

Preliminary estimation of home range size for *Meristogenys orphnocnemis*, a common Bornean Ranid, in an altered forest ecosystem using radiotelemetry

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Abstract. We tracked six female *Meristogenys orphnocnemis* for 17 ± 4.3 days (11.5–22 days) in Sabah, Malaysian Borneo to determine core area (home range size) and movement patterns. We found that the core usage area was 3351.0 ± 963.4 m². Mean distance of each female from the stream during tracking was between 4.9–29.3 m and median distance from the stream for individual females was 4–20 m. Net distance between first and last observation was 80.6 ± 24.5 m, and there was no relationship between number of days tracked and total distance traversed or core area size, nor between body size and core area size, though our sample sizes were likely too small to detect such patterns. We suggest additional radio-tracking to determine differences in movement ecology between sexes and across species, to better predict impacts on anurans from logging and fragmentation in Southeast Asia.

Key words. behaviour, radio-tracking, frogs, Malaysia

INTRODUCTION

Deforestation rates in SE Asia remain some of the highest in the world (Achard et al., 2002; Achard et al., 2014), and the majority of forest clearing is driven by increases in oil palm plantation area (Stibig et al., 2014). Historically, little attention has been paid to biodiversity conservation within oil palm plantations, but recently, some palm oil manufacturers have partnered with scientists to evaluate the efficacy of mixed plantation-forest landscapes to better preserve biodiversity (Ewers et al., 2011). Riparian buffer zones in oil palm plantations are typically 30 m, but few data exist on the efficacy of these buffers to preserve diversity in tropical settings, and some studies in temperate regions indicate that this 30 m buffer in logged areas may be inadequate to preserve biodiversity (Goates et al., 2007; Olson et al., 2007). Thus, researchers are currently evaluating biodiversity of aquatic and riparian forest fauna in buffer sizes ranging from 0–120 m (Ewers et al., 2011).

A key taxonomic group that relies on riparian zones across Southeast Asia is the Amphibia. Across the region, the majority of amphibian species are obligate stream breeders, so this group, which can comprise the majority of vertebrate

biomass in some ecosystems (Burton & Likens, 1975; Stebbins & Cohen, 1995), is dependent on the health of the stream as well as its surrounding forest habitat. Surveys of both adult and larval anurans within the Stability of Altered Forest Ecosystems (SAFE) project landscape have been conducted regularly since 2011 (unpublished data), but presence/absence data do not provide information on how amphibians utilise the landscape. Such knowledge is essential for predicting long-term impacts of deforestation, such as genetic isolation which can lead to reduced fitness and extinction debt (Hanski, 2011). Additionally, without detailed knowledge of amphibian movement and dispersal, it may take years or decades for the detrimental impacts of deforestation on genetic fitness to be reflected in population size or community composition. Thus, understanding detailed movement patterns of amphibians allows for more effective evaluation of the conservation potential of a given riparian buffer size, and allows for a more rapid assessment of the impact of riparian habitat fragmentation.

Detailed data on amphibian movement patterns largely come from temperate regions, where mark-recapture or radio-tagging of amphibians focus mainly on pond-breeders (Sinsch, 1992; Matthews & Pope, 1999; Bulger et al., 2003; Browne & Paszkowski, 2014; Timm et al., 2014). For the majority of temperate anurans, adults come to wetland sites for explosive breeding events, then disperse into surrounding habitat (Goldberg & Schwalbe, 2004; Blihovde, 2006). Fewer data are available for stream-breeding frogs, which are likely to have different home range sizes and dispersal patterns compared to those which breed in ponds or other ephemeral wetlands (Lemckert & Brassil, 2000; Rowley & Alford, 2007; Grafe, 2011; Konopik et al., 2014). Because the majority of Southeast Asia's anurans are stream-breeders (Inger &

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Fig. 1. Section of stream in SAFE Project experimental site, known as logged forest edge (LFE) stream, where all radiotracking occurred.

Stuebing, 2005), as noted above, it is necessary to collect movement data in these habitats, rather than extrapolating from data on temperate pond breeders. Additionally, existing data on anuran movement patterns in Southeast Asia, where oil palm plantation area is rapidly expanding, come mainly from mark-recapture studies (Inger, 2009). Such studies rely on spotting individuals along a given transect (usually a stream bed), rather than following individuals across the landscape regardless of their position. Thus, while mark-recapture studies are an important first step, and may be the only option for anurans too small to support the weight of radiotransmitters, radiotelemetry can reveal detailed movement patterns and indicate how anurans utilise the landscape, which, in turn, can help predict population- and community-level impacts of fragmentation before changes are detected by standard visual encounter surveys. To better understand movement ecology of Bornean frogs, we radio-tracked females of a common ranid (*Meristogenys orphnocnemis*) along one of the control streams in the SAFE project area, to determine home range size of this species in a relatively undisturbed area. These data will serve as a baseline for comparison with future radio-tracking efforts of anurans along study streams with different riparian buffer sizes.

MATERIAL AND METHODS

The study site. The study took place in lowland mixed-dipterocarp rainforest in the Stability of Altered Forest Ecosystems (SAFE) project area in eastern Sabah, Malaysia (4°43'28"N, 117°35'52"E, 420 m asl) (Ewers et al., 2011) between July–September 2016. The SAFE project area is managed by Yayasan Sabah and has been selectively logged over the past several decades, but was recently leased out to the oil palm producer Sime Darby (Ewers et al., 2011). Prior to clearing the forest for oil palm plantation, Ewers et al. (2011) worked with Sime Darby and Yayasan Sabah to create a large-scale fragmentation experiment. Thus, in 2011 the area was hilly selectively logged forest, and as of 2016, it was largely cleared of forest and oil palm had been planted, though the experimental fragments remain



Fig. 2. Female *Meristogenys orphnocnemis* showing transmitter and attachment belt.

intact (see Ewers et al., 2011 for details). The study stream on which radio tracking occurred is immediately adjacent to the project camp, with all animals tagged at least 200 m upstream from the camp itself. The forest surrounding the stream remains intact (though as noted, had been selectively logged over previous decades; Fig. 1).

The studied taxa. *Meristogenys orphnocnemis* is a medium-sized member of the family Ranidae. Males range from 35–50 mm (3–6 g) and females are 60–71 mm (19–28 g). This species is common in eastern Sabah in lowland (150–1,300 m asl) rainforest areas, usually along fast-flowing streams with gravel or rocky bottoms, and breeds throughout the year (Inger & Stuebing, 2005). While this genus contains many morphologically similar species, we determined our species to be *M. orphnocnemis* based on that species being the only member of the genus reported from extensive surveys of nearby Danum Valley Conservation Area by Inger & Voris (Inger & Voris, 1993), as well as on the description of *M. orphnocnemis* in Inger & Stuebing (2005). Additionally, we sequenced the 16S mitochondrial gene of multiple (n=6) randomly selected adults and tadpoles from across the SAFE project area, and all were identified as *M. orphnocnemis* when using the BLAST function on GenBank (unpublished data). Voucher specimens of adults and tadpoles collected from all study streams in 2015 have been deposited in the Sabah Parks Museum and the North Carolina Museum of Natural Sciences (Appendix 1).

Methodology. We attached 0.4 g radio transmitters (HOLOHIL Systems Ltd., BD-2X) to a total of 7 female *M. orphnocnemis* (Fig. 2). We limited our study to females due to size restrictions: female body weights ranged from 19–28 g, while males are often less than the recommended weight for transmitters this size (minimum 4.6 g to support transmitter plus attachment). Transmitters were attached to frogs following Groff et al. (2015), using flexible bead cord with a diameter of 0.7 mm, for a total transmitter-plus-belt weight of approximately 0.46 g, or less than 2.5% of the frog's body mass. Estimated transmitter battery life was 14–21 days. Frogs were released at their original point of

capture after being fitted with a transmitter, and that point was marked with a GPS as well as with a survey flag. Frogs were hand-tracked using a portable radio receiver (TRX-48, Wildlife Materials, Inc.) and a 3-element folding antenna. Frogs were tracked twice daily, in the morning between 0700–1100 hours and in the late afternoon between 1600–1900 hours unless inclement weather prevented safe access to the study stream. When an individual was located, its distance from the last known point was measured as a straight line from the previous known point using a metre tape, unless the distance was greater than 30 m, in which case its new location was recorded with a GPS.

Females were followed for 1.5–22 days. The single individual for which we had only 1.5 days of data was omitted from analyses (the transmitter was found in a branch pile 1.5 days after tagging). The remaining six females were tracked for 17 ± 4.3 days (11.5–22 days). For each individual tracked, a minimum convex polygon (MCP) was created using QGIS (QGIS Development Team, 2017) to calculate the total movement area and a second MCP was created using only movements that were less than 40 m from their previous positions to calculate the frog's core area.

RESULTS

Females had core areas of 3351.0 ± 963.4 m² ($\mu \pm$ SE; range: 631–6915 m²; Fig. 3), and total movement areas of 3622 ± 1012 m² (631–7069 m²). In four of our six individuals, the core area was equal to the total movement area, indicating that for the majority of individuals we tracked, there was never more than 40 m between subsequent observations. For the remaining two individuals, the difference between core area and total movement area was 154 m² and 1471 m², respectively. For all individuals, the percentage of observations within the core area ranged from 95.8–100%, and in all cases, no more than one observation was outside of the core area. While the frogs utilised the stream bed and embankments for many of their movements, we also observed regular movements perpendicular to the stream and periods of no movement.

Total distances traversed by females ranged from 103.1 m (number of observations n=21) to 360.4 m (n=31; Table 1). Maximum distance traveled between observations (within 24 hours) for each individual was 18–115 m (Table 1), and net distance between first and last observation was 80.6 ± 24.5 m (range: 20.7–215.5 m). We found no relationship between number of days tracked and total distance traversed ($F_{1,5}=0.89$, $p=0.40$; $R^2=0.18$) or core area size ($F_{1,5}=2.10$, $p=0.22$; $R^2=0.34$), nor between snout-vent length (SVL) and core area size ($F_{1,5}=0.91$, $p=0.39$; $R^2=0.18$), though our sample sizes were likely too small to detect such patterns.

Mean distance of each female from the stream during tracking was between 4.9–29.3 m (Table 1), with an overall mean distance from the stream for all observations of 10.4 ± 0.96 m. The median distance from the stream for individual females was 4–20 m (Table 1), and the median distance from the stream across all observations was 6 m.

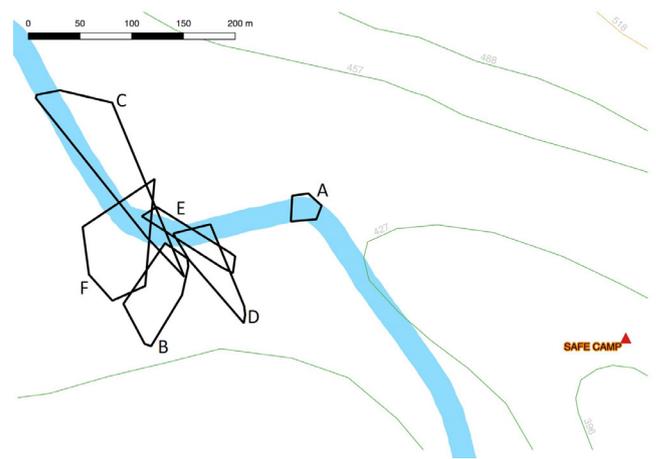


Fig. 3. Core use area of six female *Meristogenys orphnocnemis* at SAFE Project site in eastern Sabah, Malaysia.

DISCUSSION

Total movement area (home range) of *M. orphnocnemis* in this study (3621.7 ± 1012.3 m²) was similar to that reported for female *L. leporinus* by Grafe (2011) (3466.7 ± 2325.0 m²), despite the much smaller size (63–71 mm) of *M. orphnocnemis* compared to *L. leporinus* (103–106 mm) tracked in that study. We found sizeable variation in core area between individuals (*M. orphnocnemis*: 630.8–6915.4 m²), similar to inter-individual variation in core area reported for radiotracked *L. leporinus* (450–1470 m²) (Grafe, 2011). While sample sizes were too small in both studies to determine the relationship between body size and core area, the data do not strongly implicate body size in determining variation in core area (Table 1). Interestingly, despite the smaller size of *M. orphnocnemis* compared to *L. leporinus*, core areas, total movement areas (home ranges), and maximum distance traveled in a single day were larger for *M. orphnocnemis* (115 m) than for *L. leporinus* (82 m) females. This indicates that body size alone may not be a strong predictor of movement patterns among species, but additional radiotracking is necessary to determine home range and core area needs for a broad array of Bornean anurans, and whether body size across species is a strong predictor of home range size.

Both our study and the study of *L. leporinus* focus on females, but it is notable that the single radio-tracked male *L. leporinus* had a greater core and total movement area than females in that study (Grafe, 2011). However, without additional data on both sexes, it is impossible to determine whether differences in home range and movement areas are due to individual frog body size, or due to differences in movement patterns between genders. Inger (2009) marked individuals along stream transects, reporting separately on males and females of three species. Because that study used mark-recapture techniques along a stream transect, home range and core area size were not possible to calculate, as was done in the present study and that of Grafe (2011), but Inger (2009) does report net distances between first

Table 1. Movement summary of *Meristogenys orphnocnemis* in Sabah, Malaysia, 2016. All distances in metres, except where noted.

Frog ID	SVL (mm)	No. days tracked	Total distance traversed (# obs.)	Net dist. 1 st to last obs.	Max. daily dist.	Mean dist. from stream (±SE)	Median dist. from stream	Max. horizontal dist. from stream	Core area (m ²)	Total movement area (m ²)
A	65	14.5	124.2 (18)	28.7	22	4.9 ± 0.6	4	10	630.8	630.8
B	71	14	332.6 (9)	20.7	101	29.3 ± 5.8	20	75	3370.6	4841.3
C	70	19	360.4 (31)	215.5	115	10.3 ± 1.8	5.5	28	6915.4	7068.9
D	63	22	235.9 (44)	76.1	35	9.0 ± 1.0	5	25	2396.7	2396.7
E	64	11.5	103.1 (21)	98.2	18	7.7 ± 1.5	4.5	23	1549.1	1549.1
F	65	21.5	235.9 (44)	44.5	31	7.2 ± 0.6	8	15.5	5243.2	5243.2

and last capture, as well as maximum distances between successive captures. For all three species studied by Inger (*Phrynoidis asper*, *L. leporinus*, and *L. ibanorum*), males are larger than females, and in two of the three species, males had larger median and maximum distances between first and last captures, but in one species (*P. asper*), females had larger such distances (Inger, 2009), indicating that the relationship between size and movement, and between sex and movement vary across species within Borneo. We have not yet tracked male *M. orphnocnemis*, so we cannot comment on movement differences between males and females in this species. However, we encourage additional radiotracking, of both this and other species, to better understand the relationships between movement patterns and the size and gender of Borneo anurans.

Net distance between first and last observations for *M. orphnocnemis* was 80.6 ± 29.5 m (range: 20.7–215.5 m). Additional net distance between first and last observations of Borneo anurans, based on mark-recapture techniques, range from 0.6–151.2 m for *L. ibanorum* (SVL <130 mm), to 0.3–591 m for *L. leporinus* (SVL <175 mm) (Inger, 2009). The minimum values reported here are much lower than those for our smaller-bodied species, but at least part of this difference is likely due to the differences in survey techniques. However, the large-bodied diroglossids studied by Inger (2009) may actually move less than the ranid of our study, as Grafe (2011) also found that the *L. leporinus* (SVL 109–135) he radiotracked stayed close to the stream, and had smaller home range sizes than our species. Collectively, these data indicate that there are significant differences in the movements of frog species in Borneo, and additional studies using radiotracking will help determine more general movement patterns among species.

Median distances from the stream across all observations were similar for *M. orphnocnemis* (6 m) and *L. leporinus* (3 m), the only other Bornean species for which data are available (Grafe, 2011). However, the maximum distance from the stream we observed *M. orphnocnemis* was 75 m, whereas the maximum distance from the stream reported for *L. leporinus* (Grafe, 2011) was 20 m. This indicates that *M. orphnocnemis* may not be as strongly tied to streams as *L. leporinus*, and may partly explain the larger core and total movement areas for *M. orphnocnemis*. Additionally, though our sample sizes are small, this greater maximum distance from the stream in *M. orphnocnemis* may be an indication that a larger riparian buffer zone is required for *M. orphnocnemis*, despite its smaller body size. We recommend radiotracking additional species representing a variety of ecological niches, to determine riparian width required to support a robust community of anurans in Southeast Asian oil palm plantations.

We found that the transmitters performed as well or slightly better than specifications on the manufacturer’s website ($\mu=12$ days; range: 8–15 days), giving us 11–18 days of battery life. Surprisingly, we were able to get signals for all individuals fairly easily despite the very hilly terrain, which indicates that additional radiotracking of anurans should be possible in

this and other parts of Borneo. In only one instance did we observe the beginning of a possible abrasion caused by the belt attachment, which we promptly removed. This occurred on “Frog C” who had been tracked for 18 days with one transmitter, and then had a new transmitter replace the old one for a single day, at which time we noted the beginning of an abrasion and removed the new transmitter. Future work will determine whether or not this was an anomaly.

While the majority of Sabah frogs are known to breed along streams (Inger & Stuebing, 2005) and these species are suspected to migrate along riparian corridors, few data are available on the movement ecology of Southeast Asian amphibians to confirm migration and movement patterns. Thus, the current choice of 30 m as a riparian buffer along streams in oil palm plantations may not provide sufficient habitat to maintain amphibian diversity in these forests long-term, and additional radiotracking is recommended to inform policy.

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Appendix 1. Voucher specimens of *Meristogenys orphnocnemis* from study site, deposited at North Carolina Museum of Natural Sciences (NCSM) and Sabah Parks Museum.

Museum	Voucher No.	Field Tag No.	Life Stage
NCSM	90903	JAS10017	Male
NCSM	90952	JAS10027	Tadpole
NCSM	90949	JAS10039	Tadpole
NCSM	90948	JAS10040	Tadpole
NCSM	90898	JAS10054	Female
NCSM	90899	JAS10066	Male
NCSM	90901	JAS10069	Female
NCSM	90902	JAS10078	Male
NCSM	90950	JAS10097	Tadpole
NCSM	90951	JAS10102	Tadpole
NCSM	90900	JAS10128	Male
NCSM	90904	JAS10154	Female
NCSM	90908	JAS10307	Male
NCSM	90905	JAS10343	Male
NCSM	90906	JAS10344	Female
NCSM	90907	JAS10366	Male
Sabah Parks	27586	JAS10047	Female
Sabah Parks	27587	JAS10053	Male
Sabah Parks	27588	JAS10107	Female
Sabah Parks	27589	JAS10148	Male
Sabah Parks	27590	JAS10151	Male
Sabah Parks	27591	JAS10163	Female
Sabah Parks	27592	JAS10176	Male