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CORE CALLING PERIODS OF THE FROGS OF TEMPERATE NEW SOUTH WALES, AUSTRALIA

FRANCIS LEMCKERT [1, 2] *AND MICHAEL MAHONY* [1]

[1]*Faculty of Science and Information Technology, School of Environmental and Life Sciences, University of Newcastle, University Drive, Callaghan NSW, 2380, Australia*
[2]*Corresponding Author: Forest Resources Research, Forest Science Centre, NSW Department of Primary Industries, PO Box 100, Beecroft, NSW 2119, Australia, e-mail: frankl@sf.nsw.gov.au*

***Abstract.*—We used records of calling male frogs to quantitatively assess the calling patterns of the frogs found in mesic, eastern New South Wales, Australia. We obtained 17,461 calling records for 67 species and determined the core calling months for 46 species. Forty-three species have clearly defined core calling periods in which > 90% of calling records fall, all of which are based around the warmer spring-summer months. We consider two species to be essentially year-round callers. Increasing latitude usually, but not always, leads to a small reduction in the core calling period. This information can be used to better target the timing of surveys, improving opportunities for research, management, and conservation.**

Key Words.—calling period, detection, survey, New South Wales

INTRODUCTION

Male anurans produce advertisement calls that communicate their genetic quality to conspecifics within vocal range (Gerhardt and Huber 2002). These species-specific calls allow us to identify a species' presence/absence and to establish its patterns of abundance and habitat use. Calling surveys allow relatively rapid monitoring of large areas and investigators use them extensively to record the presence of species (e.g., Lemckert and Morse 1999; Hazell et al. 2001; Crouch and Paton 2002; De Solla et al. 2006) and/or to assess changes in populations over time (e.g., Buckley and Beebee 2004; Pieterson et al. 2006).

Numerous studies have found that the anuran calling is generally restricted to specific periods of the year (e.g., Aichinger 1987; Fukuyama and Kusano 1992; Bridges and Dorcas 2000; Gottsberger and Gruber 2004; Prado et al. 2005). These "active" calling periods can be considered the core calling period for any species. Outside of this period, calling may occur but is unpredictable. The situation appears similar in south-eastern Australia where calling activity is temporally restricted and encompasses the warmer months (between September and March). However, several species call during the cooler seasons (see Barker et al. 1995; Cogger 2000).

It is important that we recognize the specific timing of calling when conducting call surveys. However, accurate and consistent information on calling activity is not readily available for most species. Anstis (2002) notes that *Litoria peroni*, a hylid commonly encountered in southeastern Australia, calls spring through summer (September to March inclusive); whereas Robinson (1993) listed calling from September to January and neither Cogger (2000) nor Barker et al. (1995) comment specifically on calling periods. Cogger (2000) states *Uperoleia fusca* calls after spring and summer rains, Robinson (1993) that they have been heard in summer, Anstis (2002) that males call in spring, summer and autumn, but Barker et al. (1995) provide no specific comment on calling times. Choosing the appropriate timing for a call-based survey therefore depends on the reference chosen, and no text provides evidence as to how calling periods were determined.

In this paper, we collate calling records for species of frogs found within the eastern, more mesic half of New South Wales (NSW), to provide a more objective and information based assessment of the period when calling activity is most likely to be heard: the core calling period. We also examine whether increasing latitude varies the core calling period. Defining the core calling period should increase the effectiveness of surveys and monitoring programs and so provide better information for management and conservation planning for the frogs of the region.

MATERIALS AND METHODS

We collected calling records from the following sources: NSW National Parks and Wildlife Service Wildlife Atlas, Forests NSW Fauna Database and the personal records of the authors. We only included records clearly indicating calling activity and removed duplicate or likely erroneous observations. The

TABLE 1. Calling records and calling seasons of the Myobatrachid frogs of New South Wales, Australia. Black shading = "core" calling months. Grey shading = significant calling records outside of "core" period. Bold names = explosive callers from lower rainfall areas. Underlined species are threatened species.

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Adelotus brevis		1	1	17	80	126	93	82	74	13	3		**490**
Assa darlingtoni	1	6	2	10	16	15	3	27	11	5	5	9	**110**
Crinia parinsignifera	4	11	26	51	59	81	31	27	37	52	44	10	**433**
C. signifera	158	199	175	404	420	434	396	387	507	528	224	192	**4024**
C. sloanei				1	2	2	1	1		1			**8**
C. tinnula	15	18	16	10	13	18	14	45	7	24	35	24	**239**
Geocrinia Victoriana							1		4	6	3		**14**
Heleioporus australiacus	1		1	1	2	8		4	8	4	5	3	**37**
Lechriodus fletcheri				4	8	6	5	12	8	1			**44**
Limnodynastes dumerilii		2	8	32	73	96	54	32	80	30	4	1	**412**
L. fletcheri		1		4	26	28	13	7	7	22	13		**121**
L. interioris				3	2	4		1		1	1		**12**
L. ornatus	1			1	3	7	9	11	7	2		2	**43**
L. peroni	16	14	23	74	123	140	143	194	236	72	70	36	**1143**
L. salmini					1	2							**3**
L. tasmaniensis	3	14	22	65	92	128	53	51	63	59	39	17	**606**
L. terrareginae	1		1	3	2	3	5	4	1				**20**
Mixophyes balbus			1	19	41	14	15	32	85	59	9		**275**
M. fasciolatus		1		9	49	98	82	132	261	86	18	3	**639**
M. fleayi					1	3	7		2				**13**
M. iteratus				15	21	24	15	12	40	25	2		**154**
Neobatrachus sudelli		2		2	10	10	1	2	1	3	2	2	**35**
Notaden bennetti					2	4	1		1	5			**13**
Paracrinia haswelli	1	1	7	14	11	7	7	5	2	1	4	9	**69**
Philoria kundagungan						1				2			**3**
P. loveridgei			3	1	5	3		3	3		1		**19**
P. pughi					1	2	2	1					**6**
P. sphagnicola			2	22	45	50	22	4	2	1		1	**149**
Pseudophryne australis	6	19	20	38	58	35	31	51	51	14	16	11	**348**
P. bibronii	14	10	11	8	8	9	22	24	23	53	63	36	**281**
P. coriacea	3	11	11	25	48	145	155	198	325	107	22	16	**1066**
P. corroboree								9		1			**10**
P. dendyi				2	1	2		4	12	29	7		**57**
P. pengilleyi								61	54	7			**122**
Uperoleia fusca	2	2	2	45	80	102	51	99	61	50	8	4	**506**
U. laevigata	13	15	11	21	48	45	30	37	62	39	14	12	**347**
U. rugosa		1		4	4	5		4	4	10	2	4	**38**
U. tyleri		1			1	5	8	5	10	2			**32**
TOTAL	**239**	**302**	**338**	**782**	**1143**	**1485**	**1220**	**1331**	**1907**	**1197**	**600**	**392**	**10936**

intensity of calling activity was not differentiated (i.e. one calling male could equal 100 males) as such information was often not recorded, but such a bias is the same for all species. We included only records dated from 1940 onwards.

We combined records for the following species pairs: *Litoria phyllochroa* / *Litoria nudidigitis*, *Litoria pearsoniana* / *Litoria barringtonensis*, *Litoria subglandulosa* / *Litoria daviesae*. These are recently split, cryptic species and we cannot separate the records. Our experience indicates that each of the pair behaves similarly and so the results are applicable to both species.

We calculated the number of calling records in each month and designated the core calling period for each species as the period containing > 90% of the records. We started by excluding the month with the least records (almost always with no records) and successively added the records for the next lowest month in turn until the total reached 10% of the available records. For example, if a species had 100 records, the total combined records for the non-calling period was less than ten. We based non-calling around consecutive low calling months so that an individual month with few or no records between months of high records was included in the calling period (presumably the low record numbers is an artifact). The process was iterative and, in practice, we found determining the cut-off point was very clear.

We explored the effect of latitude by subdividing records into those south of Sydney versus those obtained from Sydney northwards (divided at latitude 34^{o} 04' South). We determined the core calling periods for each region and visually compared if they represented the same periods. We only included species with 100 or more records in each of the regions,

TABLE 2. Calling records for the Hylid frogs of New South Wales, Australia. Those with names in bold are explosive breeding species generally found in lower rainfall areas of New South Wales. Underlined species are threatened species.

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	**Total**
Cyclorana platycephala					2	4				1	2		**9**
C. verrucosa					1	1							**2**
Litoria aurea		2	8	10	11	19	22	14	10		1		**97**
L. booroolongensis								1	2				**3**
L. brevipalmata				1	2	7	3	9	16	1	1	1	**41**
L. caerulea	1	1	2	6	15	23	37	34	38	11	3	1	**172**
L. chloris					12	28	29	47	33	1			**150**
L. citropa		2	1	21	31	18	19	7	19	11	1	1	**131**
L. dentata	2	3	4	13	66	90	86	101	82	17	7	2	**473**
L. ewingii		2	1	5	4	4	15	24	14	2		3	**74**
L. fallax	7	10	19	64	129	175	134	118	118	48	22	21	**865**
L. freycineti			2	1	6	15	7	7	10	1			**49**
L. gracilenta	1	2	1	2	2	26	25	28	15		2		**104**
L. jervisiensis	1	2	2	3	7	13	1	3	3	2	5	4	**46**
L. latopalmata	5	4	2	11	31	59	60	49	32	9	6	1	**269**
L. lesueuri		3	1	18	41	54	31	25	23	14	6	1	**217**
L. littlejohni	3	7	11	32	3	3	2	4	20	12	9	2	**108**
L. nasuta					3	7	19	3	6	1		1	**40**
L. olongburensis			2		6	7	3	4	1	4		2	**29**
L. pearsoniana/barringtonesis	1	1	2	9	32	28	30	31	55	7	5	2	**203**
L. peroni	7	11	16	117	254	360	269	222	132	68	34	18	**1508**
L. phyllochroa/nudidigita	1	4	2	35	95	121	128	101	117	51	13	3	**671**
L. piperata								1					**1**
L. raniformis			1	4	7	4	3	6			1		**26**
L. revelata	1	1	1	2	7	8	5	11	15	18	3	2	**74**
L. rubella		1		3	11	16	18	2	6	5			**62**
L. subglandulosa/daviesae	1		1	31	35	8	5	4	16	11	1	2	**115**
L. tyleri	3	3	5	8	46	52	60	34	21	11	4		**247**
L. verreauxii	33	39	46	89	91	68	74	91	82	79	52	39	**783**
TOTAL	**66**	**95**	**130**	**485**	**948**	**1216**	**1083**	**980**	**871**	**374**	**172**	**105**	**6525**

which excludes most species, but provides enough to make inferences about the broad effects of latitude.

RESULTS

We obtained 17,461 calling records covering 38 myobatrachid species (Table 1) and 29 hylid species (Table 2). Fifteen myobatrachids and six hylids have less than 40 available calling records and we did not assess their calling periods, deeming their numbers insufficient to do so confidently. Nine of these are species found mostly in the low rainfall areas of New South Wales and call explosively only after heavier rains. Ten others are listed threatened species with small populations and/or ranges.

Forty of the 46 species have at least three consecutive months with few or no records (Tables 1 and 2). We can clearly identify "core" calling periods for all 46 species. We note, however, three species have relatively large numbers of calling records in all months: *Crinia signifera*, *Uperoleia laevigata* and *Litoria verreauxii*. Two other members of the *Litoria verreauxii* complex, *L. jervisiensis* and *L. littlejohni*, also have broadly scattered calling records, but the small record numbers prevents us concluding that they also have any calling pattern.

Table 3 compares the calling activity of ten species based on a latitudinal division. This includes both myobatrachids and hylids, providing a reasonable diversity of phylogeny. *Crinia signifera* has a shorter calling period in southern NSW. Seven other species have shorter core calling periods in the southern compared to the northern records. *Litoria phyllochroa* appears to have a longer calling period in the south and *Limnodynastes dumerilii* similar core calling seasons in both regions.

DISCUSSION

We obtained sufficient records to determine a core calling period for 46 species in temperate eastern NSW. All species had specific months of the year that encompassed > 90% of these records and we consider these to be the core calling periods for each frog. Calling outside of this period is usually very limited or absent. This is the typical pattern exhibited by temperate anurans (Duellman and Trueb 1986).

Three species, whilst having periods with greater numbers of calling records, appear likely to call in any month of the year: *Crinia signifera*, *Litoria verreauxii* and *Uperoleia laevigata*. The first two species are well known year-round callers (Barker et al. 1995; Cogger 2000). *Uperoleia laevigata* is not known for this habit

TABLE 3. Calling records for nine species of frogs in New South Wales, Australia, divided by latitude.

Species		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Crinia signifera	*North*	161	150	137	230	173	218	301	241	350	354	198	160	2673
	South	53	52	51	171	232	257	104	152	151	182	54	75	1534
C. parinsignifera	*North*	3	5	6	23	25	32	22	24	37	49	33	9	268
	South	1	7	23	30	33	65	9	4	1	3	11	1	188
Limnodynastes dumerili	*North*			5	16	26	39	37	29	49	20	2	1	224
	South		1	3	16	41	59	14	13	9	6	2	1	165
L. peroni	*North*	17	13	19	54	62	97	110	110	178	124	61	33	878
	South		2	5	16	31	35	32	48	43	35	13	3	263
L. tasmanieinsis	*North*	4	11	17	38	53	60	40	36	56	52	39	16	422
	South		3	10	35	37	64	13	17	13	11	2	1	206
Litoria dentata	*North*	2	4	4	14	50	64	73	89	60	16	4	2	382
	South	1			2	23	37	18	27	23	3	3		137
L. peroni	*North*	7	9	14	82	173	235	194	142	96	55	23	14	1044
	South	1	3	4	42	114	153	79	98	39	17	12	5	567
L. phyllochroa	*North*		1	2	12	41	73	103	84	101	31	9		457
	South	1	3		23	61	41	35	30	20	23	4	3	244
L. verreauxii	*North*	37	29	36	52	47	20	45	60	57	50	37	33	503
	South	13	14	13	45	56	52	30	42	26	33	22	22	368
Pseudophryne bibronii	*North*	10	5	9	6	5	8	11	10	19	28	36	15	162
	South	6	5	3	1	3	1	10	14	14	33	27	23	140

and all field guides record calling only in the warmer months. We have previously recorded distinctively seasonal calling for this species (Francis Lemckert, unpubl. data.), and we did not expect this result. Records attributed to this species could be the calls of other species, as the calls of males in this genus can be hard to distinguish (Francis Lemckert, pers. obs.). However, all species in this genus are considered to have similar calling seasons covering the warmer months of the year (e.g., Cogger 2000; Anstis 2002) and so this does not account for this result. A detailed investigation of the data may shed further light on this unexpected result.

The core calling periods for these species are in general accord with the broad calling seasons suggested in the most widely used field guides (Anstis 2002; Barker et al. 1995; Cogger 2000; Robinson 1993). However, our core calling periods are more clearly defined, being based on months rather than seasons of the year, and so provide a more specific timing to conduct surveys with the best opportunity for success.

The two main variations in calling periods using our approach were for *Uperoleia laevigata* (already discussed) and *Litoria ewingii*. However, *L. ewingii* is considered by most guides (e.g., Cogger 2000; Anstis 2002) to be essentially a year-round caller, which is similar to the other members in this species group (Francis Lemckert, pers. obs.). There is no obvious reason why this discrepancy has arisen, except that perhaps this species has a varying calling period depending on its range. This species is much better known from Victoria, South Australia, and Tasmania (Cogger 2000) where winter rainfall predominates. They may be more winter breeders there, with extended breeding at suitable times during the warmer months. Our records come from NSW where moderate rainfalls occur in all months of the year.

The effect of latitude was relatively clear and consistent. We expected calling periods to be reduced at the southern end of species ranges where mean seasonal temperatures are lower, and this proved to be the case in most species. Temperature is known to be a factor controlling calling activity in frogs (e.g., Navas 1996; Hatano et al. 2002). Activity may commence or end when environmental temperatures reach a threshold point, which may also determine the commencement of the calling period (e.g., Gibbs and Breisch 2001). The difference in March mean maximum temperatures between the central points of northern and southern NSW is only 3.5°C but this appears to be sufficient to inhibit calling in the earliest and latest parts of the period in southern NSW.

The number of calling records available for a species was clearly influenced by a couple of factors. Nine of the species with relatively few calling records (< 40) have ranges that occur mostly or totally in lower rainfall areas of New South Wales and are reliant on rainfall events to stimulate calling (Barker et al. 1995; Cogger 2000). This combination is important as species from more coastal areas, which are also explosive breeders, have larger numbers of records than do species in lower rainfall areas that have extended breeding seasons. Detectability of calls is specifically related to the effort placed into the time when a species actually calls (e.g., Pierce and Gutzwiller 2004; De Solla et al. 2005). Species that call only briefly and in rarely visited areas will likely have few records. Ten other species are recognized as "rare", having suffered serious population declines or historically have had small populations. Small populations make it harder to obtain records. Of the remaining two species, *Geocrinia victoriana* also has a very small range in NSW, but has a larger range in Victoria; thus, few records can be expected. *Uperoleia tyleri* has a much more extended coastal range in NSW and appears to have an extended breeding season similar to other coastal species in this genus. Hence, it should be expected to have significantly more records than are currently available. This species may be rarer than currently believed and should be the focus of further research to confirm its current status.

We caution that calling activity does not necessarily define the breeding period of a species. We are unsure if calling activity equates with breeding activity and, even if so, we recognize that breeding may occur in non-core months, particularly if unusual weather conditions are prevalent (e.g., an extended drought ends or there are unseasonably heavy rains). However, whether breeding is occurring is not relevant to the aims of this paper, as we are interested in how likely it is for a male frog to be calling, not if it is breeding. We do believe that breeding is likely to be strongly correlated with calling because of the costs involved. It has been demonstrated that calling activity is energetically costly (Taigen and Wells 1985; Wells and Taigen 1989) and males are at increased risk of mortality around the breeding sites (Lemckert and Shine 1993; Penman and Lemckert 2007). Hence, it would seem highly unlikely that males would call if there were no expectation of mating.

Finally, we note that undertaking surveys at any time in our indicated core calling periods does not guarantee that individuals will be calling at the time of the survey. Proximate environmental conditions play a significant role in the calling activity of frogs (e.g., Lemckert 2001; Oseen and Wassersug 2002; Penman et al. 2006; Saenz et al. 2006) and need to be considered in conjunction with the information on calling. Unfavorable climatic conditions may curtail calling activity and could prevent frogs being detected in an area where they are otherwise common, even if it is the middle of the core calling period and survey effort is high (Bridges and Dorcas 2000; Pierce and Gutzwiller 2004; De Solla et al. 2005). Surveying for frogs in the wrong environment and/or wrong type of calling habitat will equally produce a null result. Hence, care needs to be taken in planning surveys for frogs, with consideration given to a range of factors to ensure that the chances of locating frogs are at their maximum. However, recognizing the time of year when calling is most likely to be heard is a major step towards successfully locating almost any species of frog.

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Francis Lemckert received his B.S. in Zoology and Marine Sciences in 1985 and his M.S. looking at the population dynamics of *Crinia signifera* in 1992, both at the University of Sydney. He accepted a position as research scientist with the Forestry Commission of NSW in 1995, which has directed his work into the conservation of forest fauna. He has a specific interest in the ecology and management of threatened forest dependent frogs in eastern Australia. His research interests also include the ecology of threatened reptiles and using plantings to restore habitat and connectivity in agricultural landscapes. He is currently completing his PhD at the University of Newcastle looking at the habitat relationships of frogs in forests.

Michael Mahony received his doctorate in Biology from Macquarie University in Sydney, Australia in 1986 where he investigated the cytogenetics and genetics of Australian ground frogs. After working for several years in a clinical cytogenetics laboratory and as a research scientist at the South Australian Museum he took an academic position at the University of Newcastle, Australia in 1992 where his research and teaching focus is in the area of conservation biology. Current research centres on the problem of declining amphibians and the evolutionary biology of Australian amphibians.