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Movements and habitat use of the endangered giant barred river frog (*Mixophyes iteratus*) and the implications for its conservation in timber production forests

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Abstract

Movements of the endangered giant barred river frog (*Mixophyes iteratus*) were followed over 2 to 5 day periods using radio-transmitters and nylon spools. Thirty-one nights of data were obtained from 10 radio-tracked frogs and 45 nights from 22 frogs using spool-tracking. Nightly movements varied from 0 to over 100 m, with a mean of 8.3 m for radio-tracked frogs and 13.2 m for spool tracked frogs. Individuals were found to occupy two distinct daytime shelter positions — inactive under leaf litter or alert but sheltered under vegetation where frogs could avoid predators by jumping away. All frogs were captured and recorded moving within a 20 m wide band either side of streams. Unlogged buffer zones of 30 m width along each side of streams are currently used to protect the breeding habitat of this species from the possible effects of logging operations. The data indicates that these buffers should be effective in protecting the habitat generally used by giant barred river frogs. Further work is required to determine if the over-wintering habitat used differs from the spring–autumn patterns observed in this study.

Keywords: Frog; Logging; Protection; Tracking; Movement

1. Introduction

Little detailed information is currently available on the patterns of habitat use by anurans. They are known to spend some period of the year congregated around water bodies when reproducing, but how much they move during this period is essentially unknown. Post-breeding migratory movements have been better studied and individuals generally appear to disperse into habitats surrounding the breeding site to obtain food and find shelter from desiccation, predation and freezing (e.g. Denton and Beebee, 1993; Bosman et al., 1996; Spieler and Linsenmair, 1998; Lamoureaux and Madison, 1999). Movements can range from tens or hundreds of metres (e.g. Matthews and Pope, 1999) up to several kilometres from their breeding sites annually (Sinsch, 1990). Studies to determine the breeding or post-breeding movements of Australian frogs have yet to be published. The spatial and temporal movements and habitat use of Australian frogs may prove to be different to those of overseas species given Australia's more temperate and unpredictable climate.

The giant barred river frog (*Mixophyes iteratus*) is a large (up to 120 mm) ground dwelling Myobatrachid frog found within areas of moist hardwood forest and rainforest (Cogger, 1992; Barker et al., 1995; Lemckert and Morse, 1999). Breeding occurs in permanent streams and the tadpoles grow to a large size (>100 mm) and take at least 12 months to reach metamorphosis (K. Thumm, pers. comm.). Little is known about the habits of this species, including their microhabitat use and movements within the general forest landscape.

Historically this frog was found from the mountains west of Sydney to the Conondale ranges north west of Brisbane (Cogger, 1992) and, prior to the 1970s, was considered to be a relatively common and easy to locate frog throughout this range. In the late 1970s, the giant barred river frog appears to have undergone a substantial decline. It is now extinct in the most southern parts of its range and has suffered serious reductions of

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populations elsewhere (Mahony, 1993). It remains present in substantial numbers only on the coastal plain and adjacent escarpment around Coffs Harbour of northern New South Wales (NSW) (F. Lemckert, pers. obs.). This frog has been listed as a species of conservation concern in both of the Australian states in which it occurs (NSW and Queensland).

Lemckert (1999) indicated that logging activities can have a significant negative impact on this species. Conservation protocols have been developed and set in place to protect the giant barred river frog in timber production forests (SFNSW/NPWS, 1997). On streams where the giant barred river frog is known to be present a 30 m wide strip of undisturbed vegetation must be retained on each bank of the stream adjacent to where the frog has been located and extending a further 200 m upstream and downstream of this area. This strip is intended to protect both the water quality and the riparian habitat believed to be utilised for shelter and foraging, but its effectiveness as frog habitat has remained untested.

This paper reports on a tracking study of the giant barred river frog performed to record the short-term movements and the habitats used by this species at various times during a breeding season that stretches from spring to autumn. The movements of frogs relative to the riparian zone and the types of sites selected by individuals for sheltering during daylight hours are described. The likely value of the current forestry conservation protocols is evaluated in light of this information.

2. Methods

2.1. Study area

This study was carried out along four streams in the Coffs Harbour/Dorrigo area of northern NSW (Fig. 1). Three streams are located in Wild Cattle Creek State Forest on the Dorrigo escarpment at an altitude of 700 to 800 m. The escarpment area has a relatively large mean annual rainfall of 1600 mm and temperatures ranging from a mean high of 27°C in January to a mean low of −1.2°C in July (SFNSW, 1995a). The fourth stream is located adjacent to Pine Creek State Forest, just south of Coffs Harbour. This stream is at an altitude 10 m in an area with a mean annual rainfall of 1730 mm and temperatures that range from a mean high of 26.9°C in February to a mean low of 6.6°C in July (SFNSW, 1995b).

All four streams are moderately sized (3–7 m wide) and permanent. All are found within areas naturally vegetated with moist hardwood forests dominated by Eucalypt trees. The forest around each stream varies in its disturbance history. Two of the escarpment streams are found within 30 year old flooded gum (*Eucalyptus grandis*) plantation and the third in wet sclerophyll forest dominated by flooded gum and blue gum (*E. saligna*) selectively logged in the early 1970s. The coastal stream occurs in a mixed environment. The adjacent vegetation on one side consists of flooded gum dominated forest undisturbed for the last 50 years, but on the other side the vegetation has been partially cleared to within 5 m of the stream to provide grazing pasture. All frogs at this site were caught and tracked on the forested side of the stream, although a few individuals were seen on the other side of the stream immediately adjacent to cleared areas.

2.2. Study methods

The movements of frogs were measured over eight periods between December 1995 and May 1999 covering different seasons and varying weather conditions (Table 1). Frogs were not individually identifiable and so the same individual may have been tracked during two or more of the periods, however this is not considered to be of concern for the purposes of this study.

Frogs were captured from the vicinity of the study streams within 2 h of sunset. The position at which the frog was caught was noted and the frog taken to a work vehicle where the frog was sexed and its reproductive condition noted. Each individual to be tracked then had a band tied around its waist. This band was made from a piece of cotton gauze approximately 10×6 cm that was folded over several times to form an approximately 10×0.5 cm strip. The band was passed around the waist of the frog and joined together with glue so that it formed a secure (but not overly tight) fit around the narrowest point of the waist, just anterior to the join of the legs. For the first part of the study, a 0.5 g single stage transmitter (Titley Electronics, Australia) was glued on to this waist band at the point where it was central on the back of the frog. The frog was held for 1 min to ensure that the transmitter did not fall off and was then returned to the point of capture and released. The entire procedure from capture to release took no longer than 10 min.

Total mass of the transmitter package did not exceed 1.0 g and the body mass of the frogs was a minimum of 40 g (for sub-adults) so that the package was always well less than the recommended level of 10% of the body mass (Richards et al., 1994). The elastic nature of the cotton gauze also allowed the whole package to slip from the frog if it became tangled or caught. Frogs slipped free from their transmitters on three occasions and the transmitter signal was lost on four occasions. Extensive searches within a 500 m radius the frog's last known position failed to find these frogs and we presume the transmitters failed, but this is not certain.

The location of each frog carrying a transmitter was determined between 21:00 h and 23:00 h each evening

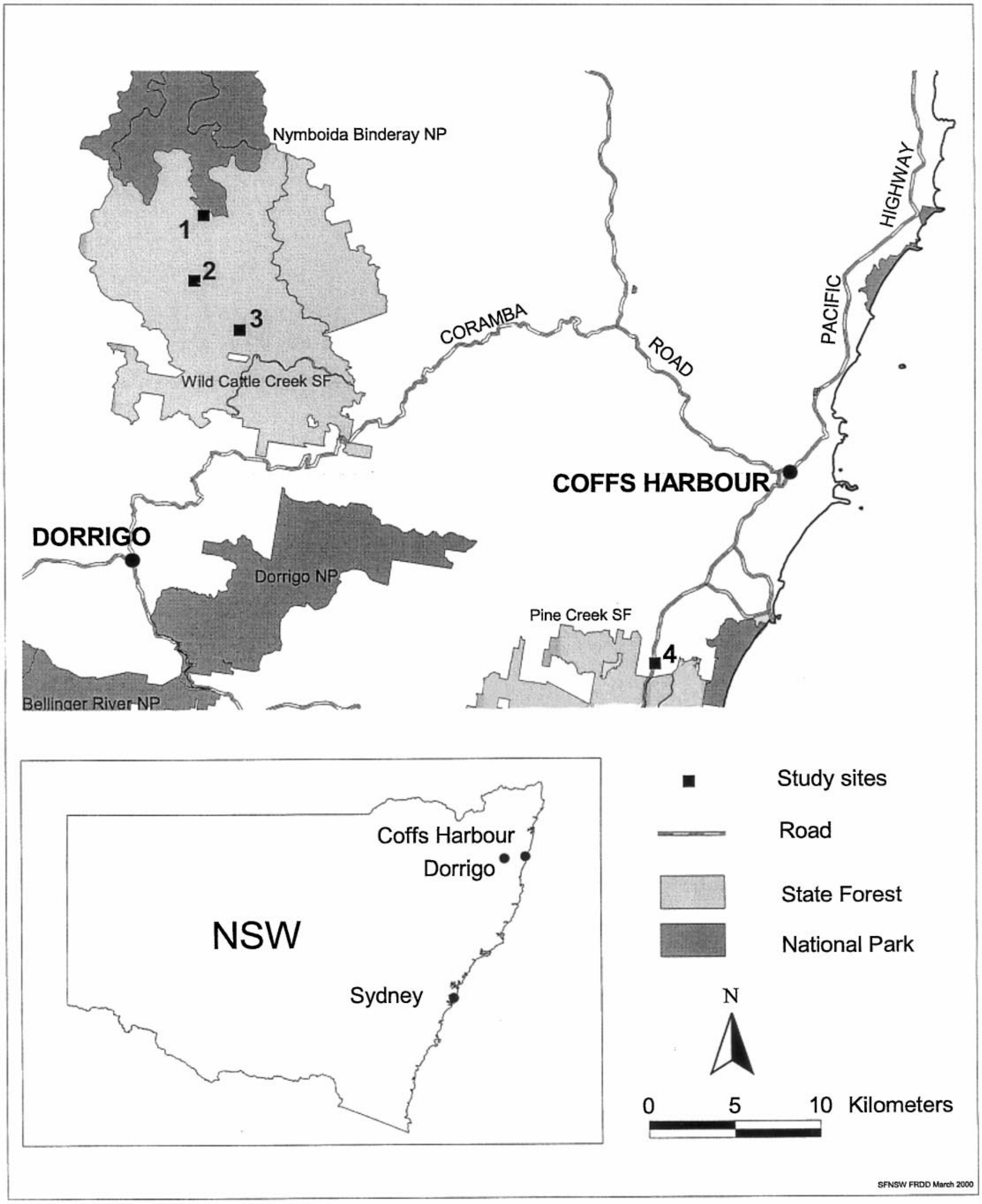

Fig. 1. Location of study sites within New South Wales.

and 9:00 and 11:30 h each day over a 2 to 5 day period using a Regal 2000 Receiver (Titley Electronics, Australia). At each morning check, the resting position of the frogs were recorded in writing, field marked and mapped and then the distances moved during each night were measured to the nearest metre. For records obtained during the day, the chosen resting position and state of the frog was recorded to provide information on sheltering positions when resting. The approximate distance (in metres) each location was from the water was also recorded. On some occasions the daytime resting position of the frog could not be accurately ascertained due either to the inaccessible position of the frog or concerns over disturbing or injuring the frog during a search within denser areas of vegetation. In this case the approximate position was recorded (within 50 cm), but data could then not be obtained on the chosen resting position of the frog.

Progress results from the radio-tracking work indicated that over the 2–5 days of study the frogs were unlikely to move more that 100 m from the initial point of capture. We also realised that our method of radio-tracking provided little detailed information on actual night-time movements. Therefore it was decided to

Table 1
Periods of study and the methods of tracking used during each period for each of the four study streams; 1, Flaggy falls (FF); 2, Plantation Crescent (PlC); 3, Mobong Picnic Area (MPA); 4, Pine Creek (PiCr). Temperature = mean temperature at 10:00 pm. Rainfall = total for period

Period	Stream	Tracking dates	Method	Temperature (°C)	Rainfall (mm)	Mean move (m)
1	FF, MPA	29–30/11/95	Telemetry	21	0.0	7.0 ($n=2$)
2	MPA	15–19/02/96	Telemetry	18	64.8	7.0 ($n=2$)
3	MPA	17–22/11/96	Telemetry	NA	20.8	7.0 ($n=2$)
4	PlC	8–10/10/97	Spool	12.5	58.5	7.0 ($n=2$)
5	MPA	1–4/12/97	Spool	NA	24.0	7.0 ($n=2$)
6	FF, PlC, MPA	14–16/03/98	Spool	20.2	4.8	7.0 ($n=2$)
7	PiCr	25–27/01/99	Spool	20.4	39.2	7.0 ($n=2$)
8	PiCr	27/04–29/05/99	Telemetry	13.8	NA	7.0 ($n=2$)

spool-track individual frogs commencing in October 1997. The spools used for tracking were commercially packed size 10 model NM 140/2 nylon spools from Danfield Ltd. (UK) with 200 m of thread. These again were glued to either a cotton gauze band or rubber band tied around the waist of the frog to be tracked. The free end of the nylon string was tied to a fixed point at the site of capture (usually a small shrub or log), the point marked with tape and the frog was then allowed to continue its activities without further disruption. The anchor point of the string was re-located the following morning and the trail of string followed to locate the daily resting position of the frog and measure the distance moved during the preceding night. The new resting site was marked so that the process could be repeated on the following morning. Frogs were again tracked for 2 to 5 days using this method. Spools were shed by the frog prior to the end of the tracking period on three occasions and once the string was broken and the frog could not be located.

Radio-tracking was again used in the last study period in May 1999, tracking three sub-adult frogs. Radio-tracking was undertaken during this period to provide some information on frog movements during late autumn and winter.

Where the frog retained its transmitter/spool to the end of the tracking period it was recaptured, the package removed and the frog released back into the shelter site.

3. Results

3.1. Numbers of frogs tracked

For the spring/summer period, radio-tracking data was obtained from three adult males, four adult females and one sub-adult over a total of 16 tracking nights (Table 2). Additionally, three sub-adult frogs were tracked during the autumn winter period over 15 tracking nights (Table 2). Spool tracking was performed on 18 adult males, three adult females and one sub-adult over a total of 45 tracking nights (Table 3).

3.2. Distances moved and area of forest used

The mean nightly movement found by radio-tracking for all frogs over the spring and summer period was 21.5 m (SD = 50.0; $n = 16$) and the median value 8 m (see Table 2). Ten of the 16 movements (62%) were 10 metres or less. Only one movement of greater than 20 m in a night was recorded and this was for a female frog that moved 2000 m along the length of the stream. If this movement is discounted, the mean nightly movement was 8.3 m (S.D. = 7.8) and the median 8 m. No attempt was made to compare the movements of the two sexes due to small number of records and because the spool tracking indicated that the radio-tracking results often did not accurately reflect true movements.

The mean nightly movement found by radio-tracking three sub-adults during the autumn/winter period was 0.25 m (S.D. 0.76; $n = 15$). This number is very low because movements occurred on only 2 of the 15 measured nights.

The spool-tracking data provided a more complex picture. Some individuals that ended up in close proximity (< 2.0 m) to the previous recorded resting position and would have seemingly moved very little were found

Table 2
Nightly movements (in m) of individual frogs followed by radio-telemetry

Site	Period	Frog's sex	Night 1	Night 2	Night 3	Night 4	Night 5
Flaggy Falls	1	Female	4				
		Male	10				
Plantation Crescent	2	Male	0.0	0.0	5.0	15.0	
		Female	3				
		Male	10.0	8.0	22.0		
Mobong Picnic Area	3	Female	200	0.0	0.0	20.0	8.0
		Female	20.0				
Pine Creek	8	Sub-adult	3	0.7	0.0	0.0	0.0[a]
		Sub-adult	0.0				
		Sub-adult	0.0	0.0			

[a] Seven extra records of no movement.

Table 3
Nightly movements (in m) of frogs followed by spool tracking

Site	Period	Sex	Night 1	Night 2	Night 3	Night 4	Night 5
Flaggy Falls	6	Male	21.2	10.0			
		Male	5.8	44.7			
		Male	7.7	24.4			
		Male	15.2				
Plantation Crescent	4	Male	18.0	2.6	0.0		
		Male	16.5	1.5	0.0	8.0	
		Sub-adult	7.0	0.0	0.0		
		Female	6.5	0.7	0.0		
Plantation Crescent	6	Female	10.1	15.8	14.6		
Mobong Picnic Area	5	Male	12.6	13.4	12.0		
		Male		0.0	22.0		
		Male		21.3	3.7		
Mobong Picnic Area	6	Male	42.1				
		Male	20.7				
		Male	13.7				
Pine Creek	7	Male		26.0	23.8		
		Male		1.0			
		Male		35.0			
		Male	17.1	14.4	9.9		
		Male		11.2			
		Male		14.4	21.5		
		Female		22.5	3.5		

to have moved several times during the night and covered more than 20 m in total. The mean movement distance for all individuals recorded using spool tracking was 13.2 m (S.D. 10.9; $n=45$), but more than 50% of all recorded movements were greater than 10 m compared to 40% noted when radio-tracking (Table 3). The largest single nightly movement by spool tracking was 44.7 m by a male frog that moved around the riparian zone and then returned back to within a couple of metres of its previous daytime position. The mean nightly movements of male frogs (15.0 m, S.D. = 11.2; $n=34$) appeared to be similar to that of female frogs (9.2 m, S.D. = 8.0; $n=8$). However, not enough individuals were followed to allow a valid statistical comparison.

All frogs used in the study were initially collected within 15 m of the edge of a stream. All subsequent tracking records were again restricted to a corridor of 20 m either side of the stream bed, even when wet conditions prevailed (see Figs. 2 and 3 for examples). Movements included jumps over low vegetation and logs and through the stream.

3.3. Daytime resting position

Frogs were found to use two distinctly different positions during the diurnal period. On 17 occasions, frogs were found burrowed under the leaf litter. In each of these cases, the frogs were completely covered and did not move, even when partially uncovered, appearing to be asleep and relatively immobile during the daylight hours. On 40 other occasions, frogs were found in a daytime position where they were sitting above the leaf litter, but where low vegetation partly or completely obscured them. This included individuals where the rear end was partially buried under leaves, but the head was clear of the leaf litter and the frogs appeared to be fully alert.

Forty-two of the 47 recorded daytime positions were 5 m or less from the edge of the stream at which they were captured. The greatest distance from the stream edge observed was 13 m and the mean distance was 2.71 m (S.D. = 2.75). Combining the radio-tracking and spool tracking results allowed a comparison between the distances males and females chose to rest from the stream. Data was only available for seven females and so seven males were chosen at random to provide a balanced data set for a *t*-test. Using only the first recorded distance for each individual tracked (to avoid the confounding effects of using repeated movements by the same individuals) the mean distance for males was found to be 3.61 m and for females 3.10 m. These numbers are not significantly different ($t=0.347$, $P=0.73$).

4. Discussion

Giant barred river frogs are recognised to be found near larger streams and rivers in wetter forests (e.g. Cogger, 1992; Barker et al., 1995). How often and how far individuals move has not previously been documented. The results here indicate that short-term movements by adult frogs may be generally restricted to an area 20 m either side of the study stream. Within this 40 m wide zone the frogs can, on any given night, make a number of movements either parallel to the stream and/or crossing over it. Although some of these movements can be over 50 m, nightly movements are usually less than 10 m and so frogs restrict their activities to a relatively small area.

We expected to find that female frogs moved over a wider area and covered greater distances each night than did male frogs because males would be "tied" to a calling site (F. Lemckert, pers. obs.). However, males were often found to move at night and there were no indications of reduced movements compared to females. This may be because males called sporadically rather than calling on a nightly basis (F. Lemckert, unpubl. data) and so on most nights the males need not defend a calling site, allowing them to move freely around. Further work comparing the movements of males in relation to calling activity would be valuable to determine how they structure their calling sites and activities.

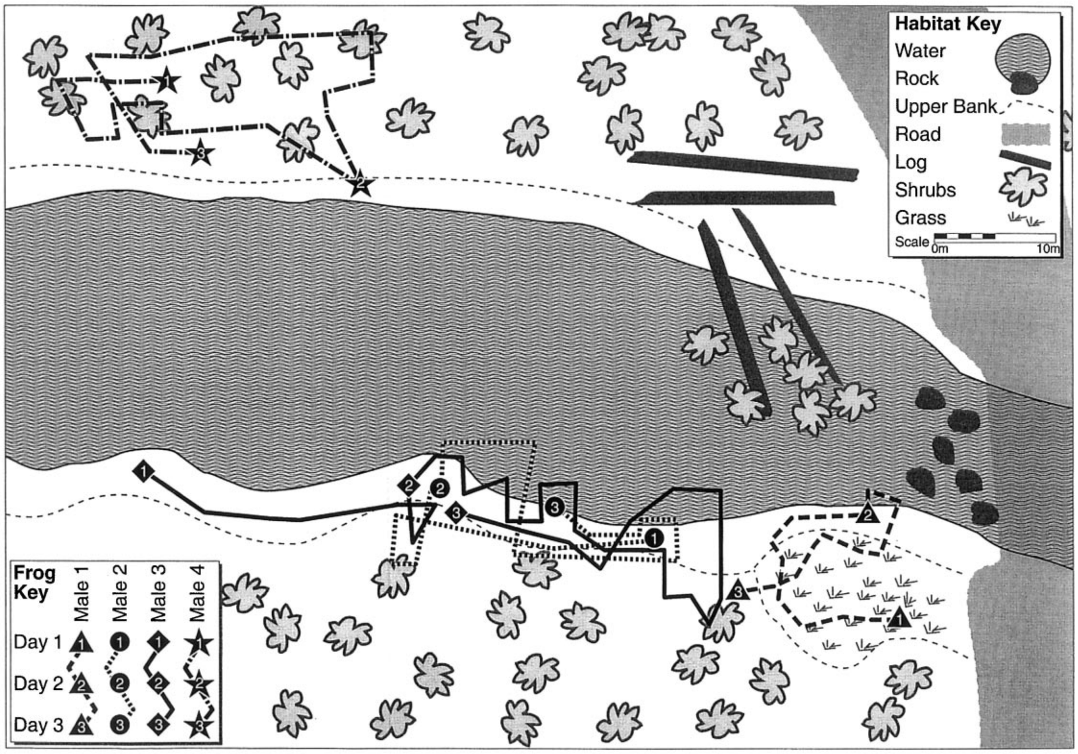

Fig. 2. Daily recorded spool-tracked movements of frogs at Flaggy Falls.

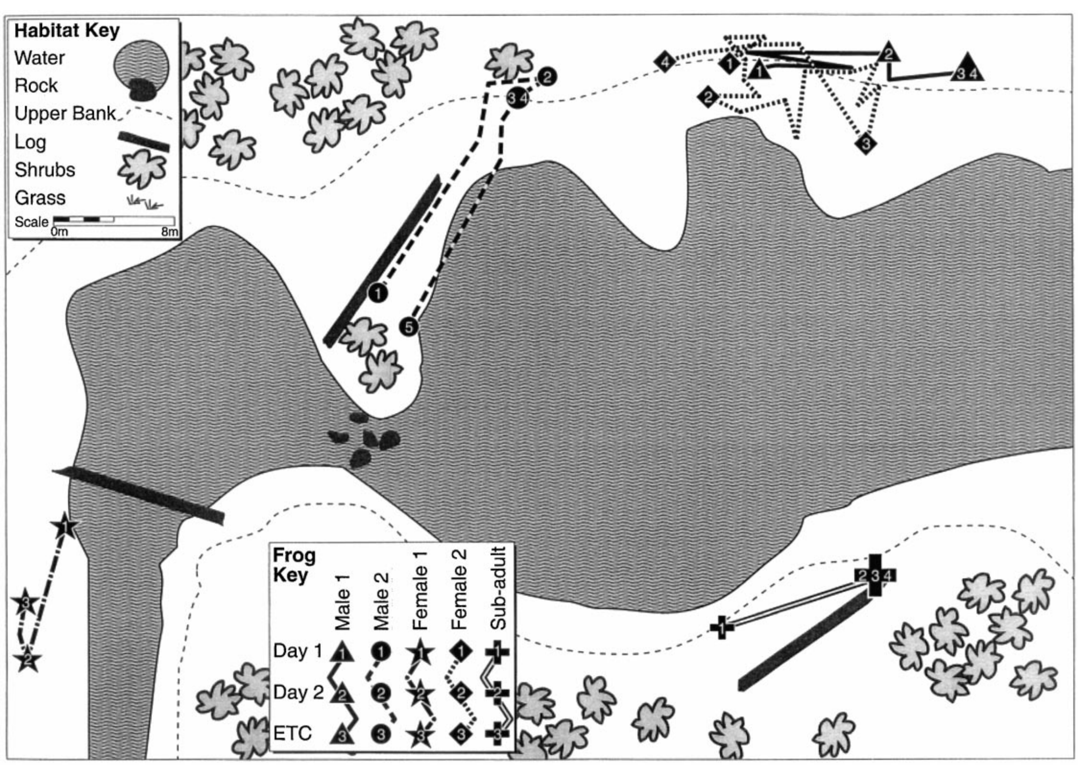

Fig. 3. Daily recorded spool-tracked movements of frogs at Plantation Cresent.

Long pre- and post-breeding movements have been demonstrated in other anuran species (e.g. Kusano et al., 1995; Bosman et al., 1996; Spieler and Linsenmair, 1998) and some individuals were expected to disperse into the surrounding forest to find post-breeding habitats. That this was not observed may simply reflect the fact that the giant barred river frog was calling in March (early Autumn), when the latest tracking took place, and so post-breeding dispersal had not yet occurred. However, adult frogs are still present in the riparian zones in late April (mid–late autumn; F. Lemckert, unpubl. data) when conditions in the Dorrigo area (upland sites) become very cool. It would appear unlikely that frogs would move long distances at this time as they would soon enter their period of winter inactivity. The three juveniles tracked during this period at the coastal site also showed no indication of dispersing. It appears that these frogs may not have significantly differing "winter" and "summer" activity areas and may remain in the riparian zone all year round. Long migrations by other species are undertaken because of a need to find refuge sites from dry conditions (Spieler and Linsenmair, 1998) or possibly to escape areas that might flood (Bosman et al., 1996). Dry conditions are unlikely to occur in this closed riverine environment and so pose no threat. Flooding might be a concern, but each stream has areas of their banks that are 2–3 m above the usual water level observed. These areas would provide relatively safe overwintering sites. Further studies following frogs through winter should indicate if frogs use specific overwintering sites within the riparian zone or if at least some individuals do move to sites outside of the riparian zone.

The habits of juvenile frogs are not yet clear. They were too small to track and they may use the available habitats differently. However, juvenile frogs (those <40 mm) have been located around the same streams on more than 50 occasions with only two records obtained away from the 20 m riparian zone (see SFNSW, 1995a). This is similar to our findings for adult frogs and it appears that juveniles have similar movement patterns.

We expected individuals to shelter in areas providing dense cover such as under leaf litter or within thick vegetation. Such sites provide protection from predators and desiccation and have been used as shelter sites by frogs in other studies (Kusano et al., 1995; Spieler and Linsenmair, 1998). Although some frogs hid below leaf litter, the majority of frogs remained in a position that left their heads clearly exposed and usually the rest of their body as well. Dehydration is unlikely to be a problem due to the humid environment provided by these riverine forests. Where dehydration is not a concern *Bufo marinus* also chooses more open sites than usual (Schwarzkopf and Alford, 1996). Predation is also not likely to be a problem when these frogs choose "open" shelter positions. The camouflage of these frogs is extremely good, even when fully exposed. Additionally, frogs sheltering above the leaf litter appeared to be very alert and readily jumped when approached closely and, on all but one occasion, were found in a position within two jumps of the stream. "Alert" individuals would be able to rapidly reach the shelter provided by water, if required, whereas frogs hiding under the leaf litter were relatively torpid and would have little ability to escape if found by a predator.

Comparisons of radio-tracking versus spool tracking indicated that the former significantly underestimates nightly movements. This was an inevitable consequence of checking the positions of frogs only once per night that resulted in us missing the many small movements that take place. This could have been overcome if we had elected to monitor each frog more often, but we felt this continuous disturbance would inhibit their movements and would also be too labour intensive. The initial objective of the radio-tracking work was to determine if frogs moved large distances perpendicular to the riparian zone and the work served to determine that this did not happen.

The presence of the tracking devices might have inhibited the movements of individuals, but it would appear unlikely that this was the case. Records of this frog have been obtained on more than 200 occasions, yet only one adult frog (a large female) and possibly two juveniles (their distance to water was uncertain) have been located more than 20 m from the edge of a stream. This strongly indicates that giant barred river frogs are generally confined to a narrow strip of vegetation either side of a stream.

The giant barred river frog proved to be a very suitable species for spool tracking. Its large size meant that it could carry a spool with a substantial length of nylon and so could be tracked for several days without having to replace the spool. It also does not burrow into the soil, where an external pack might hinder its efforts, nor does it climb into trees or crevices where a pack might tangle or get caught. Many species are unlikely to have such favourable characteristics and so spooling may be a less viable means of tracking for them. However, spool tracking appropriate species does provide more detail on their short-term movements and microhabitat use for less effort and disturbance to the animal when compared with radio-tracking. Hence, it is a method that should be more widely used.

This study has important implications for the conservation of the giant barred river frog. This species has declined markedly in the last 20 years for reasons that are uncertain, although a pathogen appears likely to have played a major role (Mahony, 1993). Although forestry has not been regarded as a major contributing factor to this decline, logging operations can negatively impact on this species (Lemckert, 1999) and any continued impact is relatively important given the low number of animals now left. Measures have recently been set in place to protect giant barred river frogs from the impacts of logging (SFNSW/NPWS, 1997). Previously, buffer zones were set at 20 m wide on each side of streams, but were increased to a 30 m wide buffer zone either side of the stream for a distance of 200 m upstream and downstream of sites where this frog occurs. This change was implemented prior to this study, the results of which suggest that such a buffer zone will protect from direct disturbance the area of streamside habitat used by giant barred river frogs during the spring to autumn activity period. A 30 m wide disturbance free zone includes an area of 10 m that appears to be rarely used and so provides a degree of buffering from any "edge" effects. Continued monitoring of this frog under the new protective regime is essential to determine if the increased protective prescriptions protect the giant barred river frog from logging impacts.

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