Two hundred and ten years looking for the Giant Burrowing Frog

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ABSTRACT

The giant burrowing frog *Heleioporus australiacus* (Shaw) is a large, morphologically distinctive, but cryptic frog found in south eastern Australia. This paper reviews the literature pertaining to the Giant Burrowing Frog. It is a forest dependent species found on the coast and adjacent ranges of south-eastern Australia, with five congeners in south-west Western Australia. The species is listed as vulnerable in NSW and Victoria and under Commonwealth legislation, although there is no obvious cause for a decline nor is it clear how much decline has occurred. Proposed threats to the species survival include forestry operations, habitat destruction, introduced species, pollutants, increased UV and disease. A large gap exists in the species distributional records and *H. australiacus* may represent two distinct species, although the evidence for this remains inconclusive. Standard detection methods for frogs do not apply well to the Giant Burrowing Frog and alternative methods are required to provide a more detailed understanding of its ecology and distribution.

Key words: review, conservation, Heleioporus, management, amphibian

Introduction

Despite being one of the first frogs described from Australia, there has been very little research into the ecology of the Giant Burrowing Frog *Heleioporus australiacus*. Shaw (1795) first described *H. australiacus* as *Rana australiaca* in Nature Miscellany. The type specimen cannot be located, however the illustration of the animal is unmistakable because this frog is in external appearance very distinctive. Since its initial description there has been very little information published on this species. Where information has been presented it has invariably been based on a small number of observations (e.g. Daly 1996; Lemckert *et al.* 1998) and usually only from a small portion of the species range. The cryptic nature of this frog has meant that no comprehensive study of its ecology has been conducted.

Heleioporus australiacus is listed as vulnerable under the NSW *Threatened Species Conservation Act* 1995, the Victorian *Flora and Fauna Guarantee Act* 1988 and the Commonwealth *Environmental Protection and Biodiversity Conservation* Act 2000. The listing has occurred primarily due to the lack of information regarding the species' ecology resulting from the paucity of records. As a result of these listings, land managers require an improved understanding of this species to ensure that management practices do not significantly impact upon the species. As there are concerns over the status and future of *H. australiacus*, a review of its biology would be valuable to assist in its management.

This paper presents a review of the published literature pertaining to the biology of *H. australiacus*. References are made to the grey literature only where they provide unpublished information that is supported by new data. The review brings together all known records from various museum specimens, the published literature and previous collations of habitat requirements. We also examine the current status of the species and discuss the field research techniques most relevant to this species. Based on this information, we identify the gaps in our current knowledge of the ecology of the frog as a means to setting priorities for research.

Phylogeny

The genus *Heleioporus* lies within the family Myobatrachidae, sub-family Limnodynastinae as defined by Lynch (1973). All myobatrachid frogs are restricted to Australia and New Guinea (Roberts and Watson 1993). The sub-family Limnodynastinae are generally species which construct foam nests. There is debate over the validity and composition of Myobatrachidae and Limnodynastinae (see for example Roberts and Watson 1993; cf Littlejohn *et al.* 1993) however this will not be discussed here.

Heleioporus was first defined by Gray (1841) based on specimens of *H. albopunctatus*. There are currently six recognised species in *Heleioporus*; *H. australiacus* is confined to the temperate lands of southeastern Australia, whereas the other five species are located in the south-west of Australia. In order to provide an evolutionary framework to account for the occurrence of several broadly sympatric species of *Heleioporus* in the southwest of Western Australia and the occurrence of a disjunct congener in south eastern Australia Main *et al.* (1958) postulated that the genus arose in eastern Australia and that speciation in the southwest resulted from repeated east to west invasions in wetter periods of the pleistocene when forested environments existed across the south of Australia. However, based on molecular evidence Maxsom and Roberts (1984) argued that *H. australiacus* has evolved from the western species via a west to east migration approximately 5 million years ago. Wells and Wellington (1985) proposed an east west split of the *Heleioporus* genus however the genetic evidence does not support this notion (Maxsom and Roberts 1984).

The type locality for *Heleioporus australiacus* is simply listed as New Holland (Shaw 1795). Gray (1841) then erected the *Heleioporus* genus separating the species from the Ranidae. In 1894, Fletcher erected the closely related genus *Philocryphus* based on the distinctness of the tympanum, creating *Philocryphus flavoguttatus*. Fletcher (1898) challenged the validity of the genus and recommended amendments to the description of the *Heleioporus* genus to incorporate *P. flavoguttatus*. Fry (1914) supported the status of *Philocryphus* citing the distinct differences in the tympanum and the differences in the degree of ossification of the sternum. Fry (1915) argued that Fletcher's *Philocryphus flavoguttatus* was the same species as Shaw's *Rana australiaca*. The original species name was adopted and the name *Philocryphus australiacus* erected. *Philocryphus* was then dissolved into *Heleioporus* and the name *H. australiacus* was adopted (Parker 1940).

Distribution

Records of the species range from south west of Singleton, NSW (Gillespie and Hines 1999) through to Walhalla, Victoria in the south (Martin 1997; Figure 1). Large numbers (300) of records exist for the northern areas of the current range, particularly from the Sydney Basin bioregion (NPWS Wildlife Atlas). In the south there are only 58 records and these are largely derived from native forest areas to the west of Eden (Webb 1991; Lemckert *et al* 1998). There are only 18 records from Victoria however these records are scattered across a relatively large proportion of the Gippsland area (see Figure 1) (Gillespie and Hines 1999). The large numbers of records around the Sydney Basin reflect the much larger survey effort that has been placed into this area.

Identification/Description

Adult

Heleioporus australiacus is a large rotund chocolate brown to bluish black frog (Barker *et al* 1995; Cogger 2000). Body lengths range from 60.0 – 89.9 mm for males and 66.7-97.0 for females (Littlejohn and Martin 1967; Barker *et al.* 1995). The skin is warty with variable yellow spotting along the sides, around the cloaca and occasionally on the limbs (Lee 1967). The belly of the animal is white and some brown

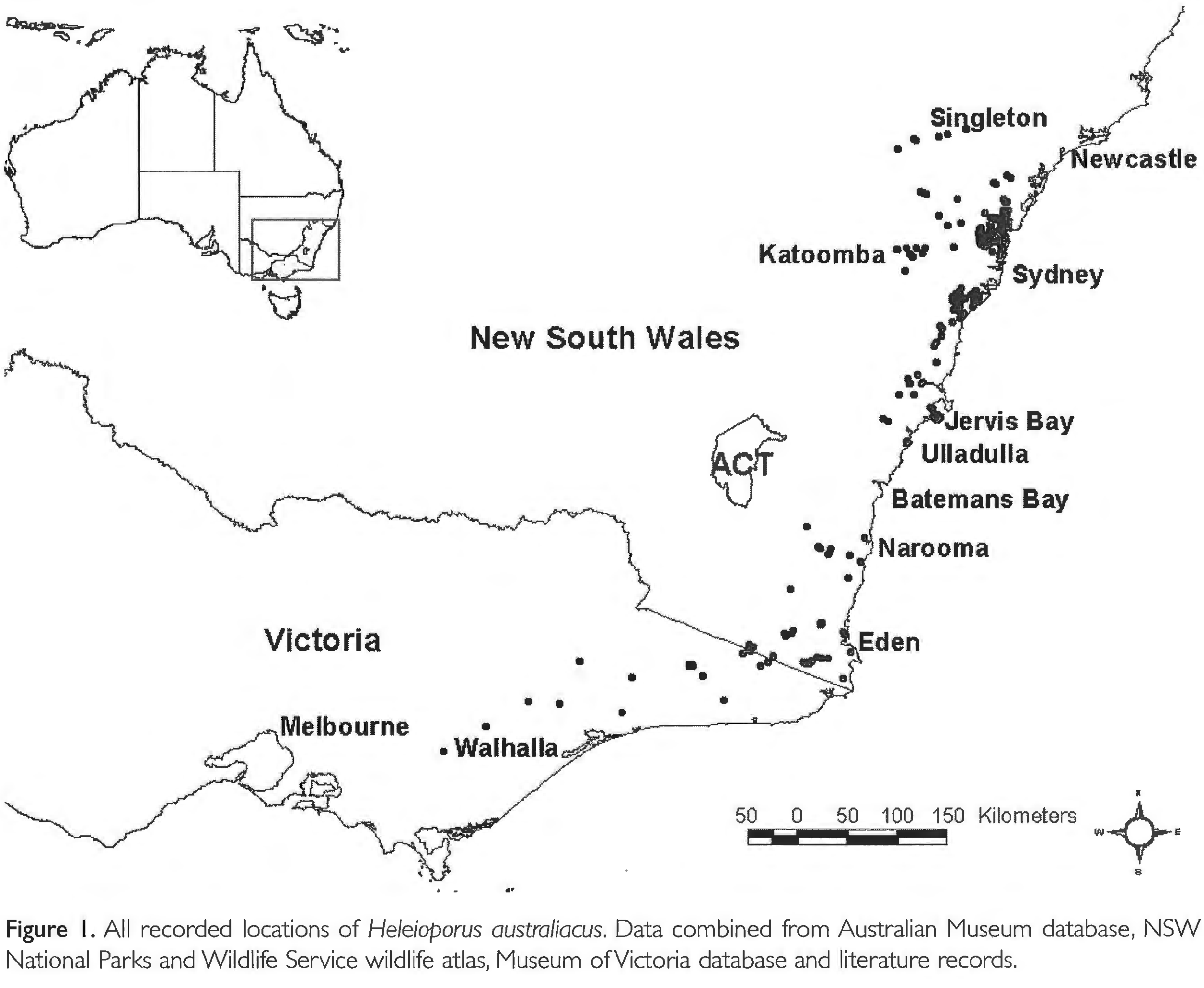

Figure 1. All recorded locations of *Heleioporus australiacus*. Data combined from Australian Museum database, NSW National Parks and Wildlife Service wildlife atlas, Museum of Victoria database and literature records.

is present on the throat (Barker *et al* 1995; Cogger 2000). Webbing is rudimentary on the toes and absent on the fingers (Barker *et al* 1995; Cogger 2000), a characteristic of the genus (Cogger 2000). A small divided flap is present in the anterior corner of the eye (Lee 1967).

Males and females can be distinguished by characteristics of the forearm and hand. Mature males have enlarged muscles on the forearms with black conical nuptial spines on thumbs, and small spines on the second and third fingers (Barker *et al.* 1995). This is typical of all members of this genus (Barker *et al.* 1995) and has probably developed in the males for the purpose of territorial combat, but may also be used in self defense (Lemckert 2001). Preliminary observations suggest that young males develop spines during early development but the muscular forearms appear to be associated with sexual development (Penman *unpub. data*).

Three vocalisations are attributed to *H. australiacus*. The first is the male advertisement call, an owl like "oo-oo-oo" (Robinson 1995). The second call attributed to *H. australiacus* is rarely heard in the field and has not been discussed in the literature. This call is an extended "wo-oo-oop" with an upward inflection and is presented on the sound recordings of Stewart (1998). This call is considered to be a territorial response call (Lemckert 2001). The third recorded type of call is an apparent distress call that has been described as an "electronic-sounding call like a whining cat, although much louder" (Lemckert 2001) which has been heard while animals are being handled or are slightly constrained.

Tadpole

The species has large unspecialised tadpoles (Watson and Martin 1973). Dorsal colour can be dark brown through to slaty gray with metallic flecking and heavy pigmentation (Harrison 1922; Lee 1967; Daly 1996; Anstis 2002) with a shiny grey-blue abdomen (Anstis 2002). They are relatively large to a total length of 85 mm (Daly 1996). The iris is blue-grey with gold around the pupil (Anstis 2002). A complete description is present by Anstis (2002). Within the literature three different tooth formulae have been described. These are discussed further below.

Egg

The species lays a relatively large number of eggs in a foamy nest in a burrow or concealed under vegetation (Watson and Martin 1973; Daly 1996). Egg masses have rarely been observed in the wild, as a consequence only a small number of egg masses have been counted. Egg counts range from 698 – 807 for animals near Jervis Bay (Daly 1996) and 775 - 1239 for populations at Walhalla, Victoria (Watson and Martin 1973). The individual eggs are relatively large with a diameter of 2.6 mm (Anstis 2002).

Habitat requirements

Heleioporus australiacus appears to be able to spend a large proportion of its time away from riparian areas (Lemckert *et al.* 1998; Lemckert and Brassil 2003). This may mean that considerable differences may exist between the breeding and non-breeding habitat requirements of this frog, but the available data consists of a small number of observations. No study has been able to demonstrate whether the species prefers any one habitat due to the paucity of records and the inability to identify sites where the species is absent.

Attempts have been made by the NSW National Parks and Wildlife Service to model the species habitat in two regions in southern NSW as part of the Comprehensive Regional Assessment process (NPWS 1998; NPWS 2000). These models were unable to identify any meaningful relationships between the distribution of the species and environmental or climatic factors. A lack of sites has meant that the models probably lack strong predictive powers.

Animals have been reported to occur in a wide range of forest communities, but the species has never been recorded from agricultural lands (Gillespie 1990). Records have been from dry open schlerophyll forest (Lemckert *et al* 1998), tall open montane forest (Webb 1991; Lemckert *et al.*1998), tall open coastal slope forest (Webb 1991), dense wet schlerophyll forests (Littlejohn and Martin 1967), montane woodland (Gillespie 1990) and heathland (Mahony 1993). Observations suggest that the composition of the understorey also varies widely (e.g. Lemckert *et al* 1998; Gillespie 1990). The absence of the species from agricultural lands is considered real, however there are no known surveys for the species in agricultural landscapes. It has been suggested that the species' absence from agricultural landscapes may be due to the tadpoles' inability to survive in the altered water conditions that occur in these areas (Gillespie 1997). Alternatively, the absence may be due to the inability or unwillingness of adults to burrow into soil cover by grasses or other crops, which has been observed in other burrowing frog species (Jansen *et al.* 2001).

Soils are likely to be an important component of the habitat of any burrowing frog, however on a coarse scale, no relationship has been demonstrated between soil type or geology and the species distribution (Gillespie 1997). The species has been recorded from clays, siliceous sands, earthy sands, Quaternary sands, gleyed podzolic soils, fertile volcanic soils and yellow podzolic soils (Rescei 1996). While not explicitly stated by Rescei, it is likely that the records from clay areas are of animals recorded in clay based waterbodies. Little information is available regarding the microhabitat in which the species burrows. A recent study found that the frog burrows at depths between 1 and 30cm below the soil surface (Lemckert and Brassil 2003). On occasions the animals do not burrow, instead they seek refuge under logs, leaf litter or in existing burrows (Lemckert and Brassil 2003).

Calling and breeding have been recorded from a wide range of waterbodies. In the Sydney Basin, breeding has been recorded in hanging swamps and ponds forming within sandstone based creeks (Harrison 1922; Mahony 1993; Daly 1996; Rescei 1996). Around Jervis Bay, breeding occurs in coastal heath (Littlejohn and Martin 1967) often associated with coral fern, *Gleichnia dicarpa* and *Gahnia spp* (Daly 1996; White 1999). Observations of breeding have rarely been recorded from within the southern populations. Where calling or breeding has been recorded, it has been from pools in creeklines or shallow creeks (Littlejohn and Martin 1967; Gillespie 1990) and fire dams (Gillespie 1990). Breeding has never been recorded from large creeks or rivers.

Calling generally occurs from concealed locations besides the waterbody such as burrows in creek banks (Littlejohn and Martin 1967) and dams (Gillespie 1990), under woody debris (Gillespie 1990), within log jams (Gillespie 1990), in sandstone burrows (Gillespie 1990), yabby burrows (Barker *et al.* 1995) and within dense vegetation (Littlejohn and Martin 1967; Gillespie 1990; Daly 1996). However, males have been observed calling sitting exposed on the ground (Lemckert *pers. obs.*; Penman *pers. obs.*).

Conservation status

Forestry operations, habitat destruction, introduced species, pollutants, increased UV and disease are all considered possible threats to the species' long term survival (Gillespie and Hines 1999; Rescei 1996), although none of these has been demonstrated conclusively to have caused any declines for *H. australiacus*. Forestry operations have been listed as the main threat to the species long-term survival in Victoria (Gillespie 1990). Introduced predatory species listed as possibly impacting *H. australiacus* are foxes and cats (Rescei 1996; Gillespie and Hines 1999). Pollutants have been proposed to cause localised declines in areas around Sydney where the species occurs on the urban fringe (Rescei 1996). Rescei (1996) also proposed that UV radiation increases might threaten *H. australiacus*. However, radiation is more likely to affect frog species which bask (Gillespie and Hollis 1996) or those which lay their egg masses in exposed locations (Kiesecker and Blaustein 1995). *H. australiacus* does neither and so we consider that increased UV radiation is unlikely to be a direct significant threat. Disease has been found to be responsible for the decline and extinction of a number of frog species world wide (Berger *et al* 1998). Only one specimen of *H. australiacus* has been found infected with the chytrid fungus (Speare and Berger 2000), however the cryptic behaviour of the adults and low level of observations make it difficult to investigate whether chytridiomycosis is a significant threat to this frog.

The major unanswered question remains whether *H. australiacus* has declined in recent times and the main difficulty in determining the nature and extent of any possible decline is the lack of historic records for this frog (Gillespie 1997). In the northern portion of the range of *H. australiacus*, many populations are known to or almost certainly occur within the formalised reserve system and this species should be well conserved in the Sydney Basin bioregion. On the other hand, very few individuals from the southern half of this frog's range have been recorded in reserved areas. Most of the known southern populations occur within land managed by State Forests of New South Wales or the Victorian Department of Natural Resources and Environment (Gillespie 1990; Lemckert *et al* 1998). The paucity of records from reserved areas in the southern populations is likely to be due to the very limited survey effort directed into these areas compared to that undertaken in forestry areas (Lemckert *et al* 1998). Given our experience in surveying for this frog, we consider it unlikely many records would have been obtained in reserves when little specialised survey effort has been expended, even if this species is widespread in these areas.

Disturbance impacts

Forests in which the species occurs are often subject to commercial logging, yet the impacts of this activity on *H. australiacus* are poorly understood. Field studies in southern NSW show that the species will use logged areas, often moving into very recently logged areas (Lemckert and Brassil 2003). There have also been suggestions that the species may possibly prefer older forests (Kavanagh and Webb 1998; Lemckert *et al.* 1998). There is no information regarding long term survival or success of animals within logged areas. Gillespie and Hines (1999) suggested that increased sediment loads resulting from forestry activities and, in particular, road construction, may be the most significant human disturbance affecting this frog. This was based on work undertaken associated with high intensity Victorian forestry operations (see O'Shaughnessy and Associates 1995). Green *et al.* (2004) found in laboratory experiments that multiple short-term sediment increases did not appear to directly negatively impact tadpoles of *H. australiacus*, suggesting that any impacts may not be as severe as postulated. They did however recommend caution with extending their laboratory results to the field. Within NSW, breeding habitats of all frog species are considered unlikely to be directly impacted by raised silt levels as current forestry practices require buffer zones (based on the stream size) to be established around all waterbodies to prevent erosion and sedimentation of the watercourses (e.g. IFOA 1999). Where *H. australiacus* is known to occur additional prescriptions are put in place to further protect breeding and non-breeding habitat of this species (e.g. IFOA 1999).

Fire is a natural part of most Australian ecosystems (Groves 1994), therefore it is likely to be encountered by *H. australiacus*. Prior to European occupation, the forests which the species occupied would have burnt regularly, through natural causes and Aboriginal burning (Kohen 1995). It is likely that the species has adapted survival mechanisms to exist under natural forest fire regimes. The impacts of fire on the species have not been studied, although some have theorised about related impacts. Lunney and Barker (1986) recorded finding the fire scarred rear portion of a *H. australiacus* on a stump and suggested that fire directly caused its death. Fire may increase the risk of desiccation to the frogs through increasing soil temperature and decreasing soil moisture (Lemckert and Brassil 2003) which may result in mortality for some individuals. Humphreys and Craig (1981) report that severe fires are required to significantly heat the soil to depths greater than 2.5cm, however short bursts of increased temperatures at greater depths may be enough to kill an individual. *H. australiacus* may be able to survive fires by burrowing deeper into the soil profile, although individuals may still be susceptible to some fires. There is a need to understand how the timing, intensity and frequency of burns impacts upon this species and its habitat.

Diet

Adult *H. australiacus* are generalist predators (Gillespie 1990). Studies of the gut contents of voucher specimens collected in pit traps have revealed that the frog primarily consume ground dwelling invertebrates including ants, beetles, spiders, scorpions, centipedes and cockroaches (Littlejohn and Martin 1967; Rose 1974; Webb 1983; Webb 1987). Occasionally the diet has included aerial invertebrates such as moths (Webb 1987).

While no study has examined the diet of the tadpole, oral morphology can be indicative of diet (Das 1994). The tadpole has many teeth rows and a large beak (Anstis 1974), which would aid the species ability to scrap food from submerged objects in the waterbody. In the wild observations suggest that the tadpole is benthic (Daly 1996); and its diet is therefore likely to be comprised of algae and bacteria present on the pond base or attached to submerged objects, as well as decaying vegetative matter.

Research Techniques

Detection of *H. australiacus* in any given area is difficult for a number of reasons. Firstly, it is an extremely cryptic species, usually detected only after heavy rain (Webb 1987; Mahony 1993). Regular surveys for this species cannot be conducted, as any survey must coincide with heavy rainfall events. Secondly, the species is thought to occur in low densities both in breeding and non-breeding areas (Rescei 1996). For this reason, encounter rates are extremely low. Thirdly, the concept of "site" used for other frog species is not directly applicable to *H. australiacus*. Waterbodies are often used to define sites that are surveyed for the presence or absence of frog species (eg Pyke and White 2001). *H. australiacus* spends much of its time in forested areas away from waterbodies (Lemckert and Brassil 2003) making large tracts of forest around the breeding site potential "sites".

Presently the most commonly used technique for detecting *H. australiacus* involves driving nocturnal road transects, as described by Shaffer and Juterbrock (1994). This technique is most successful following heavy rains and/or during rain (Webb 1987; Gillespie 1990; Lemckert *et al* 1998). During road transects success is higher when the gutters are examined as well as the road surface (A. Britton, *Pers. comm*, 2002, State Forests of NSW, Hunter Region; Penman, *unpub. data*). This technique has been adopted by the southern region of State Forests of NSW as the standard survey technique for the species (IFOA 1999). The main problem with this technique is that only a small proportion of habitat, hence population, can ever be surveyed for a short period of time on any given night. The techniques may be useful if it provided a sub-sample of the various forest habitats, however in the forests of eastern Australian access roads are constructed along ridges and often avoid valleys and creek crossings. Thus road transects do not usually provide an unbiased sampling method.

Pitfall traps have captured *H. australiacus* in a small number of studies, however capture rates have always been low. In one area, Kavanagh and Webb (1998) captured nine frogs in 8712 trap nights during a wet period following drought (1983/84) and a further three frogs were captured in 8976 trap nights the following season. Several years later (1991/92) trapping yielded no frogs in 8976 trap nights. Lemckert (*unpub.data*) caught one frog in approximately 1000 trap nights. In contrast, Gillespie (1990) reported no frogs were captured in 5400 trap nights despite traps being in appropriate habitats. Trapping success in these studies appear to have been related to climatic conditions. The efficiency of this technique compared with nocturnal surveys needs to be tested.

The use of auditory surveys is briefly discussed in the literature. Some authors report that standardised auditory surveys have not been successful in locating breeding sites (Lemckert *et al* 1998). In contrast, up to 10 breeding sites in Jervis Bay were located using standardised auditory survey techniques (White, 1999). Where call playback techniques are included in the auditory survey they have not been reported to be successful for this species at any site. As with most frog species, the timing of auditory surveys can significantly affect the success rate. It is not clear whether there is a distinct breeding season or a climatic trigger for the species to begin calling. Reports of calling activity have extended from the first rains in late winter (August) (Barker *et al*. 1995) through to autumn (Harrison 1922; Gillespie 1990). Rainfall does not appear to be necessary to initiate calling (Gillespie 1990; Daly 1996; Lemckert *et al* 1998). Calling has been recorded in air temperatures of 12 – 22° C and in water between temperatures of 13 – 21° C (Littlejohn and Martin 1967; Daly 1996). Almost all female frogs captured in the wild, and those in museum collections, are gravid (Penman, *pers obs*; Lemckert, *pers obs*) which suggests that breeding could occur throughout the year if conditions are suitable. This is supported by the fact that males have been recorded calling in most months of the year (Gillespie 1997). In contrast, the breeding season of the five congeners in the southwest of Western Australia is strongly seasonal and is linked to the autumn and winter rains (Lee 1967). The more defined breeding season in the western species has most likely arisen as this area has a defined wet autumn and winter and a dry summer, whereas rainfall may occur throughout the year in the south-east of Australia (Mackey *et al* 2002).

Tadpole surveys are likely to be successful as the species has a large conspicuous tadpole with a relatively long aquatic phase (e.g. Flectcher 1898; Harrison 1922; Lemckert *et al* 1998). The tadpoles of the species grow up 85 mm (Daly 1996) and are often seen resting on the pond/creek base. Time to metamorphosis for the species is recorded as taking between three and twelve months (Daly 1996), therefore tadpoles may be present in a waterbody for much of the year. The main difficulty with this technique is that the surveyor needs to be experienced in tadpole identification for all species in the area.

Speciation

Both Gillespie (1990) and Daly (1996) have suggested that *H. australiacus* may be comprised of two different species. This was based on the geographical disjunction between the far southern population and those from the north as a gap exists in the records from Narooma to Ulladulla, a distance of approximately 100 kilometers (Figure 1). This may be a disjunction between the northern and southern populations, but the gap is not as large as was known to be the case by either Gillespie (1990) or Daly (1996). Several new records having been obtained within this area in the last 10 years, particularly from surveys in the Bodalla and Wandella State Forests around Narooma. While surveys have been conducted in the "gap" without success (M. Crowley *pers comm* 2002, State Forests of NSW, Southern Region) we remain uncertain as to whether this merely reflects lower survey effort in this region. Many areas are not easily accessed and have not been surveyed, even though the habitat appears to be similar to that used to the north and south. There are also no obvious barriers that would restrict migration throughout this "gap". There is no current reason to believe that any significant disjunction exists.

The literature suggests that some morphological variations may exist between the northern and southern populations, particularly in the tadpoles. The tadpole tooth formula may vary between the populations. As mentioned above, three tooth row formulae for this species are presented in the literature:

```
      I
3 ________ 3   (Lee 1967)
I          I
      2

      I
4 ________ 4       (Anstis 1974; Anstis 2002)
I          I
      2

      I
5 ________ 5       (Watson and Martin 1973)
I          I
      2
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The discrepancy between the formulae may have arisen for a number of reasons. Lee's (1967) formulae was based on museum specimens could have been damaged during the preservation process. Interpretation of teeth rows can vary between authors, particularly where small split teeth rows are concerned, as is the situation here. The differences between Anstis (2002) and Watson and Martin (1973) however, may represent evidence to support the separation of the northern and southern species. Anstis' data was based on specimens from the northern populations (Mount Kiera, NSW), whereas Watson and Martin's data were from the southern populations (Walhalla, Victoria). Further research is necessary to determine if and where variation in the tadpole tooth formula exists.

The eggs have been reported as pigmented in the northern populations (Daly 1996; Anstis 2002), however Watson and Martin (1973) recorded that the eggs in Victoria are unpigmented, suggesting a separation of a northern and the southern species (Daly 1996). However, observations of egg masses through the body cavity of females from the Eden area indicates that the eggs of these populations are also pigmented (F. Lemckert *pers. obs.*).

The suggestion of two species is possibly supported by differences in the adult morphology and genetics of individuals from across the range (Mahony *et al.* in prep). This study indicates both physical and genetic separation of the northern and southern populations sufficient to warrant a split. This study has however, only included animals from the north of the postulated range of the southern population and from within the northern portion of the range of the northern population and may only represent geographic variation rather than speciation. Several populations, particularly populations in the central part of this frog's range, need to be examined.

There are minor variations in the call structure of the species reported in the literature, but the small sample sizes prevent us drawing conclusions. Spectral analysis of the call was conducted by Littlejohn and Martin (1967) for one animal from Jervis Bay, New South Wales and three animals from north of Cann River, Victoria. The data presented indicated that the calls only differed in the fundamental frequency values with the Jervis Bay animal displaying a fundamental frequency of 390 cycles/second, while the Cann River frogs displayed fundamental frequencies ranging from 320 cycles/second up to 360 cycles/second. Further call analysis may assist in delineating the boundaries between the northern and southern populations.

The evidence presented for speciation is not sufficient to determine if two species exist within *H. australiacus*. A study into this issue is warranted.

Conclusion

Like for many Australian frog species, the ecology of *H. australiacus* is poorly understood (Tyler 1997). The cryptic nature of the species has meant that a comprehensive study of the ecology and habitat requirements has not been undertaken. Publications relating to this species have been based on small areas of the species' geographic range and relatively few records.

A number of gaps in the knowledge of this species have been identified. We suggest that the following areas of research should be considered:

- A comprehensive study into the species ecology is clearly needed. This work has commenced in both the northern and southern populations.
- A study into the distribution of the species, particularly in the gap area. This study should address the factors determining the distribution of this species.
- A study into the short and long term impacts of habitat disturbance, including fire. This is especially important for the southern populations, which are frequently found in areas subject to ongoing disturbances through commercial logging operations.
- Further research is needed to understand the genetic variation within *H. australiacus*. In particular research needs to address whether the northern and southern populations are in fact separate species, and where any division occurs.

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