Former distribution and apparent disappearance of the *Litoria aurea* complex from the Southern Tablelands of New South Wales and the Australian Capital Territory

W. S. Osborne,[1] M. J. Littlejohn[2] and S. A. Thomson[1]

[1]Applied Ecology Research Group, University of Canberra, P.O. Box 1, Belconnen, Australian Capital Territory, 2616.

[2]Department of Zoology, University of Melbourne, Parkville, Victoria, 3052.

ABSTRACT

Frogs of the *Litoria aurea* complex were common and widespread in the Southern Tablelands of New South Wales and the Australian Capital Territory before they apparently suffered a major decline in abundance at the end of the 1970s. The extent of population declines in the species complex has been assessed by examination of museum specimens and records, evaluation of reports by experienced herpetologists and by undertaking field surveys, particularly in the Canberra region. Examination of museum material confirmed that three taxa occurred in the Southern Tablelands; *L. aurea, L. raniformis* and *L. flavipunctata. Litoria aurea* occurred only in the northern half of the Southern Tablelands, extending as far south as Canberra and Braidwood; *L. raniformis* occurred throughout much of the region at altitudes up to about 1 300 metres, but may not have occurred east of Lake George; and *L. flavipunctata* apparently had a restricted distribution near Canberra, Bombala and Delegate. Opportunistic surveys conducted since 1985 indicate that all members of the complex have disappeared from an extensive area of the Southern Tablelands centred on Canberra. Surveys have not been conducted in the southern Monaro or along the eastern edge of the tablelands where remnant populations may still occur. Long-term records of precipitation indicate that a series of severe droughts correlates with the period when members of the *L aurea* complex disappeared from the Southern Tablelands. However, the frogs also vanished from well-watered sites such as rivers, urban lakes and pools located in botanic gardens. This indicates that other unknown factors are likely to have been involved in the declines. Surveys to locate any remnant populations should be given a high priority and further research is required to determine the extent to which disease, climate change, increasing ultraviolet radiation and spread of the fish *Gambusia* influenced the population declines.

INTRODUCTION

The distribution of the *Litoria aurea* complex (sensu Courtice and Grigg 1975) has been previously described in detail by Courtice and Grigg (1975), Brook (1983) and Watson and Littlejohn (1985). Three species are currently recognized as occurring in eastern Australia: *L. aurea,* a species with an easterly distribution, occurring along the eastern coastal plains of New South Wales and far eastern Victoria, with inland occurrences near Canberra and Bathurst (Moore 1961; Courtice and Grigg 1975); *L. raniformis,* an inland species which has a more southerly and westerly distribution throughout much of Victoria and southern New South Wales, occurring west of the Great Dividing Range except in southern Victoria where it reaches the coast (Watson and Littlejohn 1985; Hero *et al.* 1991); and *L. flavipunctata* (Courtice and Grigg 1975; note that Cogger 1992 refers to this species as *L. castanea*). *Litoria flavipunctata* has a restricted distribution on the New England Tablelands north of Armidale where it is apparently isolated from the other two taxa (Courtice and Grigg 1975). All three species are considered to be threatened in New South Wales where they are listed on Schedule 12 of the *National Parks and Wildlife Act* 1974 (Lunney and Ayers 1993).

The taxonomy of the *L. aurea* complex in the Southern Tablelands populations is complex and somewhat unresolved (Thomson *et al.* 1996). Most authorities report only two species as occurring in the Australian Capital Territory region: *L. aurea* and *L. raniformis*. However, Humphries (1979) and Watson and Littlejohn (1985) suggested that another species resembling *L. flavipunctata* occurred near Canberra. This view is supported by a recent analysis of Southern Tablelands Bell Frogs by Thomson *et al.* (1996), and in this paper we will refer to specimens from the Southern Tablelands as *L. flavipunctata.*

Prior to the late 1970s, frogs of the *L. aurea* complex were considered to be common in the Southern Tablelands, including the Australian Capital Territory (Humphries 1979, pers. comm.; Osborne 1992; J. Wombey, pers. comm.). Osborne (1986) first commented on the decline of members of the complex in the Canberra Region, and, following further surveys (Osborne 1990), suggested that the species in the complex may have become extinct in the Australian Capital Territory. In this paper, we present detailed information on the former distribution of members of the *L. aurea* complex in the Southern Tablelands, and present the results of opportunistic surveys aimed at locating any remnant populations.

Table 1. Sites where *Litoria aurea* complex frogs were reliably reported to occur in the Canberra region prior to their disappearance, and which have been subsequently re-surveyed in the last 10 years. No *L. aurea* complex frogs were found at any of these sites in the surveys since 1985.

Location	Year	Source	Habitat	Site surveyed in last 10 years
Callemondah, Shannon's Flat NSW	1979	P. Ormay	marsh	N
Molonglo River, Queanbeyan, NSW	> 10 y.a.	R. Dencio	river	Y
Collector, NSW	1975	M. Littlejohn	farm dam	Y
Brookes Creek at Federal Highway, NSW	> 10 y.a.	J. Smith	stream	Y
Oakdale (5 km NE Sutton) NSW	1976	R. Humphries	farm dam	Y
Cooma Back Creek	> 10 y.a.	P. Johnson	stream	Y
ANU campus ponds, ACT	1975	M. Littlejohn	pond	Y
Urriara Rd/Coppins Crossing Rd, ACT	1975	M. Littlejohn	farm dam	Y
Coppin's Crossing, ACT	> 10 y.a.	R. Longmore	river	Y
Lake Burley Griffin, ACT	> 10 y.a.	C. Green	reed bed/lake	Y
Sewage Treatment Ponds, Fyshwick, ACT	> 10 y.a.	B. Baker	large ponds	Y
Urriarra Station, ACT	> 10 ya	D. Williams	farm dam	Y
University of Canberra campus, ACT	> 10 y.a.	J. Wombey	small pond	Y
Lake Ginninderra, ACT	> 10 y.a.	J. Wombey	lake	Y
Near Mt Clear camp ground, ACT	> 10 y.a.	J. Wombey	small stream	Y
Yowani Golf Course, ACT	> 10 y.a.	R. Dencio	swamp	Y
Pond near Gungahlin CSIRO, ACT	> 10 ya	R. Dencio	farm dam	Y
Jerrabomberra Creek, ACT	> 10 y.a.	T. Rutzou	lake	Y
Bruce Ridge, ACT	1970's	J. Kane	marsh	Y
Commonwealth Park, ACT	1970's	M. Cowan	large pond	Y

METHODS

Historical Records of Former Occurrence

Specimens in the Australian Museum (AM), Museum of Victoria (MV) and the Australian National Wildlife Collection (ANWC) were examined to check the identity of individual specimens from the study area. Identification was made by reference to Courtice and Grigg (1975). The date of collection of each specimen was also recorded if available and the altitude of the collection site determined from topographic maps.

Two approaches were used to assess the historic occurrence of the *L. aurea* complex in the Southern Tablelands. Firstly, one of us (MJL) undertook extensive observational surveys of anuran choruses along roads that traversed parts of the study area during late September and October 1975 and 1976. These surveys occurred in the Australian Capital Territory (29 sites) and near Collector (8), Braidwood (16), Cooma (5) and Bombala (10) in New South Wales. The approach taken involved opportunistically recording frog choruses at night and assigning individual species at each site with a qualitative index of chorus intensity (e.g., Littlejohn 1980). The field note book data available from MJL was analysed to obtain information on the number of choruses recorded and the number of choruses in which a member of the *L. aurea* complex was present. Air and water temperatures were sometimes taken at the times the frog calls were recorded and these have been examined to assess the suitability of survey conditions, and to provide a basis for determining the temperature preferences of calling frogs. The second approach involved interviewing experienced herpetologists and field naturalists about their knowledge of the former (and present) occurrence of Bell Frogs in the Southern Tablelands. Fifteen people were considered to have reliable records of the former occurrence of unidentified members of the *L. aurea* complex (Table 1).

Current Distribution

The extent of the current distribution of members of the complex has not been systematically surveyed. Instead, one of us (WSO) has conducted opportunistic searches at many sites in the Australian Capital Territoryand nearby areas of New South Wales in an area bounded by the towns of Murrumbateman, Collector, Bungendore, Captains Flat, Cooma, Jindabyne, Adaminaby and Wee Jasper (Figs 1 and 2). Searches undertaken between 1985 and 1995 included 175 farm dams, six swamps, eleven streams and three lakes. Searches in this area included most of the sites where members of the *L. aurea* complex were reliably reported to have once occurred (Table 1).

Long-term Rainfall at Canberra

Meteorological data were obtained from the Bureau of Meteorology in Canberra in order to examine monthly precipitation at Canberra for the period 1940–1994. The main breeding season for the *L. aurea* group in the Southern Tablelands was reported to have been during October–December (Humphries 1979), so precipitation totals from these months were compared with annual totals to check for any lengthy dry periods that may have adversely affected breeding success.

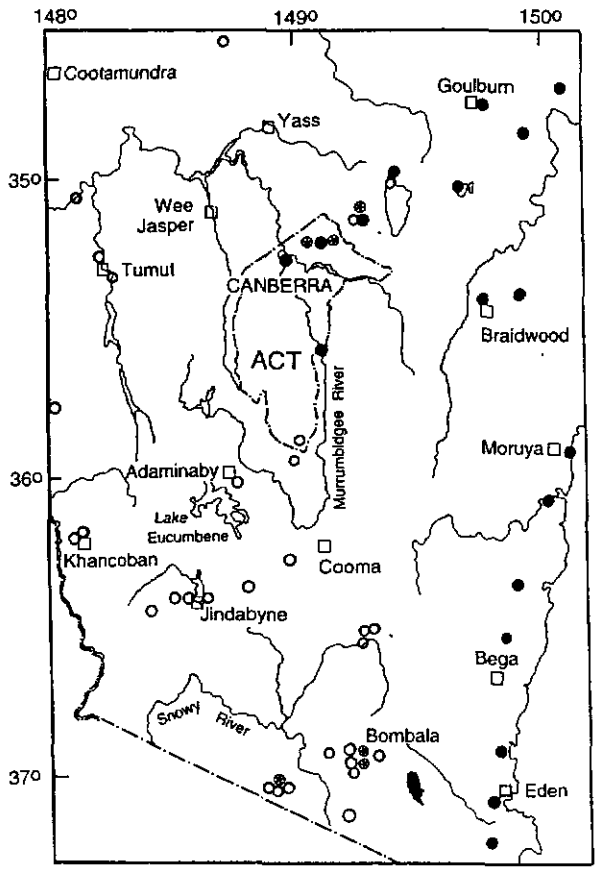

Fig. 1. Former distribution of the *Litoria aurea* complex in the Southern Tablelands of New South Wales. ● *L. aurea*; ○ *L. raniformis*; ⊛ *L. flavipunctata.*

RESULTS

Former Distribution

Examination of museum specimens and records indicated that three taxa in the *L. aurea* complex previously occurred in the Southern Tablelands (ST) of New South Wales. These were *L. aurea, L. raniformis* and *L. flavipunctata* (See Thomson *et al.* 1995).

Records of the presence of *L. aurea* in the Southern Tablelands date from the collections of Copland in 1938 (AM R84809 collected at Bundanoon) (see also Copland 1957). The most recent record of *L. aurea* from the Tablelands was obtained by M. Anstis in January 1977 at Braidwood (AM R119329). There have been a number of very recent records of *L. aurea* from the south coast of New South Wales (Daly 1995; White and Pyke 1995). The earliest record we can find of *L. raniformis* from the Southern Tablelands is a specimen collected by E. Troughton at Berridale in 1921 (R5233). Several specimens were also collected by Copland in 1955 at Adaminaby (AM R74660–74675). The most recent confirmed records of *L. raniformis* are single specimens collected in January 1980; one from Bondi State Forest (AM R108099, collected by G. Webb), and one from Big Jack Mountain near Bombala (AM R93243, collected by G. Shea). There are few existing records of *L flavipunctata*. Copland collected several specimens from near Bombala in 1955 (AM R74609 and 74610). The most recent records of this undescribed species are from Canberra where the last museum specimen was collected by K. Slater in March 1976 (ANWC A0649).

Litoria aurea was found to occur over a wide range of altitudes from sea level to about 700 m near Braidwood (700 m) (Fig. 3). *Litoria raniformis* was also widely distributed, occurring at sea level in Victoria (Hero *et al.* 1991), with an upper altitudinal limit of about 1 200 m in the Thredbo Valley in Kosciusko National Park. *Litoria flavipunctata* apparently was restricted to the tablelands between 700 and 800 m (Fig. 2).

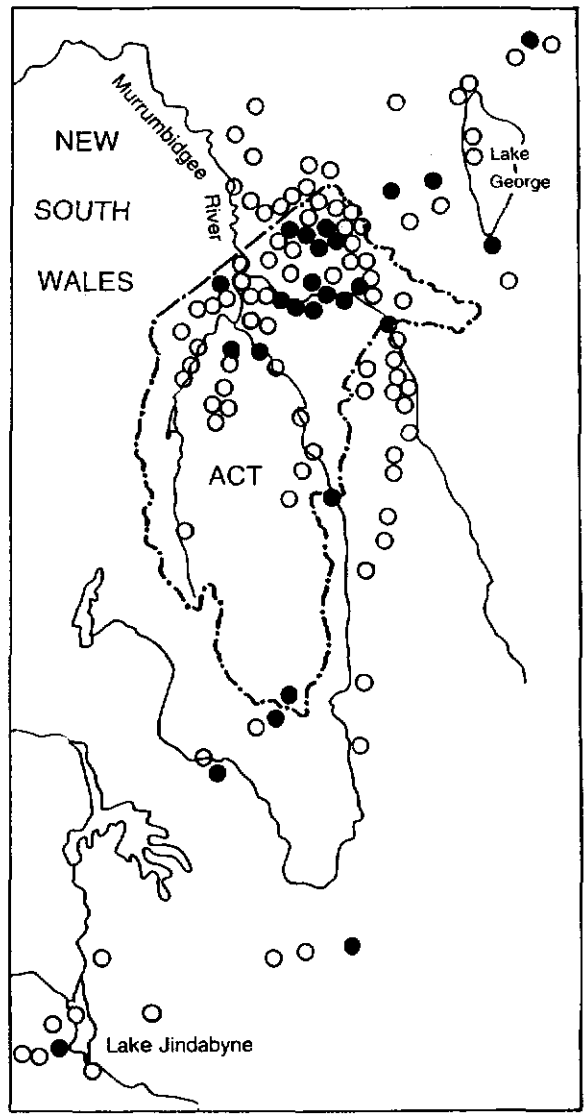

Fig. 2. Sites surveyed for frogs in the Canberra region during the period 1985 to 1995. Some circles overlap more than one site. ● represent sites where *L. aurea* complex frogs were observed or heard by reliable observers prior to 1985 (Table 1). No frogs from the complex have subsequently been found at any of these sites.

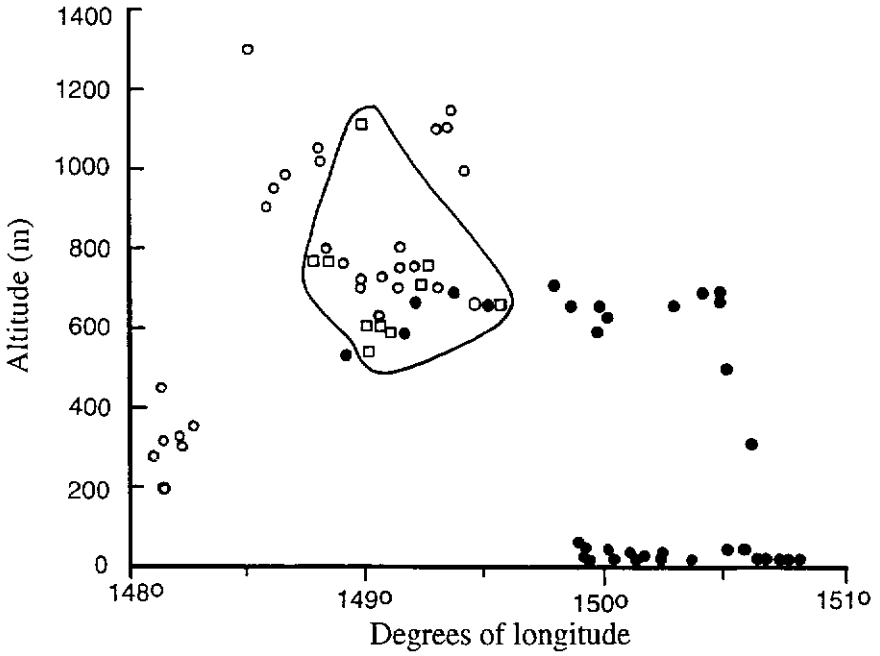

Fig. 3. Plot of altitude versus degress of longitude for *L. aurea* complex specimen sites occurring between latitude 34°S and the Victorian border. All records based on examination of museum specimens (see text). • *L. aurea*; ○ *L. raniformis;* □ *L. flavipunctata.*

Previous Abundance

There have been no estimates of population density for members of the *L. aurea* complex in the Southern Tablelands. We have obtained anecdotal information to suggest that high densities were reached in favourable sites. Reliable observers (Table 1) report that bell frogs (specific identity unknown) were very common at many sites prior to 1980. For example, the frogs frequently were seen basking on reeds, or were observed jumping into the water in large numbers, at sites such as the Fyshwick Sewage Treatment Ponds, the edge of Lake Burley Griffin, and along the Molonglo River in the Australian Capital Territory.

Moderately large populations also occurred in, and around, many livestock watering dams in cleared pasture, or in naturally treeless grasslands in the region (Humphries 1979, pers. comm.). At several locations at the edge of Canberra, the frogs were abundant enough to allow for easy collection of up to 50 specimens for university practical classes (J. Kane, pers. comm.). Qualitative information on the abundance of the frogs was obtained from field notes recorded in 1975 and 1976 (recorded by MJL). Of the 68 frog choruses recorded at different sites in the Southern Tablelands during late September and October, five choruses (7%) included *L. aurea*; five choruses (7%) included *L. raniformis*, and three choruses (4%) included *L. flavipunctata*. Overall, only 17% of all choruses included a member of the complex, although this may reflect the cold evenings experienced during some of the surveys (since information on temperature is not available for many of the surveys it is not possible to exclude all surveys that may have been undertaken on cold evenings).

The frequency of occurrence of each taxon in museum collections also provides some impression of former abundance (keeping in mind that the numbers of specimens collected may simply reflect the availability of experienced collectors and their particular bias). *Litoria raniformis* is the most frequently occurring species in the combined collections (88 specimens), followed by *L. aurea* (36) and *L. flavipunctata* (20) (Fig. 4).

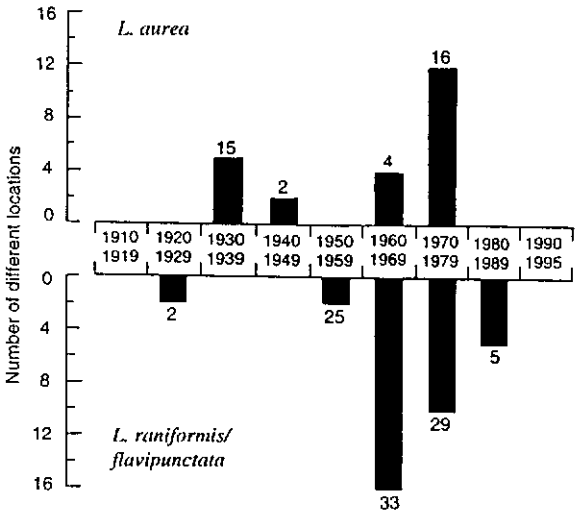

Fig. 4. Number of different locations at which *L. aurea* complex museum specimens were collected during 10-year periods from the Southern Tablelands of New South Wales during this century. Numbers at the end of each bar indicate total numbers of specimens collected during each decade. See text for further information.

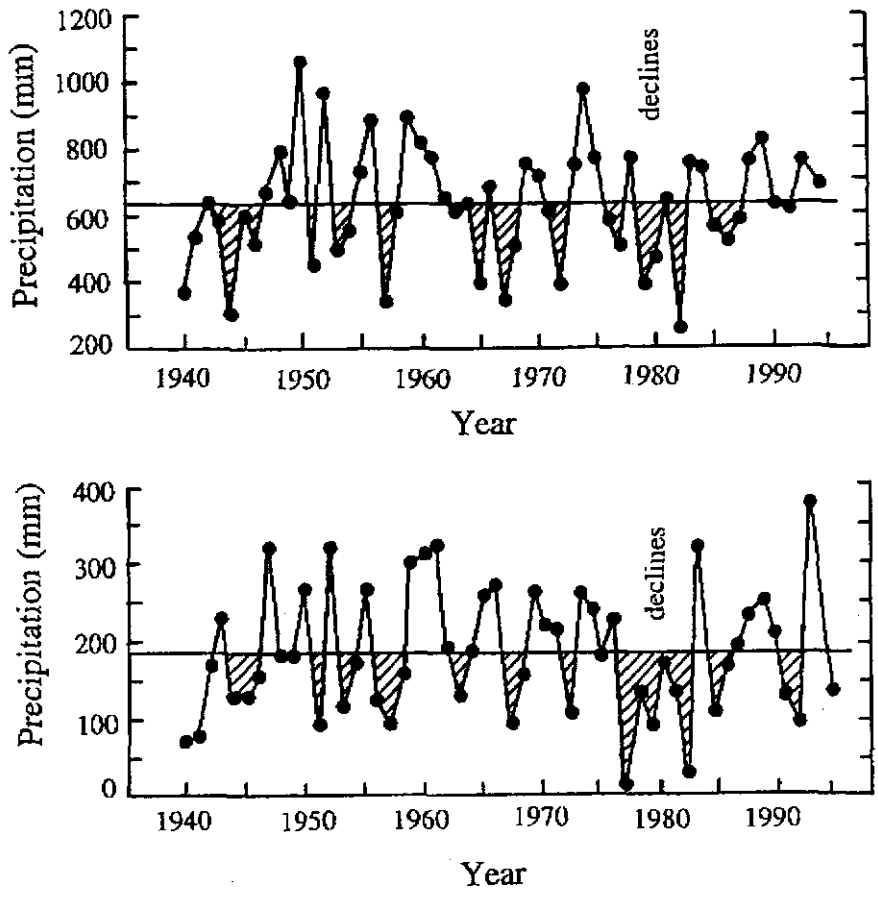

Fig. 5. Precipitation in Canberra during the period 1940 to 1993. (a) Annual rainfall; (b) Summed monthly rainfall for October + November + December of each year. Horizontal line indicates long-term mean, hatching indicates precipitation lower than the long-term mean.

Calling Season and Temperatures associated with Calling

Field note book records (made by MJL) provide some information on the calling season of the frogs in the Southern Tablelands, and allowed us to define the water and air temperature conditions associated with calling. *Litoria aurea* (n = 7 observation dates) was recorded calling between late September and throughout October at wet bulb air temperatures ranging from 7.7°C to 14°C and at water temperatures ranging from 16°C to 18°C. *Litoria raniformis* (n = 5) was recorded calling only during October. No measurements of temperature were made for this species. *Litoria flavipunctata* (n = 7) was recorded calling during the same period as *L. aurea* and over a similar range of air temperatures, and at water temperatures ranging from 12.7°C to 18°C.

Humphries (1979) suggested that near Canberra each of the species called during favourable weather in the period October to early January. However, field surveys by MJL were not conducted later than the end of October so the full extent of the calling season was not determined.

Extent of Population Declines and Relationship to long-term Precipitation

The opportunistic surveys conducted during spring and early summer 1985–1995 were all unsuccessful, with no members of the complex being recorded. Moreover, the surveys of 24 specific locations where the frogs had formerly been recorded also were unsuccessful (Table 1; Fig. 2). Most of the sites in the Australian Capital Territory have been surveyed repeatedly over a number of years (WSO unpubl. data), thus increasing the likelihood of detection of these frogs.

Long-term precipitation records (Fig. 4) indicate that drought is a regular feature of the Southern Tablelands, with lower than average precipitation occurring at irregular intervals, but rarely lasting for more than two consecutive years. Annual precipitation during the period 1976 to 1982 was generally below the long-term average (Fig. 5a) corresponding with a period of drought in the Southern Tablelands. Precipitation during the breeding season (October–December) was particularly low with virtually no rainfall occurring in 1977 and 1982, and rainfall well below average occurring during the months in the intervening years (Fig. 5b).

Plate 2a. Pond where Humphries (1979) studied both *L. aurea* and *L. flavipunctata* in the late 1970s. This, and other nearby ponds which supported the frogs, were surveyed on a number of occasions during the period 1985 to 1995, but no members of the *L. aurea* complex have been subsequently found. This pond does not contain Mosquito Fish.

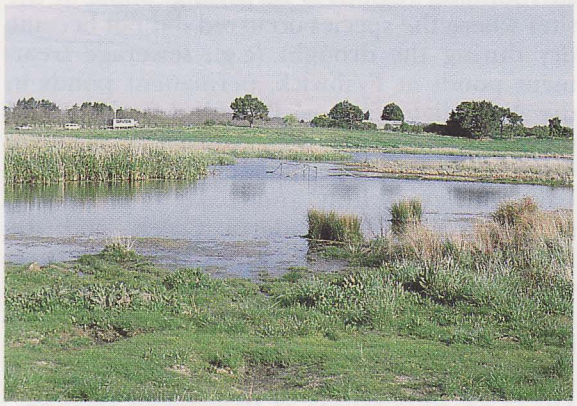

Plate 2b. Swampland at Fyshwick in the Australian Capital Territory. This area formerly supported members of the *L. aurea* complex.

DISCUSSION

The availability of museum records and reliable field observations confirm that three members of the *L. aurea* complex were wide-spread in the Southern Tablelands including the Australian Capital Territory (Fig. 1). *Litoria aurea* occurred in the region between Canberra and Braidwood and further north towards Goulburn and Moss Vale, but apparently did not occur in the Monaro region south of Canberra. This largely coastal species is not known from altitudes over 800 m. *Litoria raniformis*, another wide-spread species also apparently occurred throughout the Southern Tablelands, occurring at altitudes up to about 1 300 m. The third species *L. flavipunctata* appears to have had a restricted distribution between Canberra and Bombala, and was separated from the nearest known populations of *L. flavipunctata* in the Northern Tablelands by over 500 km.

Osborne (1986) first commented on the decline of the *L. aurea* complex populations in the Canberra region. It was in response to this concern that the surveys reported here were conducted. Our surveys confirm that all three taxa have suffered an extensive decline, with no confirmed records or observations of these taxa in the Southern Tablelands since 1980. If no remnant populations remain, then this represents a major contraction of the geographic ranges of *L. aurea* and *L. raniformis* and the likely extinction of the possible third taxon *L. flavipunctata*. On the Northern Tablelands of New South Wales *L. flavipunctata* also appears to have disappeared (M. Mahony, pers. comm.).

The population declines apparently occurred precipitously between about 1978 and 1981, and did not involve a prolonged stage when the frogs were in low numbers (such as is the current case for *Pseudophryne corroboree* in Kosciusko National Park (Osborne 1989, 1992). Despite a number of recent reports of bell frogs near Canberra and Cooma, all attempts to find the frogs in these areas have been unsuccessful (Osborne 1992; Fig. 2). Most presumed sightings or call records have, in fact, turned out to be other large-bodied frogs, or species such as *Limnodynastes dumerilii* which have growling encounter calls (MJL and WSO unpubl. obs.).

Whilst surveys in the Australian Capital Territory have been extensive and conducted over many years (see also Rauhala 1993, 1995), surveys in other parts of the Southern Tablelands have been limited (Fig. 2). In particular, the Monaro region and eastern extent of the Southern Tablelands have not been surveyed. Priority should be given to surveying these areas which may still support remnant populations.

Natural fluctuations may be typical of long-term trends in the abundance of many amphibians (Pechmann *et al.* 1991). However, we do not consider that the rapid extinction of taxa from very large geographic areas can be explained by natural fluctuations. Instead such losses are generally attributed to human disturbance. Drainage of wetlands, habitat disturbance, over-collecting, introduction of exotic fish and amphibians, increasing soil salinity, acidification of water and soil, and the use of pesticides and herbicides, have all been implicated in losses of amphibian populations (see reviews by Honegger 1981; Hayes and Jennings 1986; Ferraro and Burgin 1993). However, a number of the declines and extinctions reported recently have occurred in areas remote from obvious human influence (e.g., Corn and Fogleman 1984; Heyer *et al.* 1988; McDonald 1990), indicating that less-obvious processes may be involved. A number of explanations have been suggested to account for these more insidious declines; they include the possible influence of disease, global climatic change, various forms of pollution and an increase in ultraviolet radiation (affecting eggs and embryos in open pools, and basking species)

(Blaustein and Wake 1995). Unfortunately, there has been little experimental research on frog populations which can be used to test these theories.

The possible role of Drought

Although rarely reported, drought also has been identified as an important local determinant of losses of frog populations (Corn and Fogleman 1984), and cyclical changes in rainfall undoubtedly influence the size of amphibian populations over time (Bragg 1960; Pechmann *et al.* 1991). Tyler (1990) suggests that the El Niño-induced drought in southeastern Australia must have produced localized extinctions of frog populations, but not on the scale of declines that has been observed in this area.

Interviews with a number of reliable observers indicated that the decline of the *L. aurea* complex in the Southern Tablelands occurred during the period 1978–1980, a period subject to severe drought (Fig. 5). Very dry summers were recorded in 1979, 1981 and 1982, culminating in a drought in 1982–83 that included the worst 16-month sequence on record for the Australian Capital Territory (Daniell 1986). Because of the close dependence of frogs on moisture, the prolonged dry conditions experienced in the Canberra region undoubtedly would have had a severe impact on frog populations.

Drought can potentially affect amphibian mortality in several ways. For example, prolonged periods without rainfall can desiccate eggs and eliminate shallow pools that contain tadpoles. If the daytime sheltering places of adults and juveniles become dry, increased mortality may follow. Dry conditions are also expected to delay breeding and prevent females from moving to breeding areas. Frogs in the *L. aurea* complex are considered to be among the most aquatic species in Australia (Tyler 1976); they are semi-aquatic and often are associated with permanent waterbodies including slow-moving lotic situations, swamps and farm dams (Harrison 1922; Courtice and Grigg 1975). Unlike many other species, they apparently do not normally undertake a seasonal migration away from the edges of the water bodies; instead, these situations also provide the feeding sites and overwintering sites (Humphries 1979). There are also reports of their occurrence well away from potential breeding sites, so they obviously also undertake terrestrial movements, perhaps in search of new breeding sites after their ponds become unsuitable (Humphries 1979; Daly 1995). By undertaking such movements, it is possible that they could also seek out drought refuges.

During the drought years, many ponds and streams in the Australian Capital Territory dried or supported little water (W. Osborne, pers. obs.). Water quality in remaining water bodies may have deteriorated as a result of increasing turbidity and trampling by livestock. Many potential refuges for frogs such as earth cracks, and the soil beneath grass litter, tussocks, rocks and logs became dry. Because of their large size (SVL 50–100 mm) adults of the *L. aurea* complex may not have been able to seek out suitable moist microhabitats at this time. These aspects of their ecology may have predisposed them to decline during conditions of extreme drought. Nevertheless, the high fecundity of these frogs (van de Mortel and Buttemer 1996) should have ensured a potential for rapid recovery in the years of reliable rainfall following the cessation of drought.

Although a population decline during drought is not unexpected, the complete disappearance of the *L. aurea* complex species from the Australian Capital Territory and surrounding regions is surprising. Some of the sites where the species occurred did not become dry during the drought (e.g., sewerage treatment ponds at Fyshwick, permanent ponds in the Australian National Botanical Gardens and on the campus of the Australian National University, large permanent lakes including Lake Burley Griffin and Lake Ginninderra, large pools in Ginninderra Creek, and the Molonglo River at Coppins Crossing and Queanbeyan; Table 1) indicating that there almost certainly were other factors involved in the declines.

Other possible causes of Population Decline

In the last few years, numerous hypotheses have been raised to offer possible explanations for amphibian declines (see Mahony 1996). In coastal regions the introduced Mosquito Fish *Gambusia affinis* is strongly implicated in the disappearance of *L. aurea* from many seemingly suitable sites (Pyke and White 1995). However, Mosquito Fish are not present at many sites where bell frogs previously occurred in the Southern Tablelands (W. Osborne, pers. obs.), indicating that other factors may have contributed to the declines. The rapid loss of populations is similar to that suggested as being caused by an exotic viral infection in montane frogs in Queensland (Laurance *et al.*, in press), where declines have also been confined to high altitude populations (Richards *et al.* 1993; Trenerry *et al.* 1994; Mahony 1996).

Selective declines confined to high altitudes also fit another scenario; that of the possibility of some form of global impact that is magnified at higher altitudes. For example, Blaustein *et al.* (1994) argue that the increased ultraviolet radiation following ozone depletion has the potential to harm amphibian eggs and embryos, particularly in species living at high altitudes

(Blaustein *et al.* 1994; see van de Mortel and Buttemer, this volume, for a full discussion and further references). The direct basking habit of *L. aurea* and its relatives (Courtice and Grigg 1975) may also expose juveniles and adults to UV-B radiation, however its effect on adults is not known.

As a first step in conservation efforts for the Southern Tablelands, field surveys should be undertaken in regions not yet surveyed; particularly south of Cooma and along the eastern edge of the tablelands. Should remanent populations be found, priority should be given to their conservation. In addition to habitat protection, this will require additional research into the possible role that disease, climate change, increasing UV-B radiation and spread of the invasive fish *Gambusia* may play in preventing population recovery.

ACKNOWLEDGEMENTS

Kruno Kukolic (Australian Capital Territory Parks and Conservation Service) provided assistance and company during many of the frog surveys. The following people are thanked for providing information on the former occurrence of bell frogs in the Southern Tablelands: B. Baker (Australian Nature Conservation Agency), R. Barwick (Australian National University), M. Cowan, R. Dencio (formerly ANU), C. Green (ACTPCS), R. Humphries (formerly ANU), P. Johnson (former Cooma resident), J. Kane (University of Canberra), R. Longmore (ANCA), P. Ormay (ACTPCS), R. Pengilley (formerly ANU), T. Rutzou (ACTPCS), K. Slater (formerly Canberra CAE), D. Smith (Australian Capital Territory Field Naturalist Association), D. Williams (UC) and J. Wombey (CSIRO Wildlife and Ecology). We thank R. Sadlier and A. Greer (Australian Museum), J. Coventry (Museum of Victoria) and J. Wombey (Australian National Wildlife Collection) for their help in loan of specimens.

REFERENCES

Bragg, N. A., 1960. Population fluctuations in the amphibian fauna of Cleveland county, Okalahoma during the past twenty-five years. *Southwest Naturalist* **5:** 165–69.

Blaustein, A. R. and Wake, D. B., 1995. The puzzle of declining amphibian populations. *Scientific American* **April 1995:** 56–61.

Blaustein, A. R., Hoffman, P. D., Hokit, D. G., Kiesecker, J. F., Walls, S. C. and Hays, J., 1994. UV repair and resistance to solar UV-B in amphibaian eggs: a link to population declines? *Proc. Nat. Acad. Sci. USA* **91:** 1791–95.

Brook, A. J., 1983. *Atlas of Australian Anura.* Publication No. 7, Department of Zoology, University of Melbourne.

Cogger, H. G., 1992. *Reptiles and Amphibians of Australia.* Rev. Ed. Reed: Sydney.

Courtice, G. P. and Grigg, G. C., 1975. A taxonomic revision of the *Litoria aurea* complex (Anura: Hylidae) in south-eastern Australia. *Aust. Zool.* **18:** 149–63.

Copland, S. J., 1957. Presidential address. Australian tree frogs of the genus *Hyla. Proceedings of the Linnaean Society of New South Wales.* **82:** 9–108.

Corn, P. S. and Fogleman, J. C., 1984. Extinction of montane populations of the northern Leopard Frog *(Rana pipiens)* in Colorado. *Journal of Herpetology* **18:** 147–52.

Daly, G., 1995. Observations on the Green and Golden Bell Frog *(Litoria aurea)* (Anura: Hylidae) in southern New South Wales. *Herpetofauna* **25**(1): 2–9.

Daniell, T. M., 1986. The drought of 1979/83 and its effect on the operation and design of Canberra's water supply system. Pp. 1–22 in *The Drought of 1979–82: A Management Study* ed by M. N. Viswanathan. Hunter District Water Board: Newcastle.

Harrison, L., 1922. On the breeding habits of some Australian frogs. *Aust. Zool.* **3:** 17–34.

Hayes, M. P. and Jennings, M. R., 1986. Decline of Ranid frog species in western North America: Are bull frogs *(Rana catesbeiana)* responsible? *Journal of Herpetology* **20:** 490–509.

Heyer, W. R., Rand, A. S., Goncalvez, da Cruz, C. A. and Peixoto, O. L., 1988. Decimations, extinctions, and colonizations of frog populations in south-east Brazil and their evolutionary implications. *Biotropica* **20:** 320–35.

Hero, J-M., Littlejohn, M. J. and Marantelli, G., 1991. *Frogwatch Field Guide to Victorian Frogs.* Department of Conservation and Environment: Victoria.

Honegger, R. E., 1981. *Threatened Amphibians and Reptiles of Europe.* Akad. Verlagsges.: Wiesbaden, Germany.

Humphries, R. B., 1979. Dynamics of a breeding frog community. Ph.D. Thesis, Australian National University: Canberra.

Ferraro, T. J. and Burgin, S., 1993. Review of environmental factors influencing the decline of Australian frogs. Pp. 205–18 in *Herpetology in Australia: A Diverse Discipline* ed by D. Lunney and D. Ayres. Royal Zoological Society of New South Wales: Mosman.

Laurance, W. F., McDonald, K. R. and Speer, R., in press. Epidemic disease and the catastrophic decline of Australian rainforest frogs. *Conservation Biology.*

Littlejohn, M. J., 1980. The frogs of French Island and Phillip Island. *Victorian Naturalist* **97:** 232–34.

Lunney, D. and Ayers, D., 1993. The official status of frogs and reptiles in new South Wales. Pp. 404–08 in *Herpetology in Australia: A Diverse Discipline* ed by D. Lunney and D. Ayres. Royal Zoological Society of New South Wales: Mosman.

McDonald, K. R., 1990. *Rheobatrachus* Liem and *Taudactylus* Straughan and Lee (Anura: Leptodactylidae) in Eungella National Park, Queensland: distribution and decline. *Trans. Roy. Soc. Sth Aust.* **114:** 187–94.

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. *Aust. Zool.* **30**(2): 237–47.

Moore, J. A., 1961. The frogs of eastern New South Wales. *Bul. Amer. Mus. Nat. Hist.* **121:** 149–386.

Osborne, W. S., 1986. Frogs of the Canberra region. *Bogong* **7:** 10–12.

Osborne, W. S., 1990. Declining frog populations and extinctions in the Canberra region. *Bogong* **11:** 4–7.

Osborne, W. S., 1992. Declines and extinctions in populations of frogs in the ACT: a discussion paper. Report 92/8, Australian Capital Territory Parks and Conservation Service: Canberra.

Osborne, W. S., 1989. Distribution relative abundance and conservation status of corroboree frogs, *Pseudophryne corroboree* Moore (Anura: Myobatrachidae). *Aust. Wild. Res.* **16:** 537–47.

Pechmann, J. H. K., Scott, D. E., Semlitsch, R. D., Cadlwell, J. P., Vitt, L. J. and Gibbons, J. W., 1991. Declining amphibian populations: The problem of separating human impacts from natural fluctuations. *Science* **253:** 892–95.

Rauhala, M., 1993. The reptile, amphibian and mammal fauna of the Stony Creek Nature Reserve, Australian Capital Territory. Australian Capital Territory Parks and Conservation Service, Technical Report No 6, Canberra.

Rauhala, M., 1995. The reptile, amphibian and mammal fauna of the Gigerline Nature Reserve, Australian Capital Territory. Australian Capital Territory Parks and Conservation Service, Technical Report No 11, Canberra.

Richards, S. V., McDonald, K. R. and Alford, R. A., 1993. Declines in populations of Australia's endemic tropical rainforest frogs. *Pacific Conservation Biology* **1:** 66–77.

Thomson, S. A., Littlejohn, M. J., Robinson, W. A. and Osborne, W. S., 1996. Taxonomy of the *Litoria aurea* complex: a re-evaluation of the Southern Tablelands populations of the Australian Capital Territory and New South Wales. *Aust. Zool.* **30**(2): 158–69.

Trennery, M. J., Laurence, W. F. and McDonald, K. R., 1994. Further evidence for the precipitous decline of endemic rainforest frogs in tropical Australia. *Pacific Conservation Biology* **1:** 150–53.

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

Tyler, M. J., 1991. Declining amphibian populations — a global phenomenon? An Australian perspective. *Alytes* **9:** 43–50.

van de Mortel, T. F. and Buttemer, W. A., 1996. Are *Litoria aurea* eggs more sensitive to ultraviolet-B radiation than eggs of sympatric *L. peroni* or *L. dentata*? *Aust. Zool.* **30**(2): 150–57.

Watson, G. F. and Littlejohn, M. J., 1985. Patterns of distribution, speciation and vicariance biogeography of southeastern Australian amphibians. Pp. 91–97 in *Biology of Australasian Frogs and Reptiles* ed by G. Grigg, R. Shine and H. Ehmann. Surrey Beatty & Sons: Sydney.