THE ECOLOGY AND CONSERVATION STATUS OF THE **GROWLING GRASS FROG** (*Litoria raniformis*) WITHIN THE MERRI CREEK CORRIDOR.

SECOND REPORT: ADDITIONAL FIELD SURVEYS AND SITE MONITORING.

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Cover Illustrations: Breeding habitat of the Growling Grass Frog (*Litoria raniformis*), Merri Creek, Patullos Lane, Somerton. February 2002.
Inserts (top to bottom): *L. raniformis* tadpole (stage 44), Donnybrook; metamorphling, (stage 46), Donnybrook; sub-adult female, Bundoora.

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SUMMARY

The Growling Grass Frog (*Litoria raniformis*) was formerly common and widespread in south-eastern Australia, but is now recognised as a nationally vulnerable species. It is currently listed as threatened in Victoria under the *Flora and Fauna Guarantee Act* 1988, and is recognised as endangered by the Victorian Department of Sustainability and Environment.

Populations of *L. raniformis* appear to have been once widespread in the Merri Creek Corridor (MCC), north of Melbourne. However, population declines and disappearances have been noted, as have significant regional habitat changes. This study was initiated during November 2001, with the objective of gathering the information required to formulate a comprehensive strategy for the long-term conservation of *L. raniformis* in the MCC. This second interim report details progress made during the second season of the study (2002-2003), including additional field surveys for the species at three new sites, and monitoring of 27 sites identified and examined during the 2001-2002 season within the Merri catchment.

Litoria raniformis was located at each of the three additional field sites surveyed during the 2003 season, bringing the total number of occupied sites to 47 of 139 examined overall. Re-analysis of the regional habitat associations of the species was undertaken, incorporating these additional records and using a more statistically rigorous approach. These analyses identified three variables with a strong influence on the pattern of occurrence of *L. raniformis*:

- The length of roads within 1000 m of the sites (negative association with frog occupancy);
- The sum of the proportion of the water-body with submergent or floating vegetation (positive association with frog occupancy), and;
- The permanence of the water-body (positive association with frog occupancy).

In our previous analyses, site occupancy by *L. raniformis* was found to be positively influenced by the distance to the nearest site occupied by the species. The statistical re-analysis conducted used the autologistic model, which explicitly models the interdependence of occupancy status between adjacent sites. Fitting of the autologistic model to the data revealed that the occupancy status of adjacent sites has a very strong effect on the probability of site occupancy by *L. raniformis*: sites located close to occupied sites were likely to be occupied themselves; sites close to unoccupied sites were unlikely to be occupied.

The relationship between site occupancy and the landscape scale habitat parameters (surrounding site occupancy status, road density) indicates that there is an important interaction between sites occupied by the species. Population viability appears to be reliant upon the opportunities for dispersal across the landscape, including long-distance movements between apparent sub-populations of the frog, and small-scale movements between adjacent habitat patches. In combination with habitat degradation, the rapid habitat fragmentation that is occurring within the MCC is reducing the opportunities for these movements, and appears likely to be a major cause of the historical contraction of the species in this region.

Site monitoring during the current season proceeded with the aims of identifying temporal variation in frog detectability and site utilisation, examining the extent and timing of reproductive activity and investigating relationships between reproductive activity and habitat attributes such as water quality and the presence of predatory fish. Detectability analysis conducted on data collected during this period led to two important outcomes: (i) validation of survey results obtained during this study; (ii) recommendation that surveys for this species require at least two spotlight surveys of 90 person minutes duration to be 90% confident of correctly determining occupancy status at individual wetlands. Tadpole and metamorphling surveys conducted also provided important results, indicating that reproduction within the Merri Creek remains an important source of recruitment for the species, particularly in the north of the catchment. Sites at which reproduction was recorded consistently displayed dense submergent and floating vegetation cover but had variable physio-chemical properties and predatory fish composition. Further research is currently being undertaken to examine the extent of fish predation upon larval *L. raniformis* within the MCC.

Interim guidelines advanced for the conservation of *L. raniformis* within the MCC include:

- Development of a detailed plan identifying crucial sites for maintenance and enhancement (including habitat creation) for the conservation of *L. raniformis* with the MCC, resulting from additional habitat modelling, and;
- Immediate action to secure several known breeding sites which are threatened by land-use changes, including filling of former quarry holes;
- Further research upon the population ecology and meta-population dynamics of the species, conducted as a postgraduate research project.

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1. INTRODUCTION

1.1. Background

1.1.1. The Growling Grass Frog (*Litoria raniformis*) within the Merri Creek Corridor

The Growling Grass Frog (*Litoria raniformis*)[1] is a member of the 'Bell Frog' species complex (Anura: Hylidae), a group of large frogs found across the south-east, south-west and extreme north of Australia (Barker *et al.* 1995). *Litoria raniformis* inhabits inland regions of the Australian Capital Territory, New South Wales, Victoria and South Australia (Barker *et al*. 1995; Thomson *et al.* 1996; Osborne *et al.* 1996). Pyke (2002) provides a detailed review of the current knowledge of this species biology.

Populations of *L. raniformis* have been subject to reductions in abundance and distribution over much of their former range, particularly during the last 20-25 years. Within Victoria, severe population declines were recorded during the drought periods of the early 1980's (P. Robertson pers. obs.). Although no systematic review has been conducted, this frog appears to have disappeared from parts of its former range across the state. Subsequent to these declines, *L. raniformis* has been listed as vulnerable under the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 (EPBC). The species is currently listed as threatened in Victoria under the *Flora and Fauna Guarantee Act* 1988 (FFG), and is recognised as endangered by the Victorian Department of Sustainability and Environment (DSE 2003).

Apparent causes for the declines observed in *L. raniformis* and other members of the Bell Frog complex include habitat alteration, drought, disease, introduction of exotic fish, increasing soil salinity, pollution from industrial or agricultural runoff and global climate change (including increased ultraviolet radiation) (Osborne *et al.*1996). Given this range of threats, it is imperative that the conservation status of remaining populations of *L. raniformis* within Victoria be investigated over a variety of landscapes (Robertson in prep.). In particular, there is an urgent need to implement conservation measures in the vicinity of major urban centers, where development and habitat alteration threaten the immediate survival of extant populations.

The Merri Creek Corridor (MCC) lies within Melbourne's northern basalt plain; a gently undulating, volcanic landscape that stretches north from the suburb of Northcote to the Great Dividing Range, between the Plenty River in the east and the Moonee Ponds Creek in the west (McLellan 1994; Anon. 2001; Savio 2001). Beardsell (1997) provides a detailed description of the physiography and hydrology of this area. Populations of *L. raniformis* appear to have been once widespread in the MCC (Schulz & Webster 1991; Beardsell 1997). However, population declines and disappearances have been noted, coinciding with significant regional habitat changes, particularly habitat destruction and alteration resulting from agricultural practices, and industrial and urban development (Beardsell 1997; B. Casey, G. Turner, R. Valentic pers. comm.). The regional status of

[1] The common name presently adopted by DSE for *Litoria raniformis* is 'Growling Grass Frog'. The species is listed as 'Southern Bell Frog' in Commonwealth legislation (*EPBC Act 1999*). It has also been called 'Warty Bell Frog' or 'Warty Swamp Frog' in some popular literature, and 'Green and Gold Frog' in Tasmania – however, the name 'Green and Golden Bell Frog' is usually the related *Litoria aurea*.

this frog became a major concern during the implementation of several recent infrastructure developments, including the Craigieburn Bypass of the Hume Highway (see Williams 2001, 2002; Robertson 2002; Conole *et al.* 2003), extension of Edgar's Rd, Epping (see Organ 2003a) and decommissioning of the Craigieburn Sewage Treatment Plant (see Anon. 2002).

1.1.2. Project background

The overall objective of this project is to gather the information required to formulate a comprehensive strategy for the long-term conservation of *L. raniformis* in the MCC (Robertson & Scroggie 2001).

Research upon the ecology and conservation status of *L. raniformis* within the MCC was initiated during November 2001 in response to the concerns described above. The research is a collaborative effort instigated by the Friends of Merri Creek (FOMC), the Merri Creek Management Committee (MCMC) and the Victorian Department of Sustainability and Environment (DSE) (formerly Department of Natural Resources and Environment), with support from Yarra Valley Water (YVW).

Robertson and Scroggie (2001) divided the key ecological information required to meet this objective into four main groups, all of which were to be addressed by a field study that spanned at least two breeding seasons. These components are:

- The distribution and status of *L. raniformis* populations within the region, including the recognition of any areas of habitat considered critical for long-term population viability;
- Habitat use and requirements, including temporal patterns of habitat use on a local and regional scale;
- Movements patterns of the frog on a local and regional scale;
- Other conservation requirements, such as knowledge of the frog's demography, reproductive biology and meta-population dynamics.

The first stage of this study, a three month survey of *L. raniformis* populations within the MCC and adjacent catchments, was completed between December 2001 and March 2002, and has been reported previously (Robertson *et al.* 2002). Work conducted during that period aimed to address the first two requirements listed above and operated with five specific aims:

- Undertake a comprehensive survey of all water-bodies in the Merri Creek Corridor and adjacent catchments of the Darebin and Yuroke Creeks, to determine their use by *L. raniformis*.
- Examine relevant habitat attributes at all sites surveyed, to determine factors influencing the distribution of the species (including potential threats at these sites).
- Investigate the spatial distribution of water-bodies utilised by the species.
- Repeatedly survey a selected subset of water-bodies, to investigate temporal changes in the use of those water-bodies.
- Determine the historical distribution of the *L. raniformis* within the study area.

During this initial field season, a total of 136 field sites (including sections of streams and standing water-bodies) was surveyed, with *L. raniformis* being identified at 41 of these locations. In addition, 110 historical records of the frog within the MCC were collated. Subsequent statistical analyses identified habitat variables influencing the frogs regional distribution (Robertson *et al.* 2002). We concluded that the species is significantly threatened by habitat modifications within the study area and that further work was required to guide development of conservation strategies in the MCC.

1.2. Study objectives

Of the broader information requirements needed to guide conservation efforts for *L. raniformis* within the MCC, as identified by Robertson *et al.* (2002), the following components were considered priorities for investigation during the second stage of the project, the 2002-2003 season.

- Tadpole/metamorphling surveys - to determine which populations are recruitment sources, which patches are breeding habitat/non-breeding habitat, and the habitat parameters contributing to successful reproduction. This information contributed to our understanding of meta-population processes in the area, and of priorities for preservation of particular habitat patches should further development projects be proposed.
- Predation by fish (including *Gambusia*) on *L. aurea* and *L. raniformis* has received much attention in the literature. Gathering some definitive data on this issue was a high priority, to determine whether predation is an important factor regulating population numbers or recruitment (comparisons between stream sites and standing water-bodies were of particular interest in this regard). Surveys for fish were carried out in conjunction with tadpole/metamorphling surveys.
- Knowledge of life-history and demographic parameters which would enable population modeling and determination of critical stages for focus of conservation management.
- Information on survey effort required to reliably determine the presence or absence of the species. Inconsistent or inadequate survey effort appears to have been a general problem with many studies – obtaining data on this question has implications for all subsequent work on *L. raniformis.*

To address these information requirements, specific aims for the 2002-2003 field season were:

- To conduct single survey visits to sites not examined last season, to increase the consistency of geographic coverage of the survey, and to visit occupied sites which may have been brought to our attention since then (at which the habitat has not yet been assessed).
- To repeatedly survey a subset of the sites examined last season (including both sites at which frogs were detected and those at which they were not detected) throughout the activity period to examine:
  - variation in frog detectability and site utilisation;
  - reproductive activity and success, particularly as measured by tadpole abundance or presence/absence;
  - relationships between reproductive activity and habitat attributes such as water quality and the presence of predatory fish, and;
  - obtain information on frog demographic parameters and microhabitat use.

2. METHODOLOGY

2.1. Study area

As with the previous season, all components of this study were conducted within an area encompassing the Merri Creek Corridor and adjacent catchments of Yuroke and Darebin Creeks. Three additional sites examined during this second season were located within the catchment of the Merri Creek itself (2 sites) and the Edgar's Creek (1 site) (see below). Site monitoring along streams was restricted largely to clusters of sites along the Merri Creek between Campbellfield and Donnybrook (as identified by Robertson *et al.* 2002), whilst standing water-bodies were spread more widely (incorporating sites within the Darebin and Edgar's Creek catchments).

2.2. Additional field surveys

Surveys for *L. raniformis* were conducted at three water-bodies not examined in the previous season, but for which records of the species were subsequently obtained. These sites were: 1) a small, inundated basalt quarry approximately 1 km south-east of Bald Hill, Donnybrook (Ref. No. D021, AMG: 322146 5846532); a spring-fed dam north of Harvest Home Lane, Epping (Ref. No. E010, AMG: 323328 5834883), and; 3) a former clay quarry in Campbellfield (precise details of this site not disclosed here at the request of the land-holder).

Surveys and habitat assessments for *L. raniformis* were conducted in accordance with the protocols used in the previous season (see Robertson *et al.* 2002), to allow these sites to be included within further statistical modeling of the frog's regional habitat associations. Sites were inspected on 25/11/02 (E010), 11/5/02 & 17/3/03 (D021) and 27/3/03 (Campbellfield quarry). Site E010 (water-body north of Harvest Home Lane, Epping) was subsequently monitored between January and March 2003 (see below).

2.3. Site monitoring

2.3.1. Site selection

Twenty-six sites identified during the 2001-2002 season were selected for repeated monitoring purposes - see Table 1 and Figure 1. Of these 26 sites, 23 were systematically surveyed during the previous season, two were examined during transect surveys, and one was identified but not examined. One additional site (E010) was identified after this period, but was included within the monitoring program because of its isolation and apparent high quality as breeding habitat for the species. Three additional sites were examined only once during the monitoring period - the remaining quarry hole within the Epping Tip (S010), the bottom quarry pond at the McKimmies Rd Landfill site, Bundoora (BU006), and the newly constructed Botanica Park wetland, Bundoora (BU007).

Site selection was guided primarily by the objective to sample locations which varied in habitat attributes including size, proximity to other water-bodies, vegetation characteristics, water quality and predatory fish abundance. Additionally, it was aimed to sample sites where the frog was presumed to be both present and absent, and to include sites distributed widely across the study area. Sites selected consisted of permanent and ephemeral sections of streams, farm dams, settling ponds, swamps and former quarry holes (see Table 1).

Table 1. Details for the twenty-seven sites monitored for *Litoria raniformis* within the Merri Creek Corridor, January – March 2003.

Location	Site ref.	AMG		Survey effort: 2001 - 2002	GGF recorded (prior to 2003)	Monitoring group number
		Easting	*Northing*	*Date/s surveyed*	*Max. abundance*	*Sites within groups surveyed on the same night*
Campbellfield						
Merri Creek at Barry Rd	C001	321239	5828814	13/12/01, 15/1/02	0	1
Western settling pond at Barry Rd	C002	321181	5828882	13/12/01, 15/1/02	0	1
Eastern settling pond at Barry Rd	C003	321245	5828920	13/12/01, 15/1/02	0	1
Merri Creek south of Cooper St	C008	321350	5830863	19/1/02	0	2
Craigieburn						
Merri Creek above Summerhill Rd	CR004	320197	5839532	21/12/01	0	2
Merri Creek below Summerhill Rd	CR005	320205	5839345	21/12/01	10	2
Merri Creek below Craigieburn Rd	CR006	319181	5835971	24/12/01, 29/12/01	0	3
Merri Creek upstream of Craigieburn Rd	CR007	319181	5836771	29/12/01	0	3
Curley Sedge Creek around Craigieburn Rd	CR022	321042	5836012	not surveyed	-	3
Donnybrook						
Dam on Spring St, Donnybrook	D003	320636	5843192	6/1/02, 7/1/02	3	4
Dam south of Shell, Donnybrook	D010	318256	5842504	20/1/02, 23/1/02	5	4
Merri Creek at Donnybrook Rd	D019	319659	5842900	6/1/02 transect survey	6	5
Merri Creek at Donnybrook Rd	D006	319713	5843010	6/1/02, 7/1/02	5	5
Merri Creek at Donnybrook Rd	D007	319804	5843142	6/1/02, 7/1/02	2	5
Dam on Donnybrook Rd	D004	320005	5842780	20/1/02, 23/1/02	1	5
Kalkallo Creek at Donnybrook Rd	D020	318727	5843001	20/1/02 transect survey	10	5
Epping						
Waterbody north of Harvest Home Lane	E010	323348	5834889	not surveyed	-	7
Somerton						
Merri Creek below O'Herns causeway	S004	319703	5833002	19/12/01, 28/1/02	5	6
Merri Creek upstream of O'Herns causeway	S005	319746	5833136	19/12/01, 11/1/02, 19/1/02, 28/1/02	5	6
Curley Sedge Creek above O'Herns causeway	S006	320047	5833227	19/12/01	2	6
O'Herns Swamp	S007	320514	5832862	19/12/01	0	6
Merri Creek at Patullos Lane	S008	319271	5833890	20/12/01, 11/1/02, 12/2/02	13	7
Merri Creek below Freight Drive	S018	320424	5832340	14/2/02, 15/2/02	4	7
Wollert						
Wollert Landfill - opposite weighbridge	WL001	327419	5837371	18/2/02, 22/2/02	1	8
Wollert Landfill - north of weighbridge	WL002	327383	5837715	18/2/02	6	8
Wollert Landfill - north central quarry hole	WL003	327252	5838312	18/2/02	5	8
Wollert Landfill - west of WL002	WL004	327442	5837880	18/2/02	0	8

Figure 1. The location of sites monitored for *Litoria raniformis* within the Merri Creek Corridor, January – March 2003.

2.3.2. Monitoring procedures

Monitoring procedures varied slightly between stream sites and standing water-bodies, due to the physical differences between these habitat types. However, monitoring at all sites was based upon transect sampling procedures, as below:

- ***Stream sites*** - stream sites were limited to 50 metre sections of stream corresponding with site boundaries used in the previous season. The survey site incorporated both banks of the stream (to 10 m above the water-line) and the entire water's surface. Transects were marked at their start, middle and finish points.
- ***Standing water-bodies*** **-** the area surveyed at each standing water-body varied according to water-body size. Wherever possible, the entire circumference of the water-body was surveyed; however, in some locations safety concerns or simply the sheer size of the water-body restricted us to segments of the bank. Those segments chosen were considered representative of the site. In all cases, the area surveyed was limited to a strip of bank 20 metres in width, incorporating 10 metres either side of the water-line. The length of the transect surveyed at each site (i.e. entire circumference of the water-body or segment/s of bank) was measured by pacing. The transect length was marked at the start, middle and finish points.

Sites were divided between eight groups (a group generally being 3 sites), each surveyed fortnightly, with one group of sites being surveyed over the course of a night. Surveys were limited to suitable weather conditions (day = air temperature greater than 15^{o}C, with little or no wind; night = air temperature greater than 12^{o}C with little or no wind; Robertson *et al.* 2002). To further standardise for climatic variation, the chronology of site surveys was randomised within each fortnightly rotation. Due to logistical constraints, randomisation was based upon site groupings rather than individual sites. Random numbers were used to determine the order in which these eight groups were surveyed during each rotation.

(i) Spotlight surveys

Survey procedures followed those used during the previous season. Standard spotlight and daytime searches were again conducted at each site, resulting in a total of ten field inspections being conducted at most locations (five spotlight surveys, five day-time searches). Daytime searches were not conducted at sites that were completely dry during the survey period. Visual inspection, call recognition and limited active searching (turning surface debris) were employed in all cases.

Spotlight surveys were carried out by teams of two people between the hours of 20:30 and 03:00. At the beginning of each survey, a standard period of ten minutes was spent listening for frog calls from the water's edge. Call imitation was conducted during the last five minutes of this period, in an attempt to stimulate a response from any male *L. raniformis* that may have been present but not calling. The abundance of calling males of all frog species present was recorded during this period. Following this, each site was systematically searched for active frogs following general procedures outlined by Crump and Scott (1994).

Spotlights were used to scan all surfaces of the water-body whilst traversing its length, focussing on inspecting aquatic vegetation. Individual *L. raniformis* were detected either by direct encounter or the identification of this species' distinctive eye-shine. Upon location, the time of discovery, AMG co-ordinates, behaviour and microhabitat of each frog were recorded. All frogs were also assigned to one of three size classes:

metamorphling (specimens < 45 mm snout-groin length [SGL]), sub-adult (specimens between 45-59 mm SGL) or adult (specimens 60 mm SGL or above). We attempted to capture all frogs located, and recorded SGL (to the nearest millimetre) using a small tape measure and total weight (to the nearest 0.1 gram) using a Pesola spring balance. Sexually mature males were identified by the presence of swollen nuptial pads and brown throat color. The abdomen of each female frog was inspected for the presence of mature oocytes (eggs), visible through the translucent body-wall. In addition, the exact location of each frog was marked for later microhabitat assessment. These data will be presented elsewhere. Survey periods varied with water-body size and habitat complexity, but generally lasted for between 30 and 60 minutes. At the completion of each survey, the total abundance of each size class of *L. raniformis* was tallied, as was the abundance of all other frog species observed (including tadpoles).

Due to the diurnal habits of *L. raniformis* (see Pyke 2002.) surveys analogous to those described above were also conducted during daylight hours at most sites. Diurnal surveys coincided with tadpole trap retrieval (see below), water-quality and microhabitat sampling. They focussed on searching the entire site for specimens basking in direct or filtered sunlight.

Weather conditions were recorded at the beginning of each survey period. Air temperature (to the nearest degree) and relative humidity (to the nearest five percentage points) were determined using a whirling psychrometer. Water temperature was measured to the nearest 0.1^{o}C, one metre from the shoreline, using an ISM digital pocket thermometer. Cloud cover, rain, moonlight, wind velocity and wind direction were recorded in combination with a brief description of general weather patterns experienced prior to, and during, the survey period. All weather variables were re-recorded at the end of the survey period if it extended beyond 60 minutes.

Measures to reduce the possible spread of infectious pathogens (such as ‘chytrid’ fungus) between the survey sites were again implemented in accordance with standards described by the New South Wales National Parks and Wildlife Service (NPWS 2001).

(ii) Tadpole and metamorphling sampling

Funnel or bait traps are a proven technique for sampling aquatic amphibian larvae (Adams *et al*. 1997). Advantages include the ability to sample structurally complex or relatively inaccessible water-bodies, the ability to capture very large taxa (which may elude dip net surveys), and the ability to sample overnight when many amphibian larvae are more active (Adams *et al.* 1997). This method has received limited attention in Australia; however, these traps have previously been used to capture large numbers of *L. raniformis* tadpoles on the basalt plains of south-western Victoria (G. Peterson, La Trobe University, pers. comm.). During this study, they provided the best available technique by which to measure and compare changes in frog reproduction across time and space.

Commercially-available, collapsible bait-traps (45 cm long × 25 cm high × 25 cm wide, with a 15 cm long funnel at each end, aperture 5cm) constructed of nylon netting (mesh size 2 mm) were used to determine the presence and relative abundance of *L. raniformis* tadpoles at each monitoring site. Traps were set at the completion of each spotlight survey and retrieved the following morning (generally within 12 hours).

Fluorescent light-sticks (‘4 inch yellow cyalume light-stick’ - Omniglow Corporation, Massachusetts, USA) were placed in each trap in an attempt to attract tadpoles, and thus increase capture success. Light-based attractants are commonly employed for aquatic invertebrates and fish, but their efficacy for attracting amphibians is unknown. Placement of traps followed a randomised scheme proposed by Schaffer *et al.* (1994) and Adams *et al.* (1997). Placement varied slightly between stream sites and standing water-bodies. Five traps were spread evenly throughout stream sites by placing one trap within every 10 metre segment of the site. Within each segment, specific trap placement was randomised by dividing the water surface into three zones; namely, near bank, mid-stream and far bank, and randomly allocating traps to these zones. Traps were placed near the centre of each stream zone. In standing water-bodies, a 50 metre segment of bank was randomly chosen for funnel trapping purposes. Placement of traps within this section matched that described for stream sites. Traps were suspended so that at least part of the trap emerged above water-level, allowing any late-stage tadpoles to breathe air if necessary.

Records were maintained regarding the weather conditions prevailing during the survey period, water-level within the site (especially relevant for stream sites) and the total time traps were in the water. The bank distance, microhabitat, water-depth and water-flow were recorded for each trap. All tadpoles and fish caught within the traps were identified to species level, counted and released. Tadpoles of *L. raniformis* were divided into three broad developmental categories, those displaying no legs (stages 24-30), back-legs only (stages 31-41), or both front and back-legs (stages 42-44) (see Anstis 2002).

Dip-net surveys were undertaken at two stream sites and one standing water-body in which water levels were inadequate for the deployment of funnel traps. Ten, standard two metre long sweeps were conducted, spaced so as to cover the majority of the water-body and aquatic microhabitats therein. All sampling was conducted during daylight hours, once in each sampling round (i.e. maximum of five samples). Tadpoles and fish captures were recorded as described above.

Undertaking sampling methods specific to metamorphlings was not feasible during the survey period. Rather, metamorphling surveys between all sites simply formed a component of the adult surveys (i.e. recording the numbers observed during the standard searches, day and night). In addition to the tadpole sampling discussed above, these surveys provided an indication of the sites at which successful reproduction occurred.

(iii) Water-quality measurements

Examining variation in water quality between the monitoring sites, and specifically identifying the chemical and physical attributes of waters used by the frog for reproduction, was a priority during the 2002-2003 season. Attributes including pH, electrical conductivity (mS/cm), dissolved oxygen content (mg/L) and water temperature (^{o}C) were recorded on five occasions at each monitoring site (coinciding with daylight inspections) using a 'Horiba' U-10 water quality tester. Measurements were recorded from a one-litre sample of water, collected at the water's surface, one-metre from the water's edge.

Nutrient content and heavy metal contamination have been found to vary widely within the Merri catchment (Finlay *et al.* 1997), and high levels of these contaminants in downstream sections of the creek (particularly below Cooper St) may be implicated in the decline of the frog in these areas (Robertson *et al.* 2002). However, we were unable to measure these attributes due to funding constraints.

(iv) Predatory fish surveys

Funnel or bait traps are used extensively to determine the occurrence and relative abundance of various fish species in stream environments (J. McGuckin, Streamline Research, pers. comm.). As such, the trapping for tadpoles conducted at each monitoring site also provided standardised records of the predatory fish assemblage present. Although, it should be noted that not all fish species would necessarily be detected by these sampling methods. All fish captured were identified to species level, and counts were maintained during each trapping period. To augment trapping data, all fish seen during site spotlight surveys or subsequent daylight inspections were recorded, along with the numbers observed.

We also recorded information on predatory invertebrate abundance within each site during funnel trapping surveys. All invertebrates which may prey upon *L. raniformis* tadpoles, including odonate larvae, Dytiscid water beetles and predatory crustacea, were identified and counted.

2.4. Data analysis

2.4.1. Re-analysis of factors influencing the distribution of *Litoria raniformis*.

(i) Rationale

Analyses of the field data concerning the distribution of *L. raniformis* in the study area were carried out with the intention of developing statistical models to explain the observed pattern of presence/absence, and to allow prediction of the likely patterns of distribution of the frog within unsurveyed portions of the study area, and more generally within other parts of the species' geographic range. The primary purpose of the modelling procedure was to provide a formal framework for exploring the processes which determine the distribution of *L. raniformis,* and to use this model to gain insight into the conservation requirements (particularly habitat requirements) of the species, and the likely responses of the species to processes which modify its habitat.

The available data collected consisted of an assessment of the presence or absence of *L. raniformis* at each of the study sites, together with a large set of measured habitat variables at each of the sites. Statistical modelling proceeded with the aim of discovering patterns of association between habitat variables and the presence of the species.

Building on a previous analysis of a subset of the present data (Robertson *et al.* 2002), we sought to update this analysis in light of extra data collected during the summer of 2002-2003, and to use a more statistically rigorous and defensible approach to modelling of the data. It is hoped that this more thorough approach will improve the interpretability and utility of the resulting statistical models.

The available data present a number of challenges for rigorous statistical analysis. Firstly, a crucial issue is the lack of statistical independence between the occupancy status of sites in close proximity. It was apparent from the analysis presented in our earlier report (Robertson *et al.* 2002), that the presence of *L. raniformis* at individual sites was strongly influenced by the presence or absence of the species at other locations in close proximity. The analysis of Robertson *et al.* (2002) showed that sites were much more likely to be occupied if nearby sites were also occupied. Such a pattern of occurrence is in statistical terms, described as spatially autocorrelated.

Spatially autocorrelated data presents fundamental difficulties for the analyst, as many of the usual assumptions of standard analytic techniques are grossly invalidated (Legendre 1993; Koenig 1999; Keitt *et al.* 2002). In particular, the usual statistical assumption that the sampling errors of replicate sites are identically and independently distributed is clearly violated in cases where the pattern of presence and absence is spatially autocorrelated. Violation of this assumption means that parameter estimates, standard errors and hypothesis tests made using statistical models which assume independence between sites will be subject to bias, and hence should not be relied upon for inference or prediction. We have sought to develop statistical models for the pattern of occurrence of the species which explicitly account for the influence of occupancy of adjacent sites. By accounting for this source of variation in the data, much more reliable inferences regarding the patterns of occurrence and their causes should be obtainable.

(ii) An approach to modelling spatially autocorrelated presence/absence data

One of the simplest and most widely used statistical models for the presence and absence of a species, conditional upon measured habitat variables at each of a set of sites, is the logistic model:

$$\log_e\left(\frac{p}{1-p}\right) \sim \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots \beta_m x_m \qquad \text{(Equation 1)}$$

Where p is the probability of occurrence of the species at each site, β_0 is the intercept term, $x_1 \ldots x_m$ are a set of habitat variables measured at each site, and $\beta_1 \ldots \beta_m$ are a set of fitted linear coefficients associated with each of the habitat variables included in the model. The logistic model can be easily fitted to the observed pattern of presence and absence of a species, and a set of measured habitat variables at each of a set of sites by the method of maximum-likelihood. The fitted logistic model leads to a set of predicted probabilities of occurrence of the species at each of the surveyed sites, and can also be used to predict the probability of occurrence at other, unsurveyed sites for which measurements of the habitat variables are available.

The ordinary logistic model is not strictly suitable for modelling the pattern of occurrence of *L. raniformis* in the present study, as the probabilities of occurrence of the species at each site cannot reasonably be assumed to be independent of one another. Efficient and reliable statistical modelling of such a data set calls for a model which explicitly accounts for the pattern of interdependency between the occupancy statuses of adjacent sites. One possible approach to modelling such data is provided by the autologistic model (Besag 1972):

$$\log_e\left(\frac{p}{1-p}\right) \sim \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots \beta_m x_m + \gamma\,\text{autocov} \qquad \text{(Equation 2)}$$

Where *autocov* is an autocovariate, a term describing the pattern of occupancy in sites neighbouring each of the sites considered in the model. For the i^{th} site in the set of sites considered, which has a total of k neighbouring sites (defined as those sites within a set, predetermined distance of each focal site), the autocovariate is defined as:

$$\text{autocov}_i = \frac{\sum_{j=1}^{j=k_i} w_{ij} y_j}{\sum_{j=1}^{j=k_i} w_{ij}} \qquad \text{(Equation 3)}$$

Where, y_j are the occupancy statuses of each of the k neighbouring sites (equal to one if the site is occupied, zero if not), and w_{ij} is a weight given to the occupancy status of each neighbour, derived using the equation:

$$w_{ij} = \frac{d_{ij}^{-1/2}}{\sum_{j \neq i} d_{ij}^{-1/2}} \qquad \text{(Equation 4)}$$

This weighting scheme has the effect that the occupancy status of more distant neighbours has less influence on the value of the autocovariate than that of sites in closer proximity. The values of the autocovariate can be interpreted as the distance-weighted proportion of neighbouring sites which are occupied. The coefficient γ of the autologistic model (Equation 2) describes the strength of influence of the occupancy status of neighbouring sites: a strongly positive estimate of γ is expected in cases where the presence of adjacent occupied sites increases the probability of occupancy (i.e., positive spatial autocorrelation); a negative estimate of γ is expected in cases where nearby occupied sites lead to a reduced probability of occupancy (i.e., negative spatial autocorrelation).

Autologistic models following this, or a similar formulation, have previously been employed with some success for modelling of landscape-scale patterns of occurrence of amphibians (Knapp *et al.* 2003) and other animal species (Augustin *et al.* 1996; Gumpertz *et al.* 2000), and in other applications where analysis of spatially autocorrelated binary data is required, in particular the analysis of digital imaging data (Besag 1972; Albert & McShane 1995; Gumpertz *et al.* 1997; Augustin *et al.* 1998; Koutsias 2003).

For the purposes of this study, sites were defined as being neighbours if they were within 1000 m of each other. Selection of this value was based on an earlier regression tree model of a portion of the data (Robertson *et al.* 2002), which showed greatly reduced probabilities of occupancy, if the nearest occupied site was greater than approximately 700 m away. Some limited exploration of the effect of alternative neighbour thresholds on the final fitted model did not reveal any great influence on the final results: neighbour thresholds between 500 and 1500 m led to autocovariates which were very closely correlated with the autocovariate calculated under a 1000 m neighbourhood threshold.

While calculation of the autocovariate from the sample data is relatively straightforward, fitting of the autologistic model to the data is not. Direct, analytic solution of the model by maximum-likelihood methods are not feasible, due to the lack of a closed-form expression for the likelihood of the autologistic model (Besag 1972; Augustin *et al.* 1996). An alternative approach, which has been previously employed with some success, is to fit the model using Markov-chain Monte Carlo (MCMC) methods (Gelfand & Smith 1990; Casella & George 1992; Link *et al.* 2002), and this is the approach we have employed here.

Detailed description of the theoretical motivations and utility of this method are beyond the scope of the current report, however, some brief computational details are provided. The particular variant of the MCMC algorithm employed was a modified Gibbs sampler with block updating of the coefficients for the habitat covariates. Initial starting values (regression coefficient estimates) for the algorithm were determined by fitting the autologistic model to the data, under the assumption that the sites were independent of one another. Theoretical reasons suggest that after initial convergence is allowed for, the distributions of the samples of fitted values of the coefficients β and γ derived from using the Gibbs sampler will approximate the sampling distributions of the true values of the model parameters (Gilks *et al.* 1996; Augustin *et al.* 1998).

Some caution is needed in checking and interpreting the results of the Gibbs sampler. In particular, it is possible that the coefficient estimates obtained in the early iterations of the algorithm may not be reasonable approximations of the long-term sampling distributions of the parameters. For this reason, the first 50,000 iterations of the algorithm were discarded, and were not included in the final results. Furthermore, successive results from the algorithm are expected to exhibit serial dependence (temporal autocorrelation), although in practice this is not expected to greatly influence the distribution of the samples. In order to eliminate any possible influence of temporal autocorrelation on the final inferences, after discarding the first 50,000 iterations of the Gibbs sampler, of the next 250,000 iterations, every 5^{th} iteration was included in the final inferential results. Therefore, final inferences regarding the parameters β and γ are based on 50,000 updates of the Gibbs sample.

(iii) Model Selection

Fitting of the autologistic model using the Gibbs sampler, while relatively straightforward to implement using a statistical programming language, is computationally demanding. Running the Gibbs sampling scheme described above required approximately 17 hrs of processing time to fit any one model to the data (Intel Pentium 4 processor at 1.8 GHz, 512MB RAM, Windows 2000 Operating System). Hence, fitting of many alternative models including different sets of habitat variables using the Gibbs sampler was not practical. Therefore, initial screening of habitat variables for inclusion/exclusion in models was carried out using autologistic models fitted to the data using ordinary maximum-likelihood techniques. While the parameters estimates obtained in this way are most likely subject to considerable bias, this was the only computationally feasible means of carrying out a reasonably comprehensive exploration of the relationships between the pattern of occupancy and the large number of available habitat variables.

Comparison of the relative parsimony of alternative models was carried out by comparing the values of Akaike's information criterions (*AIC*), including the correction for small sample sizes (denoted AIC_c) proposed by Hurvich and Tsai (1989) and recommended for model selection purposes by (Burnham & Anderson 2001). AIC_c for a given candidate model is calculated as:

$$AIC_c = -2(\log_e(\ell)) + 2(k) + \frac{2k(k+1)}{n-k-1} \qquad \text{(Equation 5)}$$

Where ℓ is the likelihood of the model, k is the number of estimated parameters in the model, and n is the sample size. In general, the model with the lowest AIC_c value of the candidate models in the set is considered to be the most parsimonious. A parsimonious model can be broadly defined as one which gives the best balance between the increased explanatory power of a complex model, with many predictor variables included, and the simplicity and ease-of-interpretation of a simpler model with a smaller number of variables included (Forster & Sober, 1994).

Two broad groups of habitat variables were selected *a priori* for possible inclusion in habitat models, based on current knowledge and beliefs concerning the effects of habitat variables on the distribution of *L. raniformis,* other members of the *L. aurea* species complex, and other frog species with similar ecological characteristics.

The first group of variables examined were landscape-scale habitat variables derived from available GIS data (Table 2). The two landscape variables considered were the lengths of stream habitat within a one kilometre radius of each site, and the length of roads within a one kilometre radius of each site. It was considered possible that both of these variables may influence the probability of occurrence of *L. raniformis.* The amount of stream is a measure of total availability of an important component of habitat for the species; streams may also form dispersal routes for frogs moving between sites. The amount of roads in the vicinity of sites was considered to be a possible influence on occurrence, due to the possible effect on habitat structure and availability of the presence of roads, and the possibility that roads may form barriers to dispersal and colonisation by *L. raniformis.* Previous studies have demonstrated strong influences of road density on the occurrence and abundance of anuran amphibians (Fahrig *et al.* 1995; Vos & Chardon 1998).

Table 2. Landscape context variables determined from GIS analysis within Arcview GIS. Names of the originating GIS layers, obtained from the Department of Sustainability and Environment Corporate Geospatial Data Library (CGDL) are tabulated with the data.

Variable Name	Definition	Units	CGDL layer
Stream1000	Lengths of stream within 1000 m of site	km	Hydro25
Road1000	Lengths of roads within 1000 m of site	km	Road25

The second group of variables considered for inclusion in the habitat models were variables physically measured (or estimated) during visits to each waterbody (Table 3). The variables were selected from the larger set of habitat variables which were measured at each of the sampling locations, based on previous experience and opinion regarding their likely influence on habitat-suitability for *L raniformis* and other members of the *L. aurea* species complex. Selection of habitat variables for inclusion in the model was carried out on the basis of their effect on the AIC_c value. After initial model selection within groups of related variables, a set of variables was identified as having potential explanatory power. These variables were then included in an autologistic model fitted to the data using the Gibbs sampler.

Table 3. Habitat variables measured or estimated at each waterbody and considered for inclusion in the habitat models.

Variable name	Definition	Type
EVW	% water surface with emergent vegetation	Percentage
EVB	% water edge with emergent vegetation	Percentage
SV	% water surface with submerged vegetation	Percentage
FV	% water surface with floating vegetation	Percentage
SVFV	Sum of water surface with floating and submerged vegetation	Score between 0-200
FrV	% of surrounding area with fringing vegetation	Percentage
Gambusia	Presence or (apparent) absence of Gambusia	Binary
Floword	Flow rate of water on a scale from 0 - 3	Ordinal
Permanence	Waterbody permanence on a scale from 0-3	Ordinal
SWB	Is the waterbody a standing water-body or stream?	Binary

(iv) Model Assessment

Fitting of models to the *L. raniformis* presence/absence data leads to a predicted probability of occurrence for each site. These predicted probabilities were compared to the observed pattern of presences and absences at each site using Receiver Operating Characteristic (ROC) analysis (Zweig & Campbell 1993). The predicted probabilities of occurrence at each site (determined from the fitted models) were first converted to predicted presences and absences at a range of threshold probability values between zero and one. For each threshold value, the proportion of presence sites correctly classified (Sensitivity) and proportion of absence sites correctly classified (Specificity) was calculated. The sets of Sensitivity and Specificity values were plotted against each other to form the ROC plot. In theory, the ROC plot of a statistical model with very poor predictive power will describe a straight line across the diagonal of the plot, while a model with excellent predictive power will describe a convex curve which approaches the upper right hand corner of the ROC plot. The area underneath the ROC curve (AUC) provides a good quantitative index of the discriminatory efficiency of statistical models for binary outcomes such as presence/absence data (Zweig & Campbell 1993; Fielding & Bell 1997; Manel *et al.* 1999a,b, 2001; Pierce & Ferrier 2000). A model of poor predictive ability (i.e. no better than chance) will have AUC ~ 0.5, while the AUC of a model with excellent predictive ability will approach unity. For the finally selected autologistic model presented here, the area under the ROC curve was calculated by numerical integration, and the 95% confidence interval was estimated using the non-parametric method of DeLong *et al.* (1988).

2.4.2. Site monitoring

(i) Assessing the reliability of methods for determining occupancy status of *Litoria raniformis*

A fundamental issue in studies which use patterns of presence/absence of a species to make inferences regarding the factors influencing the pattern of occurrence of a species, is the reliability with which locations are determined to be occupied or unoccupied by the species in question. Where a species is detected at a location, the occupancy status is unequivocal. However, where the species in not detected, two explanations are possible: either the species is truly absent, or alternatively the species is present, but was not detected successfully (Gu & Swihart 2004).

MacKenzie *et al.* (2002) devised a likelihood-based statistical model for determining the probability of detection of a species, given that it is actually present, by analysis of the results of repeated surveys of a group of sites. The model estimates the probability that the species will be detected with a single survey, given that it is truly present, along with the proportion of sites which are likely to be occupied. This last quantity will include the proportion of sites where the species was actually detected, plus an estimate of the likely proportion of sites at which the species was not detected, but which are likely to be occupied. The formulation of the model is closely related to that of models used for the estimation of animal abundance and survival rates by mark-recapture (Lebreton *et al.* 1992). A detailed description of the model and its application to the analysis of wildlife survey data is provided by MacKenzie *et al.* (2002); readers requiring further detail of the rationale and statistical methodology of the model are referred to that publication.

We used the software package PRESENCE (Proteus Research and Consulting, Dunedin, New Zealand) to fit the model to repeated survey data from 27 sites in the Merri Creek catchment; a subset of the sites examined in the habitat model described above. The data consisted of the results of repeated day and night visits to the sites (up to ten visits in total), as well as survey for larvae carried out using either dip-netting or funnel trapping (generally five surveys). For each survey, the detection or non-detection of the species was noted. The model was then fitted to the data for the day, night and tadpole surveys in order to estimate the detection probability *p,* the proportion of the surveyed sites which was likely to be occupied, ϕ, as well as the effects of environmental covariates (prevailing weather conditions) on the probability of detection using each of the methods (day, night and tadpole surveys). Selection of models (i.e. which covariates should be included) was carried out with the aid of Akaike's information criterion and Akaike weights, using a similar approach to that described for the habitat modelling procedures. Estimates of the parameters of the model were obtained by maximum-likelihood; confidence intervals for the parameters were estimated using a non-parametric bootstrap, rather than an analytic/asymptotic approach, following the recommendation of MacKenzie *et al.* (2002).

2.4.3. Analytical software

With the exception of the analysis of detection rates using program PRESENCE, the *R* statistical programming environment (Ihaka & Gentleman, 1996) was used for most of the statistical analyses presented in this report. Programs were written in the *R* language in order to fit the autologistic model to the data, including an implementation of the Gibbs sampler algorithm described above. A version of the *roc* package for S-plus (Mahoney & Anderson 2001), modified to run within the *R* statistical environment was used for calculation of the Receiver Operating Characteristic statistics.

3. RESULTS

3.1. Additional field surveys

3.1.1. Additional records of *Litoria raniformis* within the Merri Creek Corridor

Each of the three additional sites examined during 2002-2003 was inhabited by *L. raniformis*, bringing the total number of occupied sites within the MCC to 47 (of 139 examined). Figure 2 provides a revised distribution map of the species within the MCC. Appendices 1 & 2 detail all individual records of *L. raniformis* within this area.

No *L. raniformis* were recorded at site D021 (quarry hole south-east of Bald Hill, Donnybrook) during the spotlight survey conducted on 17/3/03. However, one frog was recorded basking on Cumbungi (*Typha* sp.) at this site during the initial field inspection of the 11/5/02. The site lies approximately 500 metres north of a section of the Merri Creek also inhabited by the species.

The remaining two sites represent isolated breeding areas for the frog within the Merri catchment. Up to 25 *L. raniformis*, primarily adults, were recorded at Site E010 (farm dam north of Harvest Home Lane, Epping) in the Edgar's Creek catchment. A total of 13 *L. raniformis*, including sub-adults and adults, was recorded under surface debris within the Campbellfield clay quarry on the 27/3/03. This site supports the southernmost extant population of the species known within the Merri catchment.

3.1.2. Re-analysis of factors influencing the distribution of *Litoria raniformis*

Initial exploration of the effects of habitat variables on the probability of occurrence of *L. raniformis* identified three variables with a strong influence on occupancy patterns. These variables were: the length of roads within 1000 metres of the site (Roadden1000), the sum of the proportions of floating and submerged vegetation (SVFV), and the permanence of the water-body (Permanence). An autologistic model including these habitat variables, as well as the autocovariate, was fitted to the data using the Gibbs sampler, as described in the methods.

The fitted parameter estimates and their standard errors, confidence intervals, and *P*-values are presented in Table 4. The probability of occurrence of *L. raniformis* was positively influenced by increasing levels of floating and submerged vegetation, and by increased permanence of water-bodies. In contrast, increasing road density negatively influenced the probability of occurrence.

Table 4. Parameter estimates, standard errors, 95% confidence intervals and *P*-values for the fitted parameters of the autologistic model.

Parameter	Estimate	SE	95 % CI		*P*
Intercept	-4.663	0.299	-5.353	-4.198	<0.0001
SVFV	0.008	0.001	0.007	0.009	<0.0001
Roadden1000	-0.072	0.005	-0.081	0.000	<0.0001
Permanence	1.527	0.046	1.431	1.625	<0.0001
autocovariate	0.925	0.434	0.106	1.812	0.0130

Figure 2. The distribution of sites at which *Litoria raniformis* has been recorded within the Merri Creek Corridor and adjacent catchments – all sources.

The predictions of the habitat model were compared to the actual pattern of presence/absence using Receiver Operating Characteristic (ROC) analysis. The ROC curve for the autologistic model is given in Figure 3. The area under the ROC curves was 0.8490 (95% CI 0.7812, 0.9168), indicating that a high level of confidence may be placed upon the predictive model.

More formal evaluation of statistical models of ecological presence/absence data requires checking of the predictive performance of the model using additional data not used in the initial model-fitting procedure – testing of the model presented here against a comparable data set collected at another geographically separate locality is highly desirable. Nevertheless, the essential simplicity of the fitted model, and its goodness-of-fit to the data suggest that some confidence in its predictive and explanatory power is warranted.

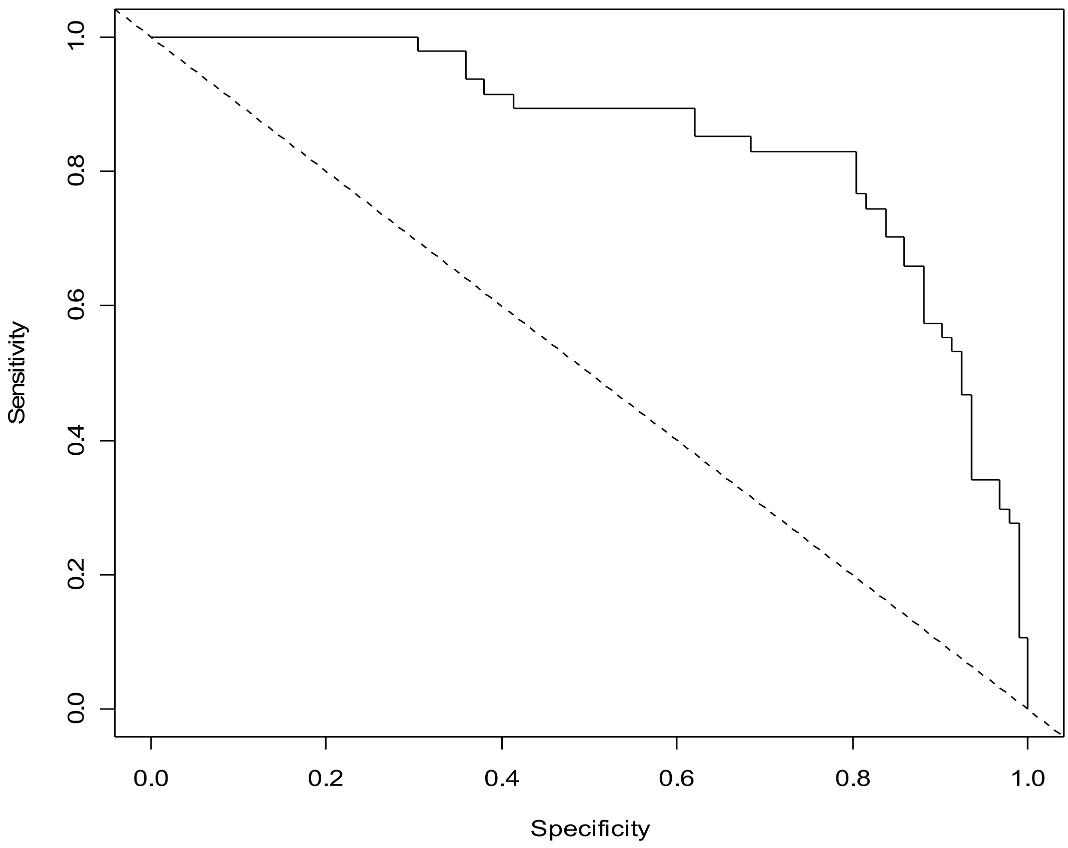

Figure 3. Receiver operating characteristic plot for the autologistic model with variables 'roaddensity', 'permanence' and 'SVFV' included as covariates. AUC = 0.8490, 95% CI for AUC = 0.7812, 0.9168.

3.2. Site monitoring

3.2.1. Frog numbers and detectability

(i) Raw count and assemblage data

Daytime surveys detected *Litoria raniformis* at only four of the 27 monitoring sites (E010, S004, S018, WL002), with a total of 15 frogs recorded (Table 5). However, spotlight surveys revealed 15 sites to be occupied during the monitoring period, with a combined total of 365 individual sightings (Table 6). As such, daytime surveys were largely uninformative, and trends observed from these surveys are consequently of little value for assessing temporal or spatial variation in frog abundance.

Total frog sightings, as detected by spotlight surveys, was highly variable between monitoring sites (range 4–103; Table 6). Nightly counts at occupied sites ranged between zero to a maximum of 45 animals, with an overall nightly mean count of 5.4 individuals (range 0.2-20.6). Some within-site variation in frog counts was also evident across the monitoring period. Several sites displayed wide variation in this factor, particularly sites E010, WL003 and WL004 (frog count ranges 3-18, 0-13 & 0-14 respectively; Table 6). Count variation was greatest on the Merri Creek north of Donnybrook Rd (site D019), where nightly counts varied between zero and 45 individuals. The other 11 occupied sites displayed much less variability in nightly counts across the monitoring period (mean range 3.5 individuals).

The relatively high temporal variation in frog numbers at some occupied monitoring sites resulted largely from apparent bursts of tadpole metamorphosis. Examination of assemblage composition reveals that most sites appeared to have greater numbers of adult animals than either sub-adults or metamorphlings (Table 7). However, at sites D019, WL003 and WL004, metamorphlings dominated counts overall, after large numbers of this cohort were detected from the second survey onwards (beginning mid to late January 2003). Their continued presence resulted in relatively high counts for each of these locations. Sites where few or no metamorphlings were detected displayed relatively stable counts (see Table 6). Additional demographic data (and some morphometric information) collected during the study are provided in Appendix 3.

Comparison of results from the monitoring period with those obtained from single spotlight surveys in the 2001-2002 season are available for 23 of the 27 sites (CR022, D019, D020 & E010 were not systematically surveyed in the previous season). With the exception of sites D006, S006 and WL002, *L. raniformis* were again detected at each site occupied in the previous season (Table 8). The apparent absence of frogs at each of these three sites may be explained by the lack of water at these locations in the current season – frogs were found in adjacent areas containing water at each site (i.e. at D019, S004 and WL004 respectively). Using the maximum frog count obtained for both seasons (2003 minus 2001), numbers were similar for the majority of occupied sites (mean difference, +1.21, range -9 to +19). Sites with the highest differences were as follows: CR005, -7; D003, +7; S008, -9; WL001, +19; WL003, +7; WL004, +16. *Litoria raniformis* remained undetected at sites C001, C002, C003, C008 (all south of Cooper St, Somerton), CR004, CR006, CR007 and S007 (note that the latter site, O'Herns Swamp, has been dry during the entire survey period).

Table 5. Results of daytime surveys at the twenty-seven sites monitored for *Litoria raniformis* within the Merri Creek Corridor, January – March 2003.
Abbreviations: GGF – Growling Grass Frog; SBTF – Southern Brown Tree Frog; SMF – Spotted Marsh Frog, CF – Common Froglet; SBF – Southern Bull Frog, VTF – Verreaux's Tree Frog.

Location	Ref no.	Surveys conducted	Search effort Person minutes (mean)	Adult GGF recorded (nightly mean & range)	Sub-adult GGF recorded (nightly mean & range)	Metamorphling GGF recorded (nightly mean & range)	Total GGF recorded (mean & range)	Other species (overall records)				
								SBTF	*SMF*	*CF*	*SBF*	*VTF*
Campbellfield												
Merri Creek at Barry Rd	C001	5	130 (26.0)	0	0	0	0	0	0	0	0	0
Western settling pond at Barry Rd	C002	5	143 (28.6)	0	0	0	0	0	0	0	0	0
Eastern settling pond at Barry Rd	C003	5	75 (15.0)	0	0	0	0	0	0	0	0	0
Merri Creek south of Cooper St	C008	5	125 (25.0)	0	0	0	0	0	0	0	0	0
Craigieburn												
Merri Creek above Summerhill Rd	CR004	4	113 (28.2)	0	0	0	0	0	0	0	0	0
Merri Creek below Summerhill Rd	CR005	1	34	0	0	0	0	0	0	0	0	0
Merri Creek below Craigieburn Rd	CR006	5	135 (27.0)	0	0	0	0	0	0	0	0	0
Merri Creek upstream of Craigieburn Rd	CR007	5	129 (25.8)	0	0	0	0	0	0	0	0	0
Curley Sedge Creek around Craigieburn Rd	CR022	0	0	-	-	-	-	-	-	-	-	-
Donnybrook												
Dam on Spring St, Donnybrook	D003	5	259 (51.8)	0	0	0	0	0	0	0	0	0
Dam south of Shell, Donnybrook	D010	4	109 (27.2)	0	0	0	0	0	0	0	0	0
Merri Creek at Donnybrook Rd	D019	5	436 (87.2)	0	0	0	0	0	0	0	0	0
Merri Creek at Donnybrook Rd	D006	5	85 (17.0)	0	0	0	0	0	0	0	0	0
Merri Creek at Donnybrook Rd	D007	5	109 (21.8)	0	0	0	0	0	0	0	0	0
Dam on Donnybrook Rd	D004	5	118 (23.6)	0	0	0	0	0	0	0	0	0
Kalkallo Creek at Donnybrook Rd	D020	0	0	-	-	-	-	-	-	-	-	-
Epping												
Small waterbody north of Harvest Home Lane	E010	4	105 (26.2)	9 (2.2, 0-4)	0	0	9 (2.2, 0-4)	0	0	0	0	0
Somerton												
Merri Creek below O'Herns causeway	S004	5	257 (51.4)	1 (0.2, 0-1)	0	0	1 (0.2, 0-1)	0	0	0	0	0
Merri Creek upstream of O'Herns causeway	S005	5	258 (51.6)	0	0	0	0	0	0	0	0	0
Curley Sedge Creek above O'Herns causeway	S006	0	0	-	-	-	-	-	-	-	-	-
O'Herns Swamp	S007	0	0	-	-	-	-	-	-	-	-	-
Merri Creek at Patullos Lane	S008	5	287 (57.4)	0	0	0	0	0	0	0	0	0
Merri Creek below Freight Drive	S018	5	247 (49.4)	1 (0.2, 0-1)	0	2 (0.4, 0-2)	3 (0.6, 0-3)	0	0	0	0	0
Wollert Landfill												
Wollert Landfill-opposite weighbridge	WL001	4	311 (77.7)	0	0	0	0	0	0	0	0	0
Wollert Landfill-north of weighbridge	WL002	4	86 (21.5)	2 (0.5, 0-2)	0	0	2 (0.5, 0-2)	0	0	0	0	0
Wollert Landfill-north central quarry hole	WL003	4	124 (31.0)	0	0	0	0	0	0	0	0	0
Wollert Landfill-west of WL002	WL004	4	89 (22.2)	0	0	0	0	0	0	0	0	0

Table 6. Results of spotlight surveys at the twenty-seven sites monitored for *Litoria raniformis* within the Merri Creek Corridor, January – March 2003.
Abbreviations: GGF – Growling Grass Frog; SBTF – Southern Brown Tree Frog; SMF – Spotted Marsh Frog, CF – Common Froglet; SBF – Southern Bull Frog, VTF – Verreaux's Tree Frog.

Location	Ref no.	Surveys conducted	Search effort Person minutes (mean)	Adult GGF recorded (nightly mean & range)	Sub-adult GGF recorded (nightly mean & range)	Metamorphling GGF recorded (nightly mean & range)	Total GGF recorded (mean & range)	Other species (overall records)				
								SBTF	*SMF*	*CF*	*SBF*	*VTF*
Campbellfield												
Merri Creek at Barry Rd	C001	5	270 (54.0)	0	0	0	0	12	0	1	0	0
Western settling pond at Barry Rd	C002	5	304 (60.8)	0	0	0	0	6	52	2	0	0
Eastern settling pond at Barry Rd	C003	5	148 (29.6)	0	0	0	0	0	7	0	0	0
Merri Creek south of Cooper St	C008	5	356 (71.2)	0	0	0	0	4	0	0	0	0
Craigieburn												
Merri Creek above Summerhill Rd	CR004	5	327 (65.4)	0	0	0	0	0	0	0	0	0
Merri Creek below Summerhill Rd	CR005	2	252 (126.0)	4 (1.3, 0-3)	0	0	4 (2, 1-3)	0	0	0	0	0
Merri Creek below Craigieburn Rd	CR006	5	302 (60.4)	0	0	0	0	0	0	0	0	0
Merri Creek upstream of Craigieburn Rd	CR007	5	316 (63.2)	0	0	0	0	0	0	0	0	0
Curley Sedge Creek around Craigieburn Rd	CR022	4	160 (40.0)	0	0	0	0	0	3	0	0	0
Donnybrook												
Dam on Spring St, Donnybrook	D003	6	639 (106.5)	32 (5.3, 1-9)	3 (0.5, 0-1)	0	35 (5.8, 1-10)	0	0	0	0	0
Dam south of Shell, Donnybrook	D010	5	214 (42.8)	1 (0.2, 0-1)	0	0	1 (0.2, 0-1)	0	0	0	0	0
Merri Creek at Donnybrook Rd	D019	5	822 (164.4)	4 (0.8, 0-2)	2 (0.4, 0-1)	97 (19.4, 0-43)	103 (20.6, 0-45)	0	2	0	0	0
Merri Creek at Donnybrook Rd	D006	5	160 (32.0)	0	0	0	0	0	0	4	0	0
Merri Creek at Donnybrook Rd	D007	5	158 (31.6)	0	0	1	1 (0.2, 0-1)	0	0	0	0	0
Dam on Donnybrook Rd	D004	5	170 (34.0)	2 (0.4, 0-1)	1 (0.2, 0-1)	0	3 (0.6, 0-2)	0	0	0	0	0
Kalkallo Creek at Donnybrook Rd	D020	5	100 (20.0)	1 (0.2, 0-1)	1 (0.2, 0-1)	0	2 (0.4, 0-1)	0	0	3	0	0
Epping												
Small waterbody north of Harvest Home Lane	E010	4	405 (101.2)	41 (10.2, 3-18)	2 (0.5, 0-2)	0	43 (10.7, 3-18)	0	0	0	0	0
Somerton												
Merri Creek below O'Herns causeway	S004	5	489 (97.8)	13 (2.6, 1-6)	1 (0.2, 0-1)	7 (1.4, 0-5)	21 (4.2, 2-7))	0	0	0	0	0
Merri Creek upstream of O'Herns causeway	S005	5	507 (101.4)	7 (1.4, 1-2)	1 (0.2, 0-1)	2 (0.4, 0-1)	10 (2, 1-3))	0	0	0	0	0
Curley Sedge Creek above O'Herns causeway	S006	5	94 (18.8)	0	0	0	0	0	1	1	0	0
O'Herns Swamp	S007	5	60 (12.0)	0	0	0	0	0	0	0	0	0
Merri Creek at Patullos Lane	S008	5	646 (29.2)	10 (2.0, 1-3)	1 (0.2, 0-1)	3 (0.6, 0-2)	14 (2.8, 1-4)	0	0	0	0	0
Merri Creek below Freight Drive	S018	5	674 (134.8)	8 (1.6, 0-6)	2 (0.4, 0-2)	5 (1.0, 0-3)	15 (3, 0-4)	4	0	0	0	0
Wollert Landfill												
Wollert Landfill-opposite weighbridge	WL001	4	944 (236.0)	51 (12.7, 8-16)	11 (2.7, 1-4)	1 (0.2, 0-1)	63 (15.7, 11-20)	0	0	0	0	0
Wollert Landfill-north of weighbridge	WL002	4	180 (45.0)	0	0	0	0	0	0	0	0	0
Wollert Landfill-north central quarry hole	WL003	4	328 (82.0)	9 (2.2, 0-5)	0	12 (3.0, 0-7)	21 (5.2, 0-13)	0	0	0	0	0
Wollert Landfill-west of WL002	WL004	4	238 (59.5)	0	5 (1.2, 0-3)	25 (6.2, 0-14)	30 (7.5, 0-16)	0	0	0	0	0

Table 7. Comparison of *Litoria raniformis* assemblage composition (adult, sub-adult, metamorphling) recorded during spotlight surveys at each of the twenty-seven sites monitored for the species within the Merri Creek Corridor, January - March 2003. Abbreviations: GGF – Growling Grass Frog.

Location	**Ref. no.**	**Surveys conducted**	**Search effort** Person minutes (mean)	**Adults** Overall proportion of assemblage (range)	**Sub-adults** Overall proportion of assemblage (range)	**Metamorphlings** Overall proportion of assemblage (range)	**Total GGF recorded**
Campbellfield							
Merri Creek at Barry Rd	C001	5	270 (54.0)	-	-	-	0
Western settling pond at Barry Rd	C002	5	304 (60.8)	-	-	-	0
Eastern settling pond at Barry Rd	C003	5	148 29.6)	-	-	-	0
Merri Creek south of Cooper St	C008	5	356 (71.2)	-	-	-	0
Craigieburn							
Merri Creek above Summerhill Rd	CR004	5	327 (65.4)	-	-	-	0
Merri Creek below Summerhill Rd	CR005	2	252 (126.0)	100	0	0	4
Merri Creek below Craigieburn Rd	CR006	5	302 (60.4)	-	-	-	0
Merri Creek upstream of Craigieburn Rd	CR007	5	316 (63.2)	-	-	-	0
Curley Sedge Creek around Craigieburn Rd	CR022	4	160 (40.0)	-	-	-	0
Donnybrook							
Dam on Spring St, Donnybrook	D003	6	639 (106.5)	91.4 (80-100)	8.6 (0-20)	0	35
Dam south of Shell, Donnybrook	D010	5	214 (42.8)	100	0	0	1
Merri Creek at Donnybrook Rd	D019	5	822 (164.4)	3.9 (0-10)	1.9 (0-25)	94.2 (75-97)	103
Merri Creek at Donnybrook Rd	D006	5	160 (32.0)	-	-	-	0
Merri Creek at Donnybrook Rd	D007	5	158 (31.6)	0	0	100	1
Dam on Donnybrook Rd	D004	5	170 (34.0)	66.7 (50-100)	33.3 (0-50)	0	3
Kalkallo Creek at Donnybrook Rd	D020	5	100 (20.0)	50 (0-100)	50 (0-100)	0	2
Epping							
Waterbody north of Harvest Home Lane	E010	4	405 (101.2)	95.3 (82-100)	4.6 (0-18)	0	43
Somerton							
Merri Creek below O'Herns causeway	S004	5	489 (97.8)	61.9 (0-100)	4.7 (0-33)	33.4 (0-100)	21
Merri Creek upstream of O'Herns causeway	S005	5	507 (101.4)	70 (50-100)	10 (0-50)	20 (0-50)	10
Curley Sedge Creek above O'Herns causeway	S006	5	94 (18.8)	-	-	-	0
O'Herns Swamp	S007	5	60 (12.0)	-	-	-	0
Merri Creek at Patullos Lane	S008	5	646 (129.2)	71.4 (33-100)	7.1 (0-25)	21.5 (0-66)	14
Merri Creek below Freight Drive	S018	5	674 (134.8)	53.3 (0-100)	13.3 (0-100)	33.4 (0-100)	15
Wollert landfill							
Wollert Landfill-opposite weighbridge	WL001	4	944 (236.0)	80.9 (73-94)	17.4 (6-27)	1.6 (0-6)	63
Wollert Landfill-north of weighbridge	WL002	4	180 (45.0)	-	-	-	0
Wollert Landfill-north central quarry hole	WL003	4	328 (82.0)	42.8 (37-100)	0	57.2 (0-63)	21
Wollert Landfill-west of WL002	WL004	4	238 (59.5)	0	16.7 (0-27)	83.3 (73-100)	30

Table 8. Comparison of the abundance of *Litoria raniformis* at sites within the Merri Creek Corridor surveyed in the 2001-2002 season, and subsequently monitored between January - March 2003. Abbreviations: GGF – Growling Grass Frog.

Location	Ref. no.	Spotlight surveys conducted, 2001-2002	Spotlight surveys conducted, 2003	Search effort, 2001-2002 Person minutes	Search effort, 2003 Person minutes (mean)	GGF recorded, 2001-2002 Maximum count	GGF recorded, 2003 Maximum count (mean, range)	Difference 2003 max. minus 2001 max.
Campbellfield								
Merri Creek at Barry Rd	C001	1	5	54	270 (54.0)	0	0	0
Western settling pond at Barry Rd	C002	1	5	35	304 (60.8)	0	0	0
Eastern settling pond at Barry Rd	C003	1	5	35	148 29.6)	0	0	0
Merri Creek south of Cooper St	C008	1	5	30	356 (71.2)	0	0	0
Craigieburn								
Merri Creek above Summerhill Rd	CR004	1	5	96	327 (65.4)	0	0	0
Merri Creek below Summerhill Rd	CR005	1	2	130	252 (126.0)	10	3 (2, 1-3)	-7
Merri Creek below Craigieburn Rd	CR006	1	5	104	302 (60.4)	0	0	0
Merri Creek upstream of Craigieburn Rd	CR007	1	5	62	316 (63.2)	0	0	0
Curley Sedge Creek around Craigieburn Rd	CR022	0	4	-	160 (40.0)	-	0	-
Donnybrook								
Dam on Spring St, Donnybrook	D003	1	6	92	639 (106.5)	3	10 (5.8, 1-10)	+7
Dam south of Shell, Donnybrook	D010	1	5	90	214 (42.8)	5	1 (0.2, 0-1)	-4
Merri Creek at Donnybrook Rd	D019	0	5	-	822 (164.4)	-	45 (20.6, 0-45)	-
Merri Creek at Donnybrook Rd	D006	1	5	30	160 (32.0)	5	0	-5
Merri Creek at Donnybrook Rd	D007	1	5	15	158 (31.6)	2	1 (0.2, 0-1)	-1
Dam on Donnybrook Rd	D004	1	5	34	170 (34.0)	0	2 (0.6, 0-2)	+2
Kalkallo Creek at Donnybrook Rd	D020	0	5	-	100 (20.0)	-	1 (0.4, 0-1)	-
Epping								
Waterbody north of Harvest Home Lane	E010	0	4	-	405 (101.2)	-	18 (10.7, 3-18)	-
Somerton								
Merri Creek below O'Herns causeway	S004	4	5	110	489 (97.8)	5	7 (4.2, 2-7)	+2
Merri Creek upstream of O'Herns causeway	S005	4	5	272	507 (101.4)	5	3 (2, 1-3)	-2
Curley Sedge Creek above O'Herns causeway	S006	1	5	50	94 (18.8)	2	0	-2
O'Herns Swamp	S007	1	5	20	60 (12.0)	0	0	0
Merri Creek at Patullos Lane	S008	3	5	56	646 (129.2)	13	4 (2.8, 1-4)	-9
Merri Creek below Freight Drive	S018	1	5	90	674 (134.8)	4	4 (3, 0-4)	0
Wollert landfill								
Wollert Landfill-opposite weighbridge	WL001	1	4	70	944 (236.0)	1	20 (15.7, 11-20)	+19
Wollert Landfill-north of weighbridge	WL002	1	4	20	180 (45.0)	6	0	-6
Wollert Landfill-north central quarry hole	WL003	1	4	34	328 (82.0)	5	13 (5.2, 0-13)	+7
Wollert Landfill-west of WL002	WL004	1	4	20	238 (59.5)	0	16 (7.5, 0-16)	+16

(ii) The reliability of methods for determining occupancy status of *Litoria raniformis*

The results of fitting the MacKenzie detectability model to data from 27 sites in the Merri Creek area are presented below. The best model of the set considered has the probability of detection $\hat{p}$ modelled as a function of whether the survey is done during the day or night.

The inclusion of parameters for the effects of environmental covariates on the probability of detection was not well supported by the data, which probably reflects the fact that the data were gathered under conditions considered to be optimal for detection of adult *L. raniformis* (i.e. surveys were not carried out during windy or cold conditions). Similarly, there was little evidence of an effect of waterbody type on detectability (frogs were not inherently more detectable at streams or standing water-bodies). Based on the most parsimonious model for detectability, the estimated probabilities of detection for day and night surveys are given in Table 9.

Table 9. Estimated probabilities of detection for adults and tadpoles of *Litoria raniformis* using single day and night surveys (adults) or single funnel trapping or dip-net surveys (tadpoles), with their 95% confidence intervals.

Time	$\hat{p}$	95% CI
Day	0.11	(0.05, 0.21)
Night	0.72	(0.61, 0.81)
Tadpole	0.36	(0.17, 0.60)

It is clear from the analysis that the probability of detecting *L. raniformis* is strongly influenced by the time of day at which the site is visited. Estimated probability of detection at night is more than six times higher than probability of detection during the day.

A similar analysis was carried out on the tadpole trapping data collected at the same sites. Because data were collected using both funnel traps and dip-nets, the possibility that the probability of detection was conditional upon the method used was considered in the model selection process. The best supported model did not include a term describing the different sampling techniques (dip-netting vs. funnel trapping). The detection probability ($\hat{p}$) for larvae of *L. raniformis* per survey using either the funnel trapping or dip-netting techniques described in the methods was 0.36 with 95% CI = 0.17, 0.60.

3.2.2. Reproduction

(i) Tadpole and metamorphling records

Evidence of reproduction was obtained at eleven of the 15 sites occupied by *L. raniformis* during the current season. At the majority of these sites, both tadpoles and metamorphlings of the frog were detected (Table 10). The greatest densities of tadpoles were observed in sections of the Merri Creek north of Donnybrook Rd - 52 tadpoles were captured from a single night of trapping at site D019. However, captures at all occupied sites over the combined survey period were generally low (mean captures 3.1 tadpoles, range 0-15).

Our tadpole survey periods were conducted at the end of the reproductive season, and therefore, most tadpoles captured were in the later stages of development. The lack of tadpole records at several sites where metamorphlings were detected (i.e. S005, WL003, WL004) probably results from most tadpoles having already undergone metamorphosis at these sites.

Table 10. Results of surveys for tadpoles and metamorphlings of *Litoria raniformis* at twenty-seven sites monitored within the Merri Creek Corridor, January - March 2003. Tadpoles captured were divided into three categories based upon limb development: no legs present, just back legs present or front and back legs present. Abbreviations: GGF – Growling Grass Frog; SBTF – Southern Brown Tree Frog; SMF – Spotted Marsh Frog.

Location	Ref. no.	Trapping surveys	Dip-net surveys	Tadpole survey results (combined counts)					Spotlight survey results (combined counts)	
				GGF tadpoles No legs	*GGF tadpoles Back legs*	*GGF tadpoles Front and back legs*	*Total GGF tadpoles*	*Other tadpoles recorded*	*Tadpoles*	*Metamorphlings*
Campbellfield										
Merri Creek at Barry Rd	C001	5	0	0	0	0	0	0	0	0
Western settling pond at Barry Rd	C002	5	0	0	0	0	0	2SBTF, 2SBF	0	0
Eastern settling pond at Barry Rd	C003	1	4	0	0	0	0	2SBTF, 2SMF	0	0
Merri Creek south of Cooper St	C008	5	0	0	0	0	0	0	0	0
Craigieburn										
Merri Creek above Summerhill Rd	CR001	5	0	0	0	0	0	0	0	0
Merri Creek below Summerhill Rd	CR005	2	0	1	1	0	2	0	0	0
Merri Creek below Craigieburn Rd	CR006	5	0	0	0	0	0	0	0	0
Merri Creek upstream of Craigieburn Rd	CR007	5	0	0	0	0	0	0	0	0
Curley Sedge Creek around Craigieburn Rd	CR022	0	0	-	-	-	-	-	-	0
Donnybrook										
Dam on Spring St, Donnybrook	D003	5	0	0	0	0	0	0	0	0
Dam south of Shell, Donnybrook	D010	3	0	0	0	0	0	0	0	0
Merri Creek at Donnybrook Rd	D019	1	2	28	25	3	56	0	>100	97
Merri Creek at Donnybrook Rd	D006	1	0	8	0	0	8	0	10	0
Merri Creek at Donnybrook Rd	D007	2	1	12	3	0	15	0	0	1
Dam on Donnybrook Rd	D004	5	0	0	0	0	0	0	0	0
Kalkallo Creek at Donnybrook Rd	D020	0	0	-	-	-	-	-	-	0
Epping										
Waterbody north of Harvest Home Lane	E010	4	0	0	0	0	0	0	0	0
Somerton										
Merri Creek below O'Herns causeway	S004	5	0	0	0	1	1	0	0	7
Merri Creek upstream of O'Herns causeway	S005	5	0	0	0	0	0	0	0	2
Curley Sedge Creek above O'Herns causeway	S006	0	0	-	-	-	-	-	-	0
O'Herns Swamp	S007	0	0	-	-	-	-	-	-	0
Merri Creek at Patullos Lane	S008	5	0	1	0	0	1	0	0	3
Merri Creek below Freight Drive	S018	5	0	1	2	0	3	0	5	5
Wollert										
Wollert Landfill - opposite weighbridge	WL001	4	0	0	0	0	0	0	0	1
Wollert Landfill - north of weighbridge	WL002	4	0	0	0	0	0	0	0	0
Wollert Landfill - north central quarry hole	WL003	4	0	0	0	0	0	0	0	12
Wollert Landfill - west of WL002	WL004	4	0	0	1	0	1	0	0	25

(ii) Habitat attributes of sites used for reproduction

Habitat data are available for 20 sites occupied by *L. raniformis* within the MCC, where survey results (standard spotlight surveys and/or tadpole trapping) can be used to assess their status as breeding habitat for the frog (Table 11). Such a small sample precludes a satisfactory analysis of potential differences in habitat attributes between sites used and not used for reproduction. Nonetheless, several observations are worthy of comment.

Sites where reproduction was recorded included standing water-bodies and slow flowing sections of streams, and were consistently those where water-levels are thought to be relatively stable. However, several ephemeral sites within the study area in which calling males have been detected previously were dry during the 2003 season, precluding an assessment of their potential as breeding habitat. It is likely that they are used when suitable conditions arise.

Vegetation composition appears a significant determinant of breeding habitat quality for this species. All sites at which reproduction has been recorded display extensive growth of either emergent or submergent vegetation (emergent vegetation: mean extent cover 51.8%, range 0-100; submergent vegetation: mean extent cover 42.9%, range 1-90). Scores for the combination variable, SVFV (the sum of submergent and floating vegetation cover) is also high in most cases (mean 84.5, range 10-185). For comparative purposes, three off-stream sites occupied by the frog in the Donnybrook area that do not appear to be used for reproduction display significantly lower submergent or floating vegetation cover than adjacent breeding habitat in the Merri Creek (SVFV score: mean along Merri Creek at Donnybrook Rd, 127; mean in adjacent off-stream waterbodies, 3.3). Elsewhere, off-stream waterbodies which were used for breeding displayed high submergent and/or floating vegetation cover. In-stream breeding habitat of the frog is depicted on the front cover of this report.

Because only a limited number of water-quality attributes were examined, it was not possible to rigorously examine which of these parameters may affect suitability for reproduction. Although somewhat variable, waters used for reproduction were alkaline (mean pH 8.7, mean range 7.8-9.9), with moderate to high electrical conductivity (mean conductivity 4.4 mS/cm, mean range 1.4-8.5) and moderate dissolved oxygen content (mean DO 7.7 mg/L, mean range 1.2-19.1). Being late summer, water temperatures were relatively high and stable (mean temperature 21.8^{o}C, mean range 18.0-29.0). Although not measured (due to meter failure), turbidity was low at all sites used for reproduction.

Cohabitation with predatory fish was commonly recorded at sites used for reproduction by *L. raniformis*. Fish species recorded included Mosquito Fish (*Gambusia holbrooki*) (known inhabitant at eight sites), Common Galaxid (*Galaxias maculatus*) (known inhabitant at four sites, probable inhabitant at four sites), Flat-headed Gudgeon (*Philypnodon grandiceps*) (known inhabitant at four sites, probable inhabitant at four sites), Short-finned Eel (*Anguilla australis*) (known inhabitant at five sites, probable inhabitant at seven sites), English Perch (*Perca fluviatilis*) (known inhabitant at one site, probable inhabitant at seven sites) and European Carp (*Cyprinus carpio*) (known inhabitant at three sites, probable at inhabitant one site). At the majority of these locations, successful recruitment of *L. raniformis* tadpoles was confirmed by the presence of metamorphs. Off-stream water-bodies were generally free of predatory fish.

Table 11. Habitat attributes of a sub-set of sites occupied by *Litoria raniformis* within the Merri Creek Corridor, categorised according to their status as breeding habitat. Known breeding sites are those where tadpoles and/or metamorphlings have been recorded, probable breeding sites are sites where reproduction has not been recorded but are isolated from other breeding habitat. Sites termed non-breeding habitat are those where surveys have failed to detect reproduction. Habitat attributes shown are primarily those found to be important to the species (as above, and see Robertson *et al.* 2002) plus water-quality measurements (displayed as the mean value with range in parentheses). Predatory fish occurrence is also shown (✓ = known inhabitant, P = probable inhabitant – generally stream sites where the species occurs nearby). na = data not available.

Location	Ref. no.	Water-flow	Water permanence (0-3)	EVB Extent cover (%)	SV Extent cover (%)	SVFV Score 0-200	pH	Conductivity (mS/cm)	Dissolved oxygen (mg/L)	Water temp. (^oC)	Fish recorded					
											Gambusia	*Galaxid*	*FH Gudgeon*	*Eel*	*Redfin*	*Carp*
Known breeding habitat																
McKimmies Rd Quarry, Bottom pond	BU006	Still	3	65	65	90	8.3	5.7	5.9	23.2	-	-	-	-	-	-
Botanica Park wetland	BU007	Still	3	na	na	na	8.6	7.1	9.3	20.9	-	-	-	-	-	-
Merri Creek below Summerhill Rd	CR005	Slow	3	100	30	130	8.0	5.8	5.2	18	✓	P	P	P	P	-
Merri Creek at Donnybrook Rd	D019	Slow	3	80	75	95	7.9 (7.9)	3.3 (2.9-3.8)	1.2 (1.1-1.3)	22.0 (19-25)	✓	P	P	P	✓	-
Merri Creek at Donnybrook Rd	D006	Still	3	55	85	185	9.1	2.4	19.1	29	✓	P	P	P	P	-
Merri Creek at Donnybrook Rd	D007	Still	3	30	1	101	8.9 (8.8-9.2)	3.2 (1.9-4.6)	12.2 (9-14.8)	24.3 (22.0-26.0)	✓	P	✓	P	P	-
Merri Creek below O'Herns Rd	S004	Slow	3	100	5	10	8.2 (7.8-8.7)	1.8 (1.4-2.1)	5.6 (3.4-6.9)	20.1 (15.6-25.0)	✓	✓	✓	✓	P	-
Merri Creek above O'Herns Rd	S005	Slow	3	75	10	85	8.3 (7.9-8.7)	1.7 (1.3-2.0)	7.1 (4.2-11.9)	21.2 (15.8-26)	✓	✓	✓	✓	P	-
Merri Creek at Patullos Lane	S008	Slow	3	90	50	145	7.8 (7.3-8.5)	1.4 (1.4-1.8)	4.9 (1.3-9.5)	20.1 (16.5-22.0)	✓	✓	P	✓	P	-
Quarry hole at Epping Tip	S010	Still	3	25	75	90	9.1	1.9	7.4	20.7	-	-	-	-	-	-
Merri Creek below Freight Drive	S018	Slow	3	100	55	56	8.3 (8.0-8.5)	1.8 (1.5-2.3)	7.1 (5.0-9.4)	21.7 (15.4-25.0)	✓	✓	✓	✓	P	✓
Wollert Landfill-opposite weighbridge	WL001	Still	3	0	25	50	9.7 (9.3-10.0)	8.5 (7.9-9.3)	8.3 (7.2-9.6)	20.5 (17.8-25.0)	-	-	-	✓	-	-
Wollert Landfill-north of weighbridge	WL002	Still	3	0	25	45	9.6 (9.4-10.0)	6.4 (6.0-6.8)	8.7 (7.5-9.6)	21.1 (18.2-25.0)	-	-	-	P	-	✓
Wollert Landfill-north central quarry hole	WL003	Still	3	5	90	91	8.9 (8.5-9.4)	8.3 (7.4-9.1)	8.3 (3.4-15.2)	22.7 (17.6-26.5)	-	-	-	P	-	P
Wollert Landfill-west of WL002	WL004	Still	3	0	10	10	9.9 (9.4-10.3)	6.0 (5.6-6.3)	9.1 (6.6-11.8)	21.9 (18.0-25.0)	-	-	-	P	-	✓
Probable breeding habitat																
Clay Quarry, Campbellfield	C009	Still	3	10	10	10	9.5	11.6	5.26	21.5	-	-	-	-	-	-
Waterbody north of Harvest Home Lane	E010	Still	3	75	80	160	9.3 (8.8-9.5)	4.2 (4.2-4.3)	8.1 (6.1-10.9)	23.5 (21.0-26.0)	-	-	-	-	-	-
Non-breeding habitat																
Dam on Spring St, Donnybrook	D003	Still	3	100	5	10	9.2 (8.1-10.2)	1.2 (0.9-1.5)	9.5 (5.5-11.9)	18.7 (13.3-22.0)	-	-	-	-	✓	-
Dam on Donnybrook Rd	D004	Still	2	25	0	0	9.3 (8.7-9.8)	2.0 (0.7-3.7)	11.3 (9.5-13.8)	21.9 (13.4-26.0)	-	-	-	-	-	✓
Dam south of Shell, Donnybrook	D010	Still	3	25	0	0	7.7 (7.5-8.2)	1.0 (0.7-1.3)	7.2 (6.5-7.9)	19.2 (16.7-21.0)	✓	-	-	-	-	-
Unknown status																
Kalkallo Creek at Donnybrook Rd	D020	Still	1	-	-	-	na	na	na	na	-	-	-	P	-	-
Curley Sedge Creek above O'Herns Rd	S006	Slow	1	60	20	80	na	na	na	na	-	-	-	P	-	-
O'Herns Swamp	S007	Still	0	30	25	50	na	na	na	na	-	-	-	-	-	-

4. DISCUSSION

The additional survey work conducted during the past season has contributed significantly to our knowledge of the ecology and conservation status of *Litoria raniformis* within the Merri Creek Corridor. Specifically, data collected during this period have extended our perception of the distribution of the species within the MCC, refined our knowledge of the habitat factors effecting the species' pattern of occurrence, provided insight into the attributes of breeding/non-breeding habitat, and provided the first quantification of the survey effort required to accurately determine the presence of the species.

4.1. Additional records and their significance

The three additional sites located during the current season represent potentially significant breeding habitat for *L. raniformis*. All, however, are located on private land and their status is subsequently insecure.

Site D021 (quarry hole SE of Bald Hill) closely resembles significant quarry hole breeding habitat located further south in the catchment (e.g. Campbellfield, Somerton and Wollert Landfill). Unfortunately, past stocking of this water-body with non-indigenous fish species (primarily English Perch) may now undermine its quality for reproduction. Instead, it probably represents additional foraging and over-wintering habitat for frogs inhabiting adjacent sections of the Merri Creek. The area surrounding this water-body is currently grazing land, but is available for bluestone extraction.

Sites E010 (water-body north of Harvest Home Lane, Epping) and the Campbellfield clay quarry represent significant sites for the frog in the Merri catchment - both are isolated but apparently viable areas of breeding habitat. Site E010 is a long-standing water-supply for the surrounding grazing land. While secure in the short-term, highly disturbed grazing land and recent industrial development now isolate the site from the nearest population (within the Epping Tip, south of Cooper St, Epping), and the general area is designated for urban development in the long-term. Opportunities for site acquisition and enhancement should be explored. Similarly, the Campbellfield population is threatened in the mid to long-term. This site, which maintains a relic group of frogs from populations that once occurred along adjacent sections of the Merri Creek, is ultimately designated for landfill. Possibilities for habitat replacement at this site are currently being pursued (L. Conole, Ecology Australia Pty. Ltd., pers. comm.).

4.2. Habitat associations

Re-analysis of the habitat data collected between December 2001 and March 2003 has provided important new insights into the habitat requirements of the species. In particular, the relationship between site occupancy and several land-scape scale habitat parameters provides important confirmation of our assessment of the factors determining the distribution of the species within the MCC and its likely response to the dramatic habitat changes that are presently occurring across this region. The following discussion focuses upon interpreting these findings at the landscape scale. The significance of within-site habitat factors including water permanence and submergent and floating vegetation cover are discussed in relation to breeding habitat quality.

4.2.1. Implications of the re-analysis of habitat data

It was apparent from the analysis presented in our earlier report (Robertson *et al*. 2002), that the presence of *L. raniformis* at individual sites was strongly influenced by the presence or absence of the species at other locations in close proximity (positive spatial autocorrelation). To reduce potential biases and to avoid invalidation of statistical assumptions of sampling independence, it was imperative that this relationship be accounted for in a rigorous manner in the present re-analysis of the habitat data. The resulting re-analysis allows for appropriate estimation of the effects of both habitat variables and spatial context on the probability of occupancy of the species within the study area. The fitted statistical model reveals that spatial context, landscape scale factors and site-level habitat variables are all significant determinants of waterbody occupancy by *L. raniformis.*

These findings have important implications when considering the effects of habitat fragmentation upon frog distribution within the MCC. As discussed in our previous report, *L. raniformis* displays a 'clustered' pattern of occurrence within the study area, with the exception of a few isolated occurrences. This pattern, and the apparent positive influence of neighbouring site occupancy on the occupancy of individual water-bodies, indicates that the Merri population actually comprises a series of sub-populations, the viability of which relies upon their ability for interaction with other sub-populations (i.e. occasional long-distance dispersal events by a few individuals), as well as on the range of wetland habitats available in the local area (and thus, opportunities for small-scale dispersal and temporal variation in habitat use). The pattern of occupancy by *L. raniformis* in the MCC is consistent with a meta-population structure, with site occupancy being heavily reliant upon opportunities for dispersal between adjacent sites. In order to remain occupied in the long term, individual sites probably require the presence of other nearby occupied sites to provide a source for recolonisation in the event of extinction at the focal site. Hence, sites close to occupied sites get colonised and are occupied - isolated sites don't get recolonised and so are unoccupied.

The importance of metapopulation dynamics and habitat fragmentation to the viability of amphibian populations has received significant attention in recent years (e.g. Sjogren 1991; Vos & Stumpel 1996; Vos & Chardon 1998; Knapp *et al.* 2003). Habitat fragmentation has the effect of not only reducing the area of available habitat, but isolating remaining habitat patches (and the sub-populations which depend upon them) from each other. It is apparent from the above studies that this process has the potential to cause serious population declines and extinction. Findings from the present study suggest that the Merri *L. raniformis* population (or meta-population) is subject to a moderately high level of habitat fragmentation across much of the catchment (at a 'stage 2' level as defined by Vos & Chardon 1998). At this level, habitat fragmentation has the potential to cause the extinction of small, isolated populations but not to unravel the overall network of local sub-populations. In the Merri catchment, it is apparent that *L. raniformis* remains widespread but that its range has been dramatically reduced in recent years. Specifically, the range has retracted from the southern sections of the study area and many of the smaller tributaries, through either random (e.g. disease, drought) or deterministic (e.g. habitat destruction) events. Further habitat fragmentation and destruction will exacerbate this process and could eventually lead to the demise of the entire population ('stage 3' of Vos & Chardon 1998).

Further evidence for the above contention is provided by the negative relationship between frog site occupancy and road density within the MCC. Roads are a significant factor in habitat fragmentation and isolation for amphibians (Fahrig *et al.* 1995; Vos &Chardon 1998; deMaynadier & Hunter 2000; Carr & Fahrig 2001; Hels & Buchwald 2001). The negative relationship with road density in the present study may be interpreted in two, largely inter-connected ways. The first is the possibility that roads represent significant dispersal barriers to *L. raniformis* (either through direct physical impediment or increased mortality), blocking movements to and from water-bodies. Such movements may be for dispersal or diel, seasonal or annual changes in habitat use (e.g. to foraging or overwintering habitat). The second interpretation, that road density is associated with habitat degradation and fragmentation, is equally plausible in this study area. For individual water-bodies, high adjacent road density may cause habitat degradation through storm-water run-off, vehicle noise etc. At the landscape level, high adjacent road density may indicate significant levels of disturbance of the surrounding environment, and thus high levels of local habitat destruction and fragmentation. As discussed above, such changes may decrease habitat quality and population viability because the waterbodies are no longer part of a habitat matrix, but become isolated habitat remnants. The interpretation that high adjacent road density is an indicator of local habitat alteration and degradation fits well with the observed decline of *L. raniformis* within the highly disturbed environments in the south of the catchment (i.e. below Cooper St), and recent disappearance from tributaries such as the Central, Edgar's, Aitken and Malcolm Creeks where urban developments have dramatically changed the landscape. Continued northerly spread of such developments will further threaten the survival of *L. raniformis* in the MCC.

4.2.2. Insights into the attributes determining breeding habitat quality

Data collected during the 2003 season are insufficient to identify the full extent of breeding habitat for *L. raniformis* within the MCC and to provide detailed information on the habitat attributes of these areas. However, the work conducted does provide important insights into both factors. Perhaps most significant of these findings is the recording of substantial recruitment from sections of the Merri Creek. Our previous surveys indicated that permanent off-stream waterbodies represent core breeding habitat for the species. While our tadpole and metamorphling surveys cannot be used to quantify the relative contributions which particular habitat patches make to population maintenance, data collected suggest that both off-stream and in-stream habitat is important for recruitment but that their relative importance may vary both across the catchment and between seasons. In the south (below Cooper St), where in-stream habitat is often heavily degraded and polluted (see Finlay *et al.* 1997), off-stream water-bodies appear to represent the only available breeding habitat and are highly important. In mid-sections of the catchment (Somerton to Craigieburn), reproduction was evident in both in-stream and off-stream areas, and thus both habitats contribute to population maintenance. In the north (i.e. Donnybrook and upstream), where the creek-line remains in better condition, reproduction appears to be largely restricted to in-stream areas. Here, off-stream water-bodies are primarily dams used for stock watering, and are devoid of the aquatic vegetation favoured by the species.

An important caveat on these findings is the dry nature of the 2003 season. *Litoria raniformis* is an opportunistic and highly mobile species (see Pyke 2002) which will readily take advantage of newly created or ephemeral wetland habitats. In our study area, reproduction in such situations has been recorded previously (e.g. newly established Botanica Park wetlands, see Table 11; drainage lines and depressions in the Donnybrook area, R. Valentic pers. comm.; O'Herns Swamp, B. Casey and W. Moore pers. comm.). These wetlands may be important recruitment sources, particularly in some high rainfall seasons. While long-term population monitoring would be required to determine the relative importance of such breeding events to population maintenance, it is apparent that they at least supplement the regular annual production from permanent in-stream or off-stream habitats.

In terms of site-specific habitat attributes, several findings are of note. Structural habitat variables contributing to breeding habitat quality appear to be very similar to those related to site occupancy. Extensive and often dense aquatic vegetation was present at all sites used for reproduction, including emergent (*Typha* spp., *Phragmites australis*, *Scheonoplectus tabernaemontani*, *Eleocharis sphacelata, Rumex bidens*), submergent (primarily *Potamogeton crispus* or *P. pectinatus*) and floating species (*Triglochin procerum*, *Azolla* spp., *Lemna* spp.). In combination with filamentous algae, which was particularly common within in-stream breeding habitat, such vegetation provides calling stages for male frogs, sites for egg deposition and development, and an abundant food and shelter resource for tadpoles (see Pyke 2002). Dense submergent vegetation in particular is probably crucial for the protection of eggs and tadpoles from predation (see below).

Hydrological characteristics of water-bodies are also likely to be important determinants of breeding habitat quality, but our data are insufficient to draw strong conclusions regarding this factor. Still or slowing flowing water is preferred generally by members of the *L. aurea* complex (Pyke & White 1996; Ashworth 1998; Patmore 2001; Hamer *et al.* 2002), and this trend is consistent with the breeding habitat identified in the MCC. Recent studies which have examined the physio-chemical properties of water-bodies inhabited by members of the *L. aurea* complex, indicate that these species have wide-tolerances to parameters including pH, conductivity, dissolved oxygen content and temperature (see Ashworth 1998; Patmore 2001; Hamer *et al.* 2002; Pyke *et al.* 2002). In a more extensive assessment, Organ (2003b) documented an apparent preference by *L. raniformis* for those waterbodies at the Western Treatment Plant (Werribee, Victoria) which displayed a lower nutrient content. In our earlier report (Robertson *et al.* 2002), we suggested that poor water-quality may be implicated in the decline of the species in the south of the Merri catchment. Unfortunately, our data collected during 2003 are insufficient to investigate this issue.

Evidence of successful recruitment in the presence of a wide range of predatory fish species was gathered during the 2003 season. Egg and tadpole predation by non-native fish species, particularly the Mosquito Fish (*Gambusia holbrooki*), is thought to be implicated in the decline of *L. aurea* (Morgan & Buttermer 1996; Pyke & White 2000), and this factor may also be detrimental to populations of *L. raniformis*. However, all eight breeding sites we monitored during the 2002-2003 season which were inhabited by this fish displayed moderate to high numbers of metamorphlings (and thus successful recruitment). It is probable that the dense aquatic vegetation (particularly submergents) present at these breeding sites offers protection from these predators. Indeed, our observations on tadpole microhabitat use indicate they rarely stray into open water and may be active primarily after dark. Such behaviours would significantly reduce contact with Mosquito Fish. Further research upon this issue is being pursued and will hopefully provide information on the long-term effect of introduced fish predation upon population viability (K. Howard, B. Malone, La Trobe University, pers. comm.).

4.3. Detectability

Detectability analysis resulting from site monitoring conducted during the 2003 season has two important implications: (i) validation of the adequacy of survey effort expended during our regional survey work, and; (ii) the development of interim survey protocols for this species.

Information on survey effort required to accurately determine the presence (or absence) of a species is an important, but often overlooked component of studies which aim to determine the distribution and habitat associations of an organism. Our detectability analysis provides reasonable validation of our survey results using single night spotlight censuses, with a probability of detection for this method of 0.72 (95% CI = 0.61, 0.81). However, considering that most sites were also examined during the day, detection probability using the combined search effort (1 day plus 1 night) was calculated at 0.7508, according to the following equation:

$$p = 1 - \prod_{1}^{N} (1 - \hat{p}_n) \qquad \text{(Equation 6)}$$

Where $\hat{p}_n$ is the estimated probability of detection on the nth sampling occasion out of a total of N occasions. Consequently, presence/absence was probably correctly classified at 75% of sites examined. Together with the consistency between survey results in the two field-seasons, these results suggest that our census data provide a reasonably reliable basis for assessing the distribution and habitat associations of *L. raniformis* within the MCC.

Implications for future survey work on this species are also significant. In the vicinity of major urban centres, particularly metropolitan Melbourne, many of the sites occupied by the species are threatened by ongoing development. The conservation of these populations has subsequently become a significant issue for many recent development projects. As conservation planning for these populations relies heavily upon assessments of their site occupancy and habitat utilisation, our detectability analysis may be used to provide guidelines for the survey effort required during these activities.

For multiple day or night visits, detection probabilities for single survey visits ($\hat{p}$) can be used to calculate the probability of detection (p) after N visits using the equation below. This simply involves applying the geometric probability distribution to the detection process (Kéry, 2002):

$$p = 1 - (1 - \hat{p})^N \qquad \text{(Equation 7)}$$

Detection probabilities resulting from this function are displayed graphically in Figure 4. These plots allow estimation of the number of visits required in order to obtain adequate certainty of presence/absence.

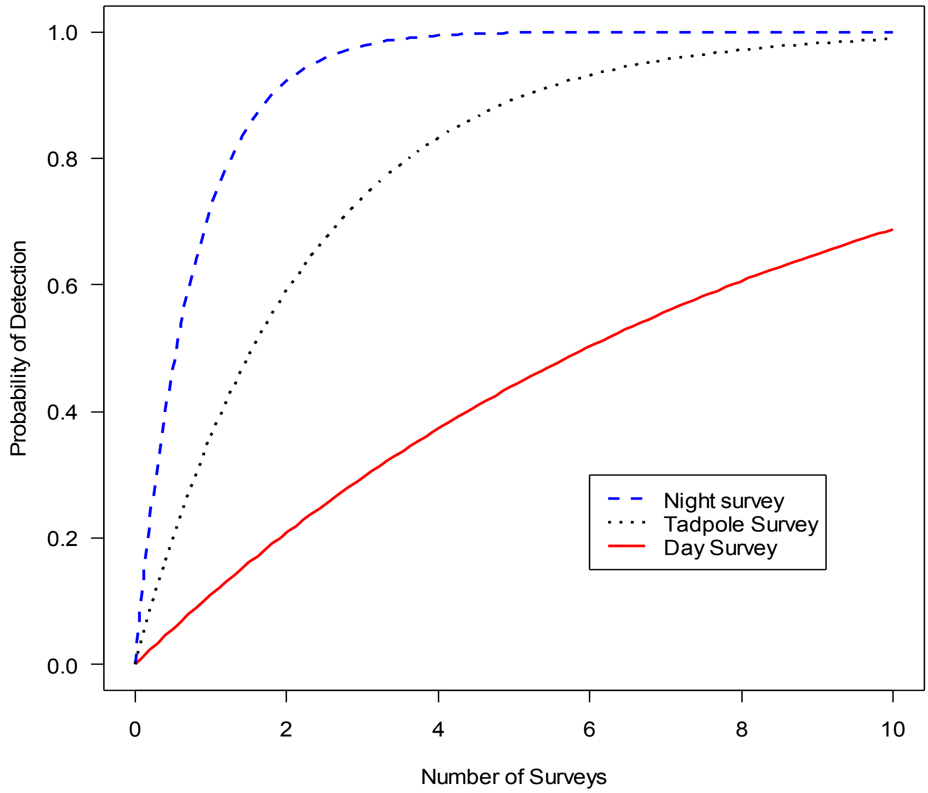

Figure 4. **Estimated probability of detection of *Litoria raniformis* at occupied sites after a specified number of surveys using each of three survey methods.**

Due to the diurnal behaviour displayed by members of the 'Bell Frog' species complex, including *L. raniformis*, determining site occupancy by these species can be significantly enhanced by the use of daytime census techniques (call censuses, active searching etc.). However, our results clearly show that such daytime censuses are unreliable for assessing site occupancy when used in isolation. With single daytime visits, *L. raniformis* might only be detected at as little as 10% of the sites where it is actually present. Even when multiple daytime visits are conducted, detection of the species is likely to be low (e.g. 5 visits for probability of detection of 0.4; Figure 4).

Instead, multiple spotlight surveys should be used to survey potential habitat for the species. Model estimations displayed in Figure 4 above indicate that the probability of detection at occupied sites reaches 90% after two spotlight surveys and > 95% after three visits. Therefore, we recommend that at least two spotlight censuses are required at sites considered to be potential habitat for *L. raniformis* before a reliable assumption of species absence can be made. Survey effort during each of these spotlight surveys may fluctuate with water-body size and habitat complexity, however, the above figures are based on a mean survey effort per site per night of 90 person minutes. Thus, at least two 45 minute surveys with two field-workers would be adequate in most situations.

An important consideration when interpreting this detection modelling exercise, is the fact that our surveys were conducted only during summer and under conditions considered suitable for activity by this species (> 15°C with little or no wind). While the modelling results did not indicate an effect of weather upon detection probabilities, variation in weather measurements during our survey period was limited by the standardised approach employed - we strongly suspect that weather has a large influence on frog detectability. Therefore, we recommend that the spotlight surveys, each of 90 person minutes duration, only be conducted under ideal conditions.

Finally, this study demonstrates that dip-net or funnel trapping surveys are an effective means for detecting *L. raniformis* tadpoles. Funnel trapping has several logistical advantages over dip-net sampling, and therefore is the technique recommended here. Our surveys results, based upon overnight trapping using five traps set at 10 metre intervals and baited with a light-stick, indicate that detection probabilities greater than 90% are achieved only after some eight trapping events. Nonetheless, detection probabilities were probably reduced by low tadpole abundance at several sites where metamorphosis was largely complete prior to our surveys. Three trapping surveys using 10 traps per site is probably adequate for detecting *L. raniformis* tadpoles between November and March.

Implications for further research and conservation planning

Research upon *L. raniformis* populations within the MCC planned during the 2003-2004 season was restricted to two student projects. As mentioned above, a study being undertaken through the Department of Zoology, La Trobe University is investigating the impact of fish predation upon tadpole survival and development. The second aims to examine the effect of road noise upon the calling behaviour of the species (M. Velik-Lord, K. Parris, Melbourne University, pers. comm.).

Of the further information requirements detailed previously (see Robertson *et al.* 2002), several remain out-standing or only partially investigated including:

- Detailed identification and assessment of the location of breeding habitat/non-breeding habitat, and the habitat parameters contributing to successful reproduction.
- Knowledge of movements within and between waterbodies, of dispersal movements, and of the phenology of such movements. (A pilot study of movements prior to winter was undertaken as student project during 2003; see Wilson 2003).
- Knowledge of over-wintering habitat requirements.
- Knowledge of life-history and demographic parameters which would enable population modelling and determination of critical stages for focus of conservation management.

Gathering such information requires much more intensive fieldwork than has been feasible during this project, and is more appropriately pursued as a post-graduate student project. One of us (GH) will undertake this research, with a proposed commencement during spring 2004. The project should allow an extensive investigation of the population ecology and meta-population processes of the frog within the MCC using modern mark-recapture and genetic techniques.

However, it is imperative that regional conservation planning and management implementation are commenced immediately. For example, planning of the Merri Creek Regional Park must incorporate provision of adequate habitat and appropriate management to ensure the long-term viability of *L. raniformis* populations. Similarly, development projects being overseen by Yarra Valley Water and VicRoads need to carefully consider the species' regional habitat requirements. Data gathered during the course of this study are adequate for commencement of these planning processes. In particular, the site-occupancy model presented here can be used to simulate the effects of the destruction or creation of habitat within the study area, in such a way as to allow prediction of the likely effects on occupancy patterns. This approach could be used for simulating the effects of particular development projects, alternative plans for habitat creation, or other proposed management scenarios. Therefore it would be invaluable from a planning perspective, allowing effective prioritisation and decision making (Knapp *et al.* 2003).

A detailed plan identifying crucial sites for maintenance and enhancement (including habitat creation) for the conservation of *L. raniformis* within the MCC could result from this process. Funding opportunities for this work should be explored, as the costs of such an exercise are likely to be small relative to the likely benefits.

In the interim, efforts to secure several known breeding sites of the frog which are in immediate danger of destruction (particularly quarry holes) should be pursued with the relevant land-holders by planning agencies and the Department of Sustainability and Environment, in accord with the FFG Action Statement for the Growling Grass Frog.

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Appendix 1. Locality data and survey details recorded from all sites surveyed for *Litoria raniformis* within the Merri Creek Corridor and adjacent catchments, December 2001 – March 2003.

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Hearns Swamp, Beveridge	320875	5850326	9/3/02	20	15	0	0	0	0	0	0
Yuroke Ck, Broadmeadows	315649	5828648	17/12/01, 28/12/01, 12/3/02	48	100	12	0	0	0	0	3
Yuroke Ck, Broadmeadows	315593	5828665	17/12/01, 28/12/01, 12/3/02	42	19	4	0	0	0	5	0
Yuroke Ck, Broadmeadows	315586	5828713	17/12/01, 28/12/01, 12/3/02	24	40	1	0	0	0	1	1
Yuroke Ck, Broadmeadows	315308	5827736	18/12/01, 12/3/02	20	17	0	0	0	0	0	0
Shankland Wetland, Broadmeadows	315460	5830492	18/12/01	13	80	2	0	0	0	0	0
Shankland Reserve, Roxburgh Park	316469	5832065	18/12/01, 12/3/02	30	190	0	0	0	0	0	0
Artificial lake, Roxburgh Park	316499	5832776	18/12/01, 12/3/02	18	40	0	0	0	0	0	0
Artificial lake, Roxburgh Park	316621	5832441	18/12/01, 12/3/02	18	50	0	0	0	3	0	0
Recreational pond, Greenvale Reservoir	314176	5832306	28/12/01, 12/3/02	15	40	0	0	0	0	2	0
Recreational pond, Greenvale Reservoir	314090	5832394	28/12/01, 12/3/02	12	40	0	0	0	0	3	0

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Recreational pond, Greenvale Reservoir	314009	5832520	28/12/01, 12/3/02	15	32	0	0	0	0	4	1
Jack Roper Reserve, Broadmeadows	318112	5826064	6/2/02		110	0	0	0	0	1	1
Wetland below Jack Roper Reserve, Broadmeadows	318289	5825921	6/2/02		90	0	0	0	0	0	1
Drainage line, Broadmeadows	319321	5826692	28/12/01		70	0	0	0	0	0	0
Darebin Ck, Broadmeadows	328170	5826699	7/1/02		60	0	0	0	0	0	0
Drainage line, Bundoora	328102	5827103	7/1/02		80	1	0	0	0	0	0
Darebin Ck, Bundoora	326882	5829068	5/2/01		80	0	0	0	0	0	0
Darebin Ck, Bundoora	327181	5827385	2/1/01, 5/1/02	40	240	14	0	0	0	0	0
McKimmies Rd Quarry, Bundoora	327621	5827802	11/1/02	40		2	0	0	0	0	0
McKimmies Rd Quarry, Bundoora	327538	5827477	11/1/02	60		5	0	0	0	0	0
Botanic Park wetland, Bundoora	327936	5827269	4/3/03	44		10	0	0	0	0	0
Merri Ck, Campbellfield	321239	5828814	13/12/01, 15/1/02	28	54	0	0	0	0	0	0
Settling pond, Campbellfield	321181	5828882	13/12/01, 15/1/02	36	35	0	0	0	5	0	11
Settling pond, Campbellfield	321245	5828920	13/12/01, 15/1/02	20	35	0	4	0	4	0	8

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Merri Ck, Campbellfield	321103	5827218	20/12/01, 15/1/02	22	60	0	0	0	0	0	0
Settling pond, Campbellfield	321101	5827287	20/12/01, 15/1/02	23	80	0	0	0	5	0	0
Small pond, Campbellfield	321071	5827195	20/12/01, 15/1/02	20	25	0	0	0	2	0	0
Former Quarry, Campbellfield	322170	5830501	21/12/01	35		15	0	0	0	0	0
Merri Ck, Campbellfield	321350	5830863	19/1/02	25	30	0	1	0	0	0	0
Clay Quarry, Campbellfield			27/3/03	30	-	13	0	0	0	0	0
Dam on Malcolm Ck, Craigieburn	316106	5838042	21/12/01		60	0	0	0	3	0	0
Malcolm Ck, Craigieburn	317103	5837871	21/12/01		56	0	0	0	2	0	0
Dam on Malcolm Ck, Craigieburn	315503	5840115	21/12/01		40	0	0	0	0	0	2
Merri Ck, Craigieburn	320197	5839532	21/12/01		96	0	0	0	0	0	0
Merri Ck, Craigieburn	320205	5839345	21/12/01	50	130	10	0	0	0	0	0
Merri Ck, Craigieburn	319181	5835971	24/12/01, 29/12/01		104	0	0	0	0	0	0
Merri Ck, Craigieburn	319181	5836771	29/12/01		62	0	0	0	0	0	0

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Aitken Ck, Craigieburn	318040	5835655	6/3/02		30	0	0	0	0	0	0
Dam on Aitken Ck, Craigieburn	314752	5836916	24/12/01		40	0	0	0	0	0	0
Dam on Aitken Ck, Craigieburn	314902	5836719	29/12/01		40	0	0	0	3	0	0
Dam opposite Nubrik, Craigieburn	320327	5836203	18/1/02	14	20	0	0	0	0	0	0
Dam opposite Nubrik, Craigieburn	320492	5836165	18/1/02	16	30	0	0	0	5	0	0
Merri Ck, Craigieburn	319708	5838421	18/1/02, 27/1/02	55	165	0	1	0	1	0	0
Merri Ck, Craigieburn	319902	5838688	18/1/02, 27/1/02, 31/1/02	70	64	3	1	0	0	0	0
Malcolm Ck, Craigieburn	318202	5837627	7/2/02	25	30	0	0	0	0	0	0
Farm dam, Craigieburn	315369	5840074	7/2/02	18	22	0	0	0	0	0	0
Dam on Malcolm Ck, Craigieburn	315820	5839320	7/2/02	30	32	0	0	0	0	0	0
Dam on Aitken Ck, Craigieburn	314578	5837280	13/2/02	15	48	0	0	0	1	0	0
Aitken Ck, Craigieburn	315891	5836356	13/2/02	38	60	0	0	0	0	0	1

Appendix 1. (contd.)

	AMG			Survey details		Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Aitken Ck, Craigieburn	317393	5836207	13/2/02, 6/3/02	30	38	0	0	0	0	0	0
Pond within the Craigieburn Golf Course	315848	5836540	13/2/02	58	76	0	0	0	1	0	0
Settlement pond, Craigieburn Nubrik	320620	5836492	26/1/02	30	62	0	0	0	1	0	0
Settling pond, Craigieburn Nubrik	320485	5836535	26/1/02	62	60	0	0	0	5	0	0
Dam at Craigieburn Nubrik	320998	5837401	26/1/02	15	48	0	0	0	1	0	1
Pond at Craigieburn Nubrik	320387	5836783	26/1/02, 28/1/02	30	140	1	0	0	20	0	15
Dam at Craigieburn Nubrik	320437	5837277	26/1/02, 28/1/02	31	54	0	0	0	0	0	0
Settling pond, Craigieburn Nubrik	320463	5836569	26/1/02, 28/1/02	25	52	0	0	0	1	0	0
Merri Ck, Donnybrook	320827	5844061	6/1/02	45	84	1	1	0	0	0	0
Merri Ck, Donnybrook	319527	5842816	6/1/02	30	96	3	0	0	0	0	0
Dam on Spring St, Donnybrook	320636	5843192	6/1/02, 7/1/02	30	92	3	0	0	0	0	0
Farm dam, Donnybrook	319695	5842859	6/1/02, 7/1/02	30	34	0	0	0	0	0	0

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Merri Ck, Donnybrook	319589	5842802	6/1/02, 7/1/02	25	30	4	0	0	0	0	0
Merri Ck, Donnybrook	319713	5843010	6/1/02, 7/1/02	30	30	5	0	0	0	0	0
Merri Ck, Donnybrook	319804	5843142	6/1/02, 7/1/02	30	30	0	0	0	0	0	1
Merri Ck, Donnybrook	321075	5844373	6/1/02, 8/1/02	40	15	2	0	0	0	0	0
Merri Ck, Donnybrook	321016	5844183	6/1/02, 8/1/02	35	45	1	0	0	0	1	0
Farm dam, Donnybrook	318256	5842504	20/1/02, 23/1/02	29	90	5	0	0	1	0	0
Merri Ck, Donnybrook	320106	5840958	20/1/02	96	80	0	0	0	0	0	0
Merri Ck, Donnybrook	319453	5841574	20/1/02	100	90	0	0	0	0	0	0
Farm dam, Donnybrook	320005	5842780	20/1/02, 23/1/02	28	60	1	0	0	0	0	0
Farm dam, Donnybrook	323027	5842713	20/1/02, 23/1/02	25	62	0	0	0	2	1	0
Farm dam, Donnybrook	320691	5842802	20/1/02, 23/1/02	17	52	0	0	0	0	0	0
Farm dam, Donnybrook	320232	5841925	20/1/02, 23/1/02	11	40	0	0	0	2	0	0
Merri Ck, Bald Hill, Donnybrook	322194	5845832	26/2/02	76	50	1	0	0	0	0	0

Appendix 1. (contd.)

	AMG			Survey details		Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Merri Ck, Bald Hill, Donnybrook	321624	5846216	26/2/02	42	70	0	0	0	0	0	0
Quarry Hole, Bald Hill, Donnybrook	322146	5846532	11/5/02, 17/3/03	45	34	1	0	0	0	0	2
Darebin Ck, Epping	326293	5831399	10/1/02		60	0	0	0	0	0	0
Darebin Ck, Epping	326495	5832481	10/1/02		60	0	0	0	0	0	0
Dam on Darebin Ck, Epping	326766	5832895	10/1/02		60	0	0	0	0	0	0
Darebin Ck, Epping	326980	5832869	10/1/02		60	0	0	0	1	0	0
Darebin Ck, Epping	327342	5834156	10/1/02	15	30	0	0	0	0	0	0
Darebin Ck, Epping	327547	5834515	10/1/02	43	68	0	2	0	2	1	0
Farm dam, Epping	322736	5832729	31/1/02	30	19	0	0	0	0	0	0
Farm dam, Epping	323966	5832525	31/1/02	19	15	0	0	0	0	0	0
Farm dam, Epping	322884	5834343	31/1/02	16	15	0	0	0	0	0	0
Waterbody north of Harvest Home Lane, Epping	323348	5834889	25/11/02, Jan-Mar 03	165	405	25	0	0	0	0	0

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Merri Ck, Fawkner	321306	5826016	20/12/01, 3/2/02		75	0	0	0	0	0	0
Central Ck, Fawkner	321963	5825987	1/2/02	35	42	0	0	0	0	0	0
Merri Ck, Fawkner	321584	5826004	3/2/02	30	81	0	0	0	0	0	0
Merri Ck, Merriang	325110	5850603	17/1/02, 25/1/02	28	14	0	0	0	0	0	0
Merri Ck, Merriang	323985	5847833	17/1/02	27	90	0	0	0	0	0	0
Merri Ck, Merriang	325078	5848128	17/1/02	108	141	1	0	0	0	0	0
Merri Ck, Merriang	324863	5849064	24/1/02	26	58	2	0	0	0	0	0
Merri Ck, Merriang	325281	5848481	24/1/02	25	60	1	0	0	0	0	0
Merri Ck, Merriang	324855	5848745	24/1/02, 25/1/02	30	74	7	0	0	0	0	0
Merri Ck, Merriang	325420	5851727	15/2/02, 17/2/02	78	54	0	0	0	0	0	0
Small pond, Reservoir	325987	5824338	30/12/01		60	0	0	0	0	0	0
Darebin Ck, Reservoir	326012	5824145	30/12/01		80	0	0	0	0	0	0

Appendix 1. (contd.)

	AMG			Survey details		Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Darebin Ck, Reservoir	326693	5825170	30/12/01		70	0	0	0	0	0	0
Merri Ck, Somerton	321197	5831239	19/12/01		74	0	0	0	0	0	0
Merri Ck, Somerton	320968	5831395	19/12/01		45	0	0	0	0	0	0
Merri Ck, Somerton	320177	5832494	19/12/01		130	3	0	1	0	0	0
Merri Ck, Somerton	319703	5833002	19/12/01, 28/1/02	20	110	5	0	0	0	0	0
Merri Ck, Somerton	319746	5833136	19/12/01, 11/1/02, 19/1/02, 28/1/02	56	272	5	0	0	0	0	0
Curley Sedge Ck, Somerton	320047	5833227	19/12/01		50	2	0	0	0	0	0
O'Herns Swamp, Somerton	320514	5832862	19/12/01		20	0	0	0	0	0	0
Merri Ck, Somerton	319271	5833890	20/12/01, 11/1/02, 12/2/02	56	140	13	0	0	0	0	0
Merri Ck, Somerton	319183	5835103	20/12/01, 18/1/02		74	0	0	0	0	0	0
Quarry hole, Somerton	320611	5832421	11/1/02	98		0	0	0	0	0	0
Small wetland, Somerton	320539	5832897	11/1/02	50		0	0	0	0	0	0
Merri Ck, Somerton	319613	5833429	11/1/02	58	80	2	0	0	0	0	0

Appendix 1. (contd.)

	AMG			Survey details		Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Merri Ck, Somerton	319298	5834891	18/1/02	30	54	0	0	0	0	0	0
Farm dam, Somerton	321368	5832876	31/1/02	19	15	0	0	0	0	0	0
Dam within the Craigieburn Grasslands, Somerton	319852	5834419	31/1/02	20		0	0	0	0	0	0
Curley Sedge Ck, Somerton	320382	5834232	28/1/02, 31/1/02	35	30	0	2	0	0	0	0
Merri Ck, Somerton	320590	5832180	14/2/02, 18/2/02	65	46	0	2	0	0	0	0
Merri Ck, Somerton	320424	5832340	14/2/02, 15/2/02	50	90	4	0	0	0	0	0
Edgar's Ck, Thomastown	324154	5827326	9/1/02		68	0	0	0	0	0	0
Edgar's Ck, Thomastown	324163	5828155	9/1/02		82	0	0	0	0	0	0
Edgar's Ck, Thomastown	324119	5829793	1/2/02		30	0	0	0	0	0	0
Edgar's Ck, Thomastown	323897	5826250	9/1/02	41	54	0	0	0	0	0	0
Drain on Station St, Wallan	323288	5856544	14/12/01, 17/1/02	15	56	0	0	0	0	0	2
Ditch on Station St, Wallan	323088	5854809	14/12/01, 17/1/02	18	50	0	0	0	1	0	0
Drain at Wallan Treatment Plant	323043	5854956	14/12/01, 17/1/02	15	36	0	0	0	1	0	2

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Dam on Station St, Wallan	323136	5854992	17/1/02, 25/1/02	30	66	0	0	0	0	0	2
Merri Ck, Wallan	323540	5856628	25/1/02	26	38	0	0	0	0	0	0
Merri Ck, Wallan	323674	5854131	7/3/02	32	42	0	0	0	0	0	1
Darebin Ck, Wollert	328057	5836852	10/1/02	28	48	0	0	0	0	0	0
Darebin Ck, Wollert	327853	5836258	10/1/02	28	48	0	0	0	0	0	0
Large dam east of Bindts Rd, Wollert	327660	5835873	10/1/02, 22/2/02	25	11	1	0	0	0	0	0
Small farm dam, Wollert	327652	5835800	10/1/02, 22/2/02	15	60	3	0	0	0	0	0
Pond opposite the weigh bridge, Wollert Landfill	327419	5837371	18/2/02, 22/2/02	24	70	1	0	0	0	0	0
Quarry hole, Wollert Landfill	327383	5837715	18/2/02	15	20	6	0	0	0	0	0
Quarry hole, Wollert Landfill	327252	5838312	18/2/02	30	34	5	0	1	5	0	5
Quarry hole, Wollert Landfill	327442	5837880	18/2/02	15	20	0	0	0	0	0	0
Large waterbody within the Wollert Quarry	326810	5838163	18/2/02	10	75	1	0	0	0	0	0

Appendix 1. (contd.)

	AMG		Survey details			Frogs recorded (maximum abundance)					
Stream or water-body	Easting	Northing	Date/s surveyed	Diurnal search effort (person minutes)	Nocturnal search effort (person minutes)	*Litoria raniformis*	*L. ewingii*	*L. verreauxii verreauxii*	*Limnodynastes tasmaniensis*	*Lim. dumerilii dumerilii*	*Crinia signifera*
Small quarry hole, Wollert Landfill	327383	5837715	18/2/02	30	30	0	0	0	0	0	0
Small pond, Wollert Landfill	327305	5838031	18/2/02	15	20	2	0	0	0	0	0
Small dam within the Wollert Landfill site	326980	5832283	18/2/02, 22/2/02	20	30	0	0	0	10	0	0

Appendix 2. Historical records of *Litoria raniformis* within the Merri Creek Corridor and adjacent catchments.
Data presented include those obtained from ecological consultants, the Atlas of Victorian Wildlife and field naturalists. Note that site co-ordinates are provided as AMG's (AGD'66) for all records except those originating from AVW (long, lat).

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Ecological consultants						
Northern Quarry Hole, Epping Tip	324110	5830580	13/12/01	1A	S	A. Organ (Biosis Research)
Northern Retarding Basin, Epping Tip	324140	5830680	24/10/01	6AM	S, H	A. Organ (Biosis Research)
Southern Quarry Hole, Epping Tip	324140	5830260	10/01/02	29A	S,H	A. Organ (Biosis Research)
Adjacent to Southern Quarry Hole, Epping Tip	324286	5830180	10/01/02	1AM	S	A. Organ (Biosis Research)
Merri Creek, downstream of O'Hern's Rd	319700	5832800	15/11/01	2AM	S	L. Williams (Ecology Australia)
Merri Creek, upstream of Summerhill Rd	320063	5839750	26/11/01	1AF	S	L. Williams (Ecology Australia)
Curley Sedge Creek, upstream of O'Hern's Rd	320047	5833227	27/11/01	1AM	H	L. Williams (Ecology Australia)
Former quarry hole (northern most) south of Coopers St	322170	5830501	19/12/01	5AM	H	L. Williams (Ecology Australia)
South-east quarry hole south of Coopers St	322000	5830000	19/12/01	3AM	H	L. Williams (Ecology Australia)
O'Hern's Swamp, Somerton	320514	5832862	15/11/01	2AM	H	L. Williams (Ecology Australia)
Water-body south of O'Hern's Swamp	320524	5832791	15/11/01	5AM	H	L. Williams (Ecology Australia)
O'Herns Swamp	320514	5832862	30/11/00	?	S/H?	Williams 2001
Small wetland to the east of O'Herns Swamp	320539	5832897	30/11/00	1AF	S	Williams 2001
Merri Creek just below the Summerhill Rd bridge	320205	5839345	6/12/00	2AM	H	Williams 2001
Merri Creek just below the Summerhill Rd bridge	320205	5839345	11/12/00	2AM	H	Williams 2001

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Ecological consultants (contd.)						
Merri Creek, c. 800m upstream of Craigieburn Rd East	319181	5836771	12/12/00	1A?	S	Williams 2001
Merri Creek, c. 100m section downstream of Summerhill Rd	320205	5839345	14/12/00	1A?	S	Williams 2001
Wetland within the Lalor Golf Course	322186	5829153	20/12/00	1AM	H	Williams 2001
Merri Creek, c. 500m section north of Summerhill Rd	320210	5839500	3/01/01	4AM, 1AF	S/H	Williams 2001
Merri Creek at the railway crossing north of Summerhill Rd	319927	5841194	8/01/01	1AM	H	Williams 2001
Curly Sedge Ck upstream of O'Hern's Rd	320190	5833130	30/11/01	3AF	S	Williams 2001
Atlas of Victorian Wildlife						
Bundoora - Yan Yean Road	14504	3742	20/04/64	?	M	AVW
Craigieburn	14456	3736	17/09/66	?	M	AVW
Darebin Creek, Preston - West Heidelberg	14502	3744	19/03/72	?	M	AVW
Roughly 2 km south of Campbellfield	14458	3741	2/12/86	10?	O	AVW
Within 2 km of La Trobe University	14503	3743	20/12/86	2?	O	AVW
Roughly 2 km west of Greenvale	14451	3738	27/01/87	1?	S	AVW
Roughly 2 km west of Greenvale	14451	3738	6/02/87	1?	O	AVW
Roughly 2 km west of Airport West	14452	3743	11/05/88	1?	O	AVW
Roughly 2km south-west of Summerhill	14457	3737	15/06/88	24?	O	AVW

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Atlas of Victorian Wildlife (contd.)						
Roughly 2 km north of Wollert	14502	3735	23/06/88	2?	O	AVW
Roughly 2 km east of Ridley Hill	14457	3734	4/07/88	1?	O	AVW
Roughly 2 km north-east of Wollert	14503	3735	4/07/88	1?	O	AVW
Within 2 km of Erinbank High School	14454	3741	2/08/88	2?	O	AVW
Roughly 2 km south-west of Bald Hill	14458	3731	20/09/88	6?	S	AVW
Roughly 2 km south of Wollert	14502	3737	29/09/88	1?	S	AVW
Roughly 2 km north of Woodstock	14502	3732	4/10/88	2?	O	AVW
Roughly 2 km north-west of Plenty Gorge	14504	3734	5/10/88	1?	O	AVW
Within 2 km of Bald Hill	14459	3730	18/10/88	1?	O	AVW
Roughly 2 km north of Woodstock	14502	3732	25/10/88	1?	O	AVW
Roughly 2 km north of Darrawiet Gium	14455	3723	23/12/88	1?	H	AVW
Roughly 2 km north-west of Quarry Hill	14503	3736	31/12/88	1?	O	AVW
Roughly 2 km north of Wollert	14502	3735	15/02/89	1?	S	AVW
Roughly 2 km north-west of Thomastown	14458	3739	15/08/89	?	O	AVW
Roughly 2 km south of Hearne's Swamp	14459	3727	14/11/89	2?	O	AVW
Roughly 2 km north-east of Mickelham	14454	3733	18/12/89	2?	O	AVW

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Atlas of Victorian Wildlife (contd.)						
Roughly 2 km north-west of Thomastown	14458	3739	31/01/90	?	O	AVW
Within 2 km of Bundoora Park	14502	3742	28/02/91	2?	O	AVW
Within 2 km of Kingsbury	14502	3743	4/03/91	3?	O	AVW
Within 2 km of Lalor Park Primary School	14502	3741	5/03/91	1?	O	AVW
Roughly 2 km south-west of Aitken Hill	14453	3738	17/05/91	2?	O	AVW
Roughly 2 km north-west of Plenty Gorge	14504	3734	4/10/91	2?	O	AVW
Roughly 4 km south of Summerhill	14458	3738	4/10/91	300?	O	AVW
Within 2 km of Mill Park	14504	3740	7/11/91	100?	O	AVW
Roughly 2 km west of Beveridge	14458	3728	11/11/91	1?	O	AVW
Roughly 2 km west of Beveridge	14458	3728	24/11/91	4?	O	AVW
Roughly 2 km east of Ridley Hill	14457	3734	24/11/91	1?	O	AVW
Roughly 2 km south-west of Donnybrook	14457	3733	28/11/91	1?	O	AVW
Roughly 2 km north of Edward's Lake	14459	3742	3/03/92	2?	O	AVW
Boral Quarry, Donnybrook	14458	3730	3/02/95	?	O	AVW
Boral Quarry, Donnybrook	14458	3730	3/02/95	?	T	AVW
Shankland Wetlands, Broadmeadows	14454	3739	15/10/96	2?	H	AVW

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Atlas of Victorian Wildlife (contd.)						
Shankland Wetlands, Broadmeadows	14454	3739	26/01/97	1?	H	AVW
Shankland Wetland, Broadmeadows	14454	3739	4/10/99	1?	H	AVW
Thomastown-Bundoora	14502	3738	10/04/00	1?	S	AVW
Thomastown	14502	3741	10/04/00	3?	S	AVW
Epping Waste Facility	14502	3741	28/09/00	27?	S	AVW
O'Hern's Rd between Curly Sedge and Merri Creeks	14457	3737	9/11/00	1AM	H	AVW
Curly Sedge Creek 200m N of O'Hern's Rd	14457	3737	9/11/00	1A	S	AVW
Curly Sedge Creek	14457	3737	9/11/00	1AM	S	AVW
O'Hern's Rd	14458	3737	9/11/00	1AF	S	AVW
Curly Sedge Creek 150m N of O'Hern's Rd	14458	3738	9/11/00	2A	S	AVW
100m S of O'Hern's Rd	14458	3738	9/11/00	2?	S	AVW
Nubrik Property	14458	3736	2/12/00	3?	H	AVW
Curly Sedge Creek	14457	3736	4/12/00	2S	S	AVW
Swamp 100m S of O'Hern's Rd	14458	3738	4/12/00	1AM	H	AVW
Merri Creek about 20m downstream of Summer Hill Rd	14457	3734	6/12/00	2?	H	AVW
100M N of O'Hern's Road on Merri Creek	14457	3737	11/12/00	2AM	S	AVW

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Atlas of Victorian Wildlife (contd.)						
100M N of O'Hern's Road on Merri Creek	14457	3737	11/12/00	1AM	H	AVW
100M N of O'Hern's Road on Merri Creek	14457	3737	11/12/00	1AF	S	AVW
Merri Ck north of O'Hern's Road	14457	3737	11/12/00	15?	S	AVW
Merri Creek north of O'Hern's Road	14457	3737	11/12/00	1AM	S	AVW
Merri Ck north of O'Hern's Road	14457	3737	11/12/00	5A	S	AVW
Merri Creek N of O'Hern's Road	14457	3737	11/12/00	1AF	S	AVW
Merri Creek N of O'Hern's Road	14457	3737	11/12/00	1AF	S	AVW
Merri Creek N of O'Hern's Road	14457	3737	11/12/00	3AM	S	AVW
Merri Creek N of O'Hern's Road	14457	3737	11/12/00	15A	S	AVW
Merri Creek N of O'Hern's Road	14457	3737	11/12/00	5A	S	AVW
Merri Creek S of O'Hern's Road	14457	3738	12/12/00	5AM	S	AVW
Confluence of Curly Sedge and Merri Creek's	14457	3738	12/12/00	1AM	H	AVW
Swamp adjacent to O'Hern's Road	14458	3738	12/12/00	2?	H	AVW
Merri Creek just below O'Hern's Road crossing	14457	3738	31/01/01	3FP	T	AVW
McKimmies Rd Quarry	14502	3741	16/03/01	77?	T	AVW
Roughly 2 km east of Summerhill	14459	3736	0/0/1986	?	O	AVW

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Atlas of Victorian Wildlife (contd.)						
Within 2 km of Lalor East Primary School	14502	3741	0/0/1986	?	L	AVW
Within 2 km of Lalor East Primary School	14502	3741	0/0/1986	?	L	AVW
Within 2 km of Bundoora Park	14502	3742	0/0/1986	?	O	AVW
Within 2 km of Kingsbury	14502	3743	0/0/1986	?	O	AVW
Within 2 km of Lalor East Primary School	14502	3741	0/0/1989	?	O	AVW
Braelands, Merri Creek, 3.5 km NE of Donnybrook	14459	3730	0/1/1993	?	H	AVW
Braelands Wetlands, 2.4 km E of Donnybrook	14459	3732	0/1/1993	?	H	AVW
Field naturalists						
Merri Creek, upstream of O'Herns Rd Somerton	319482	5833521	27/11/01	3AM	S,H	Paul Oliver & Aaron Grigo
Merri Creek below Patullos Lane	319271	5833890	27/11/01	10A	S,H	Paul Oliver & Aaron Grigo
Merri Creek, pool upstream of Patullos Lane	319582	5834064	27/11/01	4A	S,H	Paul Oliver & Aaron Grigo
Former quarry north of Coopers St	320611	5832421	16/11/01	10-20AM		B. Casey
Merri Creek, sections below Barry Rd, Campbellfield	321075	5827200	1970-75	50-60A	S	B. Casey
Small marsh just west of Gowrie station, Fawkner	319800	5825400	1970-75	Adults	S	B. Casey
Wetland west of the Merri Ck at Jukes Rd, Fawkner	321625	5824950	1970-1975	Adults	S	B. Casey
Merri Ck, just east of Baker's Rd, Coburg North	320775	5822300	1970-75	Tadpoles	S	B. Casey

Appendix 2. (contd.)

Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Field naturalists (contd.)						
Kalkallo Ck at Donnybrook Rd crossing	318707	5843009	22/01/02	1AF	S	R. Valentic
Central Creek below Davidson St	322070	5825775	1976-1979	'Many'	S	R. Valentic
Merri Ck, directly east of McBryde St, Fawkner	321875	5825400	1977	'Many'	S	R. Valentic
Aitken Ck, north-east of Mitford Cr, Craigieburn	318050	5835700	1979	'Many'	S	R. Valentic
Merri Ck east of Freight Drive, Somerton	320800	5831975	7/08/82	2A	S	R. Valentic
Merri Ck, north-east of Freight Dr, Somerton	320425	5832325	14/08/82	2SA	S	R. Valentic
Merri Ck, north-east of Freight Dr, Somerton	320500	5832325	26/08/82	10?	S	R. Valentic
Merri Ck below Barry Rd, Campbellfield (Humphreys Hill)	321200	5828550	11/12/82	1A	S	R. Valentic
Merri Ck north of Coopers St, Campbellfield	320800	5831600	2/04/83	1A	S	R. Valentic
Merri Ck below Barry Rd, Campbellfield	321200	5828550	7/05/83	3A, 1J	S	R. Valentic
Merri Ck east of Freight Drive, Somerton	320400	5832400	12/05/83	1A	S	R. Valentic
Merri Ck, east of Freight Drive, Somerton	320750	5832000	24/06/83	3A, 4SA	S	R. Valentic
Merri Ck east of Freight Drive, Somerton	320700	5832075	13/09/85	1J	S	R. Valentic
Curley Sedge Ck, upstream of O'Herns Rd	320075	5833208	11/07/93	1SA	S	R. Valentic
Merri Ck above the train-line crossing, Donnybrook	319812	5841197	Winter 2000	'Many'	S	R. Valentic

Appendix 2. (contd.)

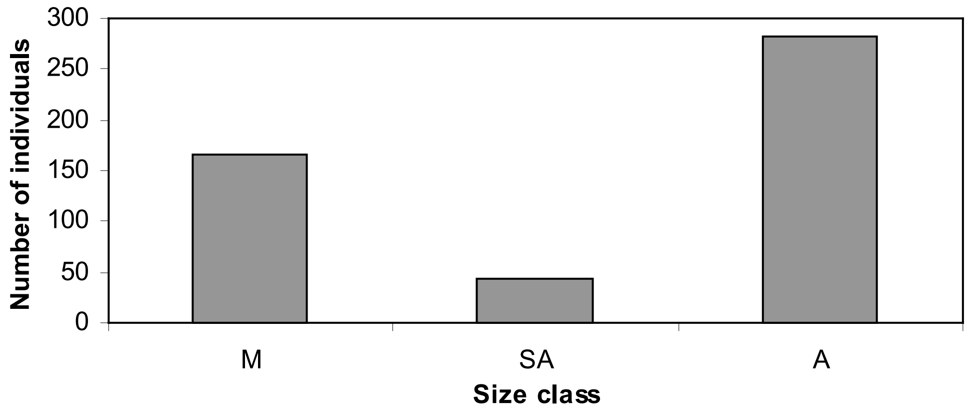
Location	Co-ordinates		Date	Abundance (each class)	Type of record	Source
	Easting	Northing				
Field naturalists (contd.)						
Johnstone St, Westmeadows (Moonee Ponds Ck, Yuroke Ck)	315000	5827150	c. 1980	‘Many’	S	C. Stevenson
Merri Ck below Barry Rd, Campbellfield	321200	5828800	1993	12A	S	C. Stevenson

Appendix 3. Demographic and morphometric data collected within the Merri Creek Corridor and adjacent catchments.

An understanding of the population ecology and demography of *Litoria raniformis* within these urban-fringe environments will be crucial for its conservation. Obtaining this information requires intensive mark-recapture programs and was therefore beyond the scope of the current study. Nonetheless, some demographic and morphometric information was collected. They are provided below as preliminary observations on these attributes – trends observed should be interpreted with caution.

(i) Size class distribution and sex ratio

All specimens of *L. raniformis* located during field surveys between December 2001 and March 2003 were allocated to one of three broad size classes: M – metamorphling, SA – sub-adult, A –adult. The definition of these size classes was changed in the second season as experience with the frog increased. Sexual maturation in this species appears to occur at around 60 mm SGL for both species (Pyke 2002; G. Heard pers. obs.). Therefore, initial size classes (metamorphling, 30 mm snout-groin length [SGL] or less; sub-adult, 31-50 mm SGL; adult, >50 mm SGL) were upgraded to: metamorphling, < 45 mm SGL; sub-adult, 45-59 mm SGL, and; adult, 60 mm or greater SGL. In the following analysis, all frogs located during the first season that could be confidently reassigned to the appropriate size class have been included.



Frequency histogram of size class distribution for 492 *Litoria raniformis* located within the Merri Creek Corridor between December 2001 – March 2003. Size classes are: M – metamorphling (< 45 mm SGL); SA – sub-adult (45-59 mm SGL), and; A – adult (60 mm or greater SGL).

The overall sample was dominated by adult animals (283) followed by metamorphlings (166) and sub-adults (43). While it is possible that the predominance of adults and relative rarity of sub-adult animals may represent a true demographic trend for this species which is capable of rapid growth and sexual maturation (Ashworth 1998; Pyke 2002), it should also be considered that this trend may result from a detection bias (e.g. sub-adult animals may occupy different microhabitats and were subsequently harder to locate). The abundance of metamorphlings in the sample results largely from surveys along the Merri Creek in Donnybrook where this size class was abundant between January and March 2003. They were much less commonly observed at the majority of survey sites.

Data gathered on sex ratios during this study have a number of limitations. Firstly, sexing of these frogs can be ambiguous. While the throat colouration and nuptial pads of sexually active males are distinctive, their absence does not necessarily identify the specimen as female. Additionally, our records are based upon frogs located active in the field, rather than systematic capture or trapping programs, and therefore may be effected by several biases (eg. different detectability or activity between sexes). Nonetheless, the following patterns were noted.

In the initial season, 145 frogs located in the field were sexed based upon physical examination or their behaviour (calling in males). Of these, 83% (120) were male (Robertson *et al.* 2002). Under this approach, results for the second season of the study were markedly different with a higher number of females recorded (sample = 105 frogs; male = 43, females = 62). However, in samples of captured frogs only, examination reveals a slightly higher proportion of females in both seasons. In this case, only frogs above 60 mm SGL that did not display male sexual characteristics were deemed to be females (the smallest male frog located displaying these characteristics being 55 mm SGL). In 2001-2002 season, 12 of 21 adult frogs captured were female (57%), compared to 47 of 77 adult frogs (61%) captured during the 2002-2003 season.

(ii) Morphometric data

Measurements obtained from 29 frogs captured during the first season were combined with those obtained during surveys between January and March 2003, for an overall analysis of the size and weight distribution of animals encountered, and the relationship between snout-groin length and mass. Sexual dimorphism in these characteristics was also explored.

Excluding metamorphling specimens (< 45 mm SGL, < 5 g weight), snout-groin length and weight of measured frogs followed an approximately normal distribution. Specimens between 56-75 mm SGL and 16-35 g in weight were most commonly encountered. As mentioned above, the abundance of metamorphlings in the data-set results from large numbers of this cohort captured along sections of the Merri Creek in Donnybrook during the 2002-2003 season (specifically at site D019). As described above (see section 3.2.2.), monitoring at this site allowed the size of metamorphlings to be examined. Metamorphling animals appeared in numbers on the 26/1/03, having left the water sometime in the proceeding 20 days (previous survey, 6/1/03). Of 38 specimens captured on this date, mean SGL was 34.28 mm (SE = 0.45, range = 29-40) with a mean weight of 3.15 g (SE = 0.14, range = 1.5–5.6). Fewer specimens were measured in subsequent trips, however, corresponding figures for the third and fifth spotlight surveys (10/2/03 and 12/3/03 respectively) are as follows: **10/2/03.** SGL, mean = 35.6 mm, SE = 1.02, range = 31-40; weight, mean = 3.65 g, SE = 0.32, range = 2.1-5.4. **12/3/03**. SGL, mean = 41.5 mm, SE = 2.53, range = 34-45; weight, mean = 5.4 g, SE = 0.84, range = 3.1-7.1). The smallest metamorphling located had a snout-groin length of 28 mm and weighed 1.6 g.

The relationship between snout-groin length and weight for a sample of 166 frogs measured between December 2001 and March 2003 (all size-classes) was investigated. To enable linear regression analysis of these data, both SGL and weight were log transformed. Linear regression analysis identified a highly statistically significant relationship between the two parametres ($R^2 = 0.98$, $F_{1, 164} = 9026.12$, $P < 0.0001$), described by the equation:

$$log(weight) = 2.9364(log(SGL)) - log(4.012).$$

Sexual dimorphism is apparent within a sample of 103 adult male and female *L. raniformis* captured and measured during the combined survey period, however, it should again be emphasised that the applicability of these trends remains questionable due to potential sampling and detectability biases (see above). The largest male examined was 79 mm SGL and 31 g total weight, while the largest female was 97 mm SGL and 58 g in weight. Comparison of the distribution of these parametres between sexes reveals that clear differences are only apparent in SGL. Both sexes were most commonly observed in 16-25 g weight category, however, males were most often recorded between 56-65 mm SGL, while females were most frequently between 66-75 mm SGL. A standard t-test shows this trend to be highly statistically significant (Male: mean SGL = 64.87 mm, SE = 0.84, n = 40; Females: mean SGL = 73.60, SE = 1.26, n = 63; t = 5.72, d.f. = 101, $P < 0.0001$).

Sex related differences in the relationship between snout-groin length and weight were also explored. As above, data were log transformed to allow linear regression analysis. In both sexes the relationship between SGL and weight is highly statistically significant (Males: $R^2 = 0.82$, $F_{1, 30} = 141.38$, $P < 0.0001$; Females: $R^2 = 0.884$, $F_{1, 48} = 365.83$, $P < 0.0001$). Equations describing these relationships are as follows:

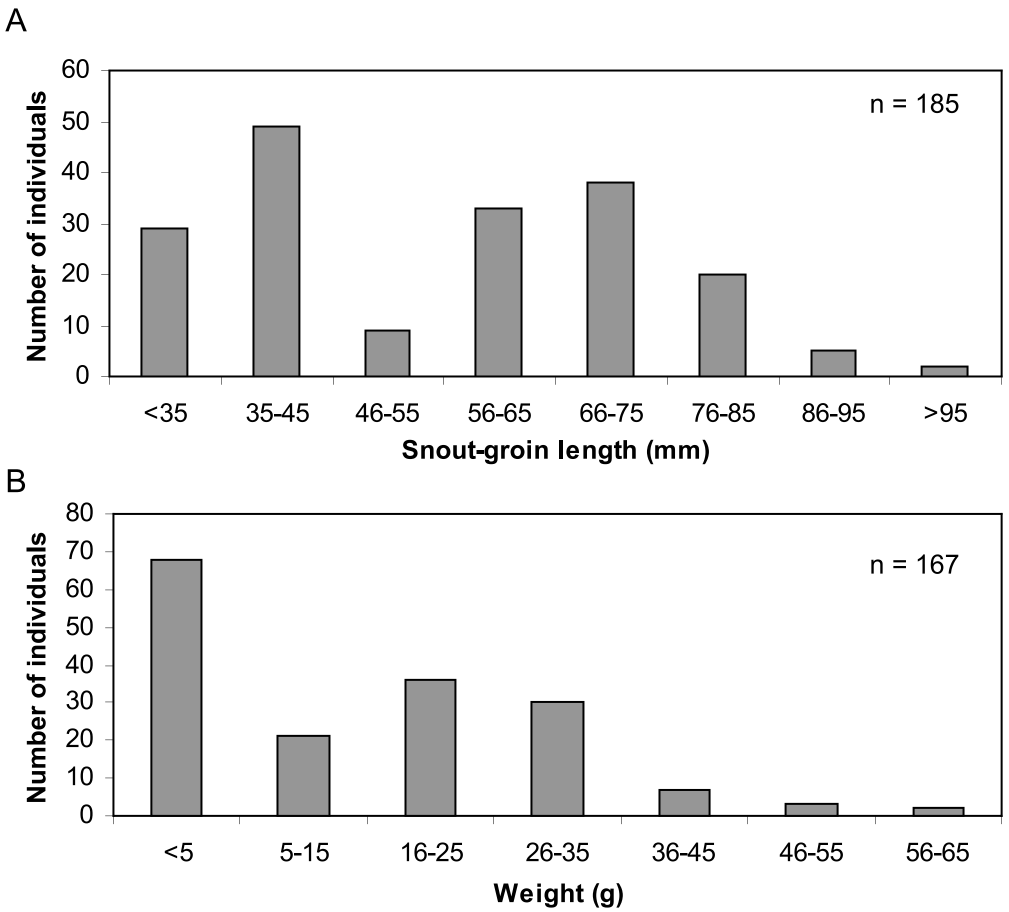
Males, *log(weight) = 2.4456(log(SGL) – log(3.1308)*;
Females, *log (weight) = 2.5253(log(SGL) – log(3.2438).*

ANOVA reveals apparent differences in the slopes of these equations (i.e. male slope, 2.4456 vs. female slope, 2.5253), and therefore the effect upon log(weight) of the interaction between log(SGL) and sex, is slightly statistically significant (see adjoining ANOVA table). This result indicates that female frogs examined during this study were slightly heavier than males of the same size.

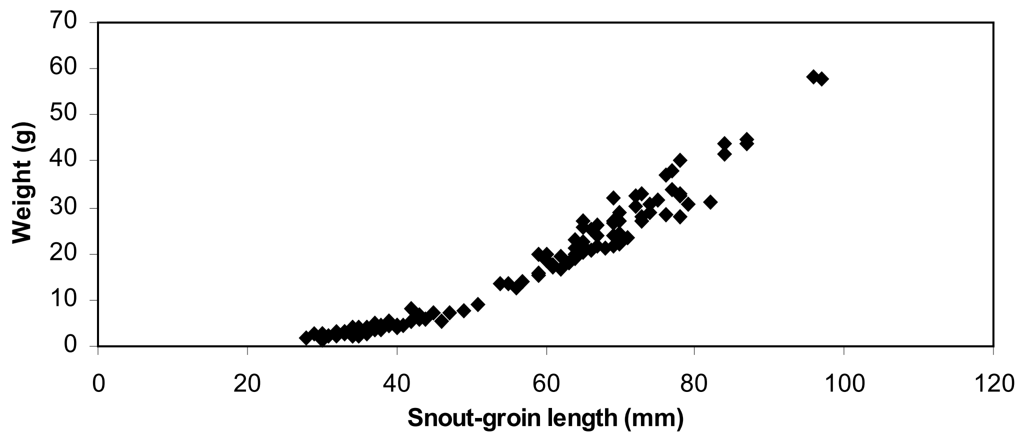
ANOVA table comparing the relationships between log(weight) of *Litoria raniformis* captured within the Merri Creek Corridor and log(SGL), sex, and the interaction term between these factors - log(SGL)*sex.

Factor	DF	SS	MS	F	P
log(SGL)	1	2.0581	2.0581	246.199	<0.0001
sex	1	0.0006	0.0006	0.082	0.779
log(SGL)*sex	1	0.0456	0.0456	5.461	0.041
Residual	10	0.0836	0.0083		

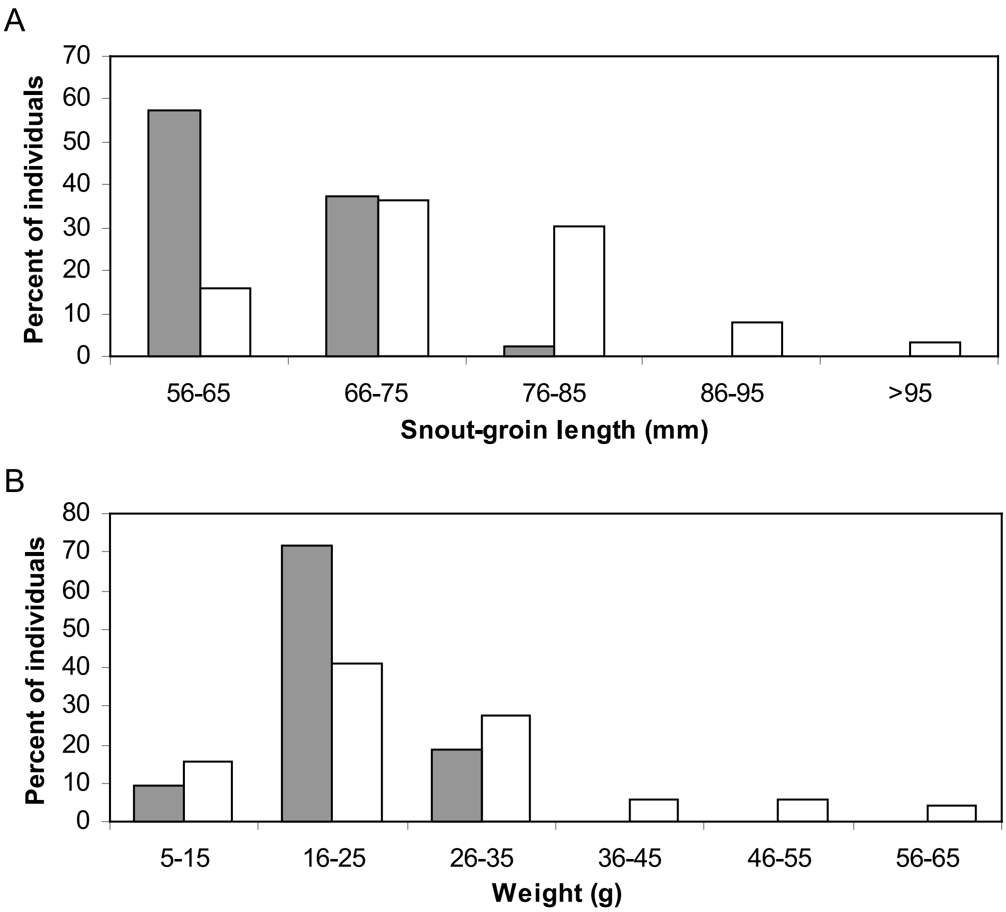
All morphometric relationships examined during this study are displayed graphically in the following pages.



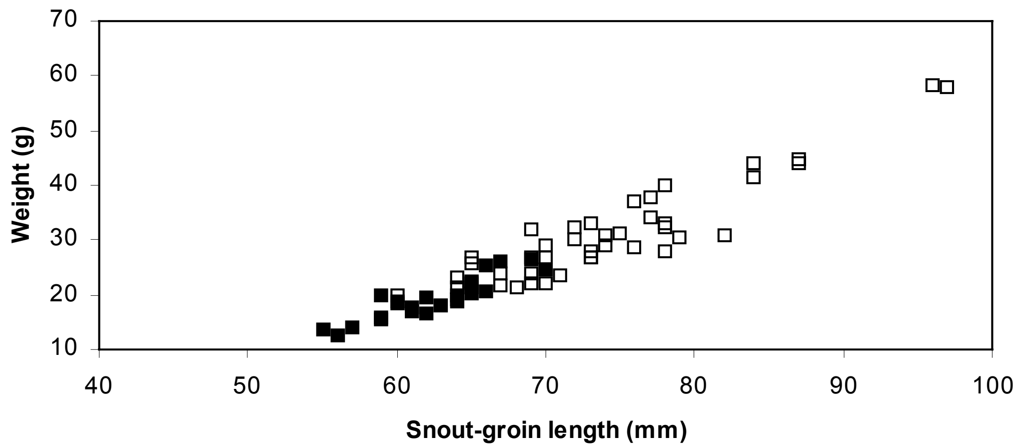
Frequency histogram of snout-groin length (A) and weight (B) for all *Litoria raniformis* captured within the Merri Creek Corridor between December 2001 and March 2003.



Relationship between snout-groin length and weight within a sample of 166 *Litoria raniformis* captured within the Merri Creek Corridor between December 2001 and March 2003.



Comparison of the distribution of snout-groin length (A) and weight (B) amongst mature male (solid bars, n = 40) and female (open bars, n = 63) *Litoria raniformis* captured within the Merri Creek Corridor between December 2001 and March 2003.



Comparison of the relationship between snout-groin length and weight between male (solid boxes, n = 32) and female (open boxes, n = 50) *Litoria raniformis* captured within the Merri Creek Corridor between December 2001 and March 2003.