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Habitat relationships and presence of the threatened heath frog *Litoria littlejohni* (Anura: Hylidae) in central New South Wales, Australia

Francis Lemckert[1,2,*]

[1]School of Environmental and Life Sciences, The University of Newcastle, Callaghan, New South Wales 2308, Australia

[2]*Present address:* Forest Science Centre, Science and Research Directorate, New South Wales Department of Primary Industries, PO Box 100, Beecroft, New South Wales 2119, Australia

ABSTRACT: The heath frog *Litoria littlejohni* has been recorded from only scattered locations in south-eastern Australia, and habitat specificity may determine this rarity. I tested for relationships between the presence/absence of this species and habitat at 2 scales. A logistic regression was used to compare 10 presence and 36 absence sites to habitat variables at ponds located in central New South Wales. Habitat information derived from Geographic Information System (GIS) datalayers was compared to 51 known presence and 13 000 absence (null) sites located within 220 km of Sydney. A predictive regression tree was also created using the 51 presence and 1000 of the absence sites. In the Watagan Mountains, heath frog presence showed a significant negative relationship with the percentage of grass cover in the surrounding forest. Heath frog presence sites in the Sydney region were positively associated with moist environments (Prescott Index) and negatively associated with terrain roughness. The regression tree indicated a 94 % probability of presence where the Prescott Index was >1.2 and the solar radiation index was >13.4. These results indicate that heath frogs are present in moist, sunny areas that are relatively flat. However, these variables are too broad to accurately predict heath frog presence at a specific water body. Based on this information, the heath frog is absent from many apparently suitable sites. Thus, its patchy distribution, if habitat related, results from a yet to be measured variable.

KEY WORDS: Habitat relationships · *Litoria littlejohni* · GIS · Presence

INTRODUCTION

Conservation of any species requires a good understanding of the elements of its environment that are essential for its survival. Pond-breeding anurans require a water body of some type in which to lay eggs and in which the tadpoles can grow to reach metamorphosis. This is an element critical to their survival, and most species use only a limited number of the available breeding sites within their range, with many apparently appropriate water bodies not used for reproduction (e.g. Lemckert et al. 2006). More recently, research has also indicated that elements of the surrounding habitat used for non-breeding activity, so called complementary habitat, are often equally important for frogs using a breeding site (Guerry & Hunter 2002, Pilliod et al. 2002, Baldwin et al. 2006, Rittenhouse & Semlitsch 2007). The distance frogs need to move to reach these important complementary habitats varies, but an approximate mean of 300 m has been estimated from a range of species (Semlitsch & Bodie 2003, Lemckert 2004a, Rittenhouse & Semlitsch 2007). These habitats provide areas for feeding and protection from predators and can also provide critical overwintering environments (Lemckert 2004a), and the absence of suitable complementary habitat will render a breeding site unsuitable for use. This additional requirement may explain the apparent disparity

*Email: frankl@industry.nsw.gov.au

in site use. Understanding the factors that produce presence/absence patterns is important to successfully manage a species, especially where anthropogenic habitat disturbance can alter this pattern and so can be controlled to ensure the maintenance of anuran populations.

A series of localised habitat features have been indicated to control the presence and/or abundance of frog populations using a breeding site (Stumpel & Van Der Voet 1998, Anderson et al. 1999, Martinez-Solano et al. 2003, Lemckert et al. 2006). The habitat variables thought to most commonly determine whether a water body will be used by a given species resident within the area include hydroperiod (Lehtinen et al. 1999, Beja & Alcazar 2003, Watson et al. 2003) and vegetation structure (Bosch & Martinez-Solano 2003, Homan et al. 2004, Porej & Hetherington 2005, Van Buskirk 2005). These important vegetation elements may be found directly in or around the water body or be more distant to it and represent both breeding and non-breeding requirements (Hartel et al. 2007).

Studies of the relationships between habitat and pond use by frogs in pond systems in Australian forested and semi-forested areas have indicated that relationships are species specific and vary widely between species. A positive relationship between canopy cover and total species richness was reported in natural and man-made ponds within an agricultural landscape on the tableland on the east coast of Australia (Hazell et al. 2001, 2004). The extent of bare ground around a pond and emergent vegetation at the water's edge also correlated with pond use by several species. Further work indicated that high species richness was associated with greater levels of emergent vegetation and the absence of fish (Hazell et al. 2004). An investigation of man-made ponds located in tableland forests found species richness and the abundance of various species to be correlated with altitude, latitude, rainfall, forest wetness and extent of dry forest (Lemckert 1999). A study of pond-breeding frogs in forested areas at low to mid-altitude sites in forests (Lemckert et al. 2006) found a wide range of variables correlated with the richness and abundance of the frogs present, with the relationships varying between species and in the direction of influence.

The heath frog *Litoria littlejohni* (Anura; Hylidae) is a recently described (White et al. 1980, 1994) anuran species of conservation concern found heterogeneously along the coast and adjacent ranges of south-eastern Australia (White & Ehmann 1997). It is listed as threatened under Australia's Environmental Protection and Biodiversity Conservation Act 1999 and Vulnerable under the New South Wales (NSW) Threatened Species Conservation Act 1995. A review of the information available for this species (Lemckert 2004b) indicated that, unlike many anurans, the heath frog has relatively broad breeding-habitat requirements. It has been recorded calling around widely differing types of ephemeral pools, ponds and streams. It has also been recorded from a range of natural vegetation types, including heath, woodland, dry and wet sclerophyll forest, but not from cleared areas, so it appears dependent on native vegetation for its presence. As this species has been recorded from a very limited number of sites within a relatively broad range (Lemckert 2004b), its presence appears most likely to be restricted by some aspect of the environment that has yet to be identified. Given its broad recorded range of breeding habitats, features of the breeding water body appear unlikely to play a part.

Here, I analysed habitat variables associated with the presence of the heath frog in central eastern NSW, considering 2 different information scales. Firstly, I recorded and compared habitat features within and around known used and unused water bodies located in the Watagan Forest block on the central coast of NSW. These were sites I was able to survey and sample directly. Secondly, I compared GIS-based habitat variables generated for a 500 m radius around presence and absence sites located within a radius of 220 km of Sydney. This approach provided a much larger number of presence and comparative 'absence' sites for analyses, but I could not sample the sites directly. Detecting associations between the presence of the heath frog and specific habitat elements may explain the restricted occurrence of the species and identify important management requirements for the conservation of this anuran.

MATERIALS AND METHODS

Study areas. The Watagan Mountains study area is comprised of a 45 500 ha block of native forest located approximately 100 km north of Sydney in south-eastern Australia (Fig. 1). The lands rise in elevation from around 100 m in the south-east to over 300 m in the west and have an annual rainfall of around 1300 mm through the area. Temperatures are mild, with a mean minimum of 6.25°C (July) and mean maximum of 27.5°C (January). Soil types vary, but loams predominate through the central part of the Watagan Mountains, whilst sandy soils are located patchily at the northern and southern edges. The forest types in the area vary from temperate rainforests to dry open hardwood forests, but dry sclerophyll forests predominate. Commercial logging of the area commenced early in the last century and has increased in intensity with mechanisation, particularly during and after the 1940s (see SFNSW 1995 for a detailed description of the area and forestry activities).

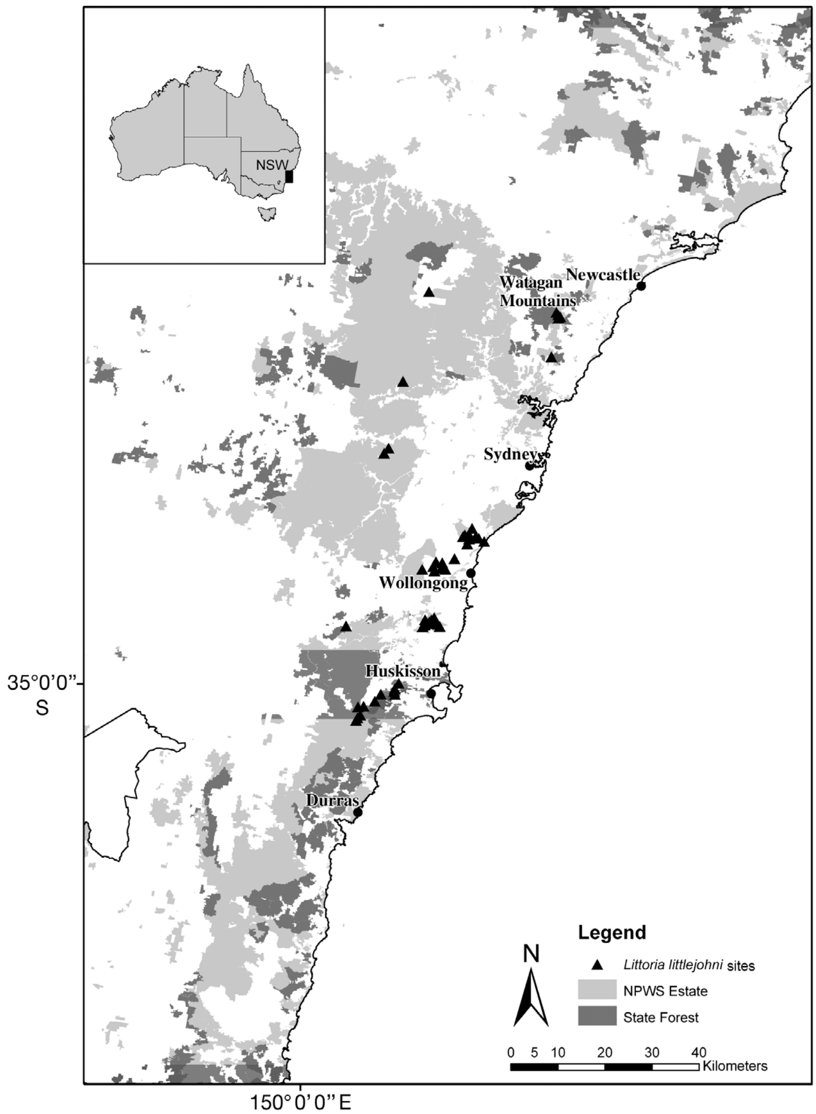

Fig. 1. Study area and heath frog record sites. All non-forest areas around the cities of Sydney, Newcastle and Wollongong are essentially urbanised and contain little suitable contiguous habitat for heath frogs. NPWS: National Park and Wildlife Service conservation lands

The broader 'Sydney Basin' study region for this investigation covered all lands within a 220 km radius of the city of Sydney, NSW, and includes the Watagan Mountains (Fig. 1). Altitudes within this region range from 0 m at the coast to over 1000 m in the Blue Mountains to the west of Sydney. The overall climate is similar to that of the Watagan Mountains. For Sydney itself, the mean maximum is around 26°C and mean minimum is 8°C, with a mean annual rainfall of around 1200 mm. Temperatures reach slightly higher and lower in western Sydney. In the higher altitude areas of the Blue Mountains, summer highs reach only 23°C, winter lows reach 2.5°C and rainfall averages 1400 mm (see Bureau of Meteorology: www.bom.gov.au/climate/averages/tables/).

The majority of the coastal land as well as the central portion of this area are urbanised landscapes of the cities of Sydney, Newcastle and Wollongong. However, a substantial portion of this region remains as native vegetation held in conservation areas and with some areas of production forest in the north (see Fig. 1). The retained vegetation consists mainly of dry sclerophyll woodlands and forests, with some wetter elements in the mountains and in valleys of the coastal areas. Much of the conservation reserve land falls on sandy soils generated from parent sedimentary rock of the Hawkesbury Sandstones formation and associated groups (Branagan & Packham 2000).

Habitat variables and analysis. For the Watagan Mountains, I obtained the locations of heath frog calling sites mainly through surveys of 41 suitable pond sites located in this region. These are detailed in Lemckert et al. (2006), and were based on a minimum of 7 night counts at each pond carried out between 1 September 2001 and 30 April 2006. Surveys commenced with an initial 3 to 5 min listening period, to record calling males, followed by a visual search of the pond and the adjacent 20 m section of bank to locate non-calling frogs. The number of heath frogs present, if any, was recorded along with the time, date and weather conditions. The ponds were visited at random, and 8 to 10 ponds were searched on any given night. This minimised the influence of any temporal (nightly cycle) and/or environmental (weather change) patterns in the analysis. The broad spread of survey times allowed me to cover a range of micrometeorological conditions and ensure that at least 2 surveys of each pond were undertaken after significant rainfall events (>30 mm in the previous 24 h). Four additional presence sites were obtained through the records of other researchers. I included in the analysis any site where heath frogs had been recorded within the previous 5 yr. These surveys provided 40 absence sites, with enough effort being undertaken for me to be confident that the heath frog was truly absent from these water bodies. All sites fall within or on the edge of forested habitat and include temporary, semi-permanent or permanent artificially created ponds, which had either been deliberately constructed as ponds for fire control or as depressions resulting from road construction.

I visited each site between June 2003 and May 2004 to collect data for 14 habitat variables chosen as being most likely to show a relationship with presence/absence, based on results from previous habitat studies and personal observations (variables listed in Table 1). Only 2 habitat-based features of the breeding pond are included: the extent of bank vegetation and the degree of pond shading. I excluded other potential pond features because the wide range of known used water bodies (Lemckert 2004b) indicates that other pond features are highly unlikely to influence the selection of sites. Instead, I concentrated on variables that were related to attributes of the surrounding vegetation and physical environment.

Habitat variables obtained for each site were compared to the presence/absence of the heath frog using logistic regression. Spatial autocorrelation of heath frog presence sites was tested using Moran's I, and the distribution of heath frogs within the ponds was found to be spatially autocorrelated (Moran's I = –0.16; $p < 0.0001$). Therefore, a spatial lag response variable (SLRV) value (using a distance of 500 m) was calculated for each site (as per Haining 2003) and included in the modelling process to account for spatial autocorrelation in the data. All variables were also tested for significant correlation ($r > 0.6$) and correlated variable sets, but none were 'highly' correlated. Finally, the logistic regression was run to calculate the p-values and estimates for each variable. To ensure an equal balance of presence and absence sites in the analysis, presence sites were given a weight of 1 and absence sites were given a weight of the number of presence sites divided by the number of absence sites (Wintle et al. 2005). Due to the very low number of presence sites, only 1 variable could be included in any model, and so all variables were analysed separately for their relationship (Quinn & Keough 2002).

The broader scale GIS-based assessment commenced with collating records of heath frogs from within a 220 km radius of Sydney. This radius encompasses the geological basin on which Sydney is centred and covers the main concentrations of records for the heath frog. Presence sites within this radius were obtained from the Department of Environment and Climate Change Wildlife Atlas, Forests NSW databases and personal records. These records come from a wide variety of sources, including targeted surveys, general surveys and incidental sightings, and have used a wide variety of techniques by numerous different people over the previous 20 yr. Where identified sites were located within 500 m of one another, only 1 site was chosen for use to maintain independence of sites. A distance of 500 m was chosen based on the findings of Lemckert (2004a), which indicated that individuals using ponds rarely moved more than 300 m from ponds; thus, 500 m provides a distance that should lead to independent populations. The site selected was that with the most recent record of a heath frog and, where sites were of the same vintage, the sites that maximised the number that could be selected from a group. This resulted in 51 separate record sites. For comparison to these presence sites, 13 000 absence sites were generated by randomly allocating points within this same region following the method of Wintle et al. (2005). This appears to be a very large number of absence sites compared to presence sites, but follows the recommendations of Wintle et al. (2005), with the large number of sites providing a detailed habitat profile of the absence sites. This approach provides a background sample of the habitat values of the region, which are then downweighted to create a balanced design. These sites could also not be guaranteed as true absence sites, but the species is almost certainly absent from nearly all of these sites and so any erroneous 'absence' sites should have no significant bearing on analyses outcomes.

Once the presence and absence sites were selected, the mean value was estimated for the following variables within a 500 m radius of the record site: aspect (relative to north), elevation (mean of 25 m grid cells), topography (calculated over a 125 m circle of 5 cells), Prescott Index, roughness, Solar Radiation Index and geology (sandstone present/absent). The Prescott Index (Prescott 1950) provides a mea-

Table 1. Variables used in the analyses and their categorisation. Those in *italics* relate directly to features of the breeding pond; the others relate to the habitat surrounding the breeding site

Variable	Categories
Bankveg[a]	*Ratio: % of pond bank covered by vegetation*
%Shade[a]	*Ratio: % of the pond shaded by vegetation*
Sand[a]	Nominal: sand or not sand
Mixed age	Nominal: mixed or even-aged forest
Mat[a]	Nominal: forest is composed of mainly mature trees or not
Stumps[a]	Continuous: mean no. of stumps on transect (0.1 ha; 20 × 50 m)
Clearing[a]	Ratio: % area cleared in a 300 m radius
Mean-fire[a]	Continuous: mean height of fire scars
Overst[a]	Ratio: mean % of canopy cover in surrounding forest
Heath	Nominal: heath in forest or not
Und-cover[a]	Ratio: maximum % of understorey cover in surrounding forest
Ground veg[a]	Ratio: mean % of vegetation as ground cover
Grass	Ratio: mean % of grass as ground cover
Litter[a]	Continuous: mean litter depth (cm)

[a]Variables used in the final modelling process

sure of the relative moisture levels present in an area, taking into consideration rainfall and evaporation. The measure used was the mean within a 500 m radius based on 25 m grid cells. Roughness is the mean SD of altitude within the same cells. Solar radiation is the mean measure of the direct exposure to solar radiation received by the grid cells within a 500 m radius calculated from slope, aspect, horizon azimuth and latitude. Geology was based on the presence/absence of sandstone within a 500 m radius.

Again, these variables were included after prior testing for interrelatedness and removal of highly correlated variables (r > 0.6). These values were derived from a 25 m digital elevation model (DEM) using ArcGIS, while the geology was provided by the NSW Department of Primary Industries (2006). Again, a radius of 500 m around each point was used, as this area is likely to contain the core breeding and non-breeding habitat required by resident populations, based on Lemckert (2004b).

These 7 variables were included in logistic regression models, using R, with all combinations of the modelled variables being calculated. All models within 2 points of the model with the best Akaike information criterion (AIC) score were assessed, and the model chosen as the best was that with the fewest variables, thereby providing the simplest result to explain among a series of models with very similar fit.

Further analysis of the data was performed by producing a regression tree for the presence and absence sites using the same data. This tree provides a clearer visual classification of presence sites in relation to the chosen variables and was also produced using R. All analyses were conducted using R v 2.8.1 (R-Development Core Team 2007).

RESULTS

Logistic regression based on 10 presence and 36 absence sites in the Watagan Mountains indicated that presence of the heath frog only correlated significantly, and negatively, with the percentage of grass in the ground cover of the surrounding forest ($p < 0.05$; beta = −0.1759).

In total, 51 independent presence sites were obtained for broader scale, GIS-based study. Analysis of these sites resulted in 15 models with similar AIC values (within 7 points) containing up to 6 of the measured variables. The model with the lowest AIC value included 6 variables; however, a model with just 2 variables provided almost as good a model fit and was chosen as the best model for consideration. This model indicated that heath frogs were significantly more likely to be found in areas with a higher mean Prescott Index ($Z = 4.22$; $p < 0.001$) and a lower mean measure of roughness ($Z = -3.62$; $p < 0.001$). That is, presence sites were more likely to be located in moister and flatter areas.

The regression tree based on the 51 presence sites and 1000 absence sites (Fig. 2) indicated a 94 % probability of the species being present at sites where the Prescott Index was >1.2 and the solar radiation index was >13.4. That is, the species is likely to be recorded in areas where there is high moisture content and a high level of solar radiation.

DISCUSSION

The habitat analysis of the Watagan Forest block sites found that the forest habitats surrounding ponds used by the frog (presence sites) had relatively little grass in the ground cover. In this area of forest, grassy ground cover is prevalent in dryer forests, suggesting that the heath frog prefers moister areas. Within the broader Sydney region, the habitat analysis found that heath frog presence was associated with higher levels of moisture and relatively flat environments. The presence sites could be clearly separated from the randomly allocated absence sites based on increasing moisture levels and increasing solar radiation levels within 500 m of the site. The results of the 2 broad-scale analyses, while only inferential, do provide reasonably strong indications that the presence of the heath frog is associated with flat sunny areas with greater levels of exposure to solar radiation and with a moist environment.

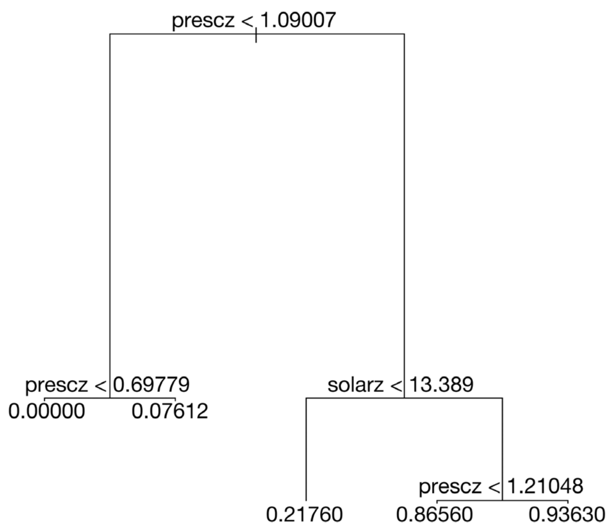

Fig. 2. Regression tree produced to classify heath frog presence sites within the Sydney region. Prescz is the Prescott Index and solarz the Solar Index. Numbers adjacent to variables are values of indices. Numbers at base of arms indicate the probability of a presence site occurring in a category

The reasons why this species would prefer moister areas are uncertain, but there are some possibilities. Areas of increased moisture could be those that have better water bodies for breeding as they are less likely to dry out. Tadpoles are adapted to a still to slow-moving water environment (Anstis 2002). Historically, slow moving or still water sites would have been rare in the environments studied, with streams providing few opportunities for reproduction. There may have been a strong reliance on more temporary pools for successful reproduction. Moister sites would have longer lasting pools that would allow tadpoles to reach metamorphosis, especially those developing during the winter months, which is common for this species (Lemckert 2004b). The hydroperiod of the pond was not included in the analysis because very few semi-temporary or temporary pools were found to be used by this species in the Watagan Mountains. In these mountains, however, the presence of forestry and the resultant construction of many permanent ponds may have provided these frogs with a greatly increased resource for reproduction and options not to use temporary pools. In areas without these ponds, the presence of temporary ponds with longer hydroperiods may be very important.

Non-breeding habitat use may also provide at least part of the answer to this question. Radio-tracking of 3 adult female frogs over a 4 wk period revealed that each frog remained on the ground and predominantly sheltered in deep leaf litter (author's unpubl. data). Deep leaf litter is a very moist environment, and frogs adapted to using leaf litter may not have well developed physiological tolerances to desiccation. Hence, physiological constraints may be critical in determining the distribution of the heath frog, as appears to be typical of other species (e.g. Baldwin et al. 2006, Rittenhouse & Semlitsch 2007); however, the ability of this frog to resist and tolerate water needs to be tested to explore this idea further.

Solar radiation levels and roughness were alternately important in the broader-scale study. It is not clear why this was the case. Perhaps increased solar radiation is the important variable and roughness has an influence on this. Sites with greater levels of solar radiation will have a relatively warmer environment, which could assist both the activity of adults and especially the tadpole stage. This frog is known to breed in winter (Lemckert 2004b), and water bodies in areas with higher solar radiation should be relatively warmer and so provide better growing conditions for the tadpoles, decreasing the time to metamorphosis and thus exposure to predators at this vulnerable stage. This is something that could be tested by recording the temperature of used and unused water bodies within the region.

It is not clear how roughness would be of advantage to this species. Roughness would reduce the likelihood of temporary pools forming, as water run-off would be increased. However, increased roughness would seem to correlate with decreased solar radiation levels at a finer scale, as rougher areas have more gullies and valleys, leading to the shading of larger proportions of the available ground. If warmer temperatures are important, these larger areas of shaded and colder habitats would not be preferred by heath frogs. Work on the thermal preferences of heath frogs may resolve this issue.

However, although moisture and sunlight levels in the environment appear to have some relationship with the presence of the heath frog, these features alone do not appear to provide an adequate explanation of the factors that determine the presence of this species, nor do they provide great predictive powers regarding its presence. A relatively grass-free understorey is not unusual in various areas of the Watagan Mountains, yet other areas with grass-free understories are not inhabited. In the Watagan Mountains, the species is essentially restricted to a compact area of approximately 5 × 5 km. Several ponds constructed within the area were colonised immediately by this species, but ponds constructed equally short distances (<500 m) outside of this area have remained unused (author's unpubl. data). Individual frogs can clearly move the required distances to access these 'outside' pond sites, so it is not a matter of spatial isolation. Rather, these findings suggest something is specifically important about the area in which the frogs remain.

Other specific and limiting non-breeding habitat requirements that could explain the patchy distribution could be either specific dietary or shelter site requirements. The diet of this species is not currently known, but the diet of Australian frogs in general appears to rarely be specific (e.g. Mac Nally 1983, Tyler 1994, Lemckert & Shoulder 2007). There is also no indication from external morphology that this species would have any dietary specialisation. Specific shelter site requirements have been indicated for several species of anurans (Lemckert 2004a), but have all related to avoidance of severe overwintering conditions (freezing) or the avoidance of storm surges when the species is inactive. As the climate in coastal NSW is mild, and freezing conditions would not be a threat, there would appear to be no need to avoid situations where freezing may occur. This species is active in all months of the year and so would not require aestivation sites that protect it during periods of inactivity. In the case of the Watagan Mountains at least, perhaps there is some historical situation that has caused contraction to this small area, but it is not clear what this would be.

The inability to detect clearer habitat relationships is influenced by the limited number of sites relative to the areas being studied. Understanding the habitat relationships of rarely recorded species is difficult because there are few records with which to assess their relationships. Only 10 presence sites were available for the first analysis, and this does not allow multiple habitat features to be included in a model (Quinn & Keough 2002) and prevents more complex modelling that may provide better insights into habitat relationships. The use of remotely determined GIS variables allowed the inclusion of a greater number of presence sites and especially a relatively large number of absence sites for comparison. However, the use of GIS data necessarily minimises the fine-scale information that can be obtained from the analysis and so provides only broad habitat relationships. These landscape features are less likely to provide sufficient detail to determine whether a breeding site is likely to be used by this species, and rather indicate that the species may simply be present in the general area.

The aim of this study was to provide a clearer understanding of the habitat requirements of this frog to allow better targeting of surveys and protective measures. The relationships uncovered did not provide a detailed understanding of the habitat features that determine the presence of this species in an area. However, the analysis did provide some encouraging signs in regards to the ability of this species to tolerate disturbance. All of the sites in the Watagan Forest block are present within timber production forests that have been logged multiple times since the 1940s. Several are immediately adjacent to plantations that have been cleared within the previous 2 yr, and all sites have been subjected to multiple fires of varying intensity. The apparent dependence on deep leaf litter and a denser ground cover might suggest that habitat disturbance would have a negative impact; however, the heath frog remains present and relatively abundant within this limited area. This may be because most of the forest is logged selectively, and substantial areas of any compartment usually remain undisturbed and so provide refuge sites while regeneration occurs.

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