Living in the 80s – seasonality and phenology of frog calling activity at Darkes Forest from 1987-1989

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ABSTRACT

We recorded the calling activity of frogs at a permanent pond 80 km south of Sydney between 1987 and 1989, documenting the calling seasons of five species and relating calling activity (within calling seasons) to temperature, humidity, barometric pressure and rainfall. Three species commenced calling in August/September with *Litoria peronii* and *Uperoleia laevigata* calling consistently throughout the summer months and *Limnodynastes dumerilii* calling more sporadically. *Limnodynastes peronii* appeared capable of calling at any time of the year, but did not call continuously. *Litoria verreauxii* called very consistently from January to September. Random effects models indicated that the probability of males calling increases with increasing temperatures in *Limnodynastes peronii, Litoria peronii* and *Uperoleia laevigata*. Increasing barometric pressure was positively associated with calling in *Limnodynastes peronii*. Calling was not related to either rainfall or humidity for any species. The calling seasons were similar to expectations based on published information. The lack of relationships between calling and rainfall and humidity may be related to the presence of permanent water and or the regular rainfall experienced throughout the study period. Historical data from this study may provide a baseline for future studies to assess changes in calling phenology linked to climate change.

Key words: frog calls, frog seasonality, frog behaviour, micrometeorology

Introduction

Micrometeorological conditions are widely recognised to influence anuran calling activity, with rainfall (Balinsky 1969, Telford and Dyson 1990, Krupa 1994, Lemckert 2001) and temperature (Jackson 1952, Einem and Ober 1956, Humphries 1979, Okuno 1985) most often being found to be of significance, usually showing a positive relationship. Other factors have also been found to relate to calling (eg, barometric pressure; Oseen and Wassersug 2002), but appear to be much less likely to be influential. Most published studies have been carried out on anurans from western Europe and North America where conditions are somewhat different from those typically found in Australia. The limited number of studies available of Australian species (eg Dankers 1977, Humphries 1979, Mac Nally 1982) suggest that similar relationships exist, but further data are needed to better understand the nature of such a relationship in Australian frogs.

A better understanding of these relationships is relevant because it may allow predictions about impacts on the ecology of amphibians from the predicted changes to global climate. Increases in temperatures after winter have been associated with the initiation of migration to breeding sites and the onset of calling activity and are likely to be instrumental in the commencement of reproduction in many temperate species (see Duellman and Trueb 1986). It has been proposed that global warming will cause earlier commencement of breeding activity in at least some species (Blaustein *et al.* 2001; Pounds *et al.*.2007) and this is already considered to have happened for some (although not all) species in Europe and North America (Beebee 1995; Gibbs and Breisch 2001). Alterations to rainfall patterns such as reduced rainfall or altered rainfall patterns (e.g. fewer but more intense storms) may be just as significant to species that respond to rainfall.

Recent reports have noted the potential for climate change to impact on Australian anurans (Howden *et al.* 2003; Dunlop and Brown 2008, WWF 2008). However, there are few data available to indicate how Australian species may be affected by the predicted changes in climate. To assess the potential impact(s) on changes to calling behaviour in Australian species, more long-term data on changes in calling activity are required.

In this paper we report the timing of calling by several species of frogs monitored in the late 1980s at a pond to the south of Sydney. We also explore possible relationships between the presence/absence of calling and the micrometeorological variables of temperature, barometric pressure, humidity and rainfall.

Methods

The study was performed at an isolated oval shaped 36 m x18 m permanent pond at Darkes Forest, 50 km south of Sydney, New South Wales (Lat 34.23S, Long 150.91E). The pond is at an elevation of 365 m. Little vegetation grew in the water during the study, but grasses, bracken ferns and some low shrubs grew on the bank resulting in approximately 50% of the bank within 3 m of the mean water level being covered in vegetation. The remainder was bare gravel, rocks and clay. The surrounding vegetation is dry sclerophyll eucalypt woodland and heathland growing on a porous, acidic and nutrient poor sandy podsol. For additional descriptions of the study site see Lemckert and Shine (1993) and Lemckert (2001).

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Calling activity was recorded using an automated Hodgeson portable cassette recorder with a Sony standard condenser microphone housed in a Stephenson screen style weather box. The record turned on for 10 seconds approximately every 16 minutes between August 1987 and February 1989, with occasional days lost due to recorder failure. Air temperature, barometric pressure and humidity were recorded hourly during the same period using a Lambrecht Thermohydrograph also housed beside the pond. Daily rainfall was obtained from the Darkes Forest (Kintyre) weather station operated by the NSW Bureau of Meteorology, which was approximately 2 km from the study pond. The variations in the measured climatic variables used in the analyses are presented in Table 1.

We listened to each 10 second recording and noted which species were calling, combining the four periods covering each hour to assess if calling activity occurred at all in that hour. Thus we determined the days of the year when calling was first recorded, the date after which calling became consistent and the actual periods over which calling was recorded: the calling seasons.

We selected 124 one hour periods from the available data in the months of January, February, March, June, September and October 1988. The hours and days were selected randomly using a dice with no more than two one hour periods being selected from any given night. Linear mixed effects modelling was used to test whether or not the occurrence of calling was related to the micrometeorological variables measured in the same hour. A binomial model was applied with the response variable being the presence of calling of a species. Predictor variables were air temperature, barometric pressure, humidity and daily rainfall. The rainfall data used were the totals recorded at 9:00 AM on the morning before the recording period and so represents rainfall immediately prior to the recording period. Some of the months included for analysis were part of the non-calling season for a given species and calling would not occur regardless of the conditions. Hence, data from April and May were excluded from the analysis for *Limnodynastes dumerilii* and April, May and August for *Litoria peronii* and *Uperoleia laevigata*.

Using data from consecutive days produces the potential for serial autocorrelation in the data, with the potential for calling on a day being significantly related to whether calling occurred the previous day/days. To account for this we ran for each species an auto-correlation function (acf) in the R-statistical package. The partial correlation coefficient is calculated for pairs of measurements at increasing lag periods (days). For example, the correlations for all pairs of consecutive measurements are estimated, then for all measurements at two day lag period etc. The function is presented graphically and the number of days over which autocorrelation was observed (hereafter the lag period) is determined as the point at which the partial correlation coefficient drops below 0.2. A simple, species-specific temporal lag variable was then calculated as the average number of calling males of the species of interest for the duration of the lag period. The temporal lag variable was then added as a co-variable to all models to remove any negative effects of the observed temporal autocorrelation.

All potential models for each species, involving all combinations of the measured variables, were generated. All models within 2% of the model with the best AIC score were assessed and the model chosen as the best of these was that with the least number of variables and so provides the simplest result to explain amongst a series of models with very similar fit. We carried out this analysis using R version 2.8.1 (2008-12-22)

Results

The frog community comprised ten species, including *Crinia signifera*. Three species, *Litoria dentata*, *Litoria freycineti* and *Pseudophryne australis,* were represented by fewer than 10 calling records in the available data set and did not warrant investigation of their calling activity. The other six species were recorded calling sufficiently often at the study pond to provide useful information about their calling behaviour. These were *Limnodynastes dumerilii*, *Limnodynastes peronii*, *Litoria peronii*, *Litoria verreauxii*, *Paracrinia haswelli* and *Uperoleia laevigata*. The months of calling activity recorded for each species over the study period are shown in Figure 1.

Table 1. Variation in the micrometeorological data used in the analyses. Note that the maximums and minimums for the month could have been higher or lower than these figures, but the random selection of time periods resulted in their exclusion from analysis. Rainfall is a 24 hour count. Baro P = Barometric Pressure.

	January	February	April	May	August	September
Max Temp (˚C)	20.4	21	16.5	15.8	15.7	17.6
Min Temp (˚C)	15.1	12.7	11.4	7.8	3.3	6.1
Mean Temp (˚C)	17.9	17.1	13.9	11.9	7.9	12.2
Max Humidity (%)	99	96	99	100	99	99
Min Humidity (%)	72	66	80	69	54	45
Mean Humidity (%)	87.8	82.7	96.0	93.3	82.4	77.0
Max Baro P (hPa)	1018	1017	1024	1025	1027	1020
Min Baro P (hPa)	1005	999	1005	1000	1006	1000
Mean Baro P (hPa)	1012	1010	1016	1012	1015	1010
Max Rainfall (mm)	11.8	1.2	98.8	83.8	12.6	8.8
Min Rainfall (mm)	0	0	0	0	0	0
Mean Rainfall (mm)	2.2	0.1	24.9	5.9	1.2	1.2

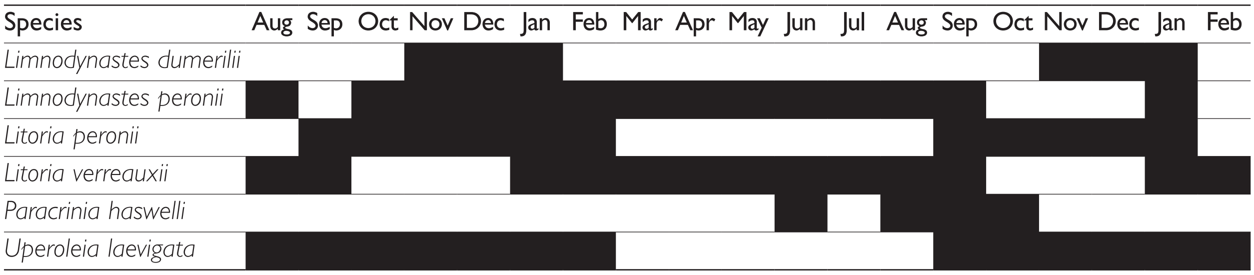

Figure 1. Calling periods of frogs using the pond at Darkes Forest. The monthly series starts in August 1987 and ends in February 1989. Months with calling activity are indicated by black cells.

Three species called only in summer (*Litoria peronii, Uperoleia laevigata* and *Limnodynastes dumerilii*) and *Limnodynastes peronii* called irregularly throughout the year. *Litoria verreauxii* called in any month except October-December. The few data we have for *Paracrinia haswelli* were from late winter and early spring. All of these species appeared to call most intensely in the first few hours after sunset after which they usually, but not always, reduced or ceased calling. Details of calling activity in each species are provided separately, below.

Litoria peronii called regularly over the spring and summer periods. In 1987, calling was first heard on 28 August and was sporadic until 18 September but was then recorded on almost every night until 10 February 1988 when calling ceased abruptly for the season. In the spring of 1988 there was no "warm up" period, strong chorusing started on the night of 9 September and continued all the way to 30 January 1989 when calling ceased. Chorus sizes ranged from 5 or 6 to more than 30 calling males. This species was recorded calling in 54% of the hourly periods analysed for this species.

Uperoleia laevigata: this species called for at least some time on almost every night over the whole spring-summer period (95% of hourly periods analysed). Calling commenced in late winter in both years, but the timing varied between years. In 1987 *Uperoleia laevigata* first called on the night of 18 August, with strong chorusing continuing from that point until mid-February. In 1988, however, whilst calling was first heard on the night of 22 August, calling activity was only sporadic until 9 September when, as for *Litoria peronii*, sustained chorusing commenced. This coincided with the start of a period of sustained increased temperatures in that spring. Calling continued thereafter until the recording ceased in February 1989.

Limnodynastes dumerilii: called for only short periods at varying times during the warmer months of the year (November to January) in both years of the study (only 6% of hours analysed). However, it did not call consistently on every night of these months. Calling usually lasted for a week or two and would then cease for some days before starting again. That is, its calling was sporadic during its calling period. The number of calling males varied from only one up to a dozen and also varied over the times when calling was recorded.

Limnodynastes peronii: was heard in every month of the year and was also sporadic in its activity, having periods of days or weeks with no calling scattered through the period (27% of hourly periods analysed) No more than 5-6 males were ever recorded calling at the pond at any one time and usually only 1-2 males were heard.

Litoria verreauxii: commenced regular calling in January of each year and ceased regular calling in September, with the start date varying only slightly between the years. This species was calling when the study started in July 1987 and males called continuously until 10 September 1987. Calling essentially ceased then until 17 January 1988 (but see below) when males resumed calling, doing so then continuously until 1 October 1988. They then ceased calling and were not heard again until 7 January 1989 after which they were recorded calling continuously to the end of the study. It was notable that this species' calling was recorded during at least the first two hours after sunset on essentially every night during its main calling period and was not heard outside of these times except for the calls of one individual on two separate nights in December 1987. Usually only 2-3 males would call on any given night in the warmer months whereas at least 20 males could regularly be heard during autumn and winter (recorded in 68% of the hourly periods selected for analysis).

Paracrinia haswelli: was heard calling for only a relatively short period and only by one or two frogs at a time. It did not call during the first half of the study period and there were insufficient records to report its calling habits with any confidence. This species did call more regularly and in greater numbers at other ponds in the Darkes Forest area.

Relationship between Calling and Micrometeorological Variables

The final random effects models chosen for each of the five analysed species are presented in Table 2. Temperature and the presence of calling were significantly and positively related in three species: *Limnodynastes peronii*, *Litoria peronii*, and *Uperoleia laevigata*. The presence of calling was positively correlated with barometric pressure in *Limnodynastes peronii.* No significant relationships were found between the calling of any species and either humidity or rainfall. The "best" models examined for each species proved to be very consistent. Temperature was significantly and positively related to calling in each model considered for *Limnodynastes dumerilii*, *Litoria peronii* and *Uperoleia laevigata*, and the other variables were never significant. Temperature and barometric pressure were significant in all four models examined for *Limnodynastes peronii* and the other variables were not. No variable was significantly related to calling in *Litoria verreauxii*.

Table 2. Best random effects models of calling activity versus temperature, humidity and rainfall for five species of frogs recorded at the Darkes Forest pond. The number of models considered in the final selection process is listed in brackets below the species name along with the total model weight explained by all of these models. SE = Standard Error.

Species	Best model weight	Model variable/s	Estimate ± SE	P value
Limnodynastes dumerilii (four models; 66%)	0.28	Temperature	0.64 ± 0.34	P < 0.1
Limnodynastes peronii (four models; 82%)	0.31	Temperature barometric pressure	0.29 ± 0.11 0.19 ± 0.06	P < 0.01 P < 0.005
Litoria peronii (five models; 82%)	0.24	Temperature	0.57 ± 0.15	P < 0.0005
Litoria verreauxii (nine models; 82%)	0.14	Temperature	-0.09 ± 0.08	P < 0.3
Uperoleia laevigata (five models; 81%)	0.25	Temperature	0.34 ± 0.11	P < 0.005

Discussion

The results indicate that each species, except *Limnodynastes peronii*, had a definable calling season that showed reasonable consistency during this study. *Limnodynastes peronii* could be heard at any time of the year which was also the case for *Crinia signifera* (Lemckert 2001). For three of the four species with a defined calling season, the major calling activity periods were based around the warmer months of the year, starting in early spring. *Litoria peronii* and *Uperoleia laevigata* called consistently from early spring to late summer whereas *Limnodynastes dumerilii* was recorded calling only between November and January. *Litoria verreauxii* extended over a long period from January to September and ceased abruptly from October to December. Comparisons of micrometeorological variables with the presence/absence of calling within the defined calling seasons indicated that calling was positively related to temperature in three species, barometric pressure was positively related to calling in just one and no relationship was found between rainfall and calling in any species.

The calling seasons we recorded tended to overlap reasonably with the published calling seasons, although there were a few differences. Lemckert and Mahony (2008) found the following calling seasons for each species in southern NSW: *Limnodynastes dumerilii* September-March; *L. peronii* potentially any month; *Litoria peronii* September-March; *Litoria verreauxii* potentially any month; *Uperoleia laevigata* warmer months. Notably, *Litoria verreauxii* did not call from October to December in our study, but has been recorded to do so elsewhere (Barker *et al*. 1995, Lemckert and Mahoney 2008). The calling season of *Limnodynastes dumerilii* was also somewhat narrower in our study. These differences are most likely a result of our study looking at calling in just one location and over only two years. The seasons of Lemckert and Mahony (2008) were based on records from across New South Wales and included records from a much wider altitudinal and latitudinal range and much wider climatic conditions that would influence calling activity.

Within the defined calling seasons, calling generally tended to show a positive relationship with temperature, which is similar to that found in other research (Einem and Ober 1956; Humphries 1979; Okuno 1985). The lack of relationship between calling and temperature for *Litoria verreauxii* is logical, as this species calls in the warmest and also the coldest months of the year and so would not seem likely to require a particular temperature for calling. *Limnodynastes dumerilii* showed a positive relationship between calling and temperature that was not quite significant, but it had the least number of calling records to compare with micrometeorological variables. It seems likely that more records would lead to a significant positive relationship being recorded. Barometric pressure has sometimes been shown to relate to calling activity (eg. Oseen and Wassersug 2002) but, as we found in this study, it usually has little evident relationship with calling. An unexpected finding was the lack of any significant relationships between the presence of calling of the different species and rainfall. Rainfall is regarded as one of the major triggers for calling in frogs and we expected this to be evident in our analyses. The lack of an evident relationship may be attributed to the constant and relatively heavy rainfall experienced during the period of the study; the recorded monthly rainfall was generally above the average for the area and often significantly so (Lemckert 2001). In such a situation, rainfall could become somewhat irrelevant as a trigger for most species as the consistent rain left few and or short non-rainy periods to influence the calling of rain sensitive frogs. The presence of a permanent water source may also mean that rainfall is of less relevance to the frogs using the pond as a calling site. Repeating the study during more "normal" years may find rainfall to be more significantly related to calling than we found.

The calling activity of these species contrasts to some degree with the results obtained from *Crinia signifera* at this site (Lemckert 2001). *C. signifera* was found to call throughout the year and it called consistently, but with peaks of activity in winter and less intense calling in summer. Calling activity of *C. signifera* did not show any relationship with temperature, which is not surprising given it calls at any time of the year. Calling intensity did, however, show a weak relationship with rainfall in the preceding three days, but only during the summer months. The finding of a relationship with rainfall in this earlier work may be because a temporal autocorrelation was present and confounded the data, but it was not tested for. It could also be that the earlier study looked at intensity of calling and not just presence/absence of calling and so may have been more sensitive to changes in activity due to rainfall. *Crinia signifera* also breeds in temporary water bodies and tends to do so explosively after rainfall events, indicating it may be more sensitive to rainfall than the other species. A reanalysis of the data from that study may provide a different result.

Figure 2a. *Litoria peronii.* Photo, G. Grigg.

Figure 2b. *Litoria. verreauxii.* Photo, F. Lemckert.

Figure 2c. *Limnodynastes dumerilii.* Photo, G. Grigg.

Figure 2d. *Limnodynastes peroni.* Photo, F. Lemckert.

Figure 2e. *Paracrinia haswelli.* Photo, G. Grigg.

Figure 2f. *Uperoleia laevigata.* Photo, F. Lemckert.

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