# Habitat-use by the Green and Golden Bell Frog *Litoria aurea* in Australia and New Zealand

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**ABSTRACT**

Patterns of habitat-use are used widely as management guides in the conservation of wildlife. However, even for relatively well-studied species, such the Green and Golden Bell Frog *Litoria aurea,* our knowledge of specific habitat requirements is lacking.

This study sought to compare the patterns of breeding habitat shown by *L. aurea* in New South Wales (NSW), Victoria and New Zealand (where it is a feral species), with those described in an earlier study of Pyke and White (1996), to review the conservation status of this species in Victoria, and to relate its observed patterns of distribution and habitat-use to the distribution of the introduced Plague Minnow (*Gambusia holbrooki* in Australia; *G. affinis* in New Zealand).

We found that *L. aurea* used similar breeding habitats in NSW, Victoria and New Zealand. Across these areas its breeding is almost completely restricted to water bodies that are still, relatively unshaded, and low in salinity (i.e., <7.3 ppt). All of its known breeding sites are highly disturbed, mostly through human activities but also through flooding and other natural processes. It generally breeds in small (i.e., <1000 sq m), shallow (i.e., <1 m) ponds that are either ephemeral or fluctuate significantly in water level, are free of *Gambusia* and other predatory fish, and have emergent aquatic vegetation. Its breeding habitat also usually has potential shelter provided by nearby rocks or thick, low vegetation.

Yet *L. aurea* is adaptable to different habitats and we found it breeding in a wide range of conditions including ponds lacking emergent vegetation and those already colonised by *Gambusia*. Breeding ponds ranged in terms of substrate, nearby terrestrial vegetation, water source, and water properties including turbidity, dissolved oxygen, oxidation reduction potential, pH and temperature.

*Gambusia* may have had a negative impact on the distribution of *L. aurea* in New Zealand and could threaten populations in Victoria. We failed to find *L.aurea* at sites in New Zealand where it had previously been reported but that are now colonised by *Gambusia*. This fish has not invaded *L. aurea* habitat in Victoria, but it can potentially do so from nearby regions. Further surveys for *L. aurea* in Victoria and New Zealand seem warranted.

Paradoxically New Zealand may offer unique opportunities for further research on the biology of Australian frogs. The commonly encountered frogs in New Zealand are three Australian species, two of which (i.e., *L. aurea* and *L. raniformis*) are considered threatened with extinction in Australia. It may be possible in New Zealand to study relatively large populations of these Australian frog species, in relatively simple frog communities and habitats. Because these species are not protected in New Zealand, field studies can also incorporate experimental manipulations not readily possible in Australia.

**Key words:** Australia, New Zealand, frog, *Litoria aurea*, *Litoria raniformis*, habitat, *Gambusia*, Plague Minnow, Mosquito Fish

## Introduction

Knowledge of patterns of habitat-use is necessary to understand, conserve and manage animal populations. Understanding how animals choose and make use of habitat allows us to formulate plans to facilitate their survival and reproduction. Moreover, this information is necessary for the development of accurate survey strategies (e.g., Soulé 1986). The compilation of habitat-use information thus represents an important first step in the conservation and management of species that are considered to be under significant risk of extinction (i.e., classified as 'threatened', 'endangered', or 'vulnerable').

Despite their importance, however, patterns of habitat-use have been little documented for frogs in general, and for frogs in Australia and New Zealand in particular. Most descriptions of habitat for Australian frogs focus on the rates of water flow and the nature of adjacent or nearby vegetation (e.g., Barker *et al.* 1995; Robinson 1993; Cogger 2000). Habitat descriptions for New Zealand frogs generally focus on broad vegetation categories, distance from water, presence/absence of shade, presence/absence of rocks and elevation range (e.g., Bell 1982a; Gill and Whitaker 1996; Newman 1996).

The most detailed studies of patterns of habitat-use for frogs of Australia and New Zealand have been carried out for three Australian species, *Litoria aurea*, *L. spenceri* and *L. pearsoniana* (Gillespie and Hollis 1996; Pyke and White 1996; Parris 2001). In an earlier study we used stepwise logistic regression to compare sites where breeding by *L. aurea* had been recorded (i.e., tadpoles and metamorphs observed) with sites where this species was known to be present, but where breeding had not yet been recorded (Pyke and White 1996). We found that *L. aurea* usually breeds in water bodies that are still, shallow, unshaded, free of predatory fish such as the introduced Plague Minnow *Gambusia holbrooki* (also known as Gambusia or Mosquito Fish), and ephemeral (rather than having fluctuating or constant water level), with sand or rock substrate and with emergent aquatic plants (Pyke and White 1996). We also found that shelter is usually provided through nearby rock or thick, low vegetation, that adjacent and nearby vegetation may vary from grassland to heath/shrubland to woodland but has not so far included forest, and that many of the sites where *L. aurea* breeds are highly disturbed by human activities (Pyke and White 1996).

Gillespie and Hollis (1996) used contingency table and Spearman rank correlation analysis to determine correlations between various quantified measures of stream habitat and both presence/absence of *L. spenceri* and its relative abundance (i.e., number adults observed per km length of stream). They found that *L. spenceri* occurred almost exclusively in association with rock habitats along streams, and that its abundance was negatively correlated with clearance of adjacent forest, human access and the presence of trout (Gillespie and Hollis 1996). Parris (2001) used stepwise logistic and linear regression to determine relationships between various climatic and habitat variables and two measures of abundance for *L. pearsoniana* (i.e., presence/absence and log transformed number of detected individuals for those sites where species was present). She found that *L. pearsoniana* was most likely to occur at large streams with mesic mid-storey vegetation in riparian zone, as indicated by presence of palms, and that, at sites where this species was present, its abundance increased with increasing stream size (Parris 2001). Similar, though less detailed, studies of habitat-use for Australian frogs have been carried out by Healey *et al.* (1997) and Lemckert (1999).

Even for *L. aurea*, *L. spenceri* and *L. pearsoniana*, however, our understanding of habitat-use remains limited. Studies of *L. aurea* habitat have not, for example, assessed water chemistry (e.g., pH, salinity, contaminants), nor physical characterisics (e.g., temperature, turbidity). How habitat-use might vary with time or location has not been considered (Pyke and White 1996). Pyke and White (1996) considered sites only within NSW and did not consider other areas where *L. aurea* also occurs. Studies of habitat-use by *L. spenceri* and *L. pearsoniana* similarly omitted physical and chemical properties of available water and were unable to provide specific detailed information in relation to breeding habitat (Gillespie 1992; Gillespie and Hollis 1996; Parris 2001). The ranges of habitats at sites where these two species occur are likely to be considerably broader than the subsets of breeding sites, as is the case for *L. aurea* (e.g., Gillespie 1996; Pyke and White 1996).

*Litoria aurea* is endemic to Australia, but it has been introduced to a number of islands in the South Pacific (see Pyke and White 2001). In New Zealand, for example, it occurs in many locations in the northern part of the North Island (Thomson 1922; McCann 1961; Bull and Whitaker 1975; Bell 1982a,b; Pickard and Towns

1988). It has also been introduced into New Caledonia, Vanuatu, the Loyalty Islands and the islands of Wallis and Futuna, and may be locally abundant in these feral populations (e.g., McCann 1961; Gibbons 1985; Tyler 1976, 1979; Bell 1982a; Bauer *et al.* 1997; Bauer and Sadlier 2000). No comparisons have been made between its patterns of habitat-use where introduced with those it shows within its endemic range

Within Australia, the legal conservation status of *L. aurea* and the factors apparently affecting its populations vary between NSW and Victoria. In NSW, it is considered 'endangered' (i.e., under the *Threatened Species Conservation Act 1995*), having disappeared from over 80% of its original distribution and with many of its remaining populations being small (White and Pyke 1996; White 1997). However, in Victoria, declines in the species have not been so apparent, and it is not presently considered as either 'vulnerable' or 'endangered' (i.e., under the *Flora and Fauna Guarantee Act 1988*) (Gillespie 1996).

The dramatic decline in the distribution and abundance of *L. aurea* in NSW appears to have resulted from habitat modification and destruction, predation on eggs and tadpoles by the introduced *G. holbrooki*, and possibly disease (e.g., Mahony 1993, 1999, 2001; Daly 1995; Morgan 1995; Goldingay 1996; Mahony 1996; Morgan and Buttemer 1996; Osborne *et al.* 1996; Pyke and White 1996; Gillespie 1997; Tyler 1997; Goldingay and Lewis 1999). In the north-east Gippsland area of Victoria, on the other hand, most of the sites where *L. aurea* occurs are free of *Gambusia*. This fish is abundant to both the north and west of this region (Cadwallader and Backhouse 1983; Gillespie 1996; Pyke and White, unpublished). Perhaps *L. aurea* has declined less in Victoria because of the absence of *G. holbrooki*. No comparison has so far been made between patterns of its habitat-use in areas where it has suffered pronounced decline and those in areas where such declines are not so evident.

The aims of the present study were therefore to compare the patterns of habitat-use shown by *L. aurea* in NSW, Victoria and New Zealand; to compare the patterns of habitat-use determined in this study with those described in the earlier study of Pyke and White (1996); to review the conservation status of this species in Victoria; and to relate its observed patterns of distribution and habitat-use to the distribution of the Plague Minnow.

## Method

Field work for this study was carried out in NSW, Victoria and New Zealand. We used similar methods in Victoria and New Zealand, and so describe those together, with methods for NSW described separately.

For all three regions, recorded frog locations within about 500 m of one another were considered to represent a single "site" as movements of up to 200-300 m are often recorded for this species, whereas movements of greater than 500 m are rarely detected (Pyke and White 2001). The minimum recorded distance between such "sites" was at least 5 km.

The Plague Minnow is one species, *G. holbrooki*, in Australia and another closely related species, *G. affinis*, in New Zealand (McDowall *et al.* 1974; McDowall 1978; Lloyd and Tomasov 1985). We assume that these two species are ecologically equivalent and use the genus name *Gambusia* to refer collectively to them.

All four authors participated in the New Zealand component of this study, whereas the Australian components involved just GP and AW. In both countries a number of volunteers assisted.

### A. Victoria and New Zealand

The Victorian and New Zealand components involved field trips, one to north-east Gippsland in Victoria, Australia (11-18 December 1996) and the other to the North Island of New Zealand (22-29 January 1997). In both cases visits were made to as many as possible of the sites where *L. aurea* had previously been found. We surveyed these sites for the presence of frogs and at each we recorded a number of habitat variables for each site. No rain fell during either of these field trips and temperatures were generally mild to warm (i.e., 15-25 $^0$ C).

We visited 41 of 97 identified *L. aurea* sites in Victoria and 12 of 31 in New Zealand (Tables 1-2). We first identified sites where the species had been recorded using information that was supplied by various Government agencies and from personal contacts or responses to media requests (Appendix). Logistical considerations then determined the sites that we were able to visit (Tables 1-2). Nevertheless, sufficient sites were visited to be able to assess patterns of habitat use.

We adjusted the time spent at each site to ensure a reasonable likelihood of detecting *L. aurea* if it were present, while allowing us to visit several sites each day. We thus spent only about 30

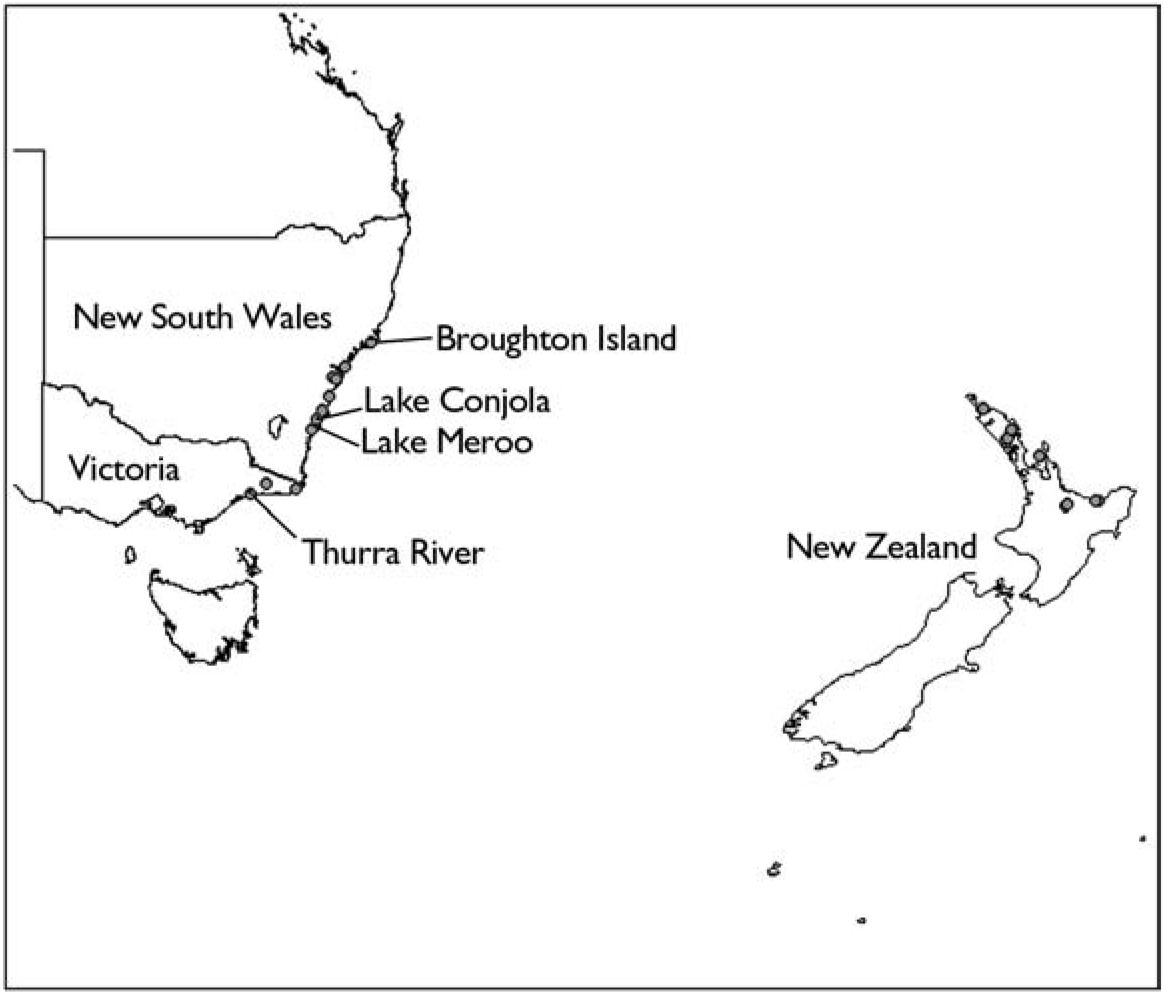


**Figure 1.** Locations of sites in Australia and New Zealand where *L. aurea* was recorded during this study. Sites where frog was found in essentially natural habitat are labelled.

minutes at sites where there was no open water present, but from one to four hours at sites with water, depending on the extent of potential habitat. Almost all surveys were carried out during daylight hours, although we visited one site in New Zealand also during the night. Given this regime, there was considerable variation in the times of day when sites were visited. At each site there were at least five people involved in the survey. With this survey procedure we detected *L. aurea* at 26% of sites in Victoria and New Zealand that had water present (see below).

At each site we visually searched for frogs sitting on reeds or other vegetation, floating in water or present under shelter. We also listened for responses to call imitations. Any frogs seen or heard were identified to species. Hand nets (about 14 x 20 cm in area, with a 40 cm long handle and 2 mm mesh) were used to survey for tadpoles and *Gambusia* whenever water was present. These were dragged for about 1 m through the water at various depths, in open water, around emergent vegetation and under overhanging vegetation with each situation being thus surveyed at least twice. Any captured tadpoles were identified to species and then released. Any captured *Gambusia* were noted and then released. In addition, we visually inspected areas of shallow water adjacent to the bank for the presence of *Gambusia*.

We visited all sites during spring and summer when reproductively active adults of *L. aurea* congregate around breeding ponds (Dankers 1977; Brook 1980; Bell 1982a; Murphy 1994). During this period both males and females of this species are often observed during the day, either in water or sitting on emergent vegetation. In addition, males of this species often call during the day, especially in response to either playing or imitating their call. We should have detected tadpoles of this species if present, because they usually occur in shallow water swimming conspicuously just below the surface and are easily captured with nets (Anstis 1974; Daly 1995). We should similarly have detected

*Gambusia* whenever present, because they too usually occur in shallow water near the surface and typically are very abundant (Pollard *et al.* 1980; Merrick & Gunther 1984; Allen 1989; Webb & Joss 1997). The time of day during daylight hours is not known to influence the results of such surveys.

For each water body we recorded the same general habitat variables as Pyke and White (1996), but with two modifications. We previously used the term "permanent" to refer to water bodies with relatively constant water level (Pyke and White 1996), but this is misleading as many people consider water bodies that fluctuate in water levels but never dry out as "permanent". In the present study, we recorded water level as being constant (C), fluctuating (F) or ephemeral (E). In addition, we previously recorded only the presence of visible signs of pollution, but this approach ignores the likelihood of water pollution resulting from land-use practices within the water catchment. Hence we also recorded any adjacent or nearby land-use practices (such as grazing of livestock) that would be expected to be sources of water pollution and were upstream of the water body. Where such situations occurred we considered that pollution of the water was likely.

We also recorded a number of physical and chemical properties of each water body using a Yeo-kal Series 6000 Water Meter. These included turbidity (nts units), dissolved oxygen (g/litre), oxidation reduction potential (millivolts), salinity (parts per thousand - ppt), pH, conductivity and water temperature.

At sites where we found no water body we recorded any areas within 50 m that showed signs of accumulating water after rain. We inferred that depressions with bottom mud or moist soil, with reeds or other emergent aquatic plants, or with deposited material indicating a previous water line constituted potential breeding sites, as *L. aurea* oviposits in semi-permanent or ephemeral water bodies (e.g., Pyke and White 1996, 2001).

### B. NSW

The third component of the study involved visits to 11 known *L. aurea* sites in NSW that were not included in the earlier study of Pyke and White (1996) (Table 3). All but one of these sites were unknown to us prior to 1994/95 when the earlier study was carried out. The Broughton Island site, though recorded earlier, was omitted for logistical reasons. The visits to these 11 sites either spanned a full year or more at some sites, or occurred during the spring/summer breeding season of *L. aurea* (i.e., September to February) (Table 3). They were all carried out between February 1997 and February 2001 (Table 3). During each visit we recorded the same information as above.

The final component involved recording just the physical and chemical properties of the water and the presence/absence of *L. aurea* tadpoles at one of the NSW sites (Kurnell South) that was included in Pyke and White (1996) (Table 3). This site was included in the present study because the earlier study did not include these physical and chemical water properties, and because frequent visits have now been made to this site at all times of year over a 2-3 year period, enabling water properties to be measured on many occasions when *L. aurea* tadpoles have been present (Table 3).

### C. Analysis

A site was considered to be a breeding site for *L. aurea* if we either heard one or more males of this species calling, observed tadpoles of the species, or observed five or more adults including individuals of both sexes, with males having dark nuptial pads (an indication of current reproductive activity; Hamer 1998; Pyke and White 2001). It is unlikely that frogs could have bred elsewhere and then moved into the site because there was never any other potential breeding area within about 500m, *L. aurea* rarely moves more than about 500m, and they are not known to move in groups (Pyke and White 2001).

We compared patterns of habitat-use that were observed for breeding in Victoria, New Zealand and NSW, and then compared patterns recorded in this study with those previously observed for other NSW sites (Pyke and White 1996). We did not compare breeding and non-breeding sites, as in Pyke and White (1996), because all but one of the sites where we detected *L. aurea* were considered to be breeding sites (see below).We compared the proportions of breeding sites with particular habitat features. As assumptions of the chi-square goodness of fit test were violated, we computed exact probabilities using 5000 iterations of the Monte Carlo simulation technique proposed by Roff and Bentzen (1989). We also compared the observed ranges for each habitat parameter among the three areas. For the purposes of comparison we have included tabulations of data collected as part of the earlier study by Pyke and White (1996).

## Results

Our degree of success in detecting *L. aurea* varied among locations in Victoria, New Zealand and NSW. *Litoria aurea* was found at 4 of 41 sites visited in Victoria, 6 of 12 in New Zealand, and all of the 11 new sites in NSW.

In New Zealand our likelihood of detecting *L. aurea* at the sites we visited was lower when *Gambusia* were present. *Litoria aurea* were detected in 6 of 10 water bodies that apparently lacked *Gambusia*, but were not detected in any of three water bodies where we found *Gambusia* (P = 0.07). *Litoria aurea* had been recorded from these latter water bodies between about 6 and 12 years earlier (Table 2). We did not find *Gambusia* at any sites in Victoria, so *L. aurea* presence or absence in habitats there must be attributed to other factors (Table 1).

Other habitat features also influenced our likelihood of detecting *L. aurea*. *Litoria aurea* were detected only at sites with still, open water, and not at any of the 15 Victorian sites that lacked water at the time of our visit, nor at any of the five Victorian sites that had only flowing water (Table 1). Still, open water was present at all of the sites in New Zealand and NSW that were visited during this study (Tables 3-4).

In New Zealand, *L. aurea* was often the only frog species present at a site (Table 2), whereas in Australia *L. aurea* was generally part of a community of several frog species (Tables 1 and 3; Pyke and White 1996). Of the five sites in New Zealand where we found *L. aurea*, *L. raniformis* was also found at one site and *L. ewingii* was found at another site (Table 2). Other frog species that we found along with *L. aurea* at the four breeding sites in Victoria included *Crinia signifera* (2 sites), *Limnodynastes dumerilii* (1 site) and *Litoria lesueuri* (1 site) (Table 1). In NSW *L. aurea* breeding sites are generally shared with *Crinia signifera* and/or *Limnodynastes peronii* (Table 3; Pyke and White 1996). As many as five other frog species may co-occur with *L. aurea* at its breeding sites in Australia (Table 3; Pyke and White 1996).

At all but one of the 21 sites where we detected *L. aurea*, we also found evidence of breeding. All of the sites in Victoria and NSW, and all but one of the New Zealand sites, were considered to be breeding sites (Tables 1-3).

Across these 20 breeding sites there was little variation in some of the general habitat parameters. All had still water that was either unshaded or only partially shaded (Table 5). Only one had *Gambusia* present, all but one were either ephemeral or fluctuating in water level, all but one had a sand or clay substrate, and all but one included thick, low vegetation as potential shelter (Table 5). Sixteen were largely or completely human-created, all but one of which was judged to receive high levels of human disturbance, and sixteen had emergent aquatic vegetation (Table 5).

In contrast, the 20 sites varied substantially in their other general habitat variables. Many water bodies were, for example, less than 50 cm in maximum depth, but a similar number were greater than 1 m deep (Table 5). Although most water bodies were less than 1000 sq m, some were larger (Table 5). At many sites nearby terrestrial vegetation included bare ground, grassland or forest, and at some sites shrubland and/or woodland of intermediate height was present nearby (Table 5). Sites where water pollution was considered unlikely and sites where it was considered likely were about equally represented (Table 5).

Variation across the 20 breeding sites was very high in all but one of the measured physical and chemical water properties. Observed ranges were 0 to 148 nts for turbidity, 3 to 16 g/l for dissolved oxygen, -531 to +351 millivolts for oxidation reduction potential, 3.7 to 9.8 for pH and 12 to 37 deg. C for water temperature (Table 6). Only for salinity was there relatively little variation with an observed range of 0 to 7.3 ppt (Table 6), which are all low compared with sea-water which has a salinity of about 34 ppt (Pyke unpublished).

There were few apparent differences between the *L. aurea* breeding habitats across the three areas. In NSW, ephemeral and fluctuating water bodies were about equally prevalent, whereas almost all the breeding sites in Victoria and New Zealand had fluctuating water bodies (Table 5). In New Zealand water sources were located in grazing land, natural vegetation or both, whereas in Victoria and NSW there were also other kinds of water sources (Table 5). Most of the New Zealand sites were considered likely to receive polluted water, whereas most of the Victorian and NSW sites were considered to be unpolluted (Table 5). Potential shelter consisted only of thick, low vegetation at the Victorian and New Zealand sites, whereas other kinds of shelter were sometimes available in NSW (Table 5).

Furthermore, the observed habitats at the breeding sites in the present study were similar in most respects to those that were considered in the earlier study of Pyke and White (1996). The proportions of the various habitat conditions were similar between the two studies in terms of the degree to which a site was natural vs artificial, substrate, shade, water flow, water pollution, emergent aquatic plants, potential shelter, the nature of nearby terrestrial vegetation, and presence/absence of *Gambusia* (Table 5), and none of the observed differences between the two studies for these habitat parameters was significant (P's>0.05).

In addition, disturbance was found to be a universal feature of the breeding habitat of *L. aurea*. Across all three regions and both studies, 35 of 39 recorded *L. aurea* breeding sites were artificial habitats that were subject to a high level of anthropogenic disturbance (Table 5; Gillespie 1996). We found evidence of *L. aurea* breeding at only four essentially natural sites in Victoria and NSW (i.e., Victoria: Thurra River; NSW: Lake Meroo, Lake Conjola (Buckley's Point) and Broughton Island; Tables 1, 3 and 5), none in New Zealand (Tables 2 and 5), and none in our earlier study (Pyke and White 1996). The four natural sites also experience disturbance through flooding, drying-out or inundation with sea-water. The sites at Lake Conjola (Buckleys Point), Shoalhaven Heads, Thurra River and Lake Meroo are known to be affected by flooding (White unpublished), while the ponds on Broughton Island occasionally either dry out or are inundated by sea-water during storms (Pyke unpublished). Hence, all of the known breeding sites of *L. aurea* experience high levels of disturbance, either naturally or through human activities.

A few significant differences emerged between the two studies. In the earlier study, there were more breeding sites with ephemeral water bodies than with fluctuating water levels, whereas the reverse held for the present study (Table 1; $P = 0.002$). In the present study most sites received water from natural vegetation, whereas few of the sites in the earlier study did so (Table 1; $P = 0.01$). Also water bodies at breeding sites tended to be shallower in the earlier study than in the present study (Table 1; $P = 0.02$).

## Discussion

The differences between NSW, Victoria and New Zealand in the total numbers of recorded sites for *L. aurea*, and how successful we were at detecting this species when we revisited sites, may reflect differences in the nature and extent of previous survey effort rather than differences in distribution and/or abundance of the species. For NSW, the total number of recorded locations for *L. aurea* (including many where it no longer occurs) is now at least 191 with 163 having been identified in White and Pyke (1996), a further 11 identified in the present study, plus at least another 7 having been discovered during the last two to three years (R. Wellington, NSW National Parks and Wildlife Service, pers. comm. 2001). Here there has been considerable survey effort targeting *L. aurea* over an extended period of time (e.g., Pyke and Osborne 1996). The 11 NSW sites added during this study were the result of recent, targeted surveys that indicated the presence of breeding populations of the species (e.g., Bannerman 1998; Pyke 1999). On the other hand, many of the 97 Victorian *L. aurea* sites have resulted from recent opportunistic observations rather than targeted survey and about 88% were based on single frogs (Table 1; Gillespie 1996; pers. comm.). Furthermore, many were based on observations of frogs found on roads during wet weather and hence may have been of dispersing frogs that were not necessarily close to breeding sites (G. Gillespie, Victorian Department of Natural Resources and Environment, pers. comm. 1997). Such frogs were unlikely to be detected when we revisited the sites during dry weather.

We have identified only 31 *L. aurea* sites in New Zealand, but there has been relatively little interest in the species here and no targeted surveys (Bishop and Waldman unpublished). The recognised geographic range of the species in New Zealand is relatively small, being restricted to the area north of about Rotorua in the North Island, although occasional unconfirmed reports have been obtained further south (Waldman and Bishop unpublished). Additional fieldwork may reveal a larger range. The recorded locations in New Zealand were based on aquatic habitats rather than on frogs found on roads, and this could explain why our rate of success in finding *L. aurea* was higher in New Zealand than in Victoria.

The status of *L. aurea* in Victoria is unclear. There are very few recorded locations for this species in Victoria based on more than one frog having been observed, and only one (Swampland near Sydenham Inlet) was based on over 100 individuals (Gillespie 1996). We found the species at only 4 of the 26 previously recorded sites in Victoria that had still, open water when we revisited them, and at only one of these sites (Tostaree Pilot Farm) did we detect in excess of 10 individuals. Further targeted surveys for this species in Victoria seem warranted.

*Gambusia* may have had a negative impact on the distribution of *L. aurea* in NSW and New Zealand, and could threaten populations of this frog in Victoria. It readily eats the eggs and tadpoles of *L. aurea* when provided with them in the laboratory, and breeding by this frog species is mostly restricted to sites where this fish is absent (Morgan and Buttermer 1996; Pyke and White 1996, 2000; White and Pyke 1996). Its presence was associated with sites in New Zealand where we failed to detect *L. aurea* but where it had been previously recorded. *Gambusia* may be absent from *L. aurea* habitat in

Victoria, but it is abundant in geographically nearby locations (Pyke and White unpublished). Furthermore, given the exceptionally broad habitat tolerances of *Gambusia* (Weatherley and Lake 1967; Arthington and Lloyd 1989; Lloyd *et al.* 1986) and the presence of apparently suitable habitat in Victoria (Pyke and White, unpublished), there would seem to be considerable potential for further spread of this fish into Victorian sites occupied by *L. aurea*.

The observed differences in *L. aurea* habitat in NSW, Victoria, and New Zealand may reflect the relative abundance of habitat types rather than differences in preferred frog habitat. In New Zealand, for example, most recorded sites were in either garden or farmland areas where water bodies tended to be relatively small and shallow. Water in these sites was likely to be affected by pollution via runoff from grazing or human household activities (Tables 4-5). In Victoria, many of the recorded sites are away from urban areas and hence from areas with high levels of habitat disturbance. These sites receive some of their water from areas of natural vegetation rather than from other sources (Tables 4-5). In NSW much of the original *L. aurea* habitat has been affected by urban and industrial expansion and very little remains untouched (Pyke and White 1996, 2001; White and Pyke 1996). Water bodies in NSW, where *L. aurea* occurs, are often near urban areas or areas of bare ground (e.g., quarries, building or industrial sites) (Tables 3 and 5). These areas and studies are therefore combined to revise descriptions of habitat for this species.

Although the present study increases the number of *L. aurea* breeding sites that we have examined from 19 to 39, the general habitat description of breeding habitat has changed little. By combining all results (Table 5), it can be seen that breeding habitat for *L. aurea* generally contains water bodies that are still (i.e., 39/39), small (i.e., 29/39 are <1000 sq. m.), shallow (i.e., 30/39 are <1m), unshaded (i.e., 33/39), free of *Gambusia* (i.e., 32/39), with emergent aquatic vegetation (i.e., 30/39), and with potential shelter provided by nearby rocks or thick, low vegetation (i.e., 38/39). It is also apparent that most of the known current breeding sites for this species are moderately to highly disturbed by human activities (i.e., 32/39). In addition, ponds where *L. aurea* breeds are either semi-permanent with significantly fluctuating water level or are completely ephemeral (i.e., 34/39), rather than being predominantly ephemeral, and have a substrate of sand, rocks or clay (i.e., 34/39), rather than predominantly just sand or rocks, thus expanding upon what was suggested earlier (Pyke and White 1996).

*Litoria aurea* is apparently quite flexible in terms of both the general habitats it uses and its aquatic environment. While sites where *L. aurea* breeds usually have the above characteristics, many pond attributes clearly are not mandatory and the species is able to breed under a wide variety of habitat conditions. It breeds, for example, at some sites where predatory fish are present (introduced *Gambusia* sp. or native *Anguilla* sp.), at some sites which lack emergent aquatic plants, and at some sites where shelter is provided by rocks rather than thick, low vegetation (Table 5). It is apparently similarly flexible in terms of substrate, with no apparently unsuitable substrate type, and in terms of nearby terrestrial vegetation and the source of water at breeding sites (Table 5). The ranges of physical and chemical properties that we have found for water containing *L. aurea* tadpoles are similarly very broad (Table 6).

However, *L. aurea* appears to restrict its breeding habitat to water bodies that are still, sunny and low in salinity. For all 39 *L. aurea* breeding sites that we have observed, water has been still, and at none of these sites has the water body been largely or completely shaded (Table 5). We did not detect this species at sites where the water was either flowing or completely shaded (Table 5). In addition, the maximum observed salinity in water containing *L. aurea* tadpoles was 7.3 ppt (Table 3 and Table 5) and mass tadpole death has been observed on Broughton Island when salinity has increased above this level through intrusion of sea-water into the ponds there (Pyke and White unpubl.). Sea-water has a salinity of about 34 ppt (Pyke unpubl.).

*Litoria aurea* might be considered a “weedy” or “colonizing” species. A high level of disturbance has been found to be a ubiquitous feature of its breeding habitat. It also has relatively high fecundity and dispersal ability and is relatively long-lived (Pyke and White 2001). These traits should enhance its ability to survive periods when conditions are unsuitable for breeding, as well as to colonise and exploit sites when disturbance renders them more suitable for breeding. At present, however, it is not known how disturbance might enhance breeding habitat.

Paradoxically, the frogs most often encountered in New Zealand are all Australian species and, while few Australians have ever encountered either *L. aurea* or *L. raniformis*, they are the only frogs that many New Zealanders have ever seen. The native frog species of New Zealand are generally secretive and have restricted ranges generally far from agricultural or urban landscapes where Australian species frequently thrive and where people generally spend their time (Bell 1982a; Newman 1996; Thurley and Bell 1994; Gill and Whitaker 1996). Thus there is little spatial overlap between the introduced Australian frog species and the New Zealand native frog species, and New Zealand native frogs are seldom encountered (Bell 1982a; Newman 1996). In Australia *L. aurea* and *L. raniformis* are relatively rare, whereas in New Zealand they are locally common and frequently encountered species (Pickard and Towns 1988; Ehmann 1996; Tyler 1997).

New Zealand may provide unique opportunities for further research into the biology of Australian frogs. That Australian frogs are commonly encountered in New Zealand suggests that their population numbers there may be relatively high. Furthermore, unlike Australia where most frog communities involve at least two and often many more frog species (e.g., Tables 1 and 3; Pyke and White 1996), those in New Zealand usually have just a single Australian species and occasionally one or two additional Australian species (e.g., Table 2; Bell 1982b; Pickard and Towns 1988; Pyke and White 1996). In addition, the areas surrounding *L. aurea* and *L. raniformis* sites in New Zealand are generally artificial, usually lack native plants, and hence may be relatively simple in terms of community structure. Hence field manipulations of these species may be readily possible without affecting any New Zealand native plants or animals. Finally, *L. aurea* and *L. raniformis* are presently considered threatened species in Australia and have been given a high level of legal protection under both State and Federal law (e.g., Edgar and Stephens 1993; Lunney and Ayers 1993; Mansergh et al. 1993; White and Pyke 1996), whereas they are unprotected feral species in New Zealand (Pickard and Towns 1988). Hence, it may be possible in New Zealand to study relatively large populations of these Australian frog species in relatively simple communities and habitats that can be experimentally manipulated without legal constraints.

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## References

**Allen, G.R. 1989**. *Freshwater Fishes of Australia*. T.F.H. Publications, Brookvale.

**Anstis, M. 1974**. An introduction to the study of Australian tadpoles. *Herpetofauna* **7:** 9-14.

**Arthington, A.H. and Lloyd, L.N. 1989.** Introduced Poeciliidae in Australia and New Zealand. Pp. 333-348 in *Evolution and Ecology of Livebearing Fishes (Poeciliidae)*, edited by G.K. Meffe, F.F. Snelson. Prentice-Hall, New York.

**Bannerman, M. 1998**. A report on the Green and Golden Bell Frog (*Litoria aurea*) at Davistown and North Avoca.Course Report. Department of Geography. University of Newcastle.

**Barker, J., Grigg, G. C. and Tyler, M. J. 1995**. *A Field Guide to Australian Frogs*. Surrey Beatty & Sons, Sydney.

**Bauer, A.M. and Sadlier, R.A. 2000**. *The Herpetofauna of New Caledonia*. Society for the Study of Amphibians and Reptiles.

**Bauer, A.M., Sadlier, R.A. and Chazeau, J. 1997**. *Litoria aurea* (Green and Golden Bell Frog). *Herpetological Review* **28**: 156.

**Bell, B.D. 1982a**. The amphibian fauna of New Zealand. Pp. 27-89 in *New Zealand Herpetology. NZ Wildlife Service Occasional Publication No. 2.*, edited by D.G. Newman. New Zealand Wildlife Service, Wellington.

**Bell, B.D. 1982b**. New Zealand frogs. *Herpetofauna* **14**: 1-21.

**Brook, A.J. 1980**. The breeding seasons of frogs in Victoria and Tasmania. *Victorian Naturalist* **97:** 6-11.

**Bull, P.C. and Whitaker, A.H. 1975**. The amphibians, reptiles, birds and mammals. Pp. 231-276 in *Biogeography and ecology in New Zealand,* edited by G. Kuschel. Junk, The Hague.

**Cadwallader, P.L. and Backhouse, G.N. 1983**. *A Guide to the Freshwater Fish of Victoria.* Victorian Government Printing Office, Melbourne.

**Cogger, H.G. 2000**. *Reptiles and Amphibians of Australia.* 6th ed. Reed New Holland, Sydney.

**Daly, G. 1995**. Observations on the Green and Golden Bell-Frog *Litoria aurea* (Anura: Hylidae). *Herpetofauna* **25:** 2-9.

**Dankers, N.M.J.A. 1977**. The Ecology of an Anuran Community. Ph.D. Dissertation, University of Sydney, Sydney. 246 p.

**Edgar, B. and Stephens, S. 1993**. Commonwealth legislation relevant to reptiles and amphibians. Pp. 39-42 in *Herpetology in Australia. A Diverse Disclipine*, edited by D. Lunney and D. Ayers. Royal Zoological Society of NSW, Sydney.

**Ehmann, H. (Ed.) 1996**. *Threatened Frogs of NSW: Habitats, Status and Conservation.* Frog and Tadpole Study Group of NSW, Sydney. 237 pages.

**Fletcher, J.J. 1889**. Observations on the oviposition and habits of certain Australian batrachians. *Proceedings of the Linnaean Society of NSW* **4:** 357-387.

**Gibbons, J.R.H. 1985.** The biogeography and evolution of Pacific Island reptiles and amphibians. Pp. 125-142 in *Biology of Australasian Frogs and Reptiles*, edited by G. Grigg, R. Shine and H. Ehmann. Surrey Beatty & Sons Pty Ltd, Sydney.

**Gill, B. and Whitaker, T. 1996**. *New Zealand Frogs and Reptiles*. David Bateman, Auckland.

**Gillespie, G. 1992.** Survey for the Spotted Tree Frog (*Litoria spenceri*) in Victoria, February-March 1992. *Victorian Naturalist* **109:** 203-211.

**Gillespie, G.R. 1996**. Distribution, habitat and conservation status of the Green and Golden Bell Frog *Litoria aurea* (Lesson 1829) (Anura: Hylidae) in Victoria. *Australian Zoologist* **30:** 199-207.

**Gillespie, G. 1997**. Impact of introduced fish on frog populations in Australia. Abstract for National Threatened Frog Workshop. Canberra 12-13 Nov 97.

**Gillespie, G.R. and Hollis, G.J. 1996**. Distribution and habitat of the Spotted Tree Frog, *Litoria spenceri* Dubois (Anura: Hylidae), and an assessment of potential causes of population declines. Wildlife Research **23:** 49-75.

**Gillespie, G. and Robertson, P. 1996**. Recovery plan (Research phase) for the Spotted Tree Frog. Annual Report to April 1996. Report prepared for ANCA Endangered Species Program.

**Goldingay, R.L. 1996**. The Green and Golden Bell Frog *Litoria aurea* - from riches to ruins: conservation of a formerly common species. *Australian Zoologist* **30:** 248-256.

**Goldingay, R. and Lewis, B. 1999**. Development of a Conservation Strategy for the Green and Golden Bell Frog in the Illawarra Region of NSW. *Australian Zoologist* **30:** 248-256.

**Hamer, A.J. 1998**. Aspects of the ecology of the Green and Golden Bell Frog (*Litoria aurea*) on Kooragang Island, NSW, Australia. M.Sc. Thesis, University of Newcastle, Newcastle, NSW.

**Healey, M,, Thompson, D. and Robertson, A. 1997**. Amphibian communities associated with billabong habitats on the Murrumbidgee floodplain, Australia. *Australian Journal of Ecology* **22**: 270-278.

**Lemckert, F. 1999**. Impacts of selective logging on frogs in a forested area of northern New South Wales. *Biological Conservation* **89**: 321-328.

**Lloyd, L.N., Arthington, A.H. and Milton, D.A. 1986**. The mosquitofish - a valuable mosquito-control agent or a pest? Pp. 6-25 in *The Ecology of Exotic Animals and Plants. Some Australian Case Histories,* edited by R.L. Kitching. John Wiley and Sons, Brisbane.

**Lloyd, L.N. and Tomasov, J.F. 1985**. Taxonomic status of the Mosquitofish, *Gambusia affinis* (Poeciliidae), in Australia. *Australian Journal of Freshwater Research* **36:** 447-451.

**Lunney, D. and Ayers, D. 1993**. The official status of frogs and reptiles in NSW. Pp. 404-408 in *Herpetology in Australia. A Diverse Discipline*, edited by D. Lunney and D. Ayers. Royal Zoological Society of NSW, Mosman.

**McCann, C. 1961**. The introduced frogs of New Zealand. *Tuatara* **8:** 107-120.

**McDowall, R.M. 1978**. *New Zealand Freshwater Fishes a guide and natural history*. Heinemann Educational Books (NZ), Auckland.

**McDowall, R.M., Hopkins, C.L. and Flain, M. 1974.** Fishes. PP. 292-308 in *New Zealand Lakes. Fisheries Research Publication No. 240,* edited by V.H. Jolly, C.L. Hopkins and M. Flain. Auckland University Press/Oxford University Press, Auckland.

**Mahony, M.J. 1993**. The status of frogs in the Watagan Mountains area of the Central Coast of NSW. Pp. 257-264 in *Herpetology in Australia. A Diverse Discipline,* edited by D. Lunney and D. Ayers. Royal Zoological Society of NSW, Sydney.

**Mahony, M. 1996**. The decline of the Green and Golden Bell Frog *Litoria aurea* viewed in the context of declines and disappearances of other Australian frogs. *Australian Zoologist* **30:** 237-247.

**Mahony, M. 1999**. Review of the declines and disappearances within the bell frog species group (*Litoria aurea* species group) in Australia. Pp. 81-93 in *Declines and Disappearances of Australian frogs*., edited by A. Campbell. Environment Australia, Canberra.

**Mahony, M. 2001**. Chytrid disease in frog populations in eastern NSW. Pp. 27-37 in *Frog Disease and Frog Hygeine,* edited by A.W. White. Frog and Tadpole Study Group of NSW, Sydney.

**Mansergh, I., Davey, G. and Robertson, P. 1993**. Reptiles and amphibians of Victoria - legislation. Pp. 373-376 in *Herpetology in Australia. A Diverse Discipline*, edited by D. Lunney and D. Ayers. Royal Zoological Society of NSW, Sydney.

**Merrick, J.R. and Gunther, E.S. 1984**. *Australian Freshwater Fishes Biology and Management*. Griffin Press, Netley, South Australia.

**Morgan, L.A. 1995**. An analysis of the impact of predation by *Gambusia holbrooki* on *Litoria aurea* tadpoles. B.Env.Sci. (Hons) Thesis, University of Wollongong: Wollongong. 69 p.

**Morgan, L.A. and Buttemer, W.A. 1996**. Predation by the non-native fish *Gambusia holbrooki* on small *Litoria aurea* and *L. dentata* tadpoles. *Australian Zoologist* **30:** 143-149.

**Murphy, M.J. 1994**. Reptiles and amphibians of Seven Mile Beach National Park. *Herpetofauna* **24:** 24-30.

**Newman, D.G. 1996**. Native Frog (*Leiopelma* spp.) Recovery Plan. Threatened Species Recovery Plan No. 18. New Zealand Department of Conservation, Wellington.

**Osborne, W.S., Littlejohn, M.J. and Thomson, S.A. 1996**. Former distribution and apparent disappearance of the *Litoria aurea* complex from the Southern Tablelands of NSW and the Australian Capital Territory. *Australian Zoologist* **30:** 190-198.

**Parris, K.M. 2001.** Distribution, habitat requirements and conservation of the cascade treefrog (*Litoria pearsoniana*, (Anura: Hylidae). *Biological Conservation* **99:** 285-292.

**Pickard, C.R. and Towns, D.R. 1988**. *Atlas of the Amphibians and Reptiles of New Zealand. Conservation Sciences Publication Number 1*. Science and Research Directorate, Dept of Conservation., Wellington.

**Pollard, D.A., Llewellyn, L.C. and Tilzey, R.D.J. 1980**. Management of freshwater fish and fisheries. Pp. 227-270 in *An Ecological Basis for Water Resource Management*, edited by W.D. Williams. Australian National University Press, Canberra.

**Pyke, G.H. 1999**. The Green and Golden Bell Frog. *Nature Australia* **Autumn 99:** 48-59.

**Pyke, G.H. and Osborne, W.S. (eds) 1996**. The Green and Golden Bell Frog *Litoria aurea* Biology and Conservation. *Australian Zoologist* **30**.

**Pyke, G.H. and White, A.W. 1996**. Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* (Anura: Hylidae). *Australian Zoologist* **30:** 224-232.

**Pyke, G.H. and White, A.W. 2000**. Factors influencing predation on eggs and tadpoles of the endangered Green and Golden Bell Frog *Litoria aurea* by the introduced Plague Minnow *Gambusia holbrooki*. *Australian Zoologist* **31:** 496-505.

**Pyke, G.H. and White, A.W. 2001.** A review of the biology of the Green and Golden Bell Frog *Litoria aurea*. *Australian Zoologist* **31**: 563-598.

**Robinson, M. 1993**. *A Field Guide to Frogs of Australia. From Port Augusta to Fraser Island including Tasmania*. Australian Museum/Reed, Sydney. 112 pages.

**Roff, D.A. and Bentzen, P. 1989.** The statistical analysis of mitochondrial DNA polymorphisms: $\div^2$ and the problem of small sample sizes. *Molecular Biology and Evolution* **6**: 539-545.

**Soulé, M.E. (Ed) 1986**. *Conservation Biology: The Science of Scarcity and Diversity.* Sinauer Associates, Sunderland, Massachusetts. 584 pages.

**Thurley, T. and Bell, B.D. 1994**. Habitat distribution and predation on a western population of terrestrial *Leiopelma* (Anura: Leiopelmatidae) in the northern King Country, New Zealand. *New Zealand Journal of Zoology* **21**: 431-436.

**Tyler, M.J. 1976**. *Frogs.* Collins, Sydney.

**Tyler, M.J. 1979**. The introduction and current distribution in the New Hebrides of the Australian hylid frog *Litoria aurea*. *Copeia* **1979:** 355-356.

**Tyler, M.J. 1997**. *The Action Plan for Australian Frogs.* Wildlife Australia, Canberra. 77 pages

**Weatherley, A.H. and Lake, J.S. 1967**. Introduced fish species in Australian inland waters. Pp. 217-239 in *Australian Inland Waters and their Fauna,* edited by A.H. Weatherley. Australian National University Press, Canberra.

**Webb, C. and Joss, J. 1997**. Does predation by the fish *Gambusia holbrooki* (Atheriniformes: Poeciliidae) contribute to declining frog populations? *Australian Zoologist* **30:** 316-323.

**White, A.W. 1997.** Green and Golden Bell Frog, *Litoria aurea*. Pp. 148-155 in *Threatened Frogs of NSW: Habitats, Status and Conservation*, edited by H. Ehmann. Frog and Tadpole Study Group of NSW, Sydney.

**White, A.W. and Pyke, G.H. 1996.** Distribution and conservation status of the Green and Golden Bell Frog *Litoria aurea* in NSW. *Australian Zoologist* **30:** 177-189.

**Table 1.** Sites visited in Victoria. All locations are in AMG Zone 55.

| Site Name | Map Grid Reference | Elevation (m) | Previous *L. aurea* Records | Present *L. aurea* Observations | Other Frog Species Detected | Nature of Water Bodies Present | Gambusia Present? |
|---|---|---|---|---|---|---|---|
| Sandy Waterhole Creek | E7297 N58589 | 160 | 1981 | | | Slow flow | No |
| Nash Camp | E7279 N58536 | 130 | 1991/92 | | | Still | No |
| Wallagaraugh | E7382 N58498 | 0 | 1991/92 | | | Still | No |
| Tobins Creek | E7254 N58479 | 40 | 1968 | | | None | No |
| Genoa | E7296 N58486 | 40 | 1990 | | | Still | No |
| Cape Conran Quarry | E6523 N58173 | 20 | 1990 and 1992 | Tadpoles | *Crinia signifera* | Still | No |
| West Yeerung | E6562 N58243 | 90 | 1990/91 | | *Litoria phyllochroa* | Moderate flow | No |
| Cape Conran | E6527 N58589 | 15 | 1990/91 and | | *Litoria ewingii* | Still | No |
| Point Ricardo | E6423 N58147 | 35 | 1990/91 | | | None | No |
| Wongabeena | E6441 N58154 | 35 | 1990/91 | | | Still | No |
| Marlo Plains | E6451 N58164 | 35 | 1990/91 | | *Litoria peronii* *Crinia signifera* | Still | No |
| Scrubby Creek | E7281 N58482 | 10 | 1988/89 | | | Still | No |
| Genoa Peak Road #1 | E7279 N58476 | 20 | 1988/89 | | | Moderate flow | No |
| Genoa Peak Road #2 | E7299 N58449 | 240 | 1988/89 | | | None | No |
| Mallacoota Airport | E7403 N58351 | 25 | - | Five males calling; 1 female captured | *Crinia signifera* | Still | No |
| Burglar Gap | E7182 N58576 | 120 | 1984/85 | | | None | No |
| Three Sisters | E6832 N58615 | 690 | 1995/96 | | | Still | No |
| Pettmans Beach | E6044 N58123 | 5 | 1992/93 | | | Still | No |
| Morass Break | E6026 N58130 | 30 | 1992/93 | | *Crinia signifera* *Litoria peronii* | Still | No |
| Hospital Creek | E6079 N58162 | 5 | 1992/93 | | | Still | No |
| Old Orbost Track | E6024 N58158 | 60 | 1992/93 | | | None | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tostaree Pilot Farm | E6046 N58173 | 50 | 1992/93 | At least 30 adults observed; males calling; tadpoles observed | *Crinia signifera* *Limnodynastes dumerilii* | Still | No |
| Montas Break | E6047 N58161 | 60 | 1992/93 | | *Paracrinia haswelli* *Litoria peronii* *Limnodynastes dumerilii* *Litoria ewingii* | Still | No |
| Bonang Highway | E6303 N58308 | 60 | 1991/92 | | | None | |
| Tostaree | E6035 N58211 | 35 | 1992/93 | | *Crinia signifera* | Still | No |
| Lake Beatle | E6246 N58178 | 50 | 1992/93 | | *Crinia signifera* *Limnodynastes dumerilii* *Litoria ewingii* | Still | No |
| Little Lake Beatle | E6240 N58169 | 25 | 1992/93 | | *Litoria ewingii* *Limnodynastes dumerilii* *Uperoleia tyleri* | Still | No |
| Ewing Marsh | E6235 N58126 | 5 | 1992/93 | | | Still | No |
| Gippsland Railway | E6179 N58208 | 15 | 1992/93 | | | None | |
| Simpsons Creek Road | E6172 N58206 | 40 | 1992/93 | | | None | |
| Princes Hwy #1 | E6071 N58207 | 55 | 1992/93 | | | None | |
| Princes Hwy #2 | E6152 N58203 | 50 | 1992/93 | | | None | |
| Princes Hwy #3 | E6142 N58205 | 25 | 1992/93 | | | None | |
| Wombat Track | E6132 N58204 | 40 | 1992/93 | Adults observed and Males calling | | None | |
| Thurra River | E6026 N58158 | 20 | None recorded | | *Litoria lesueuri* | Still | No |
| Reedy Creek | E6936 N58368 | 200 | 1991/92 | | *Litoria phyllochroa* | Moderate flow | No |
| Thurra Road | E6904 N58283 | 110 | 1991/92 | | | None | |
| Gibbs Creek | E6912 N58244 | 95 | 1991/92 | | *Litoria phyllochroa* | Moderate flow | No |
| Tamboon | E6899 N58205 | 140 | 1991/92 | | | None | |
| Tamboon River | E6882 N58227 | 5 | 1991/92 | | | Still | No |
| Bobs Bay | E6734 N58201 | 2 | 1990/91 | | *Crinia signifera* | Still | No |
| Bemm River | E6719 N58201 | 5 | 1990/91 | | | None | |
| Pearl Point | E6705 N58170 | 5 | 1990/91 | | | Still | No |

**Table 2:** Sites visited in New Zealand

| Site Name | Map Grid Reference | Elevation (m) | Previous *L. aurea* Records | Present Observations of *L. aurea* and Other Frog Species | Comments re *Gambusia* |
|---|---|---|---|---|---|
| Tauraroa | E2620, N65888 | 60 | *L. aurea* recorded in 1991/92 | No tadpoles or frogs | *Gambusia* abundant |
| Waiotira #'s 1, 2 and 3 | E2618, N65855 | 100 | *L. aurea* recorded in 1991/92 and earlier at #'s 1 and 2 | No tadpoles or frogs at #'s 1 and 2; tadpoles of *L. aurea* and *L. ewingii* at #3 | *Gambusia* abundant at #1 and no *Gambusia* recorded at #'s 2 and 3 |
| Glenbervie Forest | E2630, N66218 | 220 | *L. aurea* recorded in 1992 | Tadpoles, metamorphs and immatures of *L. aurea* | No *Gambusia* recorded |
| Lake Waiporohita | E2643, N67000 | 10 | *L. aurea* recorded in 1985/86 | No tadpoles or frogs | *Gambusia* abundant |
| Tokerau Beach | E2545, N66953 | 10 | *L. aurea* recorded and date unknown | Frogs of *L.aurea* and *L. raniformis* observed; 11 *L. aurea* captured, including 7 males in present or post-reproductive condition and 4 mature females | No *Gambusia* recorded |
| Fletcher Bay #1 | E2725, N65214 | 10 | *L. aurea* recorded in 1989 | *L. aurea* tadpoles. | No *Gambusia* recorded |
| Fletcher Bay #2 | E2725, N65218 | 10 | *L. aurea* recorded in 1989 | Tadpoles and frogs of *L. aurea*. | No *Gambusia* recorded |
| Port Jackson | E2720, N65213 | 10 | *L. aurea* recorded in 1989 | *L. aurea* frogs | No *Gambusia* recorded |
| Opotiki | E2893, N63429 | 10 | *L. aurea* recorded in 1995/96 | No tadpoles or frogs | No *Gambusia* recorded |
| Waioeka River | E2887, N63245 | 10 | *L. aurea* recorded and date unknown | No tadpoles or frogs | No area of still or slow water |
| Kapenga Swamp | E2793, N63244 | 360 | *L. aurea* recorded in 1982 | No tadpoles or frogs | No *Gambusia* recorded |
| Rotorua | E2794, N63392 | 270 | *L. aurea* recorded and date unknown | No tadpoles or frogs | No *Gambusia* recorded |

**Table 3.** Habitat information for *L. aurea* breeding sites in NSW (See Pyke and White 1996 for habitat information for Kurnell Site) and physical/chemical properties of water containing *L. aurea* tadpoles. All locations are in AMG Zone 56.

| Site Name | Meroo Lake | Currumbene | Merrylands | Lake Conjola – Buckleys Point | Lake Conjola – Pattimores Lagoon | Broughton Island ponds | North Avoca | Durras North | Pt. Kembla Steelworks | Coomaditchy | Marrickville | Kurnell |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | Natural coastal wetland | Disused clay quarry | Disused clay quarry | Series of natural dune swale ponds | Artificial pondage created by embankment | Natural ponds adjacent to ocean | Artificial pondage created by embankment adjacent to coastal lagoon | Dam | Artificial pond | Semi -natural wetland surrounded by parkland & suburbia | Artificial pond in small suburban nursery | * |
| **Map Grid Reference** | E2629 N60702 | E2878 N61290 | E3143 N62545 | E2707 N60919 | E2709 N60925 | E4364 N63911 | E3542 N62961 | E2554 N60527 | E3062 N61831 | E3070 N61814 | E3299 N62469 | * |
| **Elevation** | 5 | 40 | 40 | 5 | 20 | 5 | 5 | 15 | 10 | 20 | 20 | * |
| **Survey Dates** | Nov '99 & Feb '00 | Sept '99 | Jan '00 | Jan '00 | Feb '98 | March '98 – March '00 | Nov-Dec '98 | Dec '96 | Dec '96 | Jan '96 | Feb '99 – Feb '00 | Oct '98 -Jan '00 |
| **Record** | Calling males & tadpoles | Calling males | Tadpoles | Calling males & tadpoles | Calling males | Calling males & tadpoles | Calling males & tadpoles | Calling males & tadpoles | Calling males & tadpoles | Calling males & tadpoles | Calling males & tadpoles | Calling males & tadpoles |
| **Substrate** | Sand | Clay | Clay | Sand | Sand | Rock | Sand | Sand | Concrete | Sand | Clay | * |
| **Water Source** | Vegetation | Vegetation | Vegetation Bare Ground | Vegetation | Vegetation | Vegetation | Vegetation Urban | Vegetation | Industrial Bare ground | Parkland Urban | Town | * |
| **Water Area (sq.m.)** | 60 | 150 | 40 | 2000 | 120 | 0.1-25 | 1600 | 2800 | 400 | 15,000 | 50 | * |
| **Maximum Depth (cm)** | 35 | 200 | 15 | 55 | 45 | 45 | 70 | ~400 | >1m | >2m | 60 | * |
| **Rate of Water Flow** | Still | Still | Still | Still | Still | Still | Still | Still | Still | Still | Still | * |
| **Water Level** | E | F | E | E | F | E | E | F | F | F | F | * |
| **Shade** | Partial | None | None | Partial | None | None | Partial | None | None | None | Partial | * |
| **Emergent Aquatic Vegetation** | *Juncus sp.* | *Typha sp.* *Eleocharis sp.* | *Typha sp.* *Juncus sp.* | *Schoenoplectus sp.* | *Typha sp.* *Juncus sp.* | Mostly none & one has *Phragmites sp.* | *Phragmites sp.* | None | *Typha sp.* *Cyperus sp.* | *Typha sp.* *Eleocharis sp.* | *Typha sp.* | * |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Terrestrial Vegetation within 50m** | Woodland | Forest Shrubland Bare Ground | Shrubland Bare Ground | Forest | Grassland | Shrubland Bare Ground | Grassland Woodland Garden | Garden | Bare ground Industrial & | Grassland | Bare Ground Garden | * |
| **Pollution** | None | None | None | None | Garbage | None | Urban | None | Garbage | Garbage | None | * |
| **Potential Shelter** | Vegetation | Vegetation | Vegetation Rocks Timber Artificial | Vegetation | Vegetation Artificial | Vegetation | Vegetation Artificial | Vegetation Artificial | Vegetation Rocks | Vegetation | Vegetation | * |
| **Human Disturbance** | None | High | High | None | High | None | High | High | High | Medium | High | * |
| **Other Frog Species** | *Litoria dentata Limnodynastes peronii Crinia signifera* | *Litoria peronii Limnodynastes peronii* | *Litoria peronii Limnodynastes peronii Crinia signifera* | *Limnodynastes peronii Crinia signifera Pseudophryne bibroni* | *Limnodynastes peronii Crinia signifera* | *Limnodynastes peronii* | *Litoria peronii L. tyleri L. dentata L. caerulea Limnodynastes peronii* | *Litoria peronii Limnodynastes peronii Crinia signifera Uperoleia laevigata* | None recorded | None recorded | *Limnodynastes peronii* | * |
| **Predatory Fish** | *Anguilla sp.* | None | None | None | None | None | None | None | None | *Gambusia* | None | * |
| **Turbidity (nts)** | 2-52 | | 6 | | | 0-146 | 19-31 | 1 | 3 | 17 | 34-89 | 2-148 |
| **Dissolved Oxygen (g/l)** | 4.4-12.8 | | 4.2 | | | 3.3-16.0 | 3.3-9.1 | 7.2 | 3.8 | 1.0 | 4.0-10.5 | 3.4-14.6 |
| **ORP (mvolts)** | 41-119 | | 117 | | | -531-351 | 143-192 | 75 | 49 | 77 | 32-156 | -11-148 |
| **pH** | 6.7-7.7 | | 6.5 | | | 5.7-9.8 | 5.7-6.7 | 7.1 | 8.3 | 8.2 | 6.0-7.6 | 5.4-9.1 |
| **Salinity (ppt)** | 0.1-0.9 | | 0.1 | | | 0.2-7.3 | 3.1-6.0 | 0.7 | 0.1 | 0.1 | 0.1-0.4 | 0.0-1.2 |
| **Water Temp (deg.C)** | 16-22 | | 21 | | | 19-37 | 22-25 | 22 | 23 | 24 | 14-27 | 12-33 |

**Table 4.** Habitat information and physical/chemical properties of water for *L. aurea* breeding sites in Victoria and New Zealand

| REGION | VICTORIA | | | | VICTORIA | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Site Name** | Cape Conran Quarry | Tostaree Pilot Farm | Thurra River | Mallacoota Airport | Waiotira #3 | Glenbervie Forest | Tokerau Beach | Fletcher Bay #1 | Fletcher Bay #2 |
| **Description** | Disused rock quarry | Dam | Natural wetland adjacent to river | Dam | Dam | Dam | Dam | Cattle water trough | Small pondage on cleared grazing land |
| **Substrate** | Rock | Clay | Sand | Sand | Clay | Clay | Sand | Concrete | Sand |
| **Water Source** | Vegetation BareGround | Grazing | Vegetation | Parkland | Grazing | Vegetation | Grazing | Vegetation | Grazing |
| **Water Area (sq.m.)** | 900 | 3,000 | 15,000 | 2,800 | 800 | 10,000 | 200 | 1 | 100 |
| **Maximum Depth (cm)** | 30 | >1m | 40 | >1m | >1m | >7m | 50 | 40 | 40 |
| **Rate of Water Flow** | Still | Still | Still | Still | Still | Still | Still | Still | Still |
| **Water Level** | E | F | F | F | F | C | F | F | F |
| **Shade** | None | None | None | None | None | None | None | None | None |
| **Emergent Aquatic Vegetation** | *Schoenoplectus sp.* *Cyperus sp.* | *Eleocharis sp.* | *Phragmites sp.* *Cyperus sp.* | *Eleocharis sp.* | *Azolla sp.* *Juncus sp.* *Alisma sp.* | *Eleocharis sp.* | None | None | *Cyperus sp.* |
| **Terrestrial Vegetation within 50m** | Forest and Bare Ground | Grassland | Forest | Forest | Grassland | Forest and Shrubland | Grassland | Grassland | Grassland |
| **Pollution** | None | Grazing | None | None | Grazing | None | Grazing | Grazing | Grazing |
| **Potential Shelter** | Vegetation | Vegetation | Vegetation | Vegetation | Vegetation | Vegetation | Vegetation | Vegetation | Vegetation |
| **Disturbance** | High | High | None | High | High | High | High | High | High |
| **Predatory fish** | None | None | None | None | None | None | None | None | None |
| **Turbidity (nts)** | 27.5 | 4.5 | | | 17.6 | 3.6 | | 103.2 | 119.3 |
| **Dissolved Oxygen (g/l)** | 7.0 | 7.1 | | | 8.7 | 6.7 | | 9.1 | 5.4 |
| **Oxidation Reduction Potential (mvolts)** | 275 | 105 | | | 86 | 112 | | 152 | 65 |
| **pH** | 4.4 | 6.6 | | | 7.8 | 5.7 | | 9.5 | 6.4 |
| **Salinity (ppt)** | 0 | 0.2 | | | 0 | 0 | | 0 | 0 |
| **Water Temperature (deg. C.)** | 31 | 23 | | | 26 | 23 | | 22 | 24 |

**Table 5.** Summaries of habitat characteristics for breeding sites of *L. aurea* in NSW, Victoria and New Zealand. Values are numbers of sites.

| Parameter | Category | NSW (from Pyke and White 1996) | NSW (this study) | Victoria | New Zealand | NSW, Victoria and New Zealand (this study) |
|---|---|---|---|---|---|---|
| **Natural vs. artificial** | Mostly or completely natural | 2 | 3 | 1 | 0 | 4 |
| | Largely or entirely human-created | 17 | 8 | 3 | 5 | 16 |
| **Human disturbance** | High | 8 | 7 | 3 | 5 | 15 |
| | Medium | 8 | 1 | | | 1 |
| | None | 3 | 3 | 1 | | 4 |
| **Substrate** | Sand | 10 | 6 | 2 | 2 | 10 |
| | Clay | 4 | 5 | 1 | 2 | 9 |
| | Rock | 1 | | 1 | | |
| | Concrete | 2 | | | 1 | 1 |
| | Rubble | 2 | | | | |
| **Shade** | None | 17 | 7 | 4 | 5 | 16 |
| | Partial | 2 | 4 | | | 4 |
| | Complete | | | | | |
| **Water Level** | Ephemeral | 12 | 5 | 1 | | 6 |
| | Fluctuating | 3 | 6 | 3 | 4 | 13 |
| | Constant | 4 | | | 1 | 1 |
| **Water Flow** | Still | 19 | 11 | 4 | 5 | 20 |
| | Slow | | | | | |
| | Rapid | | | | | |
| **Water Source** | Bare Ground | 8 | 2 | 1 | | 3 |
| | Parkland | 5 | 1 | 1 | | 2 |
| | Grazing | 4 | | 1 | 3 | 4 |
| | Natural Vegetation | 2 | 8 | 2 | 2 | 12 |
| | Urban | 7 | 2 | | | 2 |
| | Industrial | 1 | 1 | | | 1 |
| **Pollution** | None | 8 | 7 | 3 | 1 | 11 |
| | Likely | 11 | 4 | 1 | 4 | 9 |
| | Grazing | 3 | | 1 | 4 | 5 |
| | Urban | 8 | 1 | | | 1 |
| | Industrial | | 1 | | | 1 |
| | Garbage | 1 | 3 | | | 3 |
| **Max. Water Depth (cm)** | 0-50 | 11 | 4 | 2 | 3 | 9 |
| | 50-100 | 7 | 3 | | | 3 |
| | >100 | 1 | 4 | 2 | 2 | 8 |
| **Water Surface Area (sq. m.)** | 0-100 | 9 | 4 | | 2 | 6 |
| | 101-1000 | 8 | 3 | 1 | 2 | 6 |
| | >1000 | 2 | 4 | 3 | 1 | 8 |
| **Nearby Terrestrial Vegetation** | Bare Ground | 8 | 5 | 1 | | 6 |
| | Garden | 6 | 3 | | | 3 |
| | Grassland G | 9 | 2 | 1 | 4 | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heathland | 1 | | | | |
| | Shrubland | 6 | 3 | | 1 | 4 |
| | Woodland | 3 | 2 | | | 2 |
| | Forest | | 2 | 3 | 1 | 6 |
| | Present | 14 | 9 | 4 | 3 | 16 |
| **Emergent Aquatic Plants** | Absent | 5 | 2 | | 2 | 4 |
| | *Typha sp.* | 11 | 5 | | | 5 |
| | *Eleocharis sp.* | 4 | 1 | 2 | 1 | 4 |
| | *Juncus sp.* | 2 | 3 | | 1 | 4 |
| | *Phragmites sp.* | 1 | | 1 | | 1 |
| | *Schoenoplectus sp.* | | 1 | 1 | | 1 |
| | *Cyperus sp.* | | 1 | 2 | 1 | 4 |
| | Low Vegetation | 16 | 10 | 4 | 5 | 19 |
| **Potential Shelter** | Rocks | 3 | 2 | | | 2 |
| | Timber | | 1 | | | 1 |
| | Artificial | 4 | 4 | | | 4 |
| | Not recorded | 14 | 9 | 4 | 5 | 18 |
| **Predatory Fish** | Recorded | 5 | 2 | | | 2 |
| | *Gambusia* recorded | 5 | 1 | | | 1 |
| | *Anguilla* recorded | | 1 | | | 1 |

**Table 6:** Comparison of physical/chemical properties of water containing *L. aurea* tadpoles in NSW, Victoria and New Zealand.

| Region | NSW | Victoria | New Zealand |
|---|---|---|---|
| Turbidity (nts) | 0-148 | 5-28 | 4-119 |
| Dissolved Oxygen (g/l) | 3-16 | 7 | 5-9 |
| ORP (millivolts) | -531 – 351 | 105-275 | 65-152 |
| pH | 5.4-9.8 | 3.7-6.6 | 5.7-9.5 |
| Salinity (ppt) | 0.1-7.3 | 0-0.2 | 0 |
| Water Temperature (Deg. C) | 12-37 | 23-31 | 22-26 |
| Number of sites | 8 | 2 | 4 |

APPENDIX

## Appendix: Description of how location records for *L. aurea* were obtained and selected.

We obtained information about the known *L. aurea* sites in Victoria from a variety of sources. In August 1996 the Victorian Department of Natural Resources and Environment provided us with a copy of all records of *L. aurea* in the Atlas of Victorian Wildlife. This yielded 120 records, representing 94 distinct sites. In November 1996 we obtained location information for *L. aurea* specimens held by both the Australian Museum and the Victorian Museum. This yielded 3 records from 2 sites for the Australian Museum collection and 73 records from 26 sites for the Victorian Museum collection. All but one of these Museum records were included in the Atlas of Victorian Wildlife data, and this one record was from a suburb of Melbourne and was considered to be probably an animal that had escaped from captivity. During and before our trip to Victoria we learnt about a further three recorded sites via personal communication. For our fieldtrip in Victoria we therefore targeted the sites in the Atlas of Victorian Wildlife plus these three additional sites, for a total of 97 sites.

We obtained information about known *L. aurea* sites in New Zealand from similar sources. In late 1996 the New Zealand Department of Conservation provided us with all the reliable *L. aurea* records contained in its Amphibian and Reptile Distribution Database. This resulted in 31 distinct site records covering the period 1982-1993. Although this database, which was originally known as Biosite, had been maintained since 1951, it relied heavily on volunteers who did not distinguish *L. aurea* and *L. raniformis* before 1982 (Bell 1982a,b) and from 1993 until 1999 the database was poorly maintained with no *L. aurea* records being added during this period. All of the records were from the North Island, except for a single record from the northern part of the South Island, which may have been the result of a misidentification as a survey of the site in 1997 yielded specimens only of *Litoria ewingii* (Bishop and Waldman unpublished). In 1996, following press releases asking for information regarding current frog distributions, many letters were received containing descriptions of frog observations. By the end of 1996 this had generated an additional 15 recorded *L. aurea* sites, of which we considered three to be reliable.

We located and surveyed 41 of the 97 targeted sites in Victoria (Table 1). We attempted to locate 61 of the 75 sites east of Lake Tyers, with time constraints preventing us from surveying 22 sites that were further west and from surveying 14 sites that were less readily accessible. There were also 20 sites that we could not confidently find, because their site coordinates were recorded only by latitude and longitude in degrees and minutes and were clearly approximations, as evidenced by the fact that some of them fell within seawater at some distance from dry land. We were able to find locations where Australian Map Grid reference coordinates were available.

For the purposes of the present study we chose 11 *L. aurea* sites to visit in New Zealand. This we did by first plotting all the known sites on 1:50,000 maps, then highlighting those sites where the largest numbers of *L. aurea* had been reported and finally choosing a route that would include sites covering most of the known range of *L. aurea* and as many as possible of the locations in the available time. We located and surveyed all eleven sites (Table 2).