Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

THE OCCURRENCE AND STATUS OF FROGS IN THE GNANGARA SUSTAINABILITY STRATEGY STUDY AREA

Report prepared on behalf of the
Department of Environment and Conservation
for the Gnangara Sustainability Strategy

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March 2009

GOVERNMENT OF WESTERN AUSTRALIA
Department of Water
Department of Agriculture and Food WA
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Gnangara Sustainability Strategy

March 2009

This document has been commissioned/produced as part of the Gnangara Sustainability Strategy (GSS). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnangara groundwater system. For more information go to www.gnangara.water.wa.gov.au

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Executive Summary

The Gnangara Sustainability Strategy (GSS) is a multi-agency taskforce initiated to provide a framework for balancing water, land and environmental issues on the Gnangara Mound, and to develop a water management regime that is socially, economically and environmentally sustainable. Because of their biology, frogs are likely to be sensitive to changes in landscape hydrology and therefore a study was undertaken to assess the status of frogs in the GSS area, and to review the biology and distribution of these frogs to determine what impacts have happened or may occur. It was also considered that frogs may provide an indication of what is happening to other facets of wetland ecosystems.

Field studies were based on aural surveys of calling males, as this was considered the most efficient method of scoring presence/absence at a large number of sites. Sixty-two sites were sampled and they included all main wetland types in the region: lakes (n=11), palusplains (n=14), sumplands (n=33) and watercourses (n=4). Aural surveys took place at night in late autumn, when several frog species call, and late winter/early spring, when most of the remaining species are vocal. The Turtle Frog *Myobatrachus gouldii* was not sampled during this programme, and the Motorbike Frog *Litoria moorei*, which calls primarily in late spring, was under-sampled. Recent data from additional sites in the GSS area, at Whiteman Park, the Lexia wetlands and Herdsman Lake, were used to supplement the results from the aural surveys, and historical records for the region were obtained from the WA Museum database. In addition, presence/absence results from pit-fall trapping in a concurrent GSS project were also accessed.

Of the 13 frog species known from the GSS area, nine species were recorded: *Crinia georgiana, Crinia glauerti, Crinia insignifera, Heleioporus eyrei, Limnodynastes dorsalis, Litoria adelaidensis, Litoria moorei, Myobatrachus gouldii,* and *Pseudophryne guentheri*. Those species historically recorded from the area but not observed during this project include: *Heleioporus albopunctatus, Heleioporus psammophilus, Heleioporus barycragus* and *Neobatrachus pelobatoides*. Those species known from the area historically but not

recorded in the 2009 surveys are all believed to be vagrants in the area. *M. gouldii* was recorded only from trapping studies and was not examined further as it is a strictly terrestrial species, largely independent of wetlands.

Patterns of distribution of frogs in the GSS area varied between species and were examined with respect to four environmental parameters: landform unit; wetland type; presence of sedges and rushes; and presence of surface water in winter. *H. eyrei* and *C. insignifera* were widespread and found in a range of sites and wetland types, irrespective of vegetation and even at sites without surface water, whereas *C. georgiana* and *P. guentheri* had restricted distributions, being found at few sites in the Bassendean land system and confined to wetlands of specific characteristics; watercourses for *C. georgiana* and palusplains and sumplands for *P. guentheri*. *L. dorsalis, L. adelaidensis* and *L. moorei* were all associated with permanent or near-permanent wetlands with riparian vegetation, and such wetlands tend to occur in the Spearwood system, although with some examples on the Bassendean landform. *C. glauerti* occurred across a range of sites, but its presence correlated with water in winter and riparian vegetation.

The patterns of distribution of frogs were associated with their biology and particularly aspects of their breeding strategy. For example, the three species associated with permanent or near-permanent wetlands all require free water in which to lay their eggs and all breed from late winter through spring. In contrast, a few species breed in early winter to take advantage of the first winter rains, and this allows them to utilize a different suite of wetlands.

Review of the biology of each frog species allowed for an assessment of their sensitivity to hydrological declines. Species could be broadly classed as follows:

- Robust in the face of hydrological decline and sensitive only to almost catastrophic change due to reliance on permanent or near-permanent wetlands. Such wetlands tend to be large systems with considerable capacity for contraction (*C. georgiana, L. dorsalis, L. adelaidensis* and *L. moorei*).
- Robust in the face of hydrological decline due to longevity and persistence even in the face of failed breeding in successive years. Longevity effectively masks impacts so that other facets of the wetland ecosystem could be profoundly affected before a change would be detected in the frog species' population (*H. eyrei*).

- Sensitive to hydrological change with populations likely to decline rapidly de to reliance on small, shallow wetlands and near-annual recruitment (*C. glauerti* and *C. insignifera*). *C. glauerti* appears to be more sensitive than *C. insignifera*.
- Very sensitive to hydrological change due to a specific and inflexible breeding biology that relies on early winter rains and very shallow wetlands (*P. guentheri*).

INTRODUCTION

The Gnangara groundwater system is located on the Swan Coastal Plain, north of Perth, Western Australia and covers an area of approximately 2, 200 km^2. The Gnangara groundwater system consists of the unconfined superficial aquifer known as the Gnangara Mound that overlies the confined Leederville and Yarragadee aquifers. The mound aquifer is recharged directly by rainfall (Allen 1981), and provides Perth with approximately 60% of its water. It supports numerous significant biodiversity assets including the largest patch of remnant vegetation on the Swan Coastal Plain south of the Moore River, numerous threatened species and ecological communities and a suite of approximately 600 wetlands. In addition to these seasonal and permanent wetlands, the mound underlies pine plantations and extensive areas of native *Banksia* woodlands.

The multi-agency taskforce Gnangara Sustainability Strategy (GSS) was initiated to provide a framework for balancing water, land and environmental issues on the Gnangara Mound, and to develop a water management regime that is socially, economically and environmentally sustainable (DOW 2008). Because of their biology, frogs are likely to be sensitive to changes in landscape hydrology. Frog species differ in their biology to the extent that they will almost certainly vary in their distribution across a region, with some wetlands being suitable for some frog species and not others, and will vary in their responses to environmental change. These characteristics potentially make frogs important indicators to changing hydrological conditions on the Gnangara Mound and are thus investigated here.

The frog fauna of the GSS study area is well-documented (Storr *et al.* 1978; Tyler *et al.* 2000), with 8 genera and 13 species expected to occur: *Crinia georgiana, Crinia glauerti, Crinia insignifera, Heleioporus albopunctatus, Heleioporus eyrei, Heleioporus psammophilus, Heleioporus barycragus, Limnodynastes dorsalis, Litoria adelaidensis, Litoria moorei, Myobatrachus gouldii, Neobatrachus pelobatoides* and *Pseudophryne guentheri*. However, local patterns of distribution are not well-understood and are discussed in this report. The aims of the investigations are:

1) To provide baseline data on the current distribution of frog species across the GSS study area and examine this distribution with respect to environmental

parameters such as soil, vegetation, presence of water, seasonal variations in water levels, presence of other species, water quality, etc.

2) To review the biology of each species in order to potentially predict sensitivity to hydrological change.

METHODS

Aural surveys and environmental parameters

Aural surveys of calling males were carried out at wetlands within the GSS study area including wetlands in urban areas. The majority of species call from late winter to late spring (see Figure 1 and Figure 2), but a few species call in autumn/early winter (the Moaning Frog *Heleioporus eyrei*, *H. psammophilus* and *H. albopunctatus* and Günther's Frog *Pseudophryne guentheri*). Thus, surveys were carried out in May/June and August/September when it was expected almost all frog species would be calling. Late spring and summer-calling species, *Litoria moorei* and particularly *Myobatrachus gouldii*, were not adequately sampled with aural surveys. In this report, the May/June and August/September survey periods are referred to as the autumn and winter surveys respectively.

Surveys took place on evenings with fine weather and warm temperatures to maximize frog observations. Mike Bamford supervised each survey with assistance from Brent Johnson (DEC), Alice Reaveley (DEC), Natalia Huang (DEC), Tracy Sonneman (DEC), Katy Montgomery (DEC) and Janine Kuehs (UWA). Sixty-two sites were selected to represent a range of wetland types across the study area, with assistance from Dr. Rob Davis. These wetland types include lakes (n=11), palusplains (n=14), sumplands (n=33) and watercourses (n=4). Plates 1 to 18 illustrate typical examples of each wetland type. Wetland type definitions were adapted from Semeniuk & Semeniuk (1995): *lake* = permanently inundated basin; *palusplain* = seasonally waterlogged flat; *sumpland* = seasonally inundated basin; *watercourse* (categorised as *creek* by the afore-mentioned authors) = seasonally inundated channel.

Locations of sites in relation to the GSS study area are shown in Figure 3. Appendix 1 details the coordinates (GDA 94) of each survey site and the dates the sites were visited in autumn and winter.

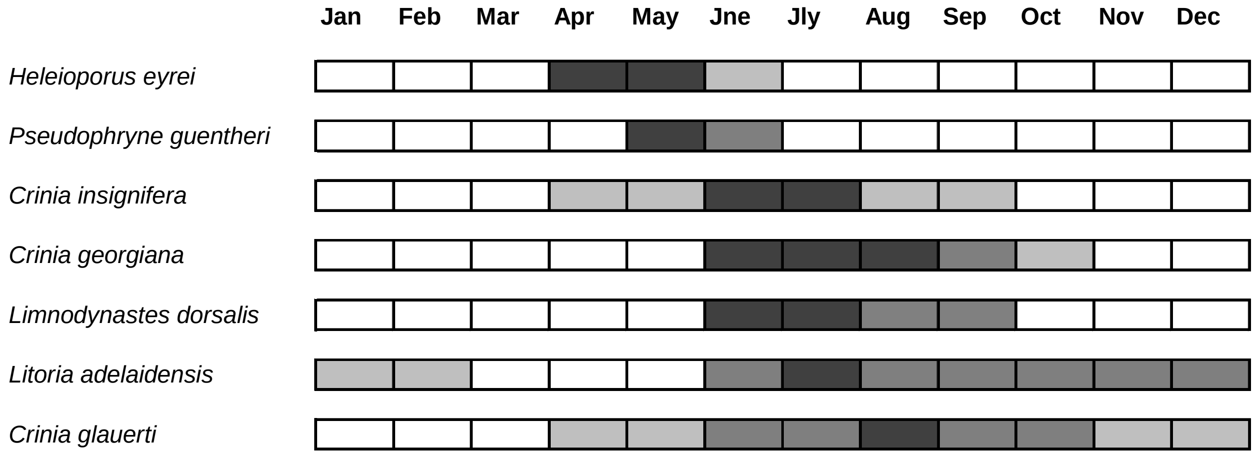

Figure 1. Frog calling phenology at Whiteman Park (from Bancroft and Bamford 2008). The darker the shading the more frogs are calling. The darkest grey represents peak calling times.

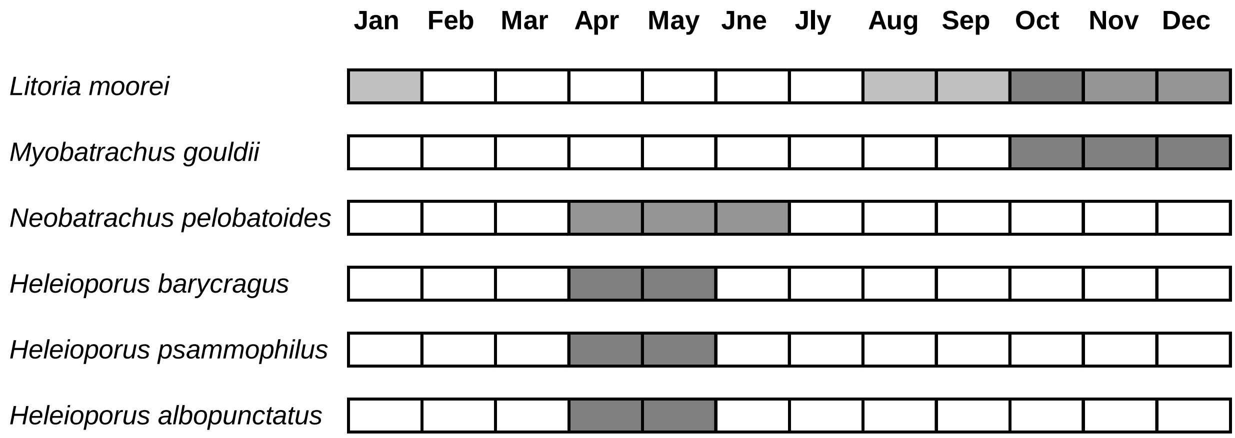

Figure 2. Frog calling phenology based on the literature, for species known from the GSS area but not reported by Bancroft and Bamford (2008). The darker the shading the more frogs are calling. The darkest grey represents peak calling times.

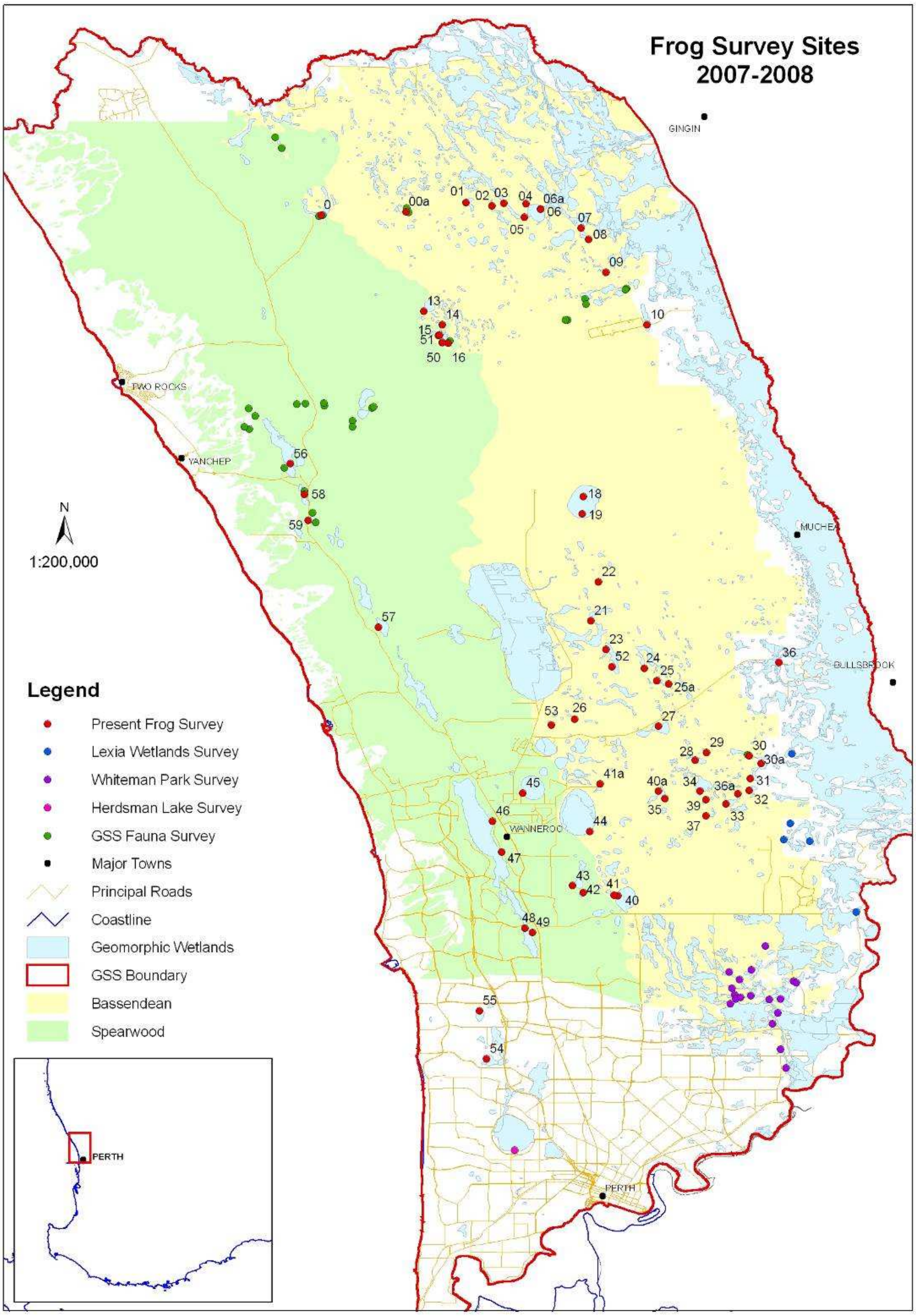

Figure 3. Frog aural survey sites in the GSS Project area (red circles with site codes). Other locations for which data are available on frogs are also indicated. Detailed maps of site locations and codes of other surveys are shown in their associated appendices. Note: species location data from the Western Australian Museum specimen records database are shown in a separate appendix (Appendix 10).

Aural surveys involved listening at each site for approximately 5 minutes and counting the number of each species heard. These abundance values were then grouped into categories: 1-10, 11-30 and >30. Further differentiation between calling individuals was difficult beyond 30. Brief descriptions of vegetation, wetland type and water levels were also recorded at each site.

In addition to the aural surveys conducted as part of this project, detailed information on the distribution of frogs at other sites in the GSS area was obtained from Bamford and Everard (2008) for the Lexia wetlands area and Bancroft and Bamford (2008) for Whiteman Park. Both locations are in the south-east of the GSS area and the detailed studies provide location information for frogs at a further 23 sites (5 at Lexia and 18 at Whiteman Park). Detailed personal observations (M. and A. Bamford) are available from Herdsman Lake in the south-west of the GSS area. Incidental capture data of frogs in pitfall traps as part of the parallel GSS fauna survey is also included. These additional sites are included on distribution maps for each species, while observations contribute to the review of their biology. Records from these other sources, including detailed site locations, are summarised in Appendices 6 to 9. In addition, the results include spatial frog specimen information extracted from NatureMap (DEC, 2007), showing data from the Western Australian Museum specimen database (see Appendix 10).

Four parameters considered important in influencing frog distribution were: i) landform unit, ii) wetland type, iii) presence of sedges and rushes, and iv) the presence of surface water in winter. Appendix 2 provides a description of each site in terms of these parameters. Appendix 3 provides a further description of the vegetation at each site. The effects, if any, of the above four parameters on the presence/absence of frog species across the wetlands were examined.

Plates 1 to 18

Plate 1. Site 0a (Tick Flat). Mostly dead paperbark trees with invading upland vegetation. Sumpland, no surface water.

Plate 2. Site 1. Palusplain severely damaged by wildfire.

Plate 3. Site 1. Palusplain regenerating from same wildfire as in 1.2.

Plate 4. Site 3. Watercourse flowing through a gallery forest of eucalypts and paperbarks.

Plate 5. Site 4. Fringe of large swamp. Shrubs and trees regenerating from recent fire.

Plate 6. Site 7. Flooded drain and a vegetated sumpland surrounded by pasture.

Plate 7. Site 9. Palusplain with paperbarks over shrubs. No surface water.

Plate 8. Site 16. Edge of sumpland supporting very large Flooded Gums; understorey vegetation removed by human activities. No surface water.

Plate 9. Site 21. Palusplain supporting dense, low shrubs. No surface water.

Plate 10. Site 24. Palusplain supporting Melaleuca teretifolia, indicative of past long seasonal inundation, but surface water in 2008 was only in deep wheel ruts.

Plate 11. Site 25a. A seasonally inundated sumpland with sedges and paperbarks.

Plate 12. Site 28. Fire-hole dug in broad sumpland contains the only water present.

Plate 13. Site 36. Paperbarks over sedges and extensive water of mound spring.

Plate 14. Site 41. (Tuscan Park) A sumpland with more or less permanent water (probably maintained) and extensive riparian vegetation.

Plate 15. Site 31. Palusplain with a belt of dense paperbarks over shrubs. No surface water.

Plate 16. Site 34. Palusplain with some paperbarks and a dense sward of sedges. No surface water.

Plate 17. Site 47. (Lake Joondalup) Very large lake with extensive riparian vegetation. This vegetation floods seasonally.

Plate 18. Site 53. Sumpland with a closed forest of Banksia littoralis. No surface water.

Review of biology of species

The review of biology of frog species involved reviewing published and unpublished literature, and meeting with recognised experts on local frog biology. Main sources of information were Tyler *et al.* (2000), Bamford (1986) and Main (1965). There was also extensive reliance on personal information (M. Bamford). The results of the review form the basis of the Discussion (Section 4) and are interpreted in relation to observations in the GSS area. For each species, key ecological characteristics that may affect their sensitivity to hydrological change were summarised:

<u>Breeding strategy</u>: When the species breeds and how it breeds (e.g. eggs dispersed, in burrow, etc). Such characteristics can affect the sensitivity of the species to changes in groundwater levels.

<u>Larval period</u>: A short larval period would be expected to make a species more robust in the face of hydrological change.

<u>Diet</u>: Larval and adult diet may have some bearing on the sorts of environments the species may occur in.

<u>Juvenile dispersal</u>: Dispersal of juveniles (i.e. metamorphs; animals that have recently metamorphosed) may determine the reliance of a species on wetlands towards the end of the breeding season.

<u>Age at maturity</u>: The age at maturity can influence the impact of a poor or a good breeding season upon the population.

<u>Longevity</u>: Short-lived species may suffer drastic population declines after only one or two poor breeding seasons, and may be sensitive to local extinction. Long-lived species may persist, enabling them to take advantage of occasional good years, or perhaps just persisting despite ongoing poor conditions. Such persistence can mask impacts.

<u>Movement patterns of adults</u>: Adults may disperse widely, undertake regular seasonal movements or be sedentary at their natal site. Differing characteristics affect the ability of a species to recolonise sites and can determine if the species is affected by factors taking place away from the breeding site.

<u>Breeding environment</u>: In what sort of environment does the species breed: seasonal or permanent wetland, riparian vegetation or bare shore? Such wetland characteristics can change with hydrological changes.

Non-breeding environment: This relates to movement patterns of juveniles and adults.
General distribution and status in the GSS area: The distribution of the species in the South-West and what is known about the species in the GSS area; where it occurs and if there is any evidence of impacts from hydrological change.
Predicted sensitivity to hydrological change: What do the above features of the species and the observations made in the Gnangara project area suggest about its sensitivity to hydrological change?

RESULTS

Results of this project are presented in two sections as follows:
The frog assemblage and environmental parameters. This provides an overview of the abundance of each species and how the key environmental parameters of landform type, wetland type, presence/absence of surface water and presence/absence of sedges affect species richness and abundance.
Species distribution patterns. This considers each species and the sorts of sites at which it was recorded. This section includes a distribution map across the GSS area for each species, including supplementary records from other sources (see above).

The frog assemblage and environmental parameters

The results of the aural survey for autumn and winter are shown in Appendix 4 and Appendix 5 respectively, and are summarised on Table 1. These surveys confirmed the presence of eight frog species and failed to locate four known from the area historically: *Heleioporus albopunctatus, Heleioporus barycragus, Heleioporus psammophilus* and *Neobatrachus pelobatoides*. The Turtle Frog *Myobatrachus gouldii* was also not recorded during aural surveys, but it calls in very late spring and thus no surveys took place at the right time of the year to detect it. The most frequently recorded species was *Heleioporus eyrei* (30 sites). Other species (in order of abundance) were: *Crinia insignifera* (23 sites), *Crinia glauerti* (21 sites), *Litoria adelaidensis* (19 sites), *Limnodynastes dorsalis* (18 sites), *Pseudophryne guentheri* (8 sites), *Litoria moorei* (4 sites) and *Crinia georgiana* (3 sites). These records should provide an accurate reflection of the distribution and abundance of the frog species across the project area except in the case of *L. moorei*, which tends to call slightly later in the year than when surveys were conducted. It may thus be more widespread than indicated and is indeed a familiar frog in suburban gardens.

No site supported all eight species, three sites had six or seven species, 17 sites had no species and 15 sites supported just one species (Figure 4). Sites with at least 4 species (50% of recorded species) are listed in Table 2 with their key environmental parameters. All of these sites had surface water in winter and sedges/rushes. Most sites with high species richness were in watercourses or lakes, four in sumplands and none in palusplain. Over half of the species-rich sites were within Bassendean landform system. The three most species-rich sites were Sites 3, 6 and 36: all were watercourses in the Bassendean landform in the north-east and east of the project area (see Figure 3). Patterns of distribution are examined further below, firstly by considering environmental parameters broadly, and then by examining the distribution of each frog species across all the sites.

Table 1. Frog survey sites at which each frog species was recorded during aural surveys (autumn and winter combined). See Appendix 4 and Appendix 5 for seasonal and abundance information.

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 0								
Frog 0a								
Frog 01				X				X
Frog 02				X				X
Frog 03	X	X	X	X	X	X		X
Frog 04			X	X	X		X	X
Frog 05		X	X	X				X
Frog 06	X		X	X	X	X	X	X
Frog 06a		X	X			X		
Frog 07		X	X	X	X		X	
Frog 08								
Frog 09								X
Frog 10								
Frog 13								
Frog 14								
Frog 15								
Frog 16								
Frog 18								
Frog 19								
Frog 21				X	X			X
Frog 22				X				
Frog 23			X	X				
Frog 24			X	X				
Frog 25				X				
Frog 25a		X	X		X		X	
Frog 26								
Frog 27			X					
Frog 28								
Frog 29				X	X		X	
Frog 30				X				
Frog 30a		X	X		X			
Frog 31				X				
Frog 32				X				
Frog 33				X				
Frog 34								
Frog 35								
Frog 36	X	X	X	X	X		X	
Frog 36a								
Frog 37				X				
Frog 39								
Frog 40		X		X				

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 40a				X				
Frog 41		X	X	X	X		X	
Frog 41a			X				X	
Frog 42			X					
Frog 43		X		X			X	
Frog 44		X	X		X		X	
Frog 45		X	X	X	X		X	
Frog 46		X	X		X		X	
Frog 47		X			X		X	
Frog 48		X		X				
Frog 49		X	X		X		X	
Frog 50				X				
Frog 51				X				
Frog 52				X				
Frog 53				X				
Frog 54		X	X	X		X	X	
Frog 55		X	X		X		X	
Frog 56		X	X		X		X	
Frog 57		X	X		X		X	
Frog 58		X					X	
Frog 59								

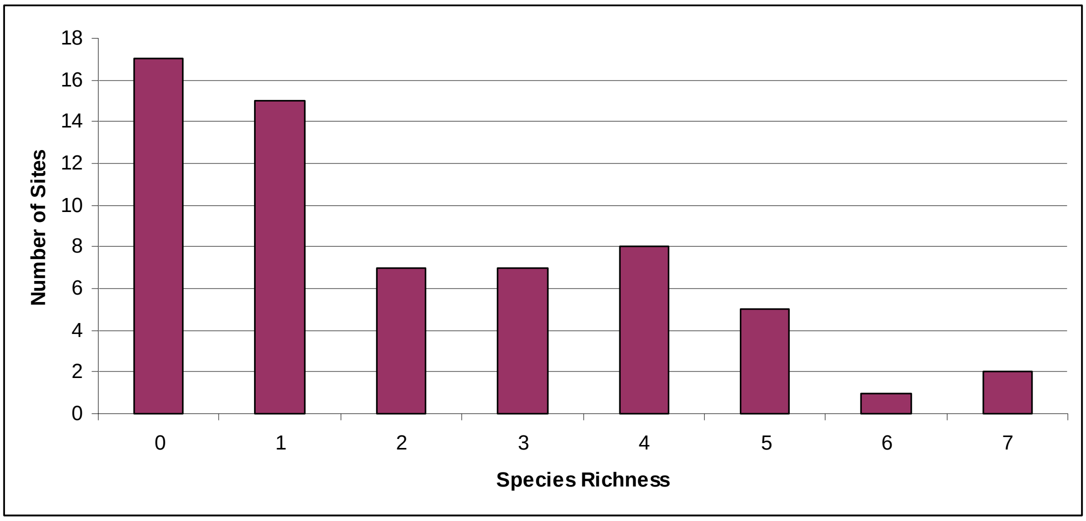

Figure 4. The frequency distribution of species richness across the sites.

Table 2. Attributes of sites with at least four frog species (50% of recorded species).

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 03	7	B	W	+	+
Frog 04	5	B	W	+	+
Frog 05	4	B	W	+	+
Frog 06	7	B	S	+	+
Frog 07	5	B	S	+	+
Frog 25a	4	B	S	+	+
Frog 36	6	B	W	+	+
Frog 41	5	B	S	+	+
Frog 44	4	B	L	+	+
Frog 45	5	S	L	+	+
Frog 46	4	S	L	+	+
Frog 49	4	S	L	+	+
Frog 54	5	S	L	+	+
Frog 55	4	S	L	+	+
Frog 56	4	S	L	+	+
Frog 57	4	S	L	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

The occurrence and distribution of each species in relation to environmental parameters are shown in Figure 5 (landform unit), Figure 6 (wetland type), Figure 7 (presence of sedges/rushes) and Figure 8 (presence of surface water in winter). Relationships between environmental parameters and frogs can be summarised as follows:

Landform unit (Figure 5). Bassendean unit supports more species (8 compared with 6 in Spearwood). The species missing from Spearwood wetlands are *C. georgiana* and *P. guentheri*. Despite this, all frog species present on Spearwood wetlands are better represented (ie. present at a higher proportion of surveyed wetlands) than on Bassendean wetlands. This relates to the nature of the wetlands, those in the Spearwood system mostly being large lakes and sumplands, whereas those in the Bassendean system often being very shallow sumplands and palusplain sites.

Wetland type (Figure 6). Watercourses and lakes, being large, permanent or near-permanent and with extensive riparian vegetation, supported more species generally at higher levels of representation than sumpland and palusplain wetlands. *P. guentheri* was absent from lakes but present at all other wetland types, while *H. eyrei* was the only species well-represented at palusplain sites. Palusplain sites supported only four species.

Presence of sedges (Figure 7). The presence of sedges may be closely related to the presence of surface water and it may be either of these parameters that is important for some frog species. Both *H. eyrei* and *P. guentheri* appear unaffected by the presence or absence of sedges, while a further four species are present at sites without sedges, albeit at lower levels of representation than among sites with sedges.

Surface water in winter (Figure 8). This was clearly an important parameter for frogs, but four species were recorded at sites without surface water; *H. eyrei* was present at over 40% of such sites compared with over 50% of sites with surface water. *H. eyrei* and *P. guentheri* had similar levels of representation at sites with and without surface water.

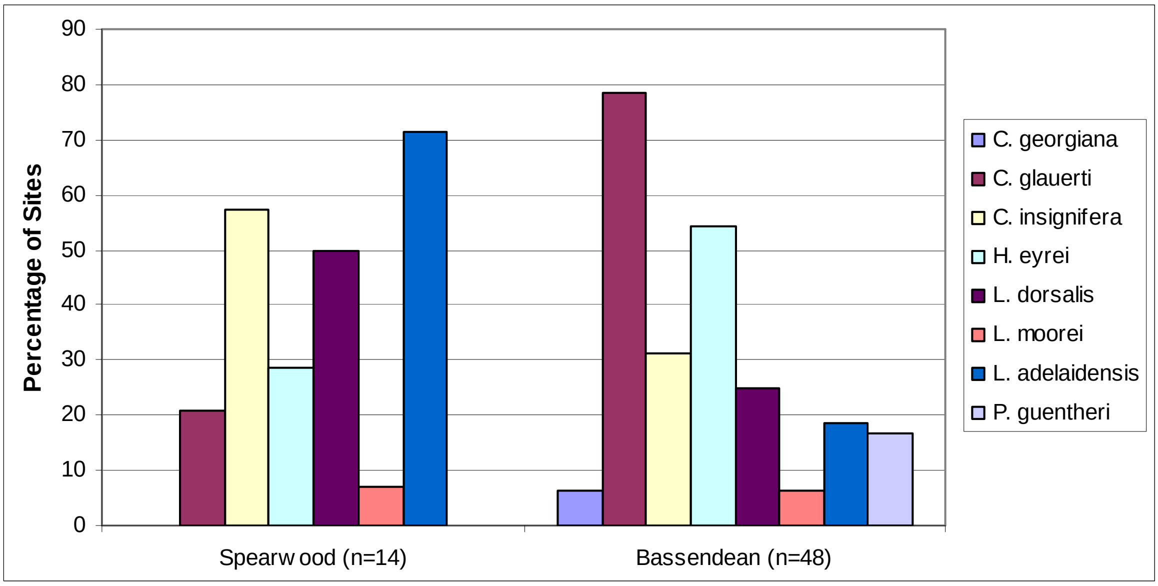

Figure 5. Occurrence of each species within landform units

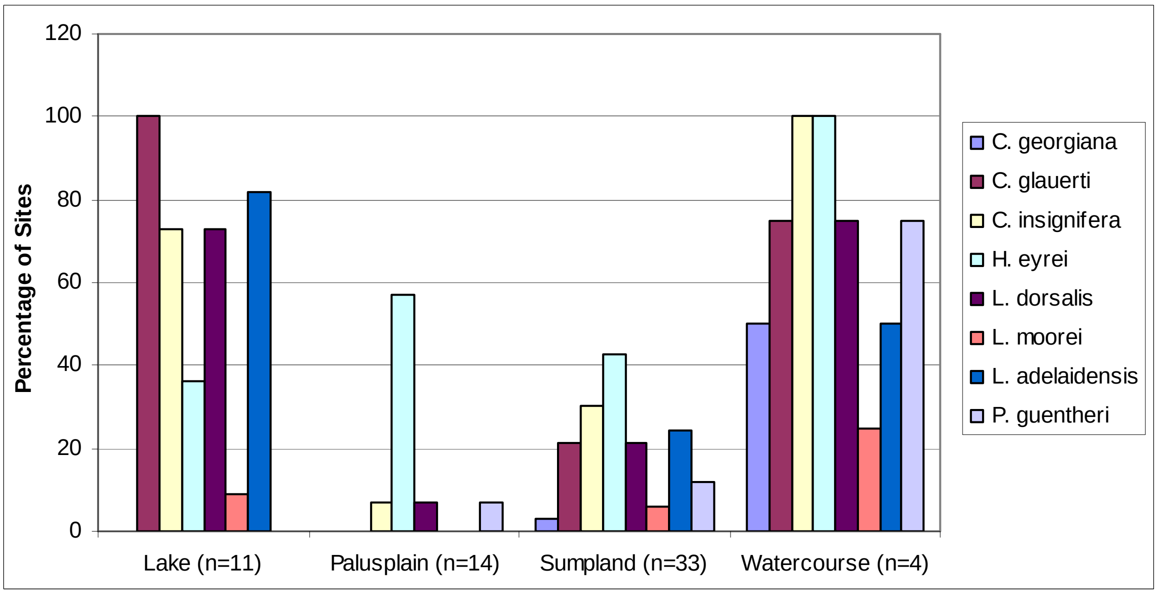

Figure 6. Occurrence of each species within wetland type

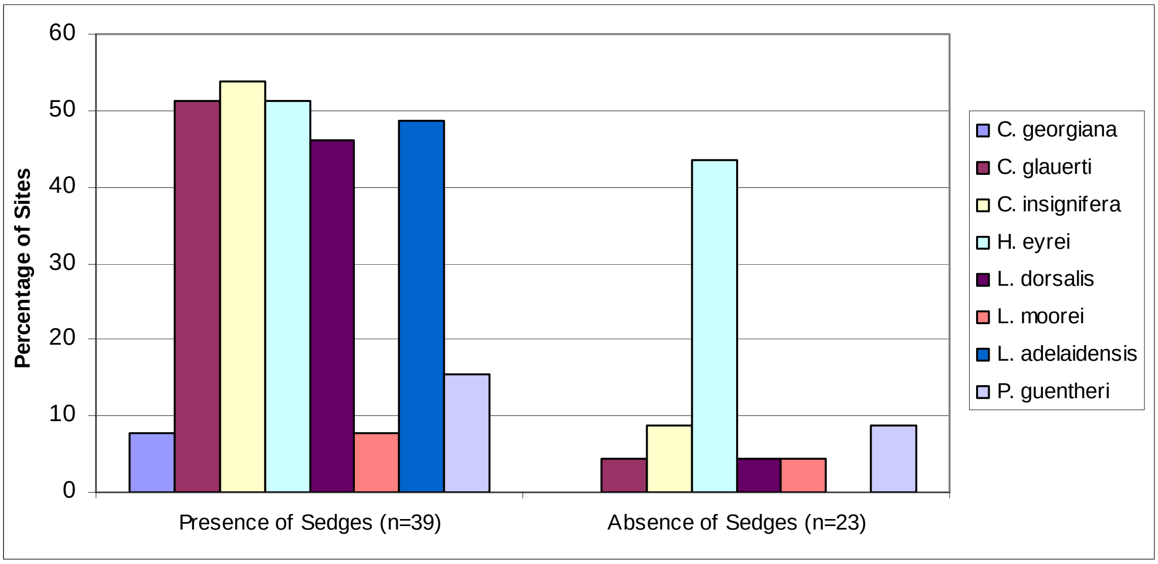

Figure 7. Occurrence of each species within sites with and without sedges/rushes.

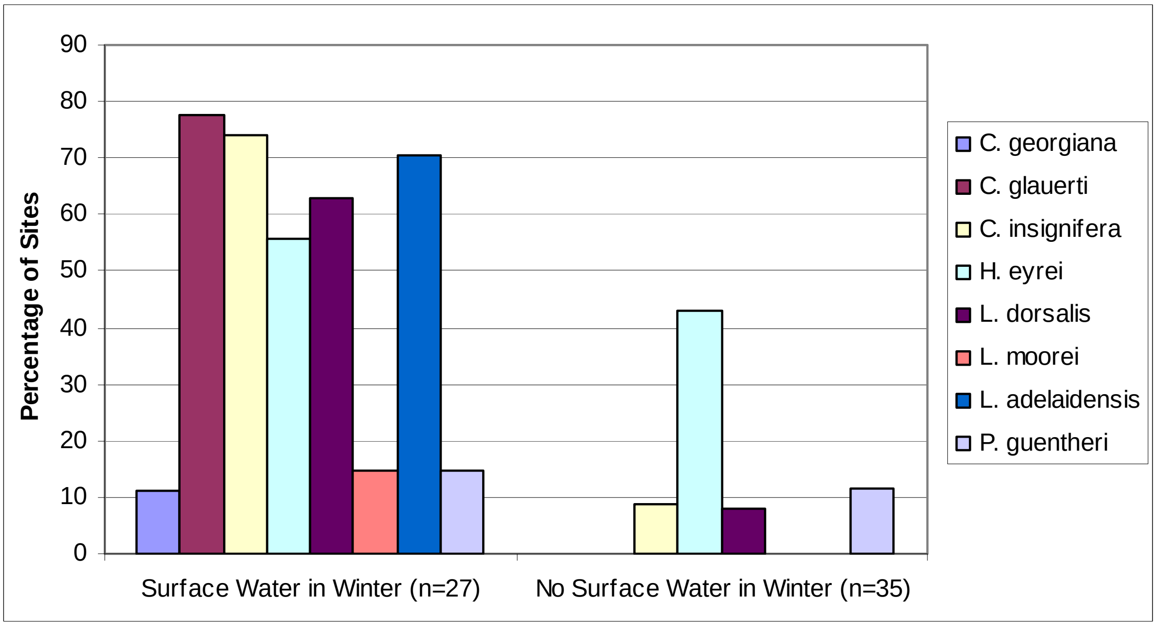

Figure 8. Occurrence of each species within sites with and without surface water in winter

Species Distribution Patterns

Crinia georgiana

C. georgiana was found at only three sites in the northeast and east of the study area (Figure 9). It was recorded only in winter. These sites were all located in Bassendean soils, and had presence of both sedges/rushes and surface water in winter. They were all also species rich. One site was a lake that was part of a watercourse, while the remaining two sites were parts of watercourses. These include Site 36, a mound spring that forms part of a complex drainage system in winter. At Whiteman Park, *C. georgiana* was also found to be largely restricted to sites along or close to watercourses.

C. georgiana was absent from a number of apparently suitable sites, particularly the large lakes with extensive riparian vegetation within the Spearwood landform system. Some of these lakes, such as those within Yellagonga Regional Park, are linked by vegetated drainage lines. It is not known why the species is absent from these sites, but it is considered to be patchily distributed on the Coastal Plain but with an extensive distribution along the Darling Scarp and in high rainfall areas of the adjacent plateau. Its absence for Spearwood lake systems may be biogeographic. Historical records are restricted to the south-eastern corner of the GSS area (Appendix 10).

Table 3. Attributes of sites where *C. georgiana* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 03	7	B	W	+	+
Frog 06	7	B	S	+	+
Frog 36	6	B	W	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

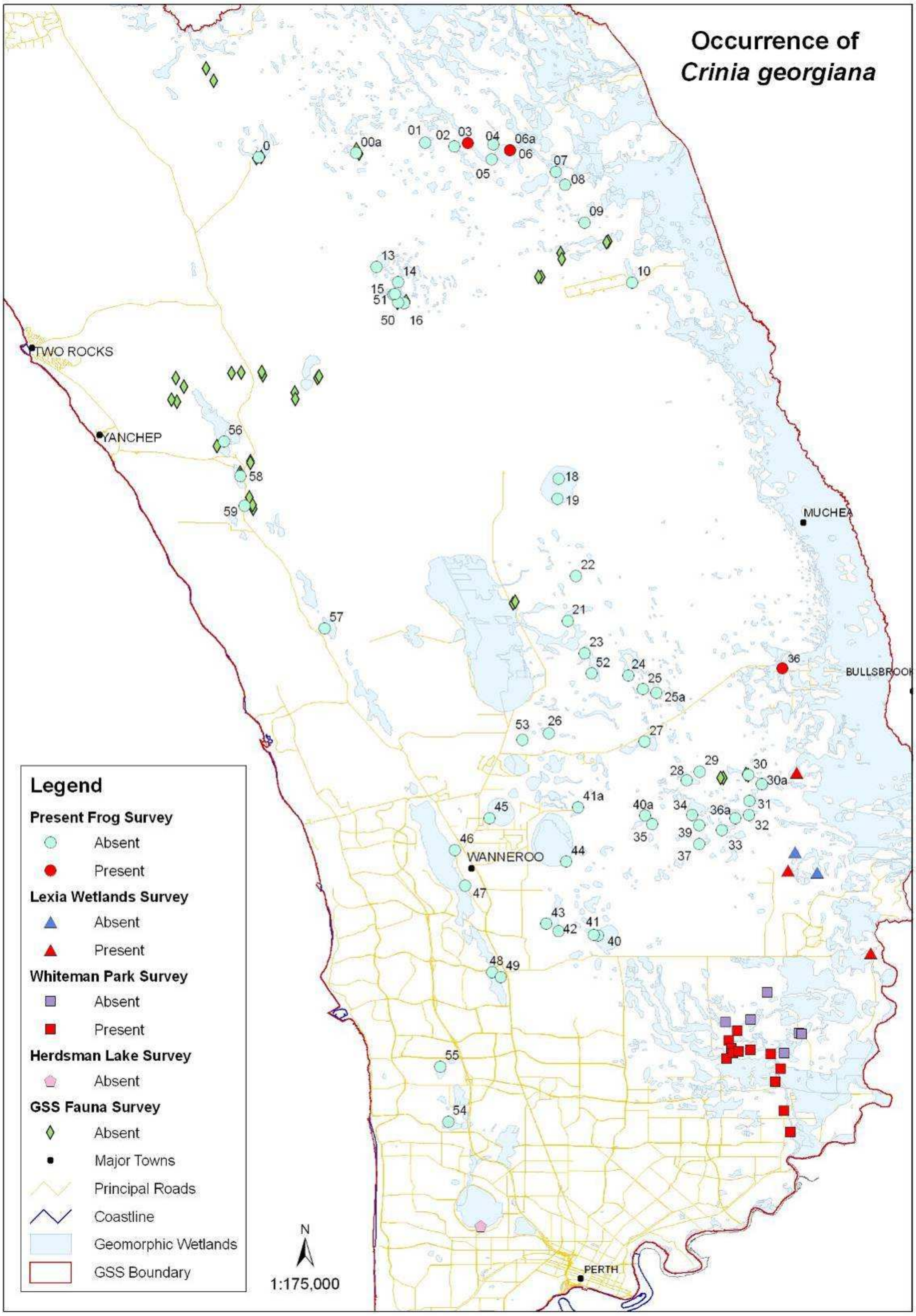

Figure 9. Occurrence of *Crinia georgiana* in the study area.

Crinia glauerti

C. glauerti was recorded at 21 sites (Table 4), being better represented at sites in the Spearwood (80% of sites) than the Bassendean (20% of sites) land systems. It was well-represented on watercourses and lakes, present at some sumplands but not present at any palusplain sites. It occurred only at sites with sedges/rushes and with water present in winter. *C. glauerti* is widespread across the GSS project area except in the central region where palusplain sites predominate, and has also been recorded in the Lexia, Whiteman and Herdsman areas (Figure 10).

Table 4. Attributes of sites where *C. glauerti* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 03	7	B	W	+	+
Frog 05	4	B	W	+	+
Frog 06a	3	B	S	-	+
Frog 07	5	B	S	+	+
Frog 25a	4	B	S	+	+
Frog 30a	3	B	S	+	+
Frog 36	6	B	W	+	+
Frog 40	2	B	L	+	+
Frog 41	5	B	S	+	+
Frog 43	3	S	S	+	+
Frog 44	4	B	L	+	+
Frog 45	5	S	L	+	+
Frog 46	4	S	L	+	+
Frog 47	3	S	L	+	+
Frog 48	2	S	S	+	+
Frog 49	4	S	L	+	+
Frog 54	5	S	L	+	+
Frog 55	4	S	L	+	+
Frog 56	4	S	L	+	+
Frog 57	4	S	L	+	+
Frog 58	2	S	S	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

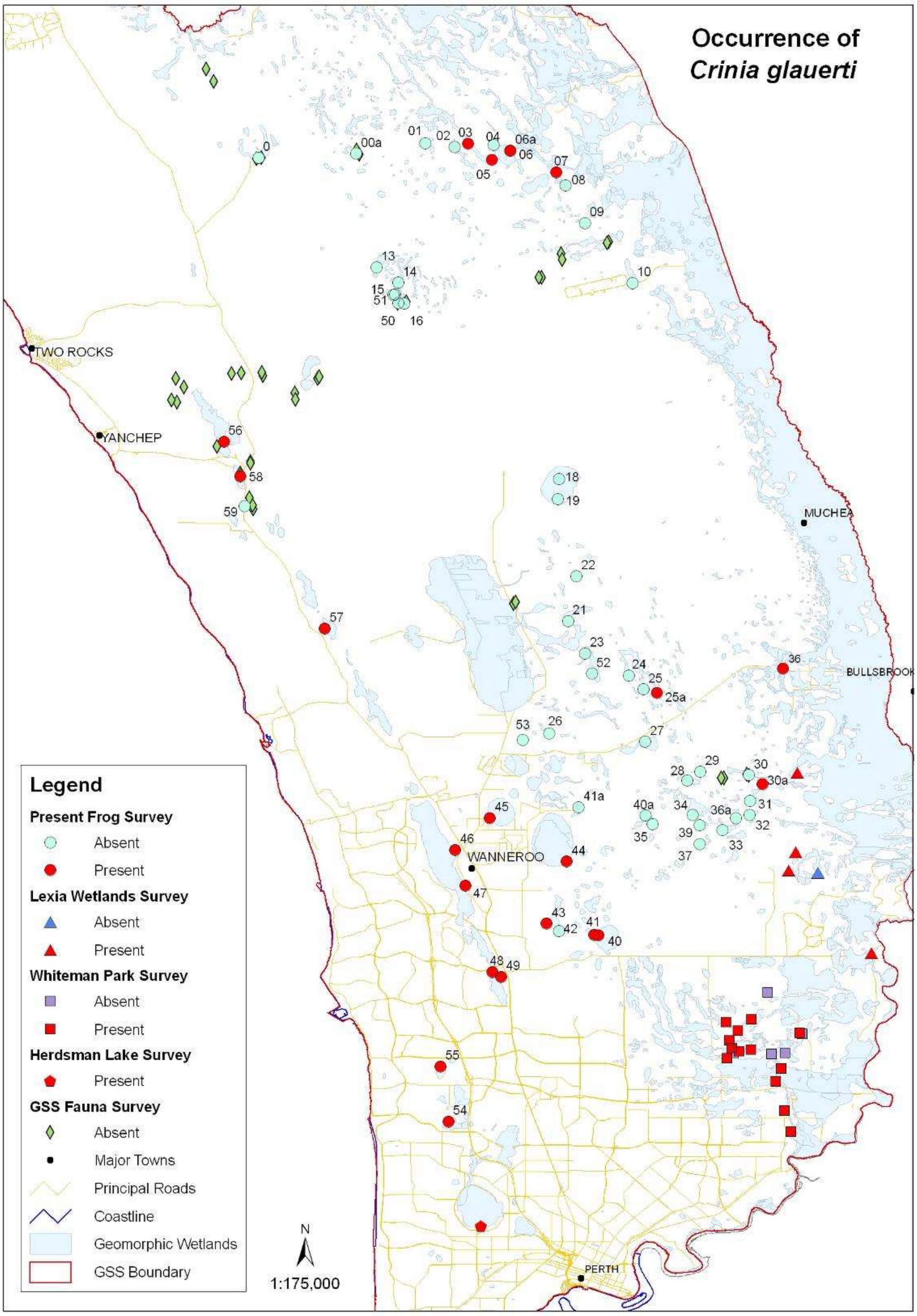

Figure 10. Occurrence of *Crinia glauerti* in the study area.

Crinia insignifera

C. insignifera was recorded at 23 sites (Table 5), being better represented at sites in the Spearwood (60% of sites) than the Bassendean (30% of sites) land systems. It was present at all watercourse sites and most lake sites, 9 % of sumplands sites and a single palusplain site. Unlike the similar *C. glauerti*, it occurred at several sites without water in winter and/or without rushes and sedges. This was the second most widespread frog species in the GSS area (after *H. eyrei*), and has also been recorded in the Lexia, Whiteman and Herdsman areas (Figure 11). It hybridizes with the similar *Crinia pseudinsignifera* between Muchea and Bindoon, on the north eastern edge of the GSS area (Bull 1979), but *C. pseudinsignifiera* was not recorded during the current surveys and there are no historical records for it within the project area.

Table 5. Attributes of sites where *C. insignifera* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 03	7	B	W	+	+
Frog 04	5	B	W	+	+
Frog 05	4	B	W	+	+
Frog 06	7	B	S	+	+
Frog 06a	3	B	S	-	+
Frog 07	5	B	S	+	+
Frog 23	2	B	S	+	-
Frog 24	2	B	P	+	+
Frog 25a	4	B	S	+	+
Frog 27	1	B	S	-	-
Frog 30a	3	B	S	+	+
Frog 36	6	B	W	+	+
Frog 41	5	B	S	+	+
Frog 41a	2	B	S	+	+
Frog 42	1	S	S	+	-
Frog 44	4	B	L	+	+
Frog 45	5	S	L	+	+
Frog 46	4	S	L	+	+
Frog 49	4	S	L	+	+
Frog 54	5	S	L	+	+
Frog 55	4	S	L	+	+
Frog 56	4	S	L	+	+
Frog 57	4	S	L	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

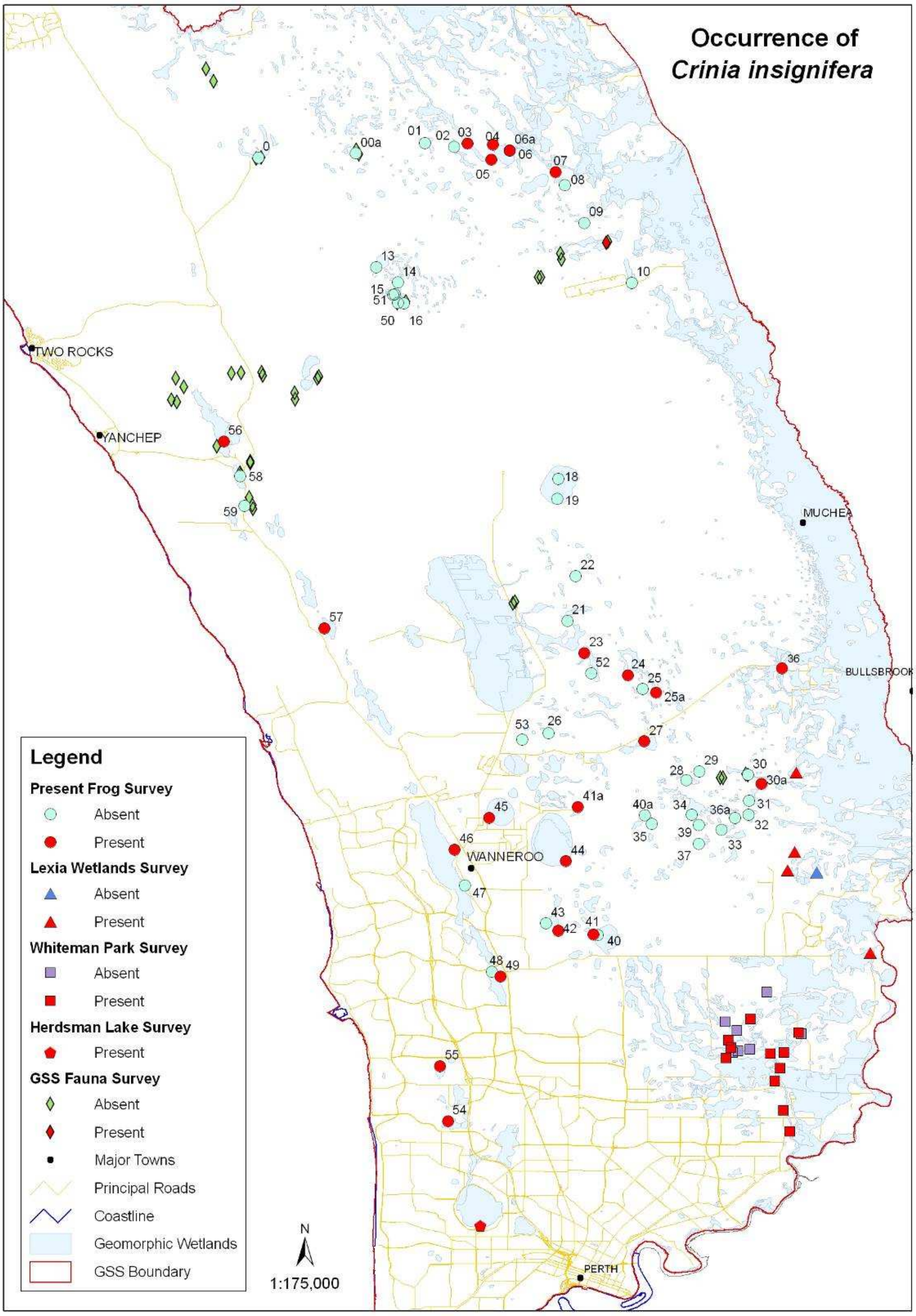

Figure 11. Occurrence of *C. insignifera* in the study area.

Heleioporus eyrei

H. eyrei was recorded at 30 sites (Table 6) and was present at a slightly higher proportion of Bassendean (51%) than Spearwood (31%) sites. It was present at all watercourses but only some lakes, at 41% of sumplands and 64% of palusplain sites. It was recorded at sites with and without rushes and sedges, and 52% of the sites where it was recorded had no surface water. It was thus the most widespread of frog species in terms of environmental parameters and across the GSS area (Figure 12). It is also widespread at Lexia and Whiteman Park, but is absent from Herdsman Lake where water level manipulation interferes with its breeding biology (D. Roberts pers. comm.). Historically it has been widely recorded in urban areas (Appendix 10).

Table 6. Attributes of sites where *H. eyrei* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 01	2	B	S	-	-
Frog 02	2	B	S	-	-
Frog 03	7	B	W	+	+
Frog 04	5	B	W	+	+
Frog 05	4	B	W	+	+
Frog 06	7	B	S	+	+
Frog 07	5	B	S	+	+
Frog 21	3	B	P	+	-
Frog 22	1	B	P	-	-
Frog 23	2	B	S	+	-
Frog 24	2	B	P	+	+
Frog 25	1	B	P	-	-
Frog 29	3	B	S	+	+
Frog 30	1	B	P	-	-
Frog 31	1	B	S	-	-
Frog 32	1	B	S	+	-
Frog 33	1	B	P	+	-
Frog 36	6	B	W	+	+
Frog 37	1	B	P	-	-
Frog 40	2	B	L	+	+
Frog 40a	1	B	P	+	-
Frog 41	5	B	S	+	+
Frog 43	3	S	S	+	+
Frog 45	5	S	L	+	+
Frog 48	2	S	L	+	+
Frog 50	1	B	S	-	-
Frog 51	1	B	S	-	-
Frog 52	1	B	P	+	-

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 53	1	B	S	+	-
Frog 54	5	S	L	+	+

* Landform units B= Bassendean, S= Spearwood;

^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

NB. Not recorded at several sites that were not surveyed in autumn, such as 06a or 25a.

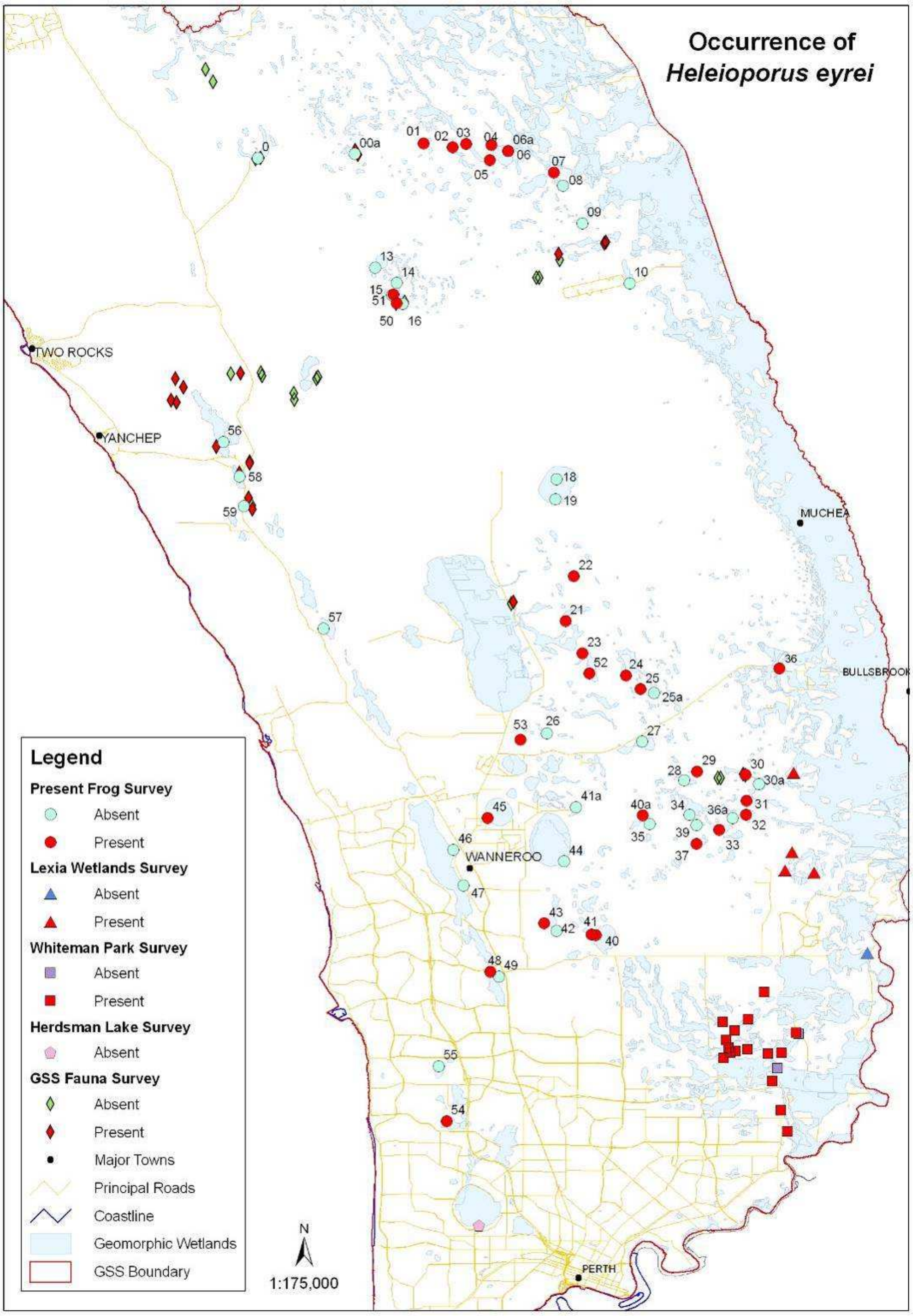

Figure 12. Occurrence of *H. eyrei* in the study area.

Limnodynastes dorsalis

L. dorsalis was recorded at 18 sites (Table 7) and was better-represented in the Spearwood (54% of sites) than the Bassendean (22% of sites) land system. It was well-represented at lakes and watercourses, poorly represented at sumplands and was present at only one palusplain sites. It was present only where there were rushes and sedges except at site 06a, which had flooded grasses in a paddock. All except the one palusplain site had water present, with many of the sites being permanent wetlands. Reflecting its bias in favour of lakes of the Spearwood system, *L. dorsalis* was widely distributed in the west of the GSS project area (Figure 13). It has been recorded at only some sites in the Lexia and Whiteman Park areas, which lie in the south-east of the GSS region.

Table 7. Attributes of sites where *L. dorsalis* was recorded.

Site	**Species Richness**	**Landform Unit***	**Wetland type^**	**Presence of Sedges/Rushes**	**Presence of Surface Water in Winter**
Frog 03	7	B	W	+	+
Frog 04	5	B	W	+	+
Frog 06	7	B	S	+	+
Frog 07	5	B	S	+	+
Frog 21	3	B	P	+	-
Frog 25a	4	B	S	+	+
Frog 29	3	B	S	+	+
Frog 30a	3	B	S	+	+
Frog 36	6	B	W	+	+
Frog 41	5	B	S	+	+
Frog 44	4	B	L	+	+
Frog 45	5	S	L	+	+
Frog 46	4	S	L	+	+
Frog 47	3	S	L	+	+
Frog 49	4	S	L	+	+
Frog 55	4	S	L	+	+
Frog 56	4	S	L	+	+
Frog 57	4	S	L	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

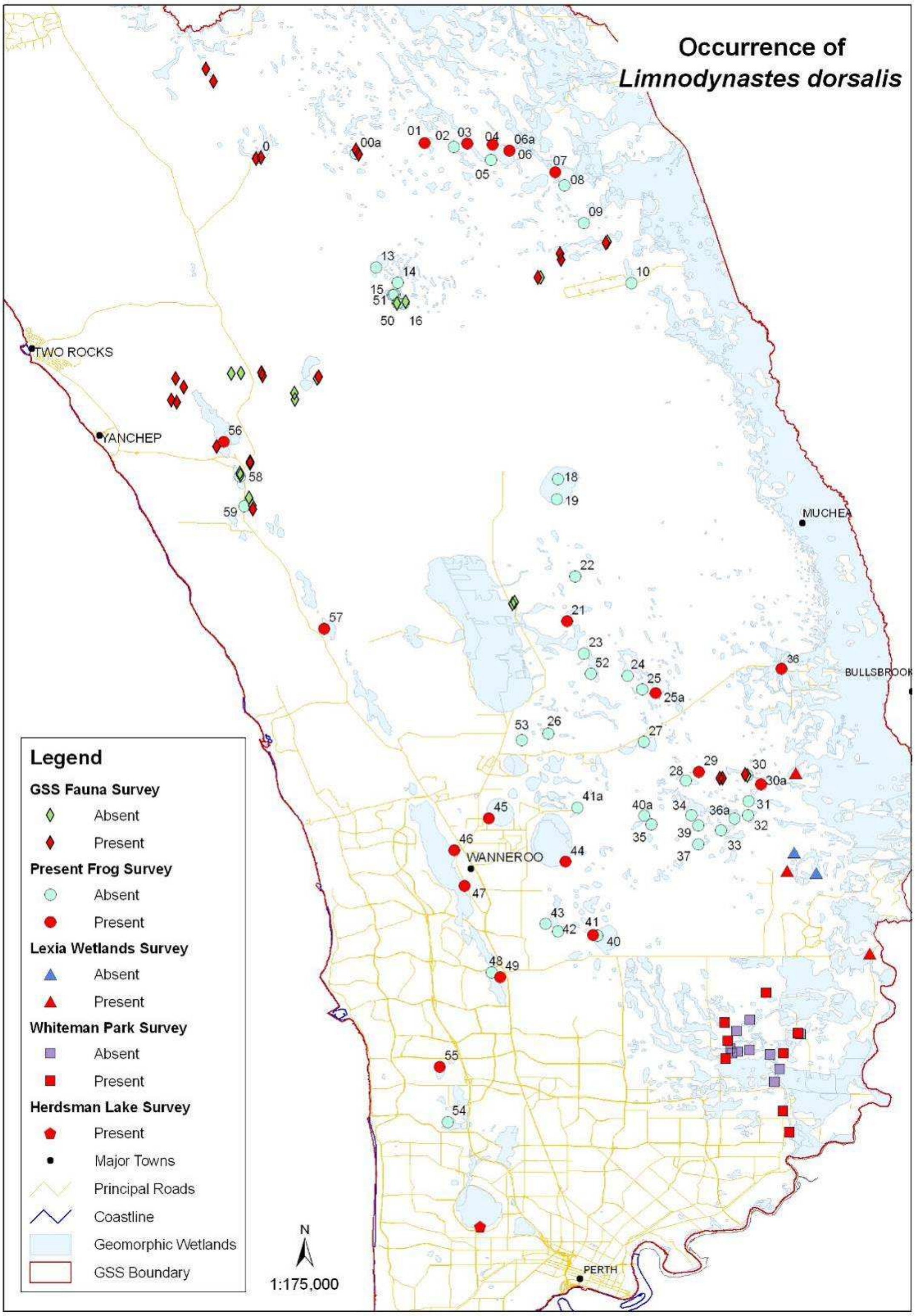

Figure 13. Occurrence of *L. dorsalis* in the study area.

Litoria moorei

L. moorei was recorded at only 4 sites (Table 8), but surveys did not take place during its peak calling period of late spring, and therefore it is probably more widespread in the GSS area than indicated. It is commonly associated with permanent and near-permanent wetlands (Tyler *et al.* 2000), and is the most familiar of frogs to residents in urban areas, being present throughout the near-coastal wetland chain from Herdsman Lake to Yanchep (M. Bamford pers. obs.; see also Appendix 10). It has not been recorded at Lexia and has a restricted distribution at Whiteman Park (Figure 14).

Table 8. Attributes of sites where *L. moorei* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 03	7	B	W	+	+
Frog 06	6	B	S	+	+
Frog 06a	4	B	S	-	+
Frog 54	5	S	L	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

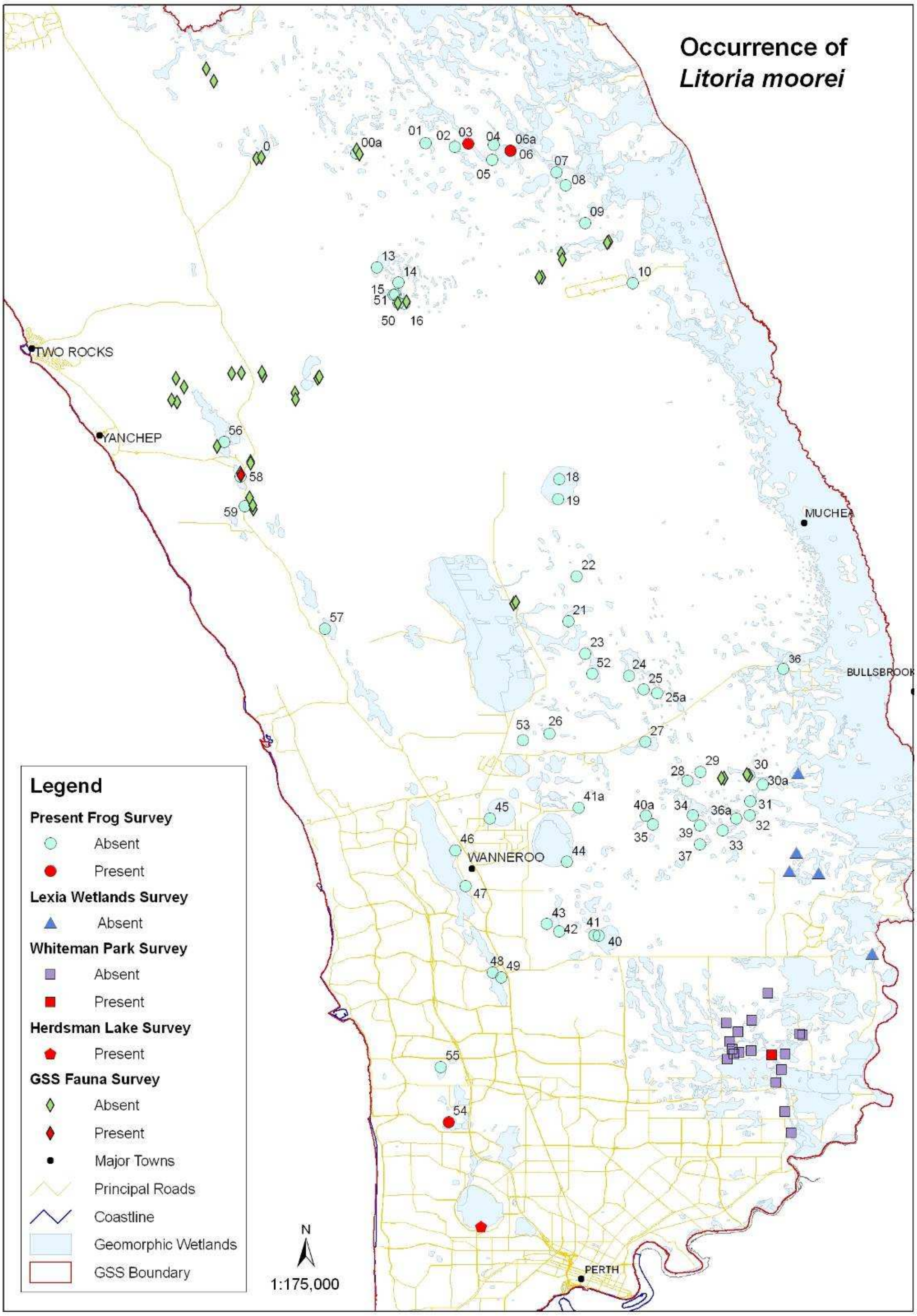

Figure 14. Occurrence of *L. moorei* in the study area.

Litoria adelaidensis

L. adelaidensis was recorded at 19 sites (Table 9) and was better-represented in the Spearwood (77% of sites) than the Bassendean (18% of sites) land system. It was present at most watercourse and lake sites, but at only 24% of sumpland sites and no palusplain sites. It was found only where there were rushes and sedges, and surface water. Reflecting its bias in favour of lakes of the Spearwood system, *L. adelaidensis* was widely distributed in the west of the GSS project area (Figure 15). It has been recorded at only some sites in the Lexia area but is widespread at Whiteman Park, where many of the wetlands are part of the Bennett Brook drainage system. It occurs throughout the near-coastal wetland chain from Herdsman Lake to Yanchep (M. Bamford pers. obs.; see also Appendix 10).

Table 9. Attributes of sites where *L. adelaidensis* was recorded.

Site	Species Richness	Landform Unit*	Wetland type^	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 04	5	B	W	+	+
Frog 06	7	B	S	+	+
Frog 07	5	B	S	+	+
Frog 25a	4	B	S	+	+
Frog 29	3	B	S	+	+
Frog 36	6	B	W	+	+
Frog 41	5	B	S	+	+
Frog 41a	2	B	S	+	+
Frog 43	3	S	S	+	+
Frog 44	4	B	L	+	+
Frog 45	5	S	L	+	+
Frog 46	4	S	L	+	+
Frog 47	3	S	L	+	+
Frog 49	4	S	L	+	+
Frog 54	5	S	L	+	+
Frog 55	4	S	L	+	+
Frog 56	4	S	L	+	+
Frog 57	4	S	L	+	+
Frog 58	2	S	S	+	+

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

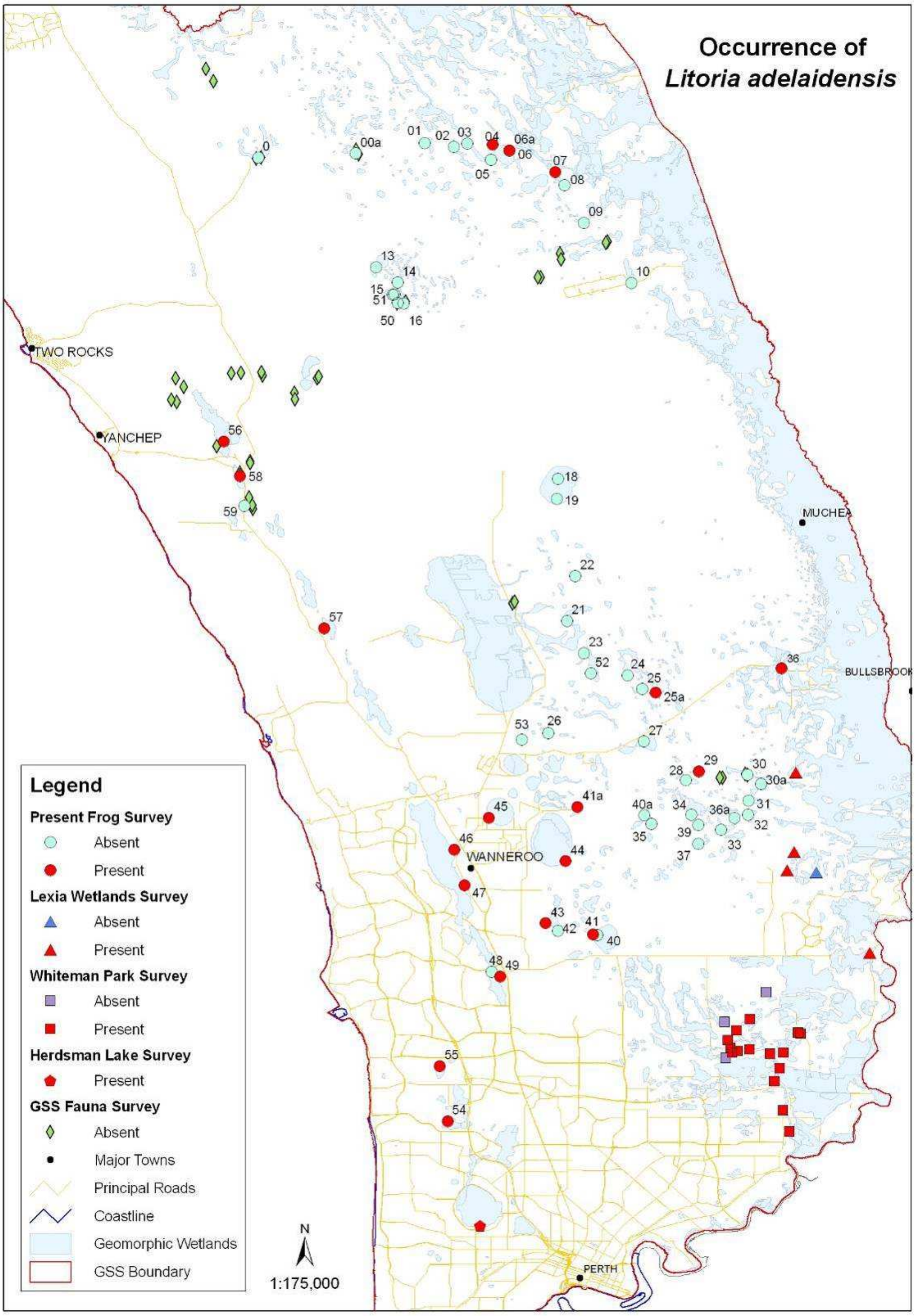

Figure 15. Occurrence of *L. adelaidensis* in the study area.

Pseudophryne guentheri

P. guentheri was recorded at only eight sites (Table 10) and thus had a more restricted distribution in the GSS area than most other frog species. It was found only at sites in the Bassendean landform system (but only at 15% of possible sites within that system), and was present along watercourses, in sumplands and at one palusplain site. At two of the eight sites where it was recorded there were no rushes or sedges, and at three of the sites there was no surface water. It was also found to have a restricted distribution at sites in Whiteman Park (Figure 16). Historical records (Appendix 10) reflect this distribution except for a single record in the west, not associated with a wetland.

Table 10. Attributes of sites where *P. guentheri* was recorded.

Site	**Species Richness**	**Landform Unit***	**Wetland type^**	**Presence of Sedges/Rushes**	**Presence of Surface Water in Winter**
Frog 01	2	B	S	-	-
Frog 02	2	B	S	-	-
Frog 03	7	B	W	+	+
Frog 04	5	B	W	+	+
Frog 05	4	B	W	+	+
Frog 06	7	B	S	+	+
Frog 09	1	B	S	+	-
Frog 21	3	B	P	+	-

* Landform units B= Bassendean, S= Spearwood;
^ Wetland type W= watercourse, S= sumpland, L= lake, P= paluslain

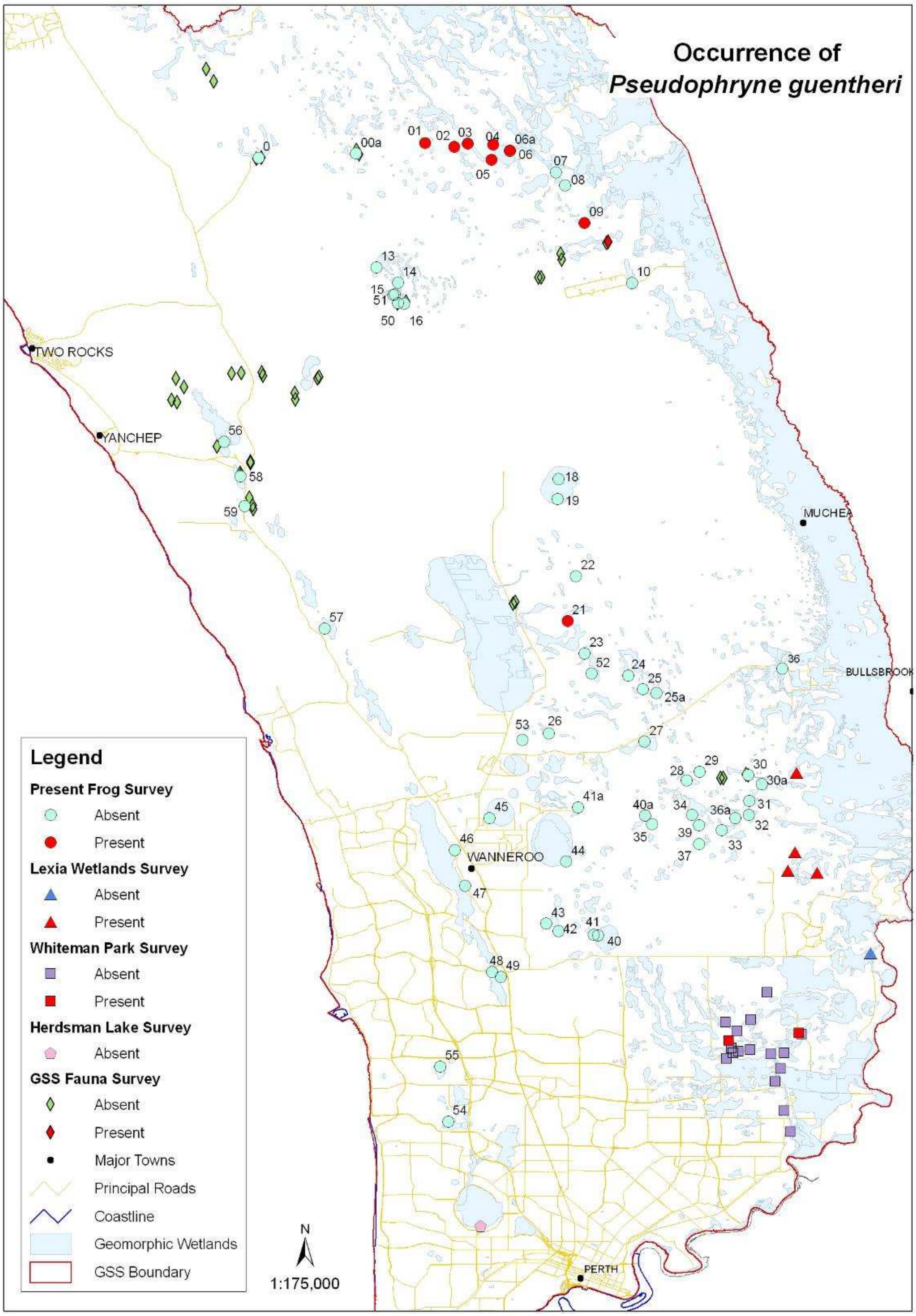

Figure 16. Occurrence of *P. guentheri* in the study area.

DISCUSSION

Distribution in the GSS area, biology and implications for hydrological management

This section brings together information from the literature review on the biology of each species and information gathered during the GSS field surveys. Importantly, it provides interpretation on the relationship between biology, field observations and potential sensitivity to hydrological change.

Crinia georgiana

Life-History Attributes

Breeding strategy

Reported to breed from July to October (Main 1965) and at Whiteman Park main calling period is June to September (See Figure 1). Males call and compete vigorously for females, often several males attempting to grasp one female. The males have massively enlarged fore-legs which may reflect this competition for mates. Eggs are scattered or loose in shallow water (not clumped or attached to vegetation). Calling usually from low riparian vegetation on water's edge. Species occurs only as far north as Gingin, so is at the northern limit of its range in the GSS area.

Larval period

According to Main (1965), development is rapid (35-45 days). Reflecting this, tadpoles can be found in temporary pools. Metamorphs are small (6mm).

Diet (larvae and adults)

No specific information.

Juvenile dispersal

No specific information. Large numbers of metamorphs can be found around the margins of wetlands in spring.

Age at maturity

Uncertain. May breed at end of year 1 but possibly not mature until end of year 2.

Longevity

Uncertain. A captive male, collected when adult (probably year 2+) lived for two years (therefore 4+).

Movement patterns of adults

Probably limited dispersal from wetlands.

Breeding environment

Shallow waters associated with near-permanent and permanent wetlands.

Non-breeding environment

Adults appear to stay close to wetlands throughout the year. At Whiteman Park, largely restricted to permanent wetlands (Bancroft and Bamford 2008). Wetlands usually have extensive low riparian vegetation for cover.

General distribution and status in GSS area

The distribution is confined to the South-West in high rainfall areas from Gingin in the north to as far east as Cape Le Grande, and inland to the western and southern Wheatbelt (Tyler *et al.* 2000). It appears to be widespread along watercourses of the Darling Scarp but to be very patchily distributed on the Swan Coastal Plain around Perth (pers. obs.) The GSS area is therefore in the extreme north of the species' range. Very fragmented distribution in the GSS area, recorded from some wetlands in the Lexia area, at Whiteman Park (Bennett Brook System), Lake Yakine (in the Swan Valley), Frog Survey Site 36 along Neaves Road (near The Maze), and at Frog Survey Sites 4, 5 and 6 that are associated with a large wetland and watercourse in the north of the area. Around Lexia, common at EPP 173 and Lake Yakine (more or less permanent wetlands) but occasional records at seasonal wetlands, possibly the result of adult dispersal (Bamford and Everard 2008). At Whiteman Park, more or less restricted to permanent wetlands that are part of the Bennett Brook drainage system, thus animals can retreat and expand their range along a connected system (Bancroft and Bamford 2008). Sites surveyed as part of the GSS project were also large, reliable, with long hydro-periods and part of interconnected systems.

Predicted sensitivity to hydrological change

Short larval stage would suggest ability to utilise temporary wetlands, but adults appear to be reliant on mesic conditions so this may be limiting. Suggests species may be limited by adult survival and reliance on mesic refugia rather than breeding biology. The GSS population is at the northern limit of the species' range and is therefore likely to suffer if the range of the species contracts.

Crinia glauerti

Life History Attributes

Breeding strategy

Reported to breed throughout the year excluding summer (Main 1965), but at Whiteman Park the calling period, 'though broad, peaks in late winter (See Figure 1). Eggs are scattered or loose in shallow water (not clumped or attached to vegetation) and tend to sink (Main 1965). Calling usually from low riparian vegetation on water's edge. Species occurs only as far north as Gingin, so is at the northern limit of its range in the GSS area.

Larval period

According to Main (1965), development is prolonged (>100 days). Metamorphs are large (8-9mm) considering the species rarely exceeds 20mm and is sexually mature at 12-13mm. Growth is concentrated in the larval stage.

Diet (larvae and adults)

No specific information. Extended larval stage with large size of metamorphs (compared with adult) suggests that access to food may be very important in the larval stage.

Juvenile dispersal

No specific information. Large numbers of metamorphs can be found around the margins of wetlands in spring.

Age at maturity

Given the large size at metamorphosis and the small size at sexual maturity (Main 1965), almost certainly able to breed when less than one year old. The small difference in metamorph size and size at sexual maturity suggests that under some circumstances, animals may breed opportunistically within the breeding season of their own development.

Longevity

Uncertain. Possibly only 2-3 years.

Movement patterns of adults

Probably limited dispersal from wetlands but presence at isolated wetlands in Whiteman Park suggests dispersal through terrestrial environments does occur (Bancroft and Bamford 2008). A very isolated seasonal wetland in Melaleuca Park appeared to be recolonised by the species (Bamford and Everard 2008).

Breeding environment

Shallow waters with emergent vegetation around permanent or seasonal wetlands. Favoured vegetation is low: sedges and grasses. This is the sort of vegetation that floods during late winter when peak calling occurs.

Non-breeding environment

Adults appear to stay close to wetlands throughout the year. At Whiteman Park (Bancroft and Bamford 2008) and Lexia (Bamford and Everard 2008), present around seasonal and permanent wetlands. Adults are presumably able to survive dry conditions by sheltering in mesic refugia at seasonal wetlands.

General distribution and status in GSS area

Confined to the South-West in high rainfall areas from the Moore River (but to Gingin according to Main 1965) in the north to as far east as the Albany area along the south coast, and inland to the edge of the western and southern Wheatbelt (Tyler *et al.* 2000). Abundant on the Darling Scarp and Swan Coastal Plain around Perth (pers. obs.) The GSS area is in the north of the species' range. Widespread in the GSS area where wetlands are reliable (either permanent or flood each winter). Notably abundant around urban wetlands where there are flooded exotic grasses.

Predicted sensitivity to hydrological change

Long larval stage may make the species vulnerable, but breeding reported to be somewhat opportunistic (Main 1965) and timing of breeding at Whiteman Park coincides with rising to peak water levels, so can take best advantage of a wetland's hydroperiod. Rapid maturity would give the species some robustness in response to variation in breeding success, but species may be short-lived, making it vulnerable to local extinction. Presumed adult dispersal would counter the effect of local extinctions. Adults can persist around seasonal wetlands. Main vulnerability may be reliance on flooded vegetation (sedges and grasses) for calling and breeding, as these may disappear and be replaced by woody riparian vegetation in some circumstances. The GSS population is at the northern limit of the species' range and is therefore likely to suffer if the range of the species contracts.

Crinia insignifera

Life History Attributes

Breeding strategy

A winter and spring breeder (Main 1965), with main calling period at Whiteman Park early winter, occurring before the main calling period of the very similar *C. glauerti* (See Figure 1). Eggs are described as "singly on bottom" of wetland (Main 1965). The location of calling animals can be quite variable: floating on the water's surface, from emergent vegetation in the water, from bare shoreline and from low riparian vegetation on water's edge.

Larval period

According to Main (1965), development is quite rapid (60 days). Metamorphs are large (8-9mm) and sexual maturity is reached at 21-22mm the following winter.
The more rapid larval stage (than *C. glauerti*) may account for the wider range of *C. insignifera*, with the species as far north as Badgingarra (M. Bamford records) and an isolated population on Rottnest Island (Main 1965).

Diet (larvae and adults)

No specific information. Adults presumably insectivorous.

Juvenile dispersal

No specific information. Large numbers of metamorphs can be found around the margins of wetlands in spring.

Age at maturity

Reported by Main (1965) to be sexually mature the winter following larval stage (ie when <1 year old).

Longevity

Uncertain. Although sexually mature at 21mm, females can attain 29mm and males 25mm, so this suggests an age of at least 3 years to achieve such a size. Main (1965) reports females (possibly longer-lived than males) living to 3-4 years. The persistence of the species in regions of quite low rainfall would be aided by such longevity to counteract the impact of failed breeding.

Movement patterns of adults

Probably limited dispersal from wetlands but presence at isolated wetlands in Whiteman Park suggests dispersal through terrestrial environments does occur (Bancroft and Bamford 2008). A very isolated seasonal wetland in Melaleuca Park appeared to be recolonised by the species (Bamford and Everard 2008).

Breeding environment

Shallow waters with emergent vegetation around permanent or seasonal wetlands. Favoured vegetation is very low: mown grass at one wetland in Whiteman Park (Bancroft and Bamford 2008). Also occurs around wetlands where there is emergent woody vegetation and little low vegetation on the shoreline.

Non-breeding environment

Adults appear to stay close to wetlands throughout the year. At Whiteman Park (Bancroft and Bamford 2008) and Lexia (Bamford and Everard 2008), present around seasonal and permanent wetlands. Adults are presumably able to survive dry conditions by sheltering in mesic refugia at seasonal wetlands.

General distribution and status in GSS area

A narrow distribution in the South-West, confined to the Coastal Plain from at least as far north as Wongonderrah Swamp (near Badgingarra, pers. obs), south to Busselton (Tyler *et al.* 2000). More widespread in the GSS area than the similar *C. glauerti*.

Predicted sensitivity to hydrological change

Probably very robust in the face of hydrological change. Has a short larval period, breeds early in the winter and has populations in much drier environments to the north, where breeding may fail completely some years and wetlands may be short-lived. Long larval stage may make the species vulnerable, but breeding reported to be somewhat opportunistic (Main 1965) and timing of breeding at Whiteman Park coincides with rising to peak water levels, so can take best advantage of a wetland's hydroperiod. Rapid maturity would give the species some robustness in response to variation in breeding success, but species may be short-lived, making it vulnerable to local extinction. Presumed adult dispersal would counter the effect of local extinctions. Adults can persist around seasonal wetlands. Main vulnerability may be reliance on flooded vegetation (sedges and grasses) for calling and breeding, as these may disappear and be replaced by woody riparian vegetation in some circumstances.
Wide range north of GSS area suggests this species able to cope with lower rainfall and shorter hydroperiod than the similar *C. glauerti*.

Heleioporus albopunctatus

Life History Attributes

Breeding strategy

Very similar to that of *H. eyrei* (see Section 4.1.5).

Larval period

Larval period is long, with metamorphosis taking place in spring.

Diet (larvae and adults)

Diet of larvae unknown. Adults presumably insectivorous and large enough to take small vertebrates.

Juvenile dispersal

Juvenile dispersal not known but probably like that of *H. eyrei*, with limited dispersal in spring and a period of wide dispersal the following autumn.

Age at maturity

Sexual maturity probably reached in the second year of life as with *H. eyrei.*

Longevity

Uncertain but may be similar to *H. eyrei*, with a minimum age of 5 years but a longevity possible of 10-20 years.

Movement patterns of adults

As with *H. eyrei*, adults may undergo true migration, moving towards breeding wetlands in the autumn and returning to the woodland immediately after breeding.

Breeding environment

Breeding burrows constructed on the margin of seasonal or permanent wetlands that experience a predictable early winter rise in water level. Soils around wetlands often clayey and *H. albopunctatus* breeds around watercourses as well as swamps and lakes (M. Bamford pers. obs).

Non-breeding environment

Immature and adult *H. albopunctatus* are entirely terrestrial and occur in upland woodland, with adults returning to the vicinity of wetlands (but rarely if ever entering water) only to breed. They are active throughout the summer, foraging at night and burrowing to avoid desiccation during the day.

General distribution and status in GSS area

Widespread in the South-West; generally encompassing the Wheatbelt but absent from higher rainfall zone (Main 1965). Not recorded in the GSS area during aural surveys, but some historical records from locations in the east. The call of *H. albopunctatus* is distinctive and carries well, so it is unlikely that the species was overlooked. Historical records may be of specimens that had dispersed from nearby, as the species is more abundant slightly north and east of the GSS area.

Predicted sensitivity to hydrological change

Probably very robust in the face of hydrological change. Early breeding allows the species to take full advantage of a wetland's hydroperiod, while longevity of individuals enables populations to persist despite successive years of failed breeding.

Heleioporus eyrei

Life History Attributes

Breeding strategy

Begins calling in late autumn and calling completed by early winter. Breeding is preceded by migration to breeding wetlands from surrounding woodland. Males call from a burrow and eggs (protected in foam) are laid in the burrow before water levels have risen in the wetland. Therefore, eggs and tadpoles initially in moist conditions in the burrow, but tadpoles able to move into the wetland as soon as water levels rise sufficiently for the burrow to be inundated. This strategy allows *H. eyrei* to breed very early, and ensures that its tadpoles get early access to the wetland. The eggs and young tadpoles are also protected from predators. Breeding is usually in seasonal wetlands and relies on a predictable seasonal rise in water level.

Larval period

Larval period is long, with metamorphosis taking place in September or more usually October and even into November; therefore 120+ days. Larvae in seasonal wetlands have been found to metamorphose at a larger size than larvae in a permanent wetland (Bamford and Everard 2008).

Diet (larvae and adults)

Blyth (1994) found that larvae of *H. eyrei* ate the tadpoles of other frog species in a trial designed to investigate the impact of predatory fish! Adults eat a very wide range of terrestrial invertebrates, including a high proportion of nocturnally-active ants (Bamford 1986).

Juvenile dispersal

Juveniles disperse around the margins of wetlands even with some tail not fully absorbed, but do not appear at woodland sites >1km from breeding wetlands until the following autumn (Bamford 1986). They may disperse slowly over summer, perhaps waiting for rare summer rains, or may remain close to wetlands until the following autumn.

Age at maturity

Sexual maturity appears to be reached in the second year of life, based on recaptures of marked animals and the size of animals found around wetlands during the breeding season (Bamford 1986).

Longevity

Uncertain. Bamford (1986) recorded animals with a minimum age of 5 years (based on recaptures and size at first capture) while J. Dell (pers comm.) has suggested the species may live for one or two decades (based on the persistence of the species on Rottnest Island where successful breeding occurs infrequently and therefore animals must be long-lived for the species to persist). Bamford and Everard (2008) found the size distribution of adults at a wetland where breeding is successful only once every 3-4 years was skewed towards large (old) animals. The persistence of the species in regions of quite low rainfall would be aided by such longevity to counteract the impact of failed breeding.

Movement patterns of adults

Adults appear to undergo true migration, moving towards breeding wetlands in the autumn and returning to the woodland immediately after breeding. Marked adults recorded at the same location in woodland, about 3km from the nearest breeding wetland, in successive years (Bamford 1986).

Breeding environment

Breeding burrows constructed on the margin of seasonal or permanent wetlands that experience a predictable early winter rise in water level. Wetlands can be small and isolated and may not flood every year. Watercourses (ie with flowing water) rarely support the species. Vegetation seems unimportant but burrows rarely constructed in very dense exotic grasses (pers. obs.).

Non-breeding environment

Immature and adult *H. eyrei* are entirely terrestrial and occur in upland woodland, with adults returning to the vicinity of wetlands (but rarely if ever entering water) only to breed. They are active throughout the summer, foraging at night and burrowing to avoid desiccation during the day.

General distribution and status in GSS area

Widespread in the South-West; north to the Geraldton area, east to Cape Arid and occurring well into the western and southern Wheatbelt (Tyler *et al.* 2000). The most widespread of recorded species in the GSS area, found calling at a very wide range of sites including many where breeding almost certainly did not occur in 2008 due to the absence of water, and may not have occurred for many years. It is not known if such populations are relictual or the result of dispersal from wetlands where breeding does occur.

Predicted sensitivity to hydrological change

Probably very robust in the face of hydrological change. Early breeding allows the species to take full advantage of a wetland's hydroperiod, while longevity of individuals enables populations to persist despite successive years of failed breeding. This longevity may also mask the impact of hydrological change, as populations may persist in areas where they can no longer breed.

Heleioporus barycragus

Life History Attributes

Breeding strategy

Very similar to that of *H. eyrei*.

Larval period

Larval period is long, with metamorphosis taking place in spring.

Diet (larvae and adults)

Diet of larvae unknown. Adults presumably insectivorous.

Juvenile dispersal

Juvenile dispersal not known but probably like that of *H. eyrei*, with limited dispersal in spring and a period of wide dispersal the following autumn.

Age at maturity

Sexual maturity probably reached in the second year of life as with *H. eyrei*.

Longevity

Uncertain but may be similar to *H. eyrei*, with a minimum age of 5 years but a longevity possibly of 10-20 years.

Movement patterns of adults

As with *H.* eyrei, adults may undergo true migration, moving towards breeding wetlands in the autumn and returning to the woodland immediately after breeding.

Breeding environment

Breeding burrows constructed on the banks of watercourses with strong seasonal flow, on clay or granite (Main 1965). These are generally forest streams in the Darling Scarp.

Non-breeding environment

Immature and adult *H. barycragus* are entirely terrestrial and occur in upland woodland, with adults returning to the vicinity of wetlands (but rarely if ever entering water) only to breed. They are active throughout the summer, foraging at night and burrowing to avoid desiccation during the day.

General distribution and status in GSS area

H. barycragus has a restricted distribution in the South-West, occurring along the Darling Scarp from Bullsbrook to Darkin and inland to Dryandra (Tyler *et al.* 2000). The GSS area is outside the main range of teh species but there are some historical records Appendix 10, probably due to animals that have dispersed from the adjacent scarp.

Predicted sensitivity to hydrological change

Probably very robust in the face of hydrological change but the reliance of forest streams may make the species sensitive to declining rainfall.

Heleioporus psammophilus

Life History Attributes

Breeding strategy

Very similar to that of *H. eyrei*.

Larval period

Larval period is long, with metamorphosis taking place in spring.

Diet (larvae and adults)

Diet of larvae unknown. Adults presumably insectivorous.

Juvenile dispersal

Juvenile dispersal not known but probably like that of *H. eyrei,* with limited dispersal in spring and a period of wide dispersal the following autumn.

Age at maturity

Sexual maturity probably reached in the second year of life as with *H. eyrei.*

Longevity

Uncertain but may be similar to *H. eyrei*, with a minimum age of 5 years but a longevity possibly of 10-20 years.

Movement patterns of adults

As with *H.* eyrei, adults may undergo true migration, moving towards breeding wetlands in the autumn and returning to the woodland immediately after breeding.

Breeding environment

Breeding burrows constructed on the margin of seasonal or permanent wetlands that experience a predictable early winter rise in water level. In a long-term study area between Cataby and Badgingarra, *H. psammophilus* is the common *Heleioporus* species where clayey soils are present in broad, ancient river valleys, while *H. eyrei* is the common species where the soils are sandy (M. Bamford pers. obs). In Jarrah and Wandoo country of the Darling Scarp, the two species appear to have similar soils associations (M. Bamford pers. obs).

Non-breeding environment

Immature and adult *H. psammophilus* are entirely terrestrial and occur in upland woodland, with adults returning to the vicinity of wetlands (but rarely if ever entering water) only to breed. They are active throughout the summer, foraging at night and burrowing to avoid desiccation during the day.

General distribution and status in GSS area

H. psammophilus has a rather restricted distribution in the South-West, with a west coast population from the Irwin River to near Busselton and inland to the western Wheatbelt, and a south coast population from Windy Harbour to Jerramungup (Tyler *et al.* 2000). Within these areas it appears to occur very patchily. Not recorded in the GSS area during aural surveys, but some historical records from locations in the east. The call of *H. psammophilus* is distinctive and carries well, so it is unlikely that the species was overlooked. Historical records may be of specimens that had dispersed from nearby, as the species is more abundant slightly north and east of the GSS area.

Predicted sensitivity to hydrological change

Probably very robust in the face of hydrological change. Early breeding allows the species to take full advantage of a wetland's hydroperiod, while longevity of individuals enables populations to persist despite successive years of failed breeding.

Limnodynastes dorsalis

Life History Attributes

Breeding strategy

A winter and spring breeder (Main 1965), with peak calling in early to mid winter (see Figure 1). Males call from flooded vegetation while almost under water and the eggs are laid in flooded vegetation in a mass of foam. Breeds in permanent water according to Tyler *et al.* (2000) and has colonised farm dams in the Wheatbelt (Main 1965), but known to utilise seasonal wetlands (M. Bamford pers. obs).

Larval period

Larval period is the longest of any frog in the South-West; up to 160 days (Main 1965). As a result, some metamorphs emerge as late as April, meaning the species relies on more or less permanent wetlands in some cases.

Diet (larvae and adults)

No information on diet of tadpoles. Bamford (1986) found adults ate a wide range of largely terrestrial invertebrates, including large numbers of nocturnal ants, and occasionally small vertebrates, including small specimens of the same species.

Juvenile dispersal

After metamorphosis juveniles disperse immediately from wetlands, appearing in woodland several kilometres from breeding sites in late spring (Bamford 1986). This is in contrast to *H. eyrei* in which juveniles do not reach woodland sites until autumn. Juveniles appear to disperse widely.

Age at maturity

Sexual maturity appears to be reached in the third year of life, based on recaptures of marked animals and the size of animals found around wetlands during the breeding season (Bamford 1986).

Longevity

Uncertain. Bamford (1986) recorded animals with a minimum age of 3 years (based on recaptures and size at first capture) which had only just reached estimated size at sexual maturity. Adults likely to live for several breeding seasons so lifespan likely to be greater than 5 years and possibly much more than this. The species is very widespread and occurs in low rainfall areas where breeding is likely to be episodic.

Movement patterns of adults

Bamford (1986) found that all specimens caught in woodland several kilometres from wetlands were juveniles or recently-matured adults, and no adults were recaptured. This suggests a pattern of movement in which juveniles disperse widely from wetlands following metamorphosis, but that with the onset of maturity, animals move back to wetlands and remain in the vicinity of the wetland thereafter. Individual adults can appear in very small wetlands, indicating that dispersal allows the species to colonise and recolonise sites.

Breeding environment

Commonly associated with permanent wetlands, either swamps/lakes or streams (Main 1965; Tyler *et al.* 2000), but also use seasonal wetlands (M. Bamford pers. obs.). Dense emergent vegetation such as rushes and even flooded grass very important for males to call from and for egg-laying sites.

Non-breeding environment

Immature *L. dorsalis* are entirely terrestrial and occur in upland woodland. It appears that adults remain in the vicinity of wetlands and do enter water to breed. They are active throughout the summer, foraging at night and burrowing to avoid desiccation during the day.

General distribution and status in GSS area

Widespread in the South-West; occurring north of Geraldton, east of Esperance and across much of the Wheatbelt (Tyler *et al.* 2000). Distribution limited in the GSS area and biased towards wetlands in the Spearwood system, with records only from some (but not all) permanent or near permanent wetlands. Presence associated with suitable emergent vegetation (rushes and sedges).

Predicted sensitivity to hydrological change

The long larval period and reliance upon emergent vegetation for calling and egg-laying limit the sorts of wetlands the species can utilise, these mostly being large and permanent or near-permanent. As a result, while the species might be expected to be sensitive to hydrological change, it occurs on wetlands that would have to experience extreme declines in water levels before they became unsuitable for it. Strong powers of dispersal and tolerance of desiccation would allow the species to persist during temporary poor conditions, and to recolonise sites.

Litoria adelaidensis

Life History Attributes

Breeding strategy

Primarily a spring breeder according to (Main 1965), but peak calling in mid-winter in Whiteman Park (Bancroft and Bamford 2008, see Figure 1). Males call from amongst flooded vegetation, often when perched in rushes or on branches of trees. Eggs are laid in the water in a mass attached to vegetation.

Larval period

Larval period is not documented, but metamorphs emerge in late spring to early summer as seasonal wetlands are drying out. The larvae are unusual in often hovering in mid-water rather than staying on the substrate of the wetland as do most tadpoles of local frog species.

Diet (larvae and adults)

No information on diet of tadpoles. Adults presumably insectivorous.

Juvenile dispersal

After metamorphosis juveniles do not appear to disperse but have been observed in large numbers amongst the emergent rushes of wetlands in early summer (M. Bamford pers. obs.). Adults and juveniles often seen on roads around wetlands following summer rain (M. Bamford pers. obs.), suggesting some localised movement does occur.

Age at maturity

Sexual maturity may be reached in the first year of life (based on regular observations of the species at an artificial wetland at Chandala, on the eastern edge of the GSS project area, where no discernable intermediate size is evident in the population (Bamford pers. obs.)).

Longevity

Uncertain. Possibly short-lived. In monthly observations of the species at Chandala, it was noted that large (therefore old?) frogs were very uncommon in the population, suggesting rapid population turnover (M. Bamford pers. obs.).

Movement patterns of adults

Possibly dispersal after summer rain. May also be individual movements resulting in dispersal and contraction of local distribution during spring, as at Chandala the species was found at poor sites (with little suitable vegetation) during spring only (M. Bamford pers. obs.). Occasional animals caught over a kilometre from the nearest wetland in winter by Bamford (1986). Animals are prone to dessication, being very elongate and having little glandular development of the skin to reduce water loss.

Breeding environment

Associated with emergent wetland vegetation, particularly rushes such as *Baumea* and *Typha*, but will also use fringing and emergent trees such as the paperbarks *Melaleuca* spp.

Found in a wide range of wetlands with suitable vegetation, including streams, lakes and swamps. Occurs in permanent or seasonal wetlands.

Non-breeding environment

Same as for breeding environment.

General distribution and status in GSS area

Widespread in the South-West; occurring naturally from at least Wongonderrah Swamp, near Badgingarra (M. Bamford pers. obs.), south and east to Esperance. Introduced in some towns including Geraldton, probably as a result of animals being moved around with plant nursery stock. Distribution limited in the GSS area, with records only from wetlands with a long hydro-period and suitable emergent rushes.

Predicted sensitivity to hydrological change

Likely to be sensitive to hydrological change because of the reliance upon emergent vegetation for calling and as general habitat, and the late breeding season requiring water in the wetland until at least early summer. The apparent short life-span, limited powers of dispersal and sensitivity to desiccation would make localised population extinction likely in the event of failed breeding over several years.

Litoria moorei

Life History Attributes

Breeding strategy

Breeds from spring to early summer, with eggs laid in the water in a mass attached to vegetation (Main 1965).

Larval period

Larval period is not documented, but metamorphs emerge from early summer to as late as April.

Diet (larvae and adults)

No information on diet of tadpoles. Adults presumably insectivorous and very probably also eat smaller frogs.

Juvenile dispersal

Metamorphs often found in large numbers around wetlands in summer and will disperse *en masse* following summer rain (M. Bamford pers. obs.). Dispersal distances at least several hundred metres.

Age at maturity

Sexual maturity probably reached in second year of life.

Longevity

Uncertain. In captivity, individuals can exceed five years (M. Bamford pers. obs).

Movement patterns of adults

Possibly dispersal after summer rain. In urban gardens, the same animal will often be found in the same location for at least several months, suggesting that adults may be sedentary (M. Bamford pers. obs). Although not able to burrow, adults are fairly stocky and have moderately glandular skin, making them less moisture-dependent than the similar *L. adelaidensis.*

Breeding environment

Associated with permanent wetlands according to Tyler *et al.* (2000), but also found in seasonal wetlands (M. Bamford pers. obs) where the animals must survive dry periods by sheltering in crevices under bark or under logs. Wetlands where the species occurs usually have abundant cover in the form of logs or rocks around the wetland margin. Often also with abundant emergent and fringing vegetation. The only local frog species that readily colonises and breeds in garden ponds. Found in a wide range of wetlands with suitable vegetation, including streams, lakes and swamps.

Non-breeding environment

Same as for breeding environment.

General distribution and status in GSS are

Very widespread in the South-West; occurring naturally from the Murchison River, into the western Wheatbelt and along the south coast east to Esperance, with the south coast population roughly east of Albany sometimes being classed as a different species (*L. cyclorhyncha*). Introduced to some inland towns, including Kalgoorlie. Very abundant in urban wetlands and suburbs in the GSS area, but restricted distribution outside urban areas, probably because of the reliance on wetlands that retain water at least well into summer. Records collected during the GSS survey were limited as the species calls mainly outside the survey period, but historical records Appendix 10 illustrate the extensive distribution in urban area.

Predicted sensitivity to hydrological change

Likely to be sensitive to hydrological change because breeding occurs in spring and summer and thus wetlands that retain water into summer are needed. However, species should have some ability to persist through several years of low water levels because adults are fairly long-lived and able to cope with dry conditions.

Myobatrachus gouldii

Life History Attributes

Breeding strategy

The only frog species in the area that does not have an aquatic larvae, with the tadpole developing entirely within the egg buried at about 1m in the soil, resulting in a small frog hatching in the autumn (Roberts 1981). Males call in late spring/early summer during and shortly after rain.

Larval period

No free-living larva, but metamorphs emerge in autumn.

Diet (larvae and adults)

Larval development entirely within the egg. Adults are not a dietary specialist as commonly reported (eg. Main 1965), with that assertion based upon the examination of two specimens collected from a termite mound; not surprising, these specimens contained termites in their guts (Calaby 1956). Bamford (1986) and Murray (1980) found a wide range of invertebrate taxa in the guts of *M. gouldii*, with most (if not all) likely to have been encountered as the frog foraged underground.

Juvenile dispersal

It is not known if any metamorph dispersal occurs; possibly not as dispersal is not concentrated in wetlands as occurs with other frogs in the region. Juveniles would therefore have no need of dispersal.

Age at maturity

Sexual maturity probably reached in second year of life.

Longevity

Uncertain. Occasional very large animals are found, suggesting a lifespan potentially in the order of 5-10 years.

Movement patterns of adults

Not known. Adults do not need to move towards wetlands to breed, so animals may be sedentary.

Breeding environment

Occurs in woodland and heath, generally with sandy soil. Extensive pitfall trapping suggests that there is no association with termite mounds as alleged by Tyler *et al.* (2000), but that the species may be more common on low sandy rises rather than in dune swales (M Bamford unpubl. data).

Non-breeding environment

Same as for breeding environment.

General distribution and status in GSS are

Very widespread in the South-West including in suitable sandy soils across the Wheatbelt. Absent from forested areas with heavy soils. Persists in urban landscapes within the GSS area where banksia woodland has been retained in reserves. Probably occurs throughout the GSS area where banksia woodlands have been retained, but no aural records as these surveys did not take place at the right time of the year for the species.

Predicted sensitivity to hydrological change

Likely to be very tolerant of hydrological change as the species is independent of surface water. Soil moisture may be important but the species occurs well to the north of the GSS area in much more arid woodlands.

Neobatrachus pelobatoides

Life History Attributes

Breeding strategy

Breeds in autumn and early winter (Main 1965); therefore similar in timing to *H. eyrei*. However, eggs are laid in shallow water rather than in a burrow. Males often call from breeding aggregations.

Larval period

Larval period is not documented, but metamorphs emerge as early as September.

Diet (larvae and adults)

No information on diet of tadpoles. Adults presumably insectivorous.

Juvenile dispersal

No information.

Age at maturity

Sexual maturity probably reached in second year of life.

Longevity

Uncertain but probably 5-10 years.

Movement patterns of adults

Little information, but adults recorded widely in banksia woodland away from wetlands for much of the year (between Cataby and Badgingarra, M. Bamford unpubl. data). This suggests movements to and from wetlands associated with breeding.

Breeding environment

Noted by Main (1965) to breed in temporary waters on clay. Between Cataby and Badgingarra, breeding recorded in clay-based wetlands that support a wet heath of

Melaleuca spp. (M. Bamford pers. obs). Such wetlands are rain-filled rather than exposed groundwater.

Non-breeding environment

Woodland in general vicinity of breeding sites. Soil not critical.

General distribution and status in GSS are

Very widespread across the Wheatbelt and adjacent pastoral zone, but absent from the lower South-West. In the GSS area, some old records from the east, where there are clay-based, seasonal wetlands, but the species was not recorded during aural surveys despite these taking place when the species should be calling. However it is reported that the call can only be heard over a short distance (Main 1965), so the species may still be present.

Predicted sensitivity to hydrological change

Likely to be tolerant of hydrological change as the adults are terrestrial and the species breeds in wetlands that are not groundwater dependent. It also occurs widely in lower rainfall zones. The potential may exist for this species top expands its range in the GSS area with declining rainfall.

Pseudophryne guentheri

Life History Attributes

Breeding strategy

Reported to bred following rain from late summer to early winter (Main 1965; Tyler *et al.* 2000), but at Whiteman Park within the GSS area, calling concentrated in May and June (Bancroft and Bamford 2008). *P. guentheri* therefore has the shortest calling period of any frog found in the area. The eggs are laid in damp soil in a tunnel, in a location that will be flooded as water levels rise in the wetland. Initial development of the larvae takes place within the egg, so that tadpoles are well-developed when they emerge

Larval period

The larval period is among the shortest of frogs found in the GSS area at as little as 42 days (Main 1965), although this excludes initial development that takes place inside the egg capsule.

Diet (larvae and adults)

No information on diet of tadpoles. Adults presumably insectivorous.

Juvenile dispersal

No information but large numbers of metamorphs can be found around breeding wetlands in late winter and early spring.

Age at maturity

Unknown. As with some other small frog species, may be mature in one year.

Longevity

Unknown.

Movement patterns of adults

Little information, but adults generally recorded only within a few hundred metres of seasonal wetlands between Cataby and Badgingarra (M. Bamford unpubl. data). This suggests limited dispersal.

Breeding environment

Margins of wetlands, particularly where very shallow water floods during winter. This can either be a seasonal wetland or associated with permanent wetlands that extend during winter. Adults often associated with logs or piles of earth. Not associated with any particular vegetation type (M. Bamford pers. obs.).

Non-breeding environment

Adults appear to remain fairly close to wetland margins throughout the year, but do move into adjacent woodland where they shelter under logs, dense leaf-litter and other mesic refugia.

General distribution and status in GSS are

Very widespread across the South-West with probably the greatest distribution of all species recorded in the GSS area. In the GSS area, all records are on sites in the east.

Predicted sensitivity to hydrological change

The biology of the species and its wide distribution suggest a high tolerance of hydrological change. Despite this, it has a restricted distribution in the GSS area, while Bancroft and Bamford (2008) suggested that it had declined due to changes in groundwater levels more than other species in Whiteman Park. This considered to be because it breeds very early in the rainy time of year and lays its eggs in areas of very shallow slope on the margins of wetlands. Therefore, it is vulnerable to failure of follow-up rains in early winter.

Frog distribution, biology and implications for hydrological management

There was considerable variation in the biology and patterns of distribution of the frogs recorded across the GSS area. *C. georgiana* and *P. guentheri* were the most restricted in distribution and both were confined to the Bassendean system, but the former occurred only along watercourses that were often permanent or at least contained water for long periods, whereas the latter occurred widely on sumplands, including sites with no surface water or sedges and rushes. The two froglets, *C. glauerti* and *C. insignifera*, were both widespread but the latter was found at slightly more sites, including sites without water and without sedges and rushes. In contrast, *C. glauerti* was recorded only at sites with surface water in winter and with sedges and rushes.

L. dorsalis and *L. adelaidensis* both showed a preference for wetlands in the Spearwood system, typically in wetlands with permanent or near-permanent water and abundant sedges and rushes. *L. moorei* is probably similar but was inadequately sampled.

M. gouldii was not recorded in the aural surveys but is known from the area historically and from trapping carried out for the GSS project. The remaining frog species known historically from the area, *H. albopunctatus*, *H. barycragus*, *H. psammophilus* and *N.*

pelobatoides, were not recorded in aural or trapping surveys. All are known historically only from sites in the east of the GSS area (see Appendix 10). Such records may have taken decades to accumulate and may represent occasional dispersing individuals from populations several kilometres to the east, as most of these species are more closely associated with the heavy soils of the Darling Scarp than the sands of the coastal plain.

The pattern of distribution of frogs across the GSS area reflects to a great extent their biology; the biology of the species interacts with the existing environment, particularly with respect to hydrology, and has implications for impacts of any changes in hydrology. For example, *L. adelaidensis* relies on emergent rushes and sedges for habitat, depends upon mesic refugia (favouring permanent wetlands) and breeds in spring when wetlands start to dry out. It is therefore confined to wetlands that are permanent or have a long hydro-period, and that provide it with suitable habitat. In contrast, *H. eyrei* is highly terrestrial, breeds as early as possible in the hydro-period of wetlands, and is long-lived so that populations can persist despite successive failed breeding seasons. The characteristics of each species that affects its sensitivity to hydrological change in the GSS area are described in Section 4.1 above, and are summarised below.

Crinia georgiana

Key characteristics:

Closely associated with watercourses, limited ability to resist desiccation, probably short-lived as an adult, at northern limit of distribution, breeding does not begin until well into winter but larval life is short with very small metamorph (therefore can take advantage of temporary pools but metamorph may be vulnerable to desiccation).

Impact of hydrological change:

Likely to remain confined to watercourses and similar wetlands in the GSS area. By being restricted to the most reliable wetland types, *C. georgiana* is likely to persist on such wetlands unless catastrophic hydrological declines occur.

Crinia glauerti

Key characteristics:

Associated with wetlands with a long hydroperiod and with emergent rushes/sedges. Probably short-lived as an adult, at northern limit of distribution, breeding does not begin until well into winter and larval life is long.

Impact of hydrological change:

Vulnerable to reduced hydroperiod and changes in riparian vegetation. Contraction of range likely with hydrological declines, and has probably already occurred, with the species absent from many wetlands. Further declines to be expected. Species likely to persist in larger wetlands that are near-permanent.

Crinia insignifera

Key characteristics

A widespread species associated with a broad range of wetland types. Evidence of persistence or colonisation at wetlands that did not support breeding in recent years. Probably short-lived as an adult, widespread north of the GSS area and breeds in early winter with a short larval life.

Impact of hydrological change

More tolerant of hydrological declines than the similar *C. glauerti*. Some declines have probably already occurred, but the ability of the species to persist for at least a few years may make it valuable as an indicator. Contraction of range likely with hydrological declines but species likely to persist in wetlands that contain water at least in most years.

Heleioporus albopunctatus

Unlikely to be resident in GSS area. Possibility species may colonise area due to hydrological decline, although soils generally unsuitable.

Heleioporus barycragus

Unlikely to be resident in GSS area and habitat not suitable. Range of species is largely to south of GSS area so more likely to disappear from general region.

Heleioporus eyrei

Key characteristics:

A very widespread species associated with a broad range of wetland types. Long-lived adults able to persist at wetlands even with infrequent breeding success. Timing of breeding enables species to make full use of a wetland's hydroperiod.

Impact of hydrological change:

Likely to persist for some years after hydrological declines make a wetland unsuitable for breeding, so impact not likely to be manifested for several years. This persistence may make the species unsuitable as an indicator of hydrological change.

Heleioporus psammophilus

Unlikely to be resident in GSS area.

Limnodynastes dorsalis

Key characteristics:

A widespread species associated with wetlands that support emergent riparian vegetation. Adults probably long-lived and able to tolerate dry conditions, but breeding biology and long larval-life make the species reliant on permanent or near-permanent wetlands.

Impact of hydrological change:

Likely to persist for some years after hydrological declines make a wetland unsuitable for breeding, particularly as juveniles are entirely terrestrial and take several years to reach maturity. In the GSS area, the species is already mostly confined to large, near-permanent or permanent wetlands. Therefore, the species may be tolerant of all but the greatest of hydrological declines.

Litoria adelaidensis

Key characteristics:

A widespread species associated with permanent or near-permanent wetlands that support emergent riparian vegetation. Adults have limited ability to tolerate dry conditions, while timing of breeding and long larval life further limit the sorts of wetlands where the species can survive.

Impact of hydrological change:

L. adelaidensis may already have disappeared from some wetlands. Many of the wetlands where it remains are large and therefore massive hydrological declines will be required before impacts on the species become apparent.

Litoria moorei

Key characteristics:

A moderately widespread species of permanent and near-permanent wetlands. Limited in distribution to such wetlands by late spring breeding and long larval life.

Impact of hydrological change:

Already appears to have disappeared from some wetlands in the GSS area. Many of the wetlands where it remains are large and therefore massive hydrological declines will be required before impacts on the species become apparent.

Myobatrachus gouldii

Key characteristics:

Probably very widespread and wholly terrestrial. Widespread to the north of the GSS area.

Impact of hydrological change:

Probably independent of hydrology, although may be reliant on soil moisture, but its survival in much drier areas suggests that declines in rainfall in the GSS area will have little if any impact upon it.

Neobatrachus pelobatoides

Key characteristics:

Occurs mainly to the north and breeds in wetlands of a type that are found only in the east of the GSS area. Well-adapted to low rainfall environments and wetlands with a short hydroperiod that may be independent of groundwater.

Impact of hydrological change:

Declines in rainfall could actually lead to this species spreading south into the GSS area.

Pseudophryne guentheri

Key characteristics:

The breeding biology of *P. guentheri* takes advantage of early winter rains and the adults are tolerant of dry conditions, but the species has a restricted distribution in the GSS area.

Impact of hydrological change:

P. guentheri is confined to shallow wetlands and appears to be absent from apparently suitable sites, possibly because its breeding biology makes it vulnerable to the failure of early winter rains. It may therefore be particularly sensitive to hydrological declines.

Summary

Of the 13 frog species recorded in the GSS area, *M. gouldii* is probably independent of any hydrological declines, while *H. albopunctatus*, *H. barycragus* and *H. psammophilus* are unlikely to occur regularly in the region. *N. pelobatoides* is not currently present at detectable levels but hydrological declines could lead to it expanding into the area, at least where there are suitable clay soils in the east. The remaining species are likely to be impacted adversely in some way.

Those species reliant on permanent or near-permanent wetlands (*C. georgiana*, *L. adelaidensis*, *L. dorsalis* and *L. moorei*) may already have suffered some local contractions in range, but the sorts of wetlands on which they depend will be robust except in the case of catastrophic hydrological change. For example, large lakes may contract in size, but there would have to be a massive fall in groundwater and rainfall for such lakes to fail to continue to support their present suite of frogs.

Those species that rely on seasonal wetlands (*C. glauerti*, *C. insignifera*, *H. eyrei* and *P. guentheri*) are most likely to react to slight or moderate hydrological changes. In the face of declining rainfall and groundwater levels, *H. eyrei* will probably persist for many years, which could mask effects on other components of the biota. *C. insignifera* and particularly *C. glauerti* would be more sensitive to change and their presence could indicate wetland systems that have not yet been adversely affected to a great degree. They could also be expected to disappear within a few years due to hydrological declines and the reliance of their populations on annual or near-annual recruitment. *P. guentheri* may already have declined across much of the GSS area and appears to be especially sensitive to hydrological declines. This makes it a species worthy of focus in monitoring studies.

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APPENDICES

Appendix 1. Survey site locations (GDA 94) and autumn/winter survey dates

Site Code	Autumn Survey Date	Winter Survey Date	Latitude	Longitude
Frog 0	13/05/2008	19/08/2008	31° 24' 5.91" S	115° 41' 49.50" E
Frog 0a	13/05/2008	19/08/2008	31° 23' 58.86" S	115° 44' 42.18" E
Frog 01	13/05/2008	19/08/2008	31° 23' 40.68" S	115° 46' 44.26" E
Frog 02	13/05/2008	19/08/2008	31° 23' 47.12" S	115° 47' 36.20" E
Frog 03	13/05/2008	19/08/2008	31° 23' 41.27" S	115° 48' 0.32" E
Frog 04	13/05/2008	19/08/2008	31° 23' 43.19" S	115° 48' 45.84" E
Frog 05	13/05/2008	19/08/2008	31° 24' 10.34" S	115° 48' 42.17" E
Frog 06	13/05/2008	19/08/2008	31° 23' 53.88" S	115° 49' 14.90" E
Frog 06a	-	19/08/2008	31° 23' 53.88" S	115° 49' 14.90" E
Frog 07	13/05/2008	19/08/2008	31° 24' 32.04" S	115° 50' 36.98" E
Frog 08	13/05/2008	19/08/2008	31° 24' 55.67" S	115° 50' 53.01" E
Frog 09	13/05/2008	19/08/2008	31° 26' 2.07" S	115° 51' 27.84" E
Frog 10	-	19/08/2008	31° 27' 48.50" S	115° 52' 51.88" E
Frog 13	14/05/2008	20/08/2008	31° 27' 20.80" S	115° 45' 17.87" E
Frog 14	14/05/2008	20/08/2008	31° 27' 48.24" S	115° 45' 56.16" E
Frog 15	-	20/08/2008	31° 28' 10.19" S	115° 45' 47.94" E
Frog 16	14/05/2008	20/08/2008	31° 28' 25.58" S	115° 46' 7.60" E
Frog 18	14/05/2008	20/08/2008	31° 33' 37.59" S	115° 50' 41.57" E
Frog 19	14/05/2008	20/08/2008	31° 34' 12.62" S	115° 50' 40.15" E
Frog 21	14/05/2008, 16/06/2008	20/08/2008	31° 37' 49.63" S	115° 50' 57.47" E
Frog 22	14/05/2008, 16/06/2008	20/08/2008	31° 36' 30.16" S	115° 51' 12.53" E
Frog 23	14/05/2008, 16/06/2008	20/08/2008	31° 38' 47.19" S	115° 51' 27.74" E
Frog 24	14/05/2008, 16/06/2008	27/08/2008	31° 39' 26.20" S	115° 52' 45.82" E
Frog 25	14/05/2008, 16/06/2008	27/08/2008	31° 39' 50.89" S	115° 53' 11.61" E
Frog 25a	-	27/08/2008	31° 39' 57.42" S	115° 53' 35.50" E
Frog 26	14/05/2008, 16/06/2008	27/08/2008	31° 41' 9.55" S	115° 50' 23.98" E
Frog 27	20/05/2008, 16/06/2008	27/08/2008	31° 41' 23.96" S	115° 53' 14.30" E
Frog 28	20/05/2008	27/08/2008	31° 42' 32.77" S	115° 54' 29.12" E
Frog 29	20/05/2008	27/08/2008	31° 42' 17.03" S	115° 54' 52.44" E
Frog 30	20/05/2008	27/08/2008	31° 42' 23.63" S	115° 56' 18.71" E
Frog 30a	-	27/08/2008	31° 42' 39.23" S	115° 56' 42.75" E

Frog 31	20/05/2008	27/08/2008	31° 43' 9.57" S	115° 56' 20.51" E
Frog 32	20/05/2008	27/08/2008	31° 43' 34.44" S	115° 56' 19.20" E
Frog 33	20/05/2008	3/09/2008	31° 44' 1.45" S	115° 55' 31.81" E
Frog 34	20/05/2008	3/09/2008	31° 43' 34.50" S	115° 54' 38.62" E
Frog 35	20/05/2008	3/09/2008	31° 43' 50.28" S	115° 53' 27.18" E
Frog 36	13/05/2008	19/08/2008	31° 39' 14.40" S	115° 57' 19.08" E
Frog 36a	20/05/2008	3/09/2008	31° 43' 40.32" S	115° 55' 55.65" E
Frog 37	20/05/2008	3/09/2008	31° 44' 25.98" S	115° 54' 50.97" E
Frog 39	20/05/2008	3/09/2008	31° 43' 52.92" S	115° 54' 51.32" E
Frog 40	20/05/2008	4/09/2008	31° 47' 8.04" S	115° 51' 51.78" E
Frog 40a	20/05/2008	3/09/2008	31° 43' 35.56" S	115° 53' 14.82" E
Frog 41	20/05/2008	4/09/2008	31° 47' 7.03" S	115° 51' 44.46" E
Frog 41a	20/05/2008	3/09/2008	31° 43' 20.35" S	115° 51' 16.23" E
Frog 42	20/05/2008	4/09/2008	31° 47' 0.94" S	115° 50' 41.42" E
Frog 43	20/05/2008	4/09/2008	31° 46' 47.43" S	115° 50' 19.99" E
Frog 44	20/05/2008	3/09/2008	31° 44' 57.01" S	115° 50' 55.50" E
Frog 45	20/05/2008	3/09/2008	31° 43' 39.76" S	115° 48' 38.90" E
Frog 46	20/05/2008	4/09/2008	31° 44' 36.53" S	115° 47' 37.37" E
Frog 47	20/05/2008	4/09/2008	31° 45' 39.52" S	115° 47' 55.75" E
Frog 48	20/05/2008, 16/06/2008	22/08/2008	31° 48' 13.58" S	115° 48' 43.58" E
Frog 49	20/05/2008, 16/06/2008	22/08/2008	31° 48' 22.17" S	115° 48' 59.25" E
Frog 50	14/05/2008	20/08/2008	31° 28' 24.24" S	115° 45' 56.16" E
Frog 51	14/05/2008	20/08/2008	31° 28' 8.76" S	115° 45' 50.40" E
Frog 52	14/05/2008	27/08/2008	31° 39' 23.04" S	115° 51' 39.96" E
Frog 53	14/05/2008	27/08/2008	31° 41' 21.12" S	115° 49' 37.49" E
Frog 54	28/05/2008	29/09/2008	31° 52' 38.86" S	115° 47' 25.66" E
Frog 55	28/05/2008	29/09/2008	31° 51' 1.42" S	115° 47' 11.50" E
Frog 56	28/05/2008	4/09/2008	31° 32' 30.69" S	115° 40' 47.56" E
Frog 57	28/05/2008	4/09/2008	31° 38' 2.99" S	115° 43' 46.34" E
Frog 58	-	4/09/2008	31° 33' 32.93" S	115° 41' 16.17" E
Frog 59	-	4/09/2008	31° 34' 25.15" S	115° 41' 24.13" E

Appendix 2. Survey Sites Description. Landform Unit: B= Bassendean, S= Spearwood; Wetland Type (adapted from Semeniuk & Semeniuk, 1995): L= Lake (permanently inundated basin), P= Palusplain (seasonally waterlogged flat), S= Sumpland (seasonally inundated basin), W= Watercourse (otherwise known as *creek*, seasonally inundated channel); Surface Water Present/Absent (+/-) in Winter, Sedges/Rushes Present/Absent (+/-)

Site Code	Landform Unit	Wetland Type	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 0	S	S	-	-
Frog 0a	B	S	-	-
Frog 01	B	S	-	-
Frog 02	B	S	-	-
Frog 03	B	W	+	+
Frog 04	B	W	+	+
Frog 05	B	W	+	+
Frog 06	B	S	+	+
Frog 06a	B	S	-	+
Frog 07	B	S	+	+
Frog 08	B	S	-	-
Frog 09	B	S	+	-
Frog 10	B	S	-	-
Frog 13	B	S	+	-
Frog 14	B	S	-	-
Frog 15	B	S	-	-
Frog 16	B	S	-	-
Frog 18	B	P	+	-
Frog 19	B	P	+	-
Frog 21	B	P	+	-
Frog 22	B	P	-	-
Frog 23	B	S	+	-
Frog 24	B	P	+	+
Frog 25	B	P	-	-
Frog 25a	B	S	+	+
Frog 26	B	S	-	-
Frog 27	B	S	-	-
Frog 28	B	S	-	-
Frog 29	B	S	+	+
Frog 30	B	P	-	-
Frog 30a	B	S	+	+
Frog 31	B	S	-	-
Frog 32	B	S	+	-
Frog 33	B	S	-	+
Frog 34	B	P	+	-
Frog 35	B	P	+	-
Frog 36	B	W	+	+
Frog 36a	B	P	-	-

Site Code	Landform Unit	Wetland Type	Presence of Sedges/Rushes	Presence of Surface Water in Winter
Frog 37	B	P	-	-
Frog 39	B	P	+	-
Frog 40	B	L	+	+
Frog 40a	B	P	+	-
Frog 41	B	S	+	+
Frog 41a	B	S	+	+
Frog 42	S	S	+	-
Frog 43	S	S	+	+
Frog 44	B	L	+	+
Frog 45	S	L	+	+
Frog 46	S	L	+	+
Frog 47	S	L	+	+
Frog 48	S	L	+	+
Frog 49	S	L	+	+
Frog 50	B	S	-	-
Frog 51	B	S	-	-
Frog 52	B	P	+	-
Frog 53	B	S	+	-
Frog 54	S	L	+	+
Frog 55	S	L	+	+
Frog 56	S	L	+	+
Frog 57	S	L	+	+
Frog 58	S	S	+	+
Frog 59	S	S	-	-

Appendix 3. Vegetation description of each site.

Site	Vegetation
Frog 0	Mixed woodland of *M. priessiana*, *E. rudis*, *B. menziesii*, *B. ilicifolia* and *B. littoralis*, over shrubs.
Frog 0a	Woodland of *M. priessiana* over shrub-thicket of *Kunzea* and *Adenanthos*.
Frog 01	Woodland of *M. priessiana* and *M. rhaphiophylla* over *Regelia* shrubland.
Frog 02	Woodland of *M. priessiana* over mixed shrub heath.
Frog 03	Gallery forest of *M. rhaphiophylla* and *E. rudis* over sedges and bracken. Sedges and trees flooded.
Frog 04	Swamp forest of *M. priessiana*, *M. rhaphiophylla* and *E. rudis* over mixed shrubs, grasses and sedges. Vegetation flooded in part.
Frog 05	Gallery forest of *M. rhaphiophylla* and *E. rudis* over sedges and bracken. Sedges and trees flooded.
Frog 06	Swamp forest of *M. priessiana*, *M. rhaphiophylla* and *E. rudis* over *M. teretifolia* and mixed shrubs, grasses and sedges. Vegetation flooded in part.
Frog 06a	Paddock (grassland) adjacent to Site 06, extensively flooded with shallow water in spring.
Frog 07	Swamp forest of *M. priessiana*, *M. rhaphiophylla* and *E. rudis* over mixed shrubs, grasses and sedges. Some impact from livestock. Also flooded pasture.
Frog 08	Woodland of *M. priessiana* over shrub-thicket of *Kunzea* and *Regelia*.
Frog 09	Woodland of *M. priessiana* over shrub-thicket of *Kunzea* and *Regelia*. Also some areas of sedge.
Frog 10	Woodland of *E. rudis*, *M. priessiana* and *M. rhaphiophylla* over *Astartea* shrubland
Frog 13	Woodland of mostly young *E. rudis* over shrub-thicket of *Kunzea* over sedges. Some *M. priessiana* and *B. littoralis* also present.
Frog 14	Woodland of very large *M. priessiana* with invading *E. rudis* and *B. attenuata*, over mixed shrub-thicket.
Frog 15	Woodland of *E. rudis* and *M. priessiana* over shrub-thicket of *Kunzea*
Frog 16	Complex of woodland of *E. rudis* and some *M. priessiana* over mixed shrub-thicket; also areas of shrub-thicket with no overstorey and some bracken.
Frog 18	Shrub-thicket of *Kunzea* over sedges with scattered emergent *B. littoralis*, *B. ilicifolia*, *M. priessiana* and *E. rudis*.
Frog 19	Forest of young (20-30 year) *M. priessiana* and *E. rudis* over sedges in broad depression; presumably an old excavation to access water. Surrounded by *Kunzea* shrub-thicket.
Frog 21	Sedgeland on peaty soil with marginal woodland of *M. priessiana* and *B. littoralis*. Scattered and stunted *M. teretifolia* across sedgeland.
Frog 22	Shrub-thicket of *Kunzea* and young *M. priessiana* with scattered *E. rudis*. Area partly cleared beneath transmission lines.
Frog 23	Open woodland of *M. priessiana* over *M. rhaphiophylla* and *M. teretifolia* over sedges.
Frog 24	Shrub-thicket of *M. teretifolia* and *Kunzea* over sedges. Few emergent *M. priessiana*. Surrounded by pine plantation.
Frog 25	Forest of *E. rudis* and *M. priessiana* with understorey of *Kunzea* and *Regelia*.
Frog 25a	Woodland of *M. priessiana* over shrub-thicket of *Kunzea* fringing wetland supporting *Baumea articulata* and *Juncus*. Surrounded by *Banksia* woodland

Site	Vegetation
Frog 26	Woodland of *M. priessiana* with some mostly young *E. rudis* and *B. littoralis* over shrubland of *Hypocalymma* and young *M. preissiana.*
Frog 27	Woodland of *M. priessiana* over heath to 1.5m of *Regelia.*
Frog 28	Low woodland of *M. priessiana* over heath of *Hypocalymma*.
Frog 29	Complex of forest of *M. priessiana* and shrub-heath of *Regelia* with some areas of sedges. Thicket of *B. articulata* in pool in fire hole. All regenerating from intense fire within previous 2 years.
Frog 30	Open woodland of *M. priessiana* with some *B. ilicifolia* and *Nuytsia* over heath of *Hypocalymma*, *Xanthorrhoea* and other shrubs.
Frog 30a	Remnant *M. priessiana* and *E. rudis* in paddock, with *B. articulata* emergent in wetland.
Frog 31	Woodland of *M. priessiana* over heath of *Hypocalymma.*
Frog 32	Woodland of *M. priessiana* over heath of *Hypocalymma* and sedgeland.
Frog 33	Low forest of *M. priessiana* over mixed shrubs, with some areas of pure shrub-thicket. Surrounded by pine plantation
Frog 34	Woodland and open woodland of *M. priessiana* and *B. littoralis* over *Hypocalymma* heath and sedgeland.
Frog 35	Woodland of *M. priessiana* and *M. rhaphiophylla* over sedges and grassy weeds.
Frog 36	Swamp forest of *M. rhaphiophylla* over pools, sedges and rushes. Flooded paddocks adjacent. This is a mound spring adjacent to The Maze along Neaves Road.
Frog 36a	Heath of *Regelia* and *Hypocalymma*
Frog 37	Heath of *Hypocalymma*
Frog 39	Open woodland of *M. priessiana* and *B. littoralis* over sedges
Frog 40	Around open water, shallows, some bare shoreline, a belt of mostly dead, low sedges (*Juncus* sp?); shrub-thicket degraded and weed invaded; and few *M. priessiana* and *E. rudis.*
Frog 40a	Low woodland of *M. priessiana* over scattered *Kunzea* and *Xanthorrhoea*, over sedgeland. Adjacent to pine plantation.
Frog 41	An urban pond with open water, extensive beds of rushes (*B. articulata* and/or similar) and some shrub-thickets, but few trees and adjacent lawn.
Frog 41a	Woodland of *M. priessiana* around a heathland of *Hypocalymma* and sedgeland. Some bare areas with shallow puddles from recent rain in spring.
Frog 42	Centre of wetland consists of a rushbed of *Typha*, *B. articulata* and pampas grass. Surrounding this is a low forest of *E. rudis, M. rhaphiophylla* and *M. priessiana* over a shrubby understorey of *Acacia*, *Viminaria* and *Hypocalymma*.
Frog 43	Lake bed completely covered by *Typha* with water present. Margins of lake cleared and replaced by weeds, including massive piles of kikuyu grass. Scattered *Acacia* regrowth and *E. rudis* and *M. priessiana*.
Frog 44	Complex vegetation in zones around wetland. *B. articulata* rushbeds in water and along shore, broad sedgeland behind this, dense heath of *Hypocalymma, Pericalymma* and *Regelia,* then woodland of *M. priessiana* and *E. rudis*.
Frog 45	Around open water, a broad belt of *Juncus* and *B. articulata*. Shrub-thickets and woodlands around this mostly cleared and replaced by weeds, but some *E. rudis* and *Melaleuca* spp. remain; also some exotic eucalypts and acacias.

Site	Vegetation
Frog 46	Around open water, broad belt of *Typha* with some *B. articulata*; little bare shoreline. Remnant forest of *M. rhaphiophylla* but most upland areas replaced by lawn.
Frog 47	Around open water, broad belt of *Typha* with some *B. articulata*; little bare shoreline but some grassy shallows amongst rushbeds. Remnant forest of *M. rhaphiophylla* and *E.rudis* more extensive than at other Lake Joondalup site (Frog 46).
Frog 48	Swamp forest of *M. rhaphiophylla* with some *E. rudis*.
Frog 49	Extensive rushbeds of *B. articulata* along shore. Scattered *E. rudis*. Damp and tangled Kikuyu grass.
Frog 50	Woodland of *M. priessiana* over shrub-thicket of *Regelia* and *Kunzea*. *B. ilicifolia* invasion around margins. Some *M. priessiana* dead.
Frog 51	Woodland of *E. rudis* and *M. priessiana* over shrub-thicket of *Kunzea*.
Frog 52	Heath of *M. teretifolia* and other shrubs with extensive sedgelands; marginal woodland of *M. priessiana* and *B. littoralis*.
Frog 53	Low forest of *M. priessiana* and *B. littoralis* over sedges.
Frog 54	Open water with extensive beds of *Typha* and *B. articulata*. Some bare shoreline, but also a lot of flooded Kikuyu grass. Some remnant *E. rudis* and *M. priessiana* and *M. rhaphiophylla* woodland, but upland areas largely replaced by lawn.
Frog 55	Open water with extensive beds of *Typha* and *B. articulata*. Some bare shoreline, but also a lot of flooded Kikuyu. Some remnant *E. rudis* and *M. priessiana* and *M. rhaphiophylla* woodland, but upland areas largely replaced by lawn.
Frog 56	Complex vegetation. Open water is fringed with very dense stands of *B. articulata* so there is almost no shoreline, except where this is a stone wall backed by lawn. Almost no shallows. Behind rushes, a swamp forest of *M. teretifolia* and *M. rhaphiophylla*. Adjacent vegetation includes lawns and eucalypt/banksia woodland
Frog 57	Complex vegetation. Around open water, extensive beds of *Typha* (a little *B. articulata*) backed by swamp forests of *M. rhaphiophylla* and *E. rudis*. Market gardens on one shore; eucalypt/banksia woodland on other.
Frog 58	Dense sedgeland (*Lepidosperma*) over shallow water in centre, fringing with dense acacias and other shrubs regenerating after fire. Scattered *E. rudis* and *M. priessiana*.
Frog 59	Mass of sapling *E. rudis* across lake bed forming a dense thicket. Dead and some live *M. rhaphiophylla* and *E. rudis* around margins, backed by eucalypt/banskia woodland

Appendix 4. Aural survey results in autumn. Data are grouped into categories of 1-10, 11-30 and >30 calling animals. Blank cells indicate null records. Asterisks indicate sites not surveyed in this season.

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 0								
Frog 0a								
Frog 01				1~10	1~10			1~10
Frog 02				1~10				1~10
Frog 03				11~30				1~10
Frog 04				>30				1~10
Frog 05				11~30				1~10
Frog 06				>30				>30
Frog 06a*								
Frog 07				11~30				
Frog 08								
Frog 09								1~10
Frog 10*								
Frog 13								
Frog 14								
Frog 15*								
Frog 16								
Frog 18								
Frog 19								
Frog 21				1~10	1~10			1~10
Frog 22				1~10				
Frog 23			1~10	1~10				
Frog 24			1~10	1~10				
Frog 25				11~30				
Frog 25a*								
Frog 26								
Frog 27			1~10					
Frog 28								
Frog 29				11~30				
Frog 30				1~10				
Frog 30a*								
Frog 31				1~10				
Frog 32				1~10				
Frog 33				11~30				
Frog 34								
Frog 35								
Frog 36		1~10		>30				
Frog 36a								
Frog 37				1~10				
Frog 39								
Frog 40				1~10				
Frog 40a				1~10				

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 41		1-10	1-10	1-10			1-10	
Frog 41a			1~10					
Frog 42			1~10					
Frog 43				>30				
Frog 44		1~10	1~10		1~10		>30	
Frog 45			1~10	>30				
Frog 46		>30	1~10					
Frog 47		>30					1~10	
Frog 48				1~10				
Frog 49		>30					1~10	
Frog 50				1~10				
Frog 51				1~10				
Frog 52				11~30				
Frog 53				1~10				
Frog 54		1~10	>30	1~10				
Frog 55		1~10	>30					
Frog 56			1~10		1~10			
Frog 57		1~10	1~10		1~10			
Frog 58*								
Frog 59*								

Appendix 5. Aural survey results in winter. Data are grouped into categories of 1-10, 11-30 and >30. Blank cells indicate null records.

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 0								
Frog 0a								
Frog 01								
Frog 02								
Frog 03	1~10	1~10	11~30		1~10	1~10		
Frog 04			>30		1~10		1~10	
Frog 05		1~10	1~10					
Frog 06	1-10		.>30		>30	1-10	1-10	
Frog 06a		1-10	1-10			1~10		
Frog 07		1~10	1~10		1~10		1~10	
Frog 08								
Frog 09								
Frog 10								
Frog 13								
Frog 14								
Frog 15								
Frog 16								
Frog 18								
Frog 19								
Frog 21								
Frog 22								
Frog 23								
Frog 24								
Frog 25								
Frog 25a		11~30	11~30		1~10		11~30	
Frog 26								
Frog 27								
Frog 28								
Frog 29				1~10	1~10		1~10	
Frog 30								
Frog 30a		1~10	11~30		1~10			
Frog 31								
Frog 32								
Frog 33								
Frog 34								
Frog 35								
Frog 36	1~10		1~10		1~10		1~10	
Frog 36a								
Frog 37								
Frog 39								
Frog 40		1~10						
Frog 40a								
Frog 41		>30	1~10		1~10		11~30	

Site Code	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
Frog 41a							1~10	
Frog 42								
Frog 43		1~10					1~10	
Frog 44		>30	1~10		1~10		1~10	
Frog 45		>30	1~10		1~10		11~30	
Frog 46		>30			1~10		>30	
Frog 47		>30			11~30		11~30	
Frog 48		11~30						
Frog 49		11~30	11~30		1~10		11~30	
Frog 50								
Frog 51								
Frog 52								
Frog 53								
Frog 54		1~10				1~10	1~10	
Frog 55		11~30			11~30		1~10	
Frog 56		>30					1~10	
Frog 57		>30			1~10		>30	
Frog 58		>30					1~10	
Frog 59								

Appendix 6. Site locations and species recorded from Lexia (Bamford and Everard 2008).

Site Code	**Site Name**	**Latitude**	**Longitude**	***C. georgiana***	***C. glauerti***	***C. insignifera***	***H. eyrei***	***L. dorsalis***	***L. moorei***	***L. adelaidensis***	***P. guentheri***
LX01	Lexia 86	31°45'13''S	115°57'29''E	X	X	X	X	X		X	X
LX02	EPP Wetland 173	31°42'19''S	115°57'45''E	X	X	X	X	X		X	X
LX03	Lexia 94	31°45'17''S	115°58'21''E				X				X
LX04	Lexia 186	31°44'40''S	115°57'42''E		X	X	X			X	X
LX05	Lake Yakine	31°47'40''S	115°59'56''E	X	X	X		X		X	

Appendix 7. Site locations and species recorded from Whiteman Park (Bancroft and Bamford 2008).

Site Code	Site Name	Latitude	Longitude	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*
WP01	Keith Maine Pool	31° 49' 42.68" S	115° 55' 38.39" E		X		X	X			
WP02	Beechboro Road Entrance	31° 50' 46.67" S	115° 55' 40.51" E	X	X	X	X	X			
WP03	Bennett Brook Tributary 1	31° 50' 14.87" S	115° 55' 43.73" E	X	X	X	X	X		X	X
WP04	Bennett Brook Tributary 2	31° 50' 28.56" S	115° 55' 48.71" E	X	X	X	X			X	
WP05	Bennett Brook Tributary 3	31° 50' 37.35" S	115° 55' 51.46" E	X			X			X	
WP06	Trap Site 2 (Emu Way)	31° 49' 58.12" S	115° 55' 59.14" E	X	X		X			X	
WP07	Bennett Brook Tributary 4	31° 50' 34.18" S	115° 56' 1.01" E	X	X		X			X	
WP08	Trap Site 1	31° 50' 31.21" S	115° 56' 22.16" E	X	X		X			X	
WP09	Kangaroo Flat Pool	31° 49' 38.18" S	115° 56' 23.14" E		X	X	X			X	
WP10	Trap Site 4	31° 48' 50.35" S	115° 56' 51.64" E				X	X			
WP11	Mussel Pool	31° 50' 38.88" S	115° 56' 58.78" E	X		X	X		X	X	
WP12	Bennett Springs Drive	31° 51' 27.98" S	115° 57' 6.22" E	X	X	X	X			X	
WP13	Cranleigh Street	31° 51' 5.66" S	115° 57' 16.36" E	X	X	X				X	
WP14	Horse Swamp	31° 50' 37.78" S	115° 57' 22.76" E			X	X	X		X	
WP15	Near Catchment Centre	31° 52' 19.75" S	115° 57' 22.00" E	X	X	X	X	X		X	
WP16	Grogan Swamp	31° 52' 57.20" S	115° 57' 33.75" E	X	X	X	X	X		X	
WP17	Swamp alongside Lord Street	31° 50' 1.62" S	115° 57' 49.04" E		X	X	X	X		X	X
WP18	Lord Street Entrance Pool	31° 50' 4.26" S	115° 57' 53.58" E							X	

Appendix 8. Site locations and species recorded at Herdsman Lake (M. and A. Bamford pers. obs.).

Site Name	**Latitude**	**Longitude**	***C. georgiana***	***C. glauerti***	***C. insignifera***	***H. eyrei***	***L. dorsalis***	***L. moorei***	***L. adelaidensis***	***P. guentheri***
Herdsman Lake	31° 54' 43.71" S	115° 48' 5.22" E		X	X		X	X	X	

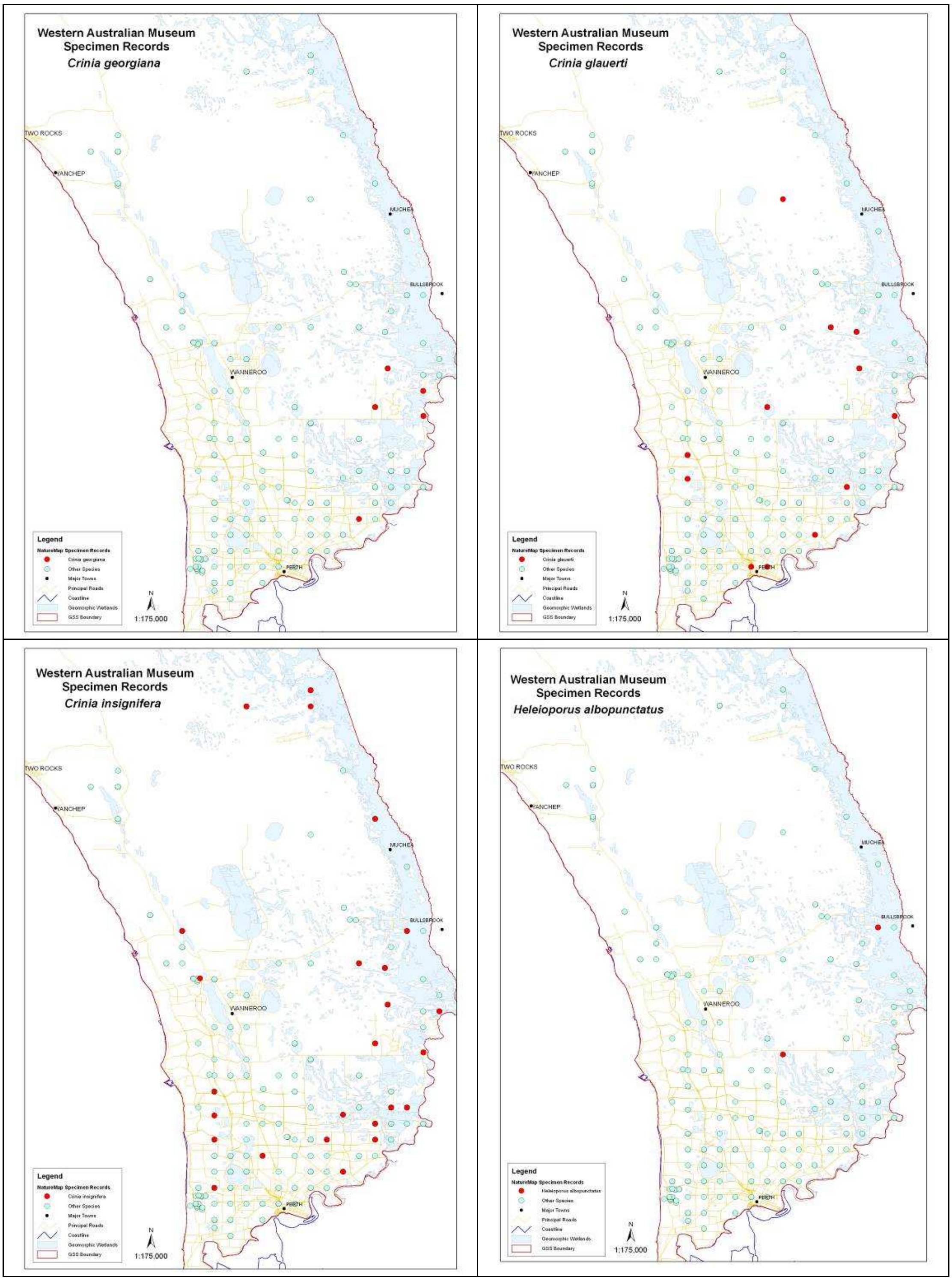
Appendix 9. Site locations and species recorded from parallel GSS fauna survey. Species recorded were captured in pitfall traps, except for a single capture of the Motorbike Frog *Litoria moorei* in an Elliott trap at Site 15A.

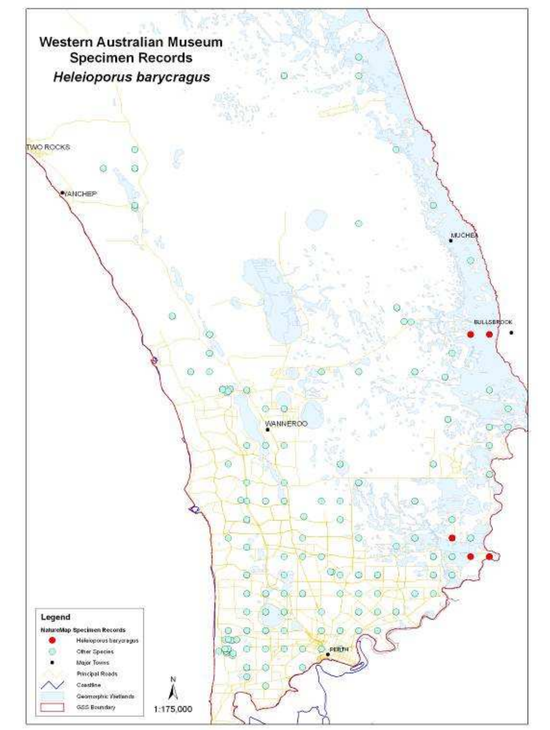
Site Code	Latitude	Longitude	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*	*M. gouldii*
GSS/01A	31° 30' 38.30" S	115° 39' 22.46" E				X	X				
GSS/01B	31° 30' 53.48" S	115° 39' 36.29" E				X	X				
GSS/02A	31° 31' 15.82" S	115° 39' 14.47" E				X	X				
GSS/02B	31° 31' 19.84" S	115° 39' 24.09" E				X	X				
GSS/03A	31° 21' 27.81" S	115° 40' 16.30" E					X				
GSS/03B	31° 21' 49.86" S	115° 40' 29.63" E					X				X
GSS/04A	31° 28' 24.83" S	115° 45' 55.19" E									X
GSS/04B	31° 28' 21.37" S	115° 46' 10.86" E									X
GSS/05A	31° 31' 3.69" S	115° 42' 53.13" E									X
GSS/05B	31° 31' 15.56" S	115° 42' 54.03" E									X
GSS/06A	31° 23' 51.50" S	115° 44' 43.03" E				X	X				X
GSS/06B	31° 23' 59.94" S	115° 44' 47.16" E				X	X				X
GSS/07A	31° 26' 35.09" S	115° 52' 9.79" E				X				X	
GSS/07B	31° 26' 37.42" S	115° 52' 7.07" E			X	X	X				X
GSS/08A	31° 27' 6.44" S	115° 50' 47.08" E					X				
GSS/08B	31° 26' 55.98" S	115° 50' 45.15" E				X	X				X
GSS/09A	31° 27' 38.74" S	115° 50' 6.26" E					X				X
GSS/09B	31° 27' 38.02" S	115° 50' 10.54" E									X
GSS/10A	31° 34' 23.69" S	115° 41' 38.76" E									
GSS/10B	31° 34' 29.85" S	115° 41' 39.26" E				X					
GSS/11A	31° 33' 5.62" S	115° 41' 34.24" E									
GSS/11B	31° 33' 8.69" S	115° 41' 35.02" E									
GSS/12A	31° 30' 28.52" S	115° 41' 17.86" E				X					X
GSS/12B	31° 30' 29.35" S	115° 41' 0.71" E									X
GSS/13A	31° 30' 33.38" S	115° 41' 56.66" E					X				X
GSS/13B	31° 30' 27.11" S	115° 41' 55.07" E									X
GSS/14A	31° 32' 38.85" S	115° 40' 35.13" E				X	X				
GSS/14B	31° 34' 10.14" S	115° 41' 32.51" E				X					

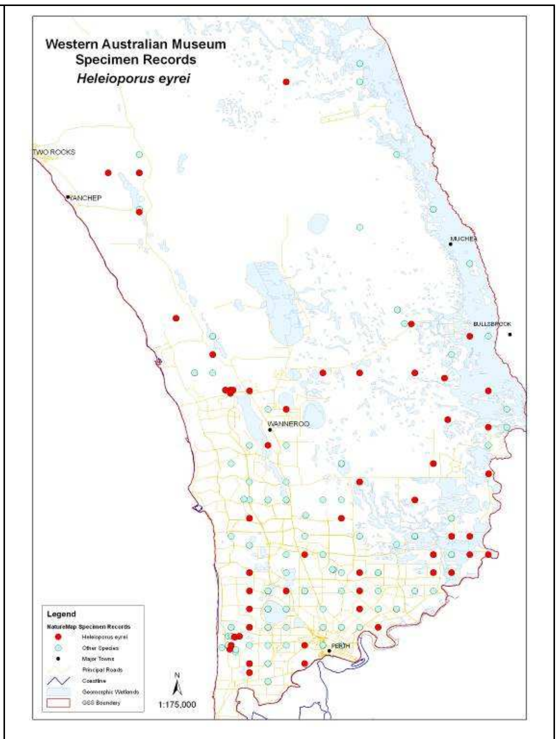
Appendix 9 (cont.)

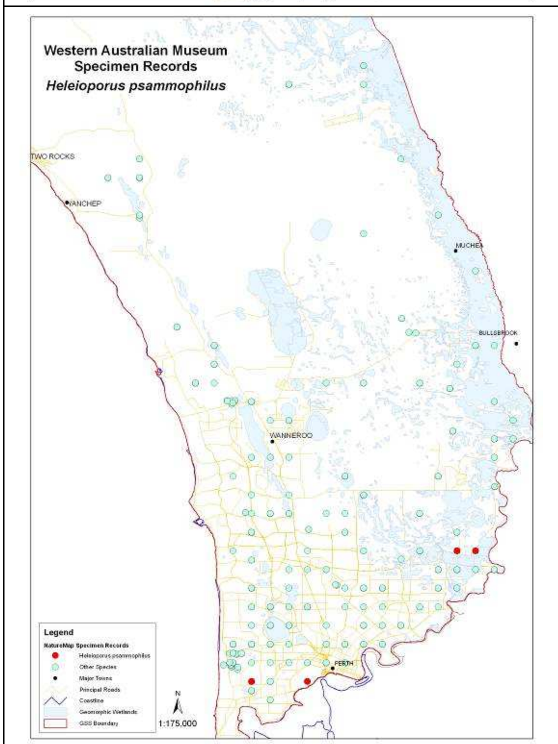
Site Code	Latitude	Longitude	*C. georgiana*	*C. glauerti*	*C. insignifera*	*H. eyrei*	*L. dorsalis*	*L. moorei*	*L. adelaidensis*	*P. guentheri*	*M. gouldii*
GSS/15A	31° 33' 29.71" S	115° 41' 17.58" E						X			
GSS/15B	31° 33' 25.96" S	115° 41' 16.17" E				X					
GSS/16A	31° 30' 37.58" S	115° 43' 33.48" E									X
GSS/16B	31° 30' 35.33" S	115° 43' 36.83" E									X
GSS/17A	31° 24' 7.69" S	115° 41' 45.05" E					X				X
GSS/17B	31° 24' 5.83" S	115° 41' 53.41" E					X				X
GSS/18A	31° 37' 17.97" S	115° 49' 20.79" E									
GSS/18B	31° 37' 15.32" S	115° 49' 25.09" E									
GSS/19A	31° 42' 23.65" S	115° 56' 18.63" E									
GSS/19B	31° 42' 21.55" S	115° 56' 14.87" E				X					
GSS/20A	31° 42' 27.59" S	115° 55' 29.32" E									
GSS/20B	31° 42' 28.06" S	115° 55' 33.95" E									

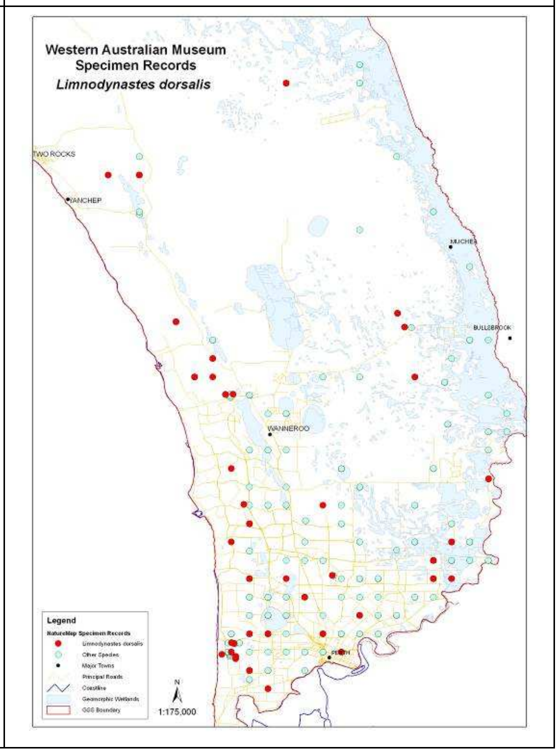
Appendix 10. Frog records in the GSS area from Naturemap.



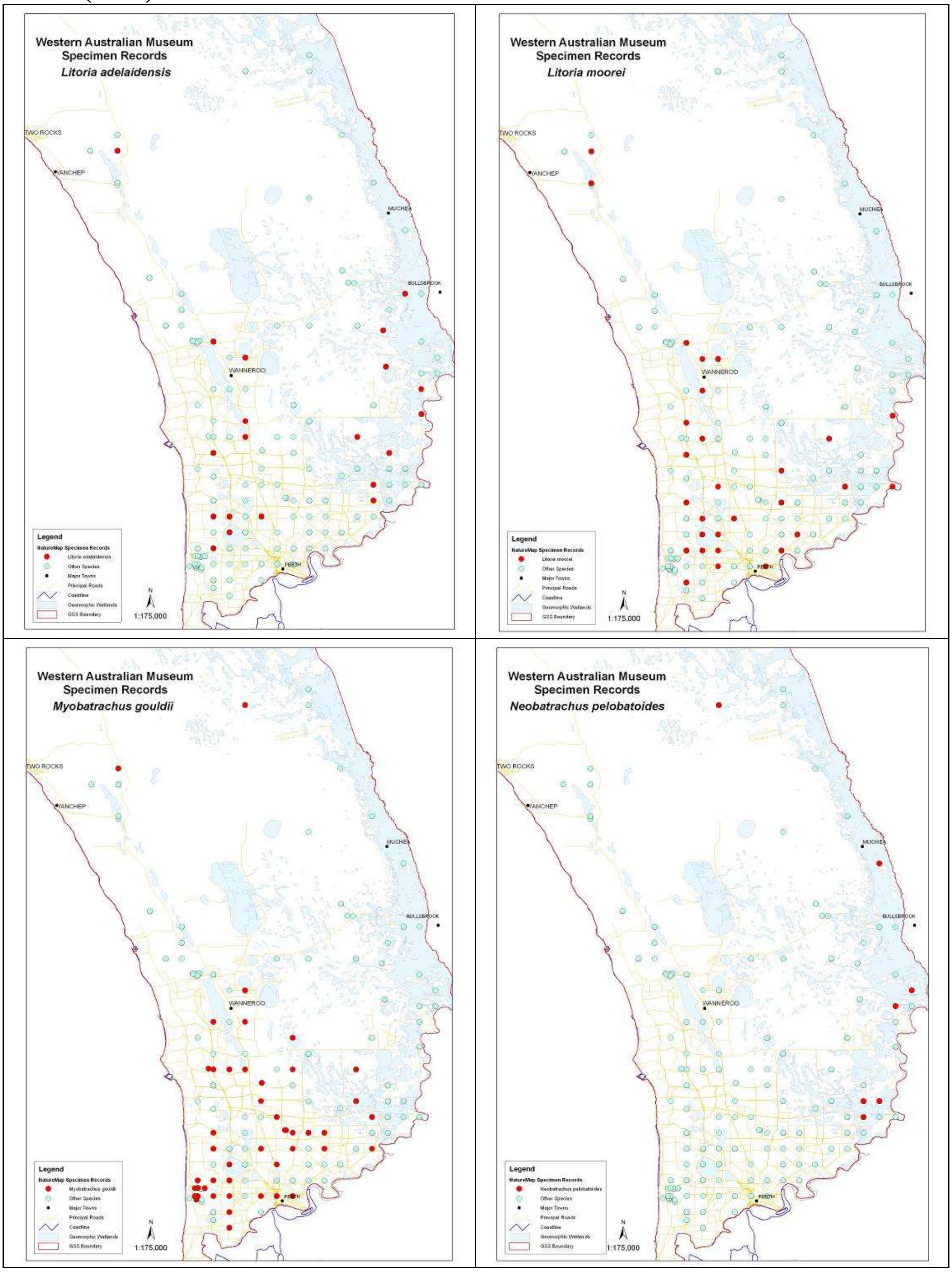

Western Australian Museum
Specimen Records
Heleioporus barycragus
WO ROCKS
YANCHEP
MUCHEA
BULLSBROOK
WANNEROO
PERTH
Legend
NatureMap Specimen Records
Heleioporus barycragus
Other Species
Major Towns
Principal Roads
Coastline
Geomorphic Wetlands
GSS Boundary
N
1:175,000

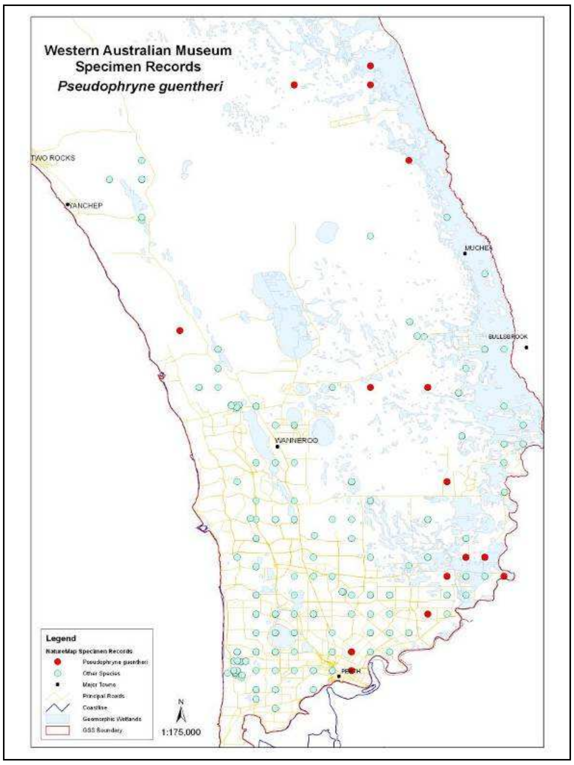

Western Australian Museum
Specimen Records
Heleioporus eyrei
WO ROCKS
YANCHEP
MUCHEA
BULLSBROOK
WANNEROO
PERTH
Legend
NatureMap Specimen Records
Heleioporus eyrei
Other Species
Major Towns
Principal Roads
Coastline
Geomorphic Wetlands
GSS Boundary
N
1:175,000


Western Australian Museum
Specimen Records
Heleioporus psammophilus
WO ROCKS
YANCHEP
MUCHEA
BULLSBROOK
WANNEROO
PERTH
Legend
NatureMap Specimen Records
Heleioporus psammophilus
Other Species
Major Towns
Principal Roads
Coastline
Geomorphic Wetlands
GSS Boundary
N
1:175,000


Western Australian Museum
Specimen Records
Limnodynastes dorsalis
WO ROCKS
YANCHEP
MUCHEA
BULLSBROOK
WANNEROO
PERTH
Legend
NatureMap Specimen Records
Limnodynastes dorsalis
Other Species
Major Towns
Principal Roads
Coastline
Geomorphic Wetlands
GSS Boundary
N
1:175,000

Appendix 10 (cont.)




Western Australian Museum
Specimen Records
Pseudophryne guentheri
TWO ROCKS
YANCHEP
WANNEROO
BULLSBROOK
Legend
NatureMap Specimen Records
Pseudophryne guentheri
Other Species
Major Towns
Principal Roads
Coastline
Geomorphic Wetlands
GSS Boundary
N
1:175,000