

Using Radio Telemetry to Assess Movement Patterns in a Giant Rhinoceros Beetle: Are There Differences Among Majors, Minors, and Females?

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Introduction

The Japanese horned beetle *Trypoxylus dichotomus* is a peculiar example of a male-dimorphic species that does not exhibit any alternative reproductive tactics. Typically, differences in male morphology correspond to marked differences in mating behaviors (Dominey 1984; Gross 1996). Large males tend to adopt aggressive, territorial tactics to attract and secure females, while small or otherwise inferior males try to mate via sneak or satellite tactics, or by dispersing away from dominant males (reviewed in Oliveira et al. 2008). Alternative reproductive tactics are expected to favor distinct male morphologies, because exaggerated weapons that confer fighting advantages to dominant males should impair dispersal and sneaking capabilities (Moczek and Emlen 2000; Madewell and Moczek 2006).

Although alternative reproductive tactics have been described in a number of dimorphic beetle species (Eberhard 1982; Rasmussen 1994; Emlen 1997; Moczek and Emlen 2000), *T. dichotomus* major and minor males apparently do not have distinct mating behaviors. Large major males have a long, branched head horn and short, sharp thoracic horn that they use to pry rival males away from sap sites that attract females. Small minor males have short head and thoracic horns, yet they engage in direct combats with other males just as readily as major males, and do not fight in qualitatively different ways (Hongo 2003). Even though minor males engage in sneak-like behaviors, major males also sneak copulations, and the only male that is known to have successfully mated after sneaking was a major male (Hongo 2007).

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Previous studies, however, have assumed that all matings occur at night and near sap sites. To date, no study has examined how far *T. dichotomus* travel, where beetles roost during the day, or whether they roost communally or alone. Without this basic information about the beetles' biology, the assumption that matings only occur at night and at sap sites is premature.

Here I present the results of a radio-telemetry study that examined the movement patterns of *T. dichotomus* major males, minor males, and females. I compare the daytime roosting behavior and distances traveled by major and minor morphs in order to assess two potential, but previously overlooked, alternative reproductive tactics. First, minor males may travel farther to and from sap sites in order to encounter more females per night than major males. Second, minor males may attempt to mate with females during the day at roost sites, or at sap sites after the major males have departed. Because only a few studies have tracked flying insects with radio transmitters (Hedin and Ranius 2002; Beaudoin-Ollivier et al. 2003; Rink and Sinsch 2007; Wikelski et al. 2010), I also discuss the effectiveness of using radio telemetry to monitor movement patterns in a giant rhinoceros beetle.

Methods

Radio telemetry was used to assess the movement patterns of *T. dichotomus* from June to August 2009 on the National Chi Nan University campus in central Taiwan (23.954°N, 120.927°E; 1,310–1,330 m). The study site contains many *Fraxinus* trees, which is the exclusive host plant of *T. dichotomus* in Taiwan. Beetles chew into the bark and feed on the exuding sap, and populations can be easily located by the presence of wounds (sap sites) on the trees. All beetles found in the study site were collected from their natural sap sites, and individually marked with quick drying paint markers. Horn length of all males, and prothorax width and elytra length of both males and females were measured to the nearest 0.01 mm with dial calipers (Mitutoyo). Mass of both males and females was measured to the nearest 0.1 g with a spring scale (Pesola).

To measure how far beetles travel, I glued 0.2 g radio transmitters (ATS, Series A2405) onto the pronotum of 7 major males, 8 minor males, and 5 females (Fig. 1). The battery life of the transmitters was approximately 10 days. Major males used for telemetry were among the largest third of the population (horn length >28 mm), and minor males were among the smallest third (horn length <21 mm). Sample size was limited by the cost of the transmitters and difficulty in tracking the beetles. Transmitters represented only 2–4 % of a beetle's mass, and were affixed with a portable hot glue gun (Portasol). To assess whether the radio transmitters affected flight performance, I used a high performance radar gun (Stalker ATS Performance Radar Gun) to measure how fast beetles flew both before and after attaching the radio transmitters. There was no difference in flight speed between beetles with radios (2.21 ± 0.33 m/s) and those without (2.16 ± 0.39 m/s; $T = -0.28$, $df = 14$, $P = 0.78$). Radio-tagged beetles appeared to feed and mate normally.

Each transmitter had a unique frequency (141.900–141.340 Hz) so multiple beetles could be followed simultaneously. Transmitter signals were detected using a portable, hand-held scanning receiver (ATS, R410) and a three-element Yagi antenna. I searched for the radio-tagged beetles every 4 h at night when the beetles are most

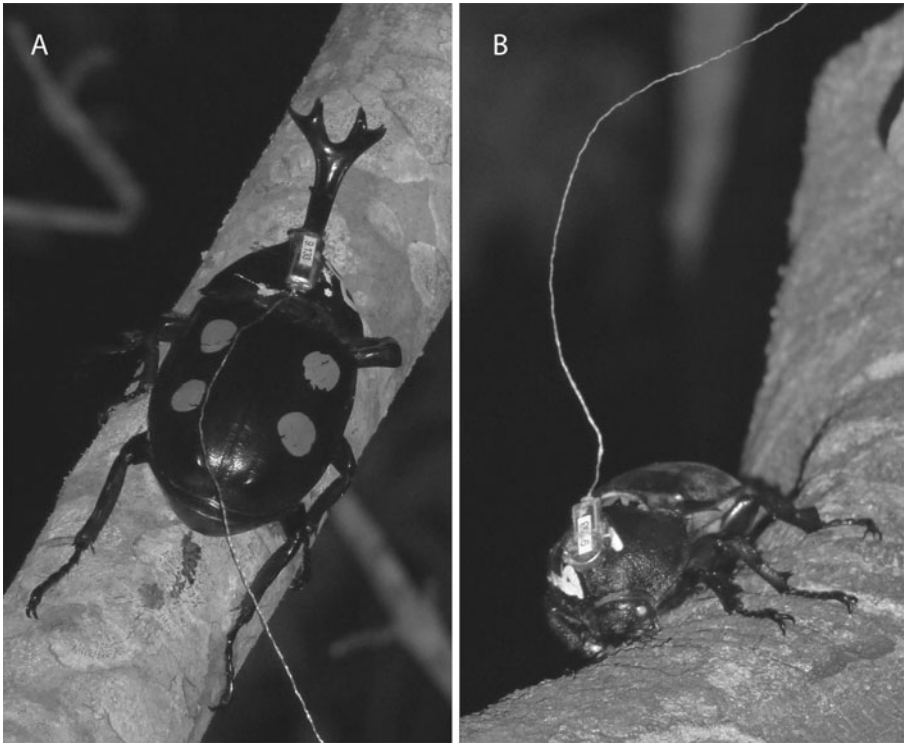


Fig. 1 *Trypoxylus dichotomus* major male (a) and female (b) with paint markings and equipped with radio transmitters

active (from 20:00 to 04:00 h), and once during the day (between 10:00 and 16:00 h). To search for a beetle, I started at the tree where the beetle was most recently located and searched outward on foot up to 1 km in all directions. Typically, a beetle could be located within a few minutes if it was in the same general location as previous visits. However, sometimes searches for a single beetle lasted more than an hour if the beetle had traveled to a new site.

The distance between beetle locations was measured to the nearest 1 m with a global positioning system (Garmin GPSMAP 60CSx). Distances were not corrected for time because there was no relationship between distance traveled and the time interval between sightings ($R^2=0.002$, $F_{1,84}=0.20$, $P=0.66$). All distances that were recorded for the radio-tagged beetles were included in the analyses. Because the movement data did not follow a normal distribution, non-parametric tests were used to compare distances traveled among major males, minor males, and females.

Results and Discussion

In total, I collected and measured 198 males and 135 females as part of a larger study. Of these, I successfully monitored movement for 17 individuals (7 majors, 6 minors, 4 females). The tracking period for individual beetles varied between 1 and 10 days (median=3 days). A few beetles remained on *Fraxinus* trees well after sunrise to

continue feeding or mating. If minor males employ an alternative reproductive tactic of mating with females during the day after the major males have departed, I would expect minor males to stay frequently at sap sites after sunrise. This clearly is not the case. Of the 198 marked males, only 21 remained at feeding sites on at least one morning, and only 11 (52 %) were minor males. [See Kotiaho and Tomkins (2001) for details on classifying major and minor morphs, and Hongo (2007) for a description of male dimorphism in *T. dichotomus*.] These results suggest that minor males do not gain significantly more mating opportunities by remaining at sap sites longer than major males during the day.

Radio telemetry revealed that most beetles hide during the day in tree canopies. Although some beetles buried themselves in the grass or leaf litter at the base of their feeding tree, most beetles hid in the canopy of a tree close to their nighttime feeding site. Beetles often returned to the same feeding trees night after night, but roosted in different hiding trees on subsequent days. Beetles may therefore be relatively faithful to feeding sites, but not to roost sites. I never observed individuals roosting in close proximity with other beetles, which suggests that they do not aggregate at daytime roosts. Although this does not preclude the possibility that males may attempt to mate opportunistically during the day, the scattered nature of roosting sites suggests that daytime mating will not represent a significant source of matings for minor males.

The distance between nighttime sap sites and daytime roosts ranged from 0 to 402 m. Contrary to my prediction that minor males would travel farther than major males to encounter more females or find sap sites not guarded by major males, minors actually traveled shorter distances between sap sites and roosts than majors (Wilcoxon rank sum test: $W=472$, $P<0.001$). The distance between sap sites and roost sites ranged from 0 to 107 m (median=9 m) for minor males, and 0 to 402 m (median=39 m) for major males. Although these differences may be confounded by small sample sizes, it is clear that minor males do not travel farther distances than major males. Thus, despite the impressive variation in horn size and the expectation that distinct male morphologies will favor alternative reproductive tactics, there is no evidence that major males and minor males have distinct dispersal and roosting behaviors for finding and securing females.

I was unable to track females for more than a few days. Radio-tagged females either flew out of the detection range of the receiver, or buried deeply in the clay soil, presumably to oviposit, and dislodged the transmitters. Distances between sap sites and roost (or oviposition) sites for females ranged from 0 to 99 m (median=16 m), which suggests that females do not travel significantly farther than males (Wilcoxon rank sum test: $W=521$, $P=0.54$). However, most females flew beyond the tracking capabilities of the receiver, so the distance measurements are likely to underestimate typical female dispersals. In a similar radio telemetric study on *Scapanese australis*, females routinely flew out of detection range (Beaudoin-Ollivier et al. 2003), which suggests that females in other rhinoceros beetle species also travel long distances between mating and oviposition sites.

The radio telemetry evidence reported here suggests that *T. dichotomus* typically travel less than 100 m between feeding sites and roost sites. These results, however, should be taken cautiously as several radio-tagged beetles (2 major males, 1 minor male, and 3 females) flew out of detection range and therefore could not be followed. This observation alone suggests that long-distance movements may be relatively

common. Moreover, I recaptured two beetles (1 major and 1 minor) that flew over 3 km between my study site at the university campus and a second site alongside a mountain road that was monitored briefly as a side study. Because I recaptured these beetles several days after their initial sighting, it is unknown whether beetles can fly 3 km in a single, continuous flight. Male stag beetles are capable of flying at least 1,700 m in a single flight (Rink and Sinsch 2007), and it is likely that rhinoceros beetles are able to fly continuously for long distances as well. Regardless, the fact that beetles can and sometimes do fly several kilometers between resource sites may have important implications on the dispersal and colonization capabilities of this species. Detailed information on the typical movement patterns of rhinoceros beetles will be critical for conservationists aimed at protecting local populations, as many species, including *T. dichotomus*, are intensely harvested by insect vendors and hobbyists (New 2005).

The maximum detection range for radio-tagged beetles was approximately 800 m, although hills, trees, vegetation, and other obstacles could dramatically reduce detection range. Given that many rhinoceros beetles, including *T. dichotomus*, live in dense habitats where detecting transmitter signals is particularly difficult, radio telemetry may not be the appropriate method for tracking movements of these insects. Technological advances over the past decade have made it possible to use radio telemetry on small animals, including flying insects (Hedin and Ranius 2002; Beaudoin-Ollivier et al. 2003; Rink and Sinsch 2007; Wikelski et al. 2010). The data reported here indicate that small radio-transmitters were effective in assessing the movement patterns of rhinoceros beetles over small spatial scales. However, improvements in signal strength and detection range may still be necessary before radio-telemetry becomes the ideal method for tracking movement patterns in flying insects like rhinoceros beetles that inhabit dense habitats and are capable of long-range dispersals.

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