.publish.csiro.au/paper/WR07095.htm
http://www.publish.csiro.au/nid/144.htm
http://researchoutput.csu.edu.au/R/-?func=dbin-jump-full&object_id=8065&local_base=GEN01-CSU01
http://bonza.unilinc.edu.au:80/F/?func=direct&doc_number=000500025&local_base=L25XX

CRO Number: 8065

Movement patterns of southern bell frogs (*Litoria raniformis*) in response to flooding.

Skye Wassens [A], Robyn J. Watts[A]., Amy Jansen[A], and David Roshier[A]

[A] Institute for Land, Water and Society, School of Environmental Sciences, Charles Sturt University, Locked bag 588, Wagga Wagga, NSW, 2678, Australia.

Abstract

Within the semi-arid regions of NSW, Australia, the endangered southern bell frog (*Litoria raniformis*) occupies a landscape that is characterised by unpredictable rainfall and periodic flooding. Limited knowledge of the movement and habitat occupancy patterns of this species in response to flood events has hampered conservation efforts. We used radio tracking to assess changes in movement patterns and habitat occupancy of *L. raniformis* (n=40) over three different time periods (November, January and April/May) which coincided with the flooding, full capacity and subsequent drying of waterbodies within an irrigation landscape. We assessed (1) the use of permanent and ephemeral habitats in response to flooding and drying and (2) distances moved, turning angles and dispersion of frogs during wetland flooding, full capacity and drying. Individuals remained in permanent waterbodies in November but had abandoned these areas in favour of flooded ephemeral waterbodies by January. As the ephemeral waterbodies dried, radio tracked individuals moved back into permanent waterbodies. The movement patterns of radio tracked individuals were significantly different in the three radio tracking periods, but did not differ significantly between sexes. Individuals moved significantly greater distances over 24hours, in straighter lines and movements were more dispersed while they occupied ephemeral waterbodies during January than when they occupied permanent waterbodies during November and April/May. Local weather conditions did not influence movement patterns when all three tracking-periods were modelled together using a single linear stepwise regression. The dynamic distribution of habitat patches over space and time, combined with changing patterns of resource utilisation and movement of *L. raniformis,* highlights the importance of incorporating both permanent and ephemeral habitat patches into conservation plans. Reductions in flood frequency and extent of ephemeral wetlands due to modified flooding regimes have the capacity to limit dispersal of this species, even when permanent waterbodies remain unchanged.

Key words: Amphibian movements; Habitat occupancy; Amphibian Conservation; Wetlands; Irrigation landscapes

Introduction

Conservation strategies for endangered species frequently strive to maintain populations within highly modified landscapes. While the majority of research has focused on maintenance of populations within remnants of their former habitat (Saunders *et al.* 1991), there is increasing awareness that some taxa rely heavily on anthropogenic habitats (Pechmann *et al.* 2001; Mazerolle 2005). In flood irrigated landscapes, the creation of ephemeral wetlands during spring and summer to grow crops and the maintenance of vegetated canals provides a range of foraging opportunities for waterbirds, amphibians, aquatic macro-invertebrates and other fauna (Acosta *et al.* 1996; Lane and Fujioka 1998; Lawler 2001; Elphick 2004). These landscapes are also highly disturbed as a result of stubble burning, pesticide use and intermittent cattle grazing which create a host of additional challenges for resident taxa.

The long-term persistence of amphibian populations within such temporally variable and highly disturbed landscapes is linked to their ability to opportunistically colonise newly created habitats as well as take refuge in more favourable areas when the temporary habitats dry. The need to move in response to changing habitat conditions presents numerous challenges for amphibians that are typically vulnerable to desiccation and predation when moving. For example, the salamander *Ambystoma maculatum* is reluctant to cross open grasslands (Rittenhouse and Semlitsch 2006) and has a lower chance of successfully moving large distances within cleared areas due to the higher rates of predation and desiccation (Rothermel and Semlitsch 2002). Where the area of intervening habitat is relatively hostile to movement, willingness of individuals to cross edges and to move greater distances can be influenced by climatic conditions, particularly precipitation (Schwarzkopf and Alford 2002; Chan-Mcleod 2003). Thus, connectivity can be temporally variable.

The southern bell frog (*Litoria raniformis*) is an endangered Australian amphibian that is presently restricted to flood irrigated landscapes in the north-eastern part of its former range (Pyke 2002). Prior to its decline, *Litoria raniformis* occupied a greater variety of aquatic habitats at elevations ranging from sea level to 1200m and across a number of climate zones, from warm temperate, to cool sub-alpine zones and across the semi-arid zone (Osborne *et al.* 1996). Within the wetter parts of its range, *L. raniformis* is commonly associated with permanent waterbodies and slow moving streams (Osborne *et al.* 1996; Heard *et al.* 2006). However, in the hotter and dryer parts of its range, populations are associated with more variable floodplain wetland systems and irrigation areas, both of which are comprised of small areas of permanent waterbodies and large areas of seasonally inundated ephemeral waterbodies (Wassens *et al.* 2007). Throughout its range, habitat occupancy is likely to be linked to aquatic vegetation cover; particularly the presence of emergent vegetation, as is the case for the closely related species, *Litoria aurea* from coastal areas (Hamer *et al.* 2002). Over-winter aestivation within dense vegetation is common amongst members of the Bell Frog complex (Osborne *et al.* 1996). However the species capacity for summer aestivation during dry conditions is unknown. Breeding is not dependent on the presence of permanent water as it has been recorded in both permanent and ephemeral waterbodies (Anstis 2002).

The opportunistic use of ephemeral habitats by *Litoria raniformis* suggests that individuals have relatively high mobility, but this has never been tested. Investigation of the habitat requirements and movement patterns of resident populations in irrigation landscapes can provide insights relevant to the conservation of this species, because the patterns of wetting and drying in irrigated landscapes are similar to those historically experienced in floodplain wetlands formerly occupied by this species. In this paper we describe the temporal changes in the movement patterns of *L. raniformis* in response to changing patterns of habitat availability.

Methods

Study area

The study was conducted on three commercial rice-growing properties (properties 104, 171 and 212) in the Coleambally Irrigation Area (CIA) in south-western New South Wales, Australia (Figure 1). The CIA presently occupies an area of 80,000 ha and lies to the south of the Murrumbidgee River, which is the principle water source for irrigation. The CIA area contains 477 km of supply canals which distribute irrigation water from the Coleambally Main Canal to individual properties. The principle supply canals contain water throughout the year to meet general stock watering and domestic needs.

The climate of this region is categorised as Mediterranean (E2) with hot dry summers and cooler winters (Hutchinson *et al.* 2005). The mean annual rainfall is 406 mm per year. Severe droughts and periods of low rainfall are common and drought conditions prevailed during the period of this study between 2001 and 2003. Temperatures regularly exceeded 30C between December and February. Winter temperatures are cool and frosts are common between May and August.

Selection of study sites

The three sites were selected on the basis of the presence of *L. raniformis*, proximity to irrigation canals, dams and rice bays and landholder consent. The sites contained between 70 and 150 ha of irrigated rice bays, along with supply canals, pasture and other crops. All three sites had similar cropping and irrigation regimes, rice bays were flood-irrigated in November and pooled water remained on the crops until March, after which rice bays were drained in preparation for harvest in mid to late April.

Before surveys commenced, a total of 70 sample points were selected randomly from within rice bays, irrigation canals, dams and overflows within the three study sites. These sample points formed the basis of surveys of vegetation, water depth and as the mid points for surveys transects to capture *L. raniformis* individuals during each tracking period.

General habitat surveys

General surveys of vegetation and water physicochemistry were conducted for each of the 70 sample points on all three tracking periods. The dominant vegetation type (vegetation making up more than 20% cover), percent cover of aquatic and percent cover of fringing vegetation was estimated from ten 1m square quadrats located approximately two metres apart with their midpoint coinciding with each of the 70 set sample points. The quadrats for aquatic vegetation were placed one metre from the water line, while the percent cover of fringing vegetation was estimated from quadrats on the water line.

Water quality, particularly conductivity, turbidity and water temperature have been linked to occupancy patterns and recruitment success of members of the Bell Frog complex e.g. (Cree 1984; Christy and Dickman 2002; Hamer et al. 2002; Browne and Edwards 2003). In this study we recorded conductivity, pH, turbidity and water temperature in each quadrat using a hand held water quality meter (Hydrolab), water depth was also recorded as this can influence breeding site selection amongst some frog species (Brooks and Hayashi 2002).

Capture and transmitter attachment

Visual searches for *Litoria raniformis* individuals were conducted at night, along 50m transects with their midpoint coinciding with each of the 70 sample points. A spotlight was used to search along the water's edge and amongst vegetation. Individuals were collected and held in a new zip-lock plastic bag and their capture location was marked with GPS. Individual were weighed, sexed and their snout to vent length was recorded using callipers. Individual less than 38g were released at the point of capture, individual greater than 38g were fitted with a radio transmitter using belt made of 2 mm surgical-grade silicon tubing threaded with cotton string and tied around the inguinal region. The transmitters were supplied by Sirtrack, New Zealand, and weighed 1.50g with a battery life of 8 weeks. The total weight of the transmitter and belt was less than 1.65g and did not exceed 5% of the total body weight of the frog. Radio tagged frogs were given a permanent mark by removing the last digit of single toe with a pair of sterilised scissors.

Radio tracking schedule

Because battery life of the radio transmitters was limited, it was not possible to radio track continuously during the seven month irrigation season. Instead radio tracking, habitat and frog surveys were timed to coincide with the pattern of flooding and drying. Initial flooding (10th November 2002 to 1st December 2002 (November)), mid-season (3rd January to 29th January 2003 (January)), and water body drying (6th April to 9th May 2003 (April/May)).

The location of radio tagged frogs was recorded every 24 hours ($\pm$2 hours) for between 2-12 days, with a mean of seven days (SE 0.51). The rate of transmitter loss and failure was relatively high, so new individuals were added throughout each tracking period. In all, data was collected for a total of 40 frogs (20 males and 20 females).

All radio tracking was conducted during the day so as not to disrupt normal nocturnal activities, particularly foraging and breeding behaviours. The general position of radio tagged individuals was determined using triangulation and the precise location was obtained by circling around the point until the location of the frog could be pin-pointed to a 0.25m square area. Frogs were almost always concealed under or within vegetation and close range radio tracking within 0.25m very rarely disturbed individuals so that they moved away from their original position. Once determined, the location of each individual was recorded with a GPS to an accuracy of 1m. Daily weather data was obtained from the Bureau of Meteorology station at Griffith, 30km from the study area.

Shelter site selection

For each positive frog location, data were recorded on the dominant vegetation species and percent cover, water depth (if individuals were located in water), and the type of habitat (bay, canal, overflow or open area). The behaviour of individuals prior to capture for transmitter attachment and when sighted during radio tracking was also recorded. Behaviour was classed as calling, perching/foraging, basking, and sheltering. Shelter sites were classified as emergent aquatic vegetation, submerged aquatic vegetation, floating aquatic vegetation, fringing vegetation and underground.

Data analysis

The distance that each frog moved between each location point was calculated as a straight-line distance. For each frog, we calculated the distance moved every 24 hours ($\pm$2 hours), cumulative distance moved, total displacement and mean turning angle using Animal Movement Analysis ArcView extension (ARCVIEW version 3.3) (Hooge and Eichenlaub 1997). The mean square distance (r^2) from the centre of activity was used to estimate the dispersion of the daily locations for each individual (Hooge and Eichenlaub 1997).

Because multiple climatic variables may act to influence movement patterns a step wise approach was used to select a subset of variables that best explain the relationship between local climatic variables (air temperature at 0900, humidity at 0900, dew point at 0900, and mean wind speed over 24 hours (km/h)) and the distance moved over 24 hours and local weather. Precipitation was excluded from the analysis because there was only one rain event during the study period (1mm during April/May). At the initial step, each of the local weather variables were tested separately against the distance moved over 24 hours for the three sample periods combined and for each individual sample period. Variables with a significance value of $p < 0.25$ when tested in the univariate models were included in a backwards step-wise regression (probability of F to remove set at $\geq$0.100).

In order to reduce the variability associated with day-to-day movements and the problems of temporal dependence of movement from one day to the next, the mean distance moved by each frog over 24 hours and the mean turning angle (radians) were used all the analyses. Non-parametric rank-transformation tests (Potvin and Roff 1993) were employed because the data distribution was heavily skewed (Quinn and Keough 2002). Transformed data were then analysed using Univariate General Linear Models (GLM). The dependent variables included in the model were the mean distance moved over 24 hours, mean turning angle (radians) and dispersion (r^2). Independent variables included in the model were sample period, sex and the interaction between sex and sample period. A Tukey's Post Hoc test was used to test the differences between each sample period. Statistical comparisons and analysis of these data were undertaken using SPSS version 11.5 (2002).

The frequency of occupancy of the five classes of shelter site during the three tracking periods, and of males and females over the three tracking periods, was determined using Pearson's Chi-Square. Univariate General Linear Models were used to test for significant relationships between the vegetation and water physicochemistry of shelter sites occupied by males and females during each tracking period. Tukey's Post Hoc tests were used to test the differences between each tracking period. Statistical comparisons and analysis of these data were undertaken using SPSS version 11.5 (2002).

Results

The distribution of water across the study sites was highly variable over time, particularly in rice bays where the area inundated ranged from 151.2 ha in November and January to approximately 2.3ha by late April. The area of canals containing water during the study was less variable over time ranging from 44.8 ha in November to 31.01ha in April/May. Aquatic vegetation cover changed little in canals but was variable in rice bays ranging from 10% in November to 90% in January.

The results of night time transects survey indicated that activity was focused close to the water body with individuals rarely observed more than 3m from water. The patterns of habitat occupancy of radio tagged individuals mirrored the changes in habitat availability (Figure 2). Radio tagged frogs remained close to or in irrigation canals during November (95% of locations) and April/May (84% of locations). In January activity was focused on flooded rice bays and the vast majority of movements occurred within this habitat type (98% of locations) (n = 277).

Movement patterns

The day to day movement distances of frogs were highly variable. Radio tagged individuals typically made small daily movements, with an occasional large displacement. The distance moved over 24hours ranged from 0 to 212m. Just over half (51%) of the frogs made at least one movement greater than 50m over a 24 hour period, while a further 20% moved between 20 and 49m. A small percentage of the frogs (10%) were relatively sedentary, never moving more than 10 m during any 24 hour period.

The mean distance moved, mean turning angle and mean dispersion all changed significantly over the three tracking periods. Frogs moved shorter distances during November and April/May, than in January ($f = 10.831$, $p<0.000$) (Post Hoc: January > November, $p=0.004$; January > April/May, $p<0.000$) (Figure 3a). There were no significant differences between sexes, or interactions between sex and sample occasion for mean distance, turning angle or dispersion.

During November and April/May, movement patterns were characterised by low displacement distances with radio tagged individuals frequently turning back towards their previous location. In January, movements were straighter and about-face turns were uncommon. Consequentially, the mean turning angles were significantly lower in January than in either November (Post Hoc $p=0.009$) and or April/May (Post Hoc $p=0.055$), but the latter relationship was of marginal significance (Figure 3b). Dispersion from the centre of activity was also higher in January than in either November (Post Hoc $p=0.002$) or April/May (Post Hoc $p=0.001$) (Figure 3c).

Individual movement patterns

While there were no overall significant differences in movement patterns between sexes or sites. Groups of individuals exhibited quite different movement patterns during the same sample periods, particularly during January. For example one group containing three radio-tracked males remained faithful to a 50m-diameter patch of cumbungi within a rice bay during the entire tracking period (4 days). In contrast a second group of four males made a series of large movements (>50m over 24hours) and the position of the entire calling aggregation changed nightly.

The movement patterns of individual females were also variable in January. In areas where the males were more mobile, females moved in a similar direction and similar distances as the resident males. In areas where males were faithful to a small area, some females moved large distances to and from calling aggregations while others stayed close to the calling group for extended periods of time.

Influence of weather conditions

This study was conducted under drought conditions; daytime temperatures were high and rainfall was low. In January the maximum daily temperature was frequently over 38 C^0 (mean 38.3 C^0). No precipitation was recorded during November or January and only 1mm fell in April/May. Humidity was also very low throughout the study period, ranging from 34.9% during November to a high of 57% in April/May. Hot, westerly winds with a mean speed of 20km/h occurred throughout January, with calmer conditions during November and April/May.

Overall there were no significant relationships between the distance moved over 24 hours and any of the weather variables included in the univariate linear regression models and no step-wise analysis was undertaken. However, when the relationship between the distances moved over 24 hours and weather variables was analysed separately for each sample period, a different pattern emerged. During November there was a weak but significant negative relationship between air temperature at 0900 and the distance moved over 24 hours ($t=-2.240$, $p=0.029$, $R^2=0.077$). However, this result should be treated with caution because the r^2 of the model is very low and two large movements that occurred at relatively low temperatures had a large influence on the negative relationship. There were no significant relationships between the measured the weather variables and the distance moved each 24hours during January. In April/May there was a significant positive relationship between the distance moved over 24 hours and percent humidity at 0900, but the relationship explained little of the variance ($t=3.083$, $p=0.003$, $R^2=0.141$).

Shelter site selection

The majority of individuals selected day time shelter sites within dense vegetation, either at the waters edge or in the water. Typical shelter sites included fringing grasses and rushes (e.g Paspalum, Barnyard grass and Juncus), emergent aquatic vegetation (typically rice), floating aquatic vegetation (e.g floating pondweed) and underground sites (clay cracks and crayfish holes) (Figure 4).

The probability of frogs leaving their shelter sites was highest in January when 100% of radio tagged frogs vacated their shelter site each night. In April/May radio tagged frogs only emerged from their shelter site 84% of the time, with some individuals remaining within a shelter site for up to three days. Once a shelter site had been vacated, an individual did not return to the same site.

The percent cover ($f = 9.305$, $p<0.000$) and water depth ($f = 17.182$, $p<0.000$) of shelter sites differed significantly with tracking period but not for site or sex. The percent cover of vegetation was lowest in November and highest during April/May (Post Hoc: November < January, $p=0.022$; November < April/May, $p<0.000$). During April/May individuals always selected shelter sites above the water line, as a result water depth was significantly lower in April/May than in either November or January (Post Hoc: April/May < January, $p<0.000$; April/May < November, $p<0.000$).

While the vegetation cover and water depth of shelter sites did not differ significantly with sex, there were significant differences between the types of shelter site utilised by males and females over the three tracking periods (χ =11.549, $p=0.009$). Females utilised fringing vegetation more often than males during January and underground sites more often than males during April/May.

Discussion

In irrigation landscapes, *L. raniformis* occupies habitats that are dynamic in space and time. Flood events inundate large areas, connecting formerly isolated habitat patches. The expansion of ephemeral habitat following flooding means that most movements will occur within, rather than between discrete habitat patches. This differs from amphibian movement patterns in less variable landscapes where movements occur between discrete habitat patches via corridors or across a non-habitat matrix (e.g. Whiteman *et al.* 1994; Schabetsberger *et al.* 2004).

Radio tracked individual’s utilised two distinct habitat types, canals and rice bays, during the course of this study. Canals are known to act as important refuge habitats for amphibians within disturbed landscapes (Mazerolle 2005). In this study, canals provided a more reliable habitat than rice bays, because vegetation cover and water depth changed little over time. The presence of permanent water is important for *L. raniformis* populations in semi-arid landscapes, because they lack water conserving adaptations such as burrowing, and the low rainfall combined with high evaporation rates limits the availability of moist terrestrial habitats (Pyke, 2002).

Rice bays were preferentially occupied during January, even though habitat conditions within canals remained relatively unchanged. Temporary waterbodies are often favoured by amphibians because the seasonal drying precludes predators (Snodgrass *et al.* 2000; Adams 2000) and the availability of food resources is often high (Whiteman *et al.* 1994). Rice bays are highly productive systems, supporting high abundances of arthropods and aquatic snails (Fasola and Ruiz 1996; Lawler 2001), both of which are important food sources for *L. raniformis* (Robinson 1993). The delay in occupying rice bays in November was probably due to the low vegetation cover immediately after flooding which limited the availability of day time shelter sites.

Within patch movement patterns

Movement patterns of radio tracked frogs changed significantly depending on whether they occupied canals or rice-bays. Male calling activity was common in both November and January, but had ceased completely by April/May. Despite these behavioural differences, there were no significant differences in movement patterns between November and April/May. This suggests that the physical differences between bays and canals (such as area, shape and distribution of vegetation) may have contributed to the differences in movement patterns during these two periods.

In irrigation landscapes, canals have sharp boundaries and the surrounding areas are typically dry with little vegetation cover. This lack of suitable habitat in the surrounding landscape can impede movement and increase site fidelity (Marsh *et al.* 2000; Gray *et al.* 2004). In the absence of suitable habitat elsewhere, radio tracked individuals have little motivation to move from their existing locations. Canals can facilitate the movement of individuals throughout the landscape (Mazerolle 2005), however, linear movements along canals were uncommon during this study. Failure to move along canals may simply reflect the absence of suitable habitat at points along the canals. Movements along linear patches like canals can also be impeded by the condition of the surrounding landscape. For example, tadpoles of the Tailed Frog (*Ascaphus truei*) moved shorter distances along stream reaches that were surrounded by clear cut vegetation than in reaches surrounded by forest (Wahbe and Bunnell 2001). In contrast to canals, rice bays cover large areas and have relatively homogenous vegetation cover so there is a lower probability of encountering boundaries.

Influence of local weather conditions

Short term changes in amphibian movement patterns are often strongly correlated with local weather conditions, particularly precipitation and temperature (Sinsch 1990; Grist 1994; Schwarzkopf and Alford 2002; Chan-Mcleod 2003). In this study, when all three tracking periods were analysed together, local weather conditions had little influence on the changes in movement patterns. However, local weather conditions were significantly correlated with the distance moved within individual tracking periods. The weak but significant correlation between air temperature and distance moved in November was due to a single individual who moved to another calling group; rather than a general trend within the sample group. Weather conditions did not influence movement patterns during January, probably because occupancy of large flooded areas buffered individuals from the day to day impact of weather. Movement distances increased with increasing humidity during April/May, and this relationship was largely driven by individuals moving from the drying rice bay sites to refuge sites. Because the extent of water across the site was limited, individuals were more likely to move during periods of high humidity which decreases the risk of desiccation (Chan-Mcleod 2003).

Shelter site selection

The use of dense vegetation as day time and winter shelter sites is typical of members of other members of the bell frog complex (Christy 2000; Hamer et al. 2003). The use of vegetation may also occur because other types of shelter sites such as rocks and fallen timber were not available. Rocks and timber can offer better protection from dehydration than vegetation (Seebacher and Alford 2002) and may be important shelter habitat natural wetland systems which typically contain large amounts of fallen timber. Personal observations indicate that clay cracks may also act as shelter sites for many amphibians in dryer regions. In this study one female utilised a clay crack while another utilised an abandoned crayfish hole. These types of shelter site may be important in areas where vegetation is limited or during very dry periods.

Conservation implications

These data indicate that care must be taken when delineating habitats for *L. raniformis*. The majority of amphibian surveys are usually timed to coincide with peak breeding events when frogs are easy to detect. This approach may overlook important non-breeding habitats, particularly fringing vegetation along irrigation canals which in this study was utilised as over-winter habitats. Furthermore, the common practice of burning or spraying vegetation along the edges of irrigation canals or dredging to remove aquatic vegetation is likely to be a key factor limiting the distribution of *L. raniformis* in irrigation landscapes.

The mosaic of permanent and ephemeral waterbodies that occurs within irrigation canals is a common feature of the remaining *L. raniformis* habitats in semi-arid Australia, such as the Lowbidgee region in south-western NSW. In these habitats, flooding creates areas of new habitat thereby changing the spatial configuration of habitat patches as well as the level of connectivity within the landscape. While other studies have demonstrated a strong link between increases in amphibian movement and periods of high precipitation e.g. (Schwarzkopf and Alford 2002; Chan-Mcleod 2003), our results indicate the flooding may play a similar role in facilitating movement. This has important implications for local population processes and spatial dynamics. At smaller spatial and temporal scales the occurrence of ephemeral habitat is likely to influence recruitment success. At larger spatial scales flood events have been shown to facilitate the dispersal of a range of different taxa (Ward and Stanford 1995; Jenkins and Boulton 2003; Arthington *et al.* 2005), allowing for recolonisation of vacant habitats as well as gene flow. The tendency for individuals to make large movements within rice bays rather than through terrestrial habitats suggests that flooding may also be an important mechanism driving movements of *L. raniformis* in Mediterranean and semi-arid areas. This relationship between dispersal and flooding highlights the potential threats caused by the modification of natural flooding regimes as a result of regulation of river flows, water extraction and flood mitigation (Kingsford 2000; Lemly *et al.* 2000; Kingsford 2001). As well as reducing the availability of breeding habitats across both space and time, reduced flooding has the potential to limit dispersal and recolonisation opportunities thereby threatening the long-term viability of floodplain populations.

Acknowledgements

This study was funded by the CRC for Sustainable Rice Production and Murray-Darling Basin Commission. S. Wassens was supported by an Australian Postgraduate Award. A. Robertson provided comments on early drafts of this manuscript. We are grateful for the helpful comment by two anonymous referees G. Pyke and W. Osborne assisted in establishing survey techniques. S. Patmore, S. Sass, and C. Coombs assisted with fieldwork. We thank land managers for giving us access to the study sites. This research was conducted under NSW National Parks and Wildlife Service Licence (S3053). Ethics approval was granted by Charles Sturt University Animal Care and Ethics Committee (01/034)

References

Acosta, M., Mugica, L., Mancina, C., Ruiz, X., (1996). Resource partitioning between Glossy and White Ibises in a rice field systems in south central Cuba. *Colonial Waterbirds* **19**, 65-72.

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

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

Arthington, A. H., Balcombe, S. R., Wilson, G. A., Thoms, M. C., Marshall, J., (2005). Spatial and temporal variation in fish-assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone floodplain river, Cooper Creek, Australia. *Marine and Freshwater Research* **56**, 25-35.

Brooks, R. T., Hayashi, M., (2002). Depth-area-volume and hydroperiod relationships of ephemeral (vernal) forest pools in Southern New England. *Wetlands* **22**, 247-255.

Browne, R. K., Edwards, D. L., (2003). The effect of temperature on the growth and development of the endangered green and golden bell frog (*Litoria aurea*). *Journal of Thermal Biology* **28**, 295-299.

Chan-Mcleod, A. C.,(2003). Factors affecting the permeability of clearcuts to Red-Legged Frogs. *Journal of Wildlife Management* **67**, 663-671.

Christy, M.T., 2000. The ecology and conservation biology of the Green and Golden Bell Frog *Litoria aurea* (Lesson) (Anura: hylidae). Unpublished PhD Thesis, University of Sydney.

Christy, M.T., Dickman, C.R., 2002. Effects of salinity on tadpoles of the Green and Golden Bell Frog (*Litoria Aurea*). *Amphibia-Reptilia* **23**, 1-11.

Cree, A., 1984. Breeding biology, respiration, and larval development of two introduced frogs (*Litoria raniformis* and *L. ewingi*). New Zealand Journal of Zoology **11**, 179-188.

Elphick, C. S., (2004). Assessing conservation trade-offs: identifying the effects of flooding rice fields for waterbirds on non-target bird species. *Biological Conservation* **117**, 105-110.

Fasola, M. Ruiz, X., (1996). The value of rice fields as substitutes for natural wetlands for waterbirds in the Mediterranean region. *Colonial Waterbirds* **19**, 122-128.

Gray, M. J., Smith, L. M., Leyva, R. I., (2004). Influence of agricultural landscape structure on a southern high plains, USA, amphibian assemblage. *Landscape Ecology* **19**, 719-729.

Grist, E. P. M., (1994). Climatic factors affecting the activity of Natterjacks (*Bufo calamita*) and Common toads (*Bufo bufo*) outside the breeding season: Mathias revisited. *Herpetological Journal* **4**, 126-131.

Hamer, A. J., Lane, S. J., Mahony, M. J., (2002). Management of freshwater wetlands for the endangered Green and Golden Bell Frog (*Litoria Aurea*): roles of habitat determinants and space. *Biological Conservation* **106**, 413-424.

Hamer, A. J., Lane, S. J., 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.

Heard, G. W., Robertson, P., Scroggie, M. C., (2006). Assessing detection probabilities for the endangered growling grass frog (*Litoria raniformis*) in southern Victoria. *Wildlife Research* **33**, 557-564.

Hooge, P. N. Eichenlaub, B. (1997). 'Animal movement extension to ArcView, version 1.1.' (Alaska Biological Science Centre, U.S. Geological survey: Anchorage.)

Hutchinson, M. F., McIntyre, S. Hobbs, R. J. Stein, J. L., Garnett, S. and Kinloch, J. (2005). Integrating a global agro-climatic classification with bioregional boundaries in Australia. *Global Ecology and Biogeography*, **14**, 197-212

Jenkins, K. M. Boulton, A. J. (2003). Connectivity in a dry land river: short-term aquatic microinvertebrate recruitment following floodplain inundation. *Ecology* **84**, 2708-2723.

Kingsford, R.T., (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* 25, 109-127.

Kingsford, R.T., (2001). Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee River in Arid Australia. NSW National Parks and Wildlife Service, Sydney.

Lemly, A.D., Kingsford, R.T., Thompson, J.R., (2000). Irrigated agriculture and wildlife conservation: conflict on a global scale. Environmental Management 25, 485-512.

Lane, S. J. Fujioka, M., (1998). The impact of changes in irrigation practices on the distribution of foraging egrets and herons (ARDEIDAE) in the rice fields of central Japan. *Biological Conservation* **83**, 221-230.

Lawler, S. P., 2001. Rice fields as temporary wetlands: A review. Israel Journal of Zoology 47, 513-528.

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

Mazerolle, M. J., 2005. Drainage ditches facilitate frog movements in a hostile landscape. *Landscape Ecology* **20**, 579-590.

Osborne, W. S., Littlejohn, M. J., Thompson, S. A., (1996). Former distribution and apparent disappearance of the *Litoria aurea* complex from the Southern Tablelands of New South Wales and the Australian Capital Territory. *Australian Zoologist* **30**, 190-198.

Pechmann, J. H.., Estes, R. A., Scott, D. E., Gibbons, J. W., (2001). Amphibian colonization and use of ponds created for trial mitigation of wetland loss. *Wetlands* **21**, 93-111.

Potvin, C. Roff, D. A. (1993). Distribution-free and robust statistical methods: viable alternatives to parametric statistics? *Ecology* **74**, 1389-1400.

Pyke, G.H., 2002. A review of the biology of the Southern Bell Frog Litoria raniformis (Anura: Hylidae). Australian Journal of Zoology 32, 32-48.

Quinn, G. P. Keough, M. J. (2002). 'Experimental design and data analysis for biologists.'(University Press: Cambridge.)

Rittenhouse, T. A. G. Semlitsch, R. D., (2006). Grasslands as movement barriers for a forest-associated salamander: Migration behaviour of adult and juvenile salamanders at a distinct habitat edge. *Biological Conservation* **131**, 14-22.

Robinson, M., (1993). A record of the warty swamp frog, *Litoria raniformis* feeding underwater. *Herpetofauna*. 23, 39.

Rothermel, B. B. Semlitsch, R. D., (2002). An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. *Conservation Biology* **16**, 1324-1332.

Saunders, D. A., Hobbs, R. J., Margules, C. R., (1991). Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* **5**, 18-32.

Schabetsberger, R., Jehle, R., Maletzky, A., Pesta, J., Sztatecsny, M., (2004). Delineation of terrestrial reserves for amphibians: post-breeding migrations of Italian Crested Newts (*Triturus C. Carnifex*) at high altitude. *Biological Conservation* **117**, 95-104.

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

Seebacher, F., Alford, R.A., 2002. Shelter Microhabitats Determine Body Temperature and Dehydration Rates of a Terrestrial Amphibian (Bufo Marinus). Journal of Herpetology 36, 69-75.

Sinsch, U., (1990). Migration and orientation in anuran amphibians. *Ethology, Ecology and Evolution* **2**, 65-79.

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

Wahbe, T. R. Bunnell, F. L., (2001). Preliminary observations on movements of Tailed Frog tadpoles (*Ascaphus truei*) in streams through harvested and natural forests. *Northwest Science* **75**, 77-83.

Ward, J. V. Stanford, J. A. (1995). Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers* **11**, 105-119.

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

Whiteman, H. H., Wissinger, S. A., Bohonak, A. J., (1994). Seasonal movement patterns in a sub-alpine population of the Tiger Salamander, Ambystoma-*Tigrinum nebulosum*. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **72**, 1780-1787.

List of Figures

Figure 1. The distribution of radio tracking sites within the Coleambally Irrigation Area in relation to flooded rice bays and the main irrigation canal.

Figure 2. The general areas utilised by all radio tagged frogs at property 171 during each radio tracking period (November, January and April/May).

Figure 3. (a) Box plot of the distance moved by individual frogs during each radio tracking period (b) The mean turning angle between sequential locations (radians) and (c) Dispersion (r^2). Circles show outliers.

Figure 4. The percent of occasions that males and females occupied each shelter site type over the three radio tracking periods. Open bars = Fringing grasses and rushes, Diagonal bars = underground, Shaded bars = Floating aquatic vegetation, Closed bars = emergent aquatic