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ACTIVITY PATTERNS IN A CAPTIVE COLONY OF JAMAICAN FRUIT BATS, *ARTIBEUS JAMAICENSIS*

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ABSTRACT. We examined activity patterns of a captive colony of Jamaican fruit bats (*Artibeus jamaicensis*) using an Anabat II echolocation detection system and visual observations. Results showed that this colony, subjected to a light-reversal circadian cycle (darkness *ca.* 1000–2000 h daily), adjusted its activity patterns to maximize activity during dark hours. Major activities, including flying and feeding, were most frequent shortly after dark hours began, and roosting alternately increased throughout the dark time blocks. Additionally, captive bat behavior appeared to follow expected patterns of natural populations; they fed away from the source of food and preferred to roost in smaller groups rather than in large ones. We, therefore, provide quantitative evidence that captive colonies may be useful in elucidating the behaviors of natural populations.

Keywords: *Artibeus jamaicensis*, behavior, circadian activity, echolocation

Jamaican fruit bats (Phyllostomidae: *Artibeus jamaicensis*) are leaf-nosed bats whose native range includes Brazil, the Bahamas, Antilles, Trinidad, Tobago, Key West, and from central Mexico south to Bolivia. This species tends to roost in caves, rock overhangs, rock fissures, buildings, hollow trees, and self-made leaf tents (Gorog 1999). Primarily frugivorous with a specialty in figs (*Ficus* spp.), Jamaican fruit bats also feed on mangos (*Mangifera* spp.), avocados (*Persea americana*), bananas (*Musa* spp.), and espave nuts (*Anacardium excelsum*; Morrison 1978; Ortega & Castro-Arellano 2001). This species often transports fruit to night roosts for feeding, acting as influential dispersers of tropical fruits (Gorog 1999). Often referred to as "whispering bats," Jamaican fruit bats emit three low-intensity FM pulses used primarily for obstacle avoidance while flying or perching (Heffner et al. 2003). A series of 40–60 kHz pulses usually precedes a 60–110 kHz harmonic, followed by pulses at 30–33 kHz (Novick 1963).

Fenton & Kunz (1977) found that wild populations of Jamaican fruit bats were most active during the first hours after dusk, which equates to *ca.* 2000–2200 h during summer months. Additionally, they found that activity peaked around midnight (*ca.* 2–4 h after dusk) and activity was less predictable and more sporadic in remaining dark hours (Fenton & Kunz 1977). Whether this species follows a similar pattern of activity in captivity is unknown.

The roosting behavior of wild colonies has focused on caves, in which a harem-like social hierarchy exists. Typically, one dominant male roosts with 2–14 females (Kunz et al. 1983; Ortega & Arita 1999), but larger groups of up to 20 individuals may form if subdominant males are present. Outside of harems, fruit bats may roost individually or in small clusters (Ortega & Arita 1999). Given the typically skewed sex ratio in captive fruit bat colonies, as well as limitation for space, it is unknown whether these group sizes will be as large or as socially structured in captivity as in the wild.

Altered fruit bat activity with respect to changes in light pattern is a generally accepted conjecture (Erkert 1978). However, the extent of change in behavioral activity has rarely been quantified (e.g., Erkert & Kracht 1978; Marimuthu 1984). To quantify how a captive colony of Jamaican fruit bats has acclimated to a complete light-reversal, we utilized an Anabat II detection system (Titley Electronics, Australia) to record echolocation calls in 24 h

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cycles. We supplemented this work with visual observations throughout their most active hours to document specific behavioral patterns. From these two methods of study, we hypothesized: 1) captive Jamaican fruit bats would alter their activity patterns (as documented by echolocation calls) in response to reverse light conditions. Specifically, they would mimic wild bat populations by markedly increasing activity immediately after lights were shut off and peak activity *ca.* 2–4 h after darkness had begun; 2) captive bat active behavioral patterns would reflect these echolocation patterns; bats would fly, feed, vocalize, and crawl more often immediately after lights were dimmed, and these bats would roost more often in later hours; 3) captive Jamaican fruit bats would roost and feed in ways similar to their wild counterparts, roosting in smaller groups and feeding away from the original food source. Given the limited space and minority of males in our captive colony, we expected a tendency toward small groups or solitary individuals. However, because we could not readily distinguish males from females in the enclosure, we could not speculate on the possibilities of social hierarchies in this captive environment.

METHODS

Enclosure.—We studied a captive-born and -bred colony of 167 (32♂, 135♀) Jamaican fruit bats at the Potawatomi Zoo, South Bend, Indiana. Also in the exhibit were 19 Egyptian fruit bats (Pteropodidae: *Rousettus aegyptiacus*), which is one of the few megachiropteran bat species that echolocates (peak frequency = 20–40 kHz [von Herbert 1985 as referenced in Holland et al. 2004]). The 5.3 m long × 3.3 m wide × 2.7 m high enclosure contained two large horizontal plastic perches, four smaller plastic branches, as well as a large vertical perch that spanned the height of the enclosure. The glass display window also provided perching opportunities along a rim which butted up against the ceiling, as did air vents in the ceiling.

The zookeepers of the exhibit practiced reverse-daylight conditions to maximize bat activity during hours of public viewing. The enclosure was illuminated with fluorescent ceiling lights from *ca.* 2000–1000 h every day. Due to the interior location of the exhibit within the zoo building, the bats were not exposed to any natural daylight. Bats were fed chopped fruit twice daily (*ca.* 1030 h and 1330 h) placed in three hanging bowls while whole bananas were hung from smaller branches. Whole apples (*Malus* spp.) and oranges (*Citrus sinensis*) were also occasionally provided on smaller branches.

Echolocation patterns.—Bat activity was monitored in ten 24 h sampling periods (September 2005–April 2006) using an Anabat II detector and ZCAIM unit (Titley Electronics, Australia). This unit was set up in a corner of the enclosure, with the microphone/detector pointed at a *ca.* 45° angle toward the middle of the enclosure to maximize call recording ability and quality. If the Anabat system detected a call, it saved the call(s) in a file that encompassed 15 sec of elapsed time. In Analook 4.9g (Corben 2003), we documented the time at which these data files contained quality calls (>3 individual call pulses; Johnson et al. 2002). Because of the presence of Egyptian bats in the enclosure, only calls with average frequencies ≥40 kHz were counted as Jamaican fruit bat calls (von Herbert 1985 as referenced in Holland et al. 2004). The number of files with documented fruit bat calls was summed across 15 min periods, and the average number (with standard error) of files per 15 min was graphed to observe patterns across the 24 h sampling periods.

Behavioral observations.—Individual behaviors for colony members were observed in three-hour observational periods, all of which fell between 1000–1700 h when it was dark (and during hours in which zoo staff allowed access). Every 15 min, we documented the number of individuals performing any of five actions: flying, feeding, vocalizing (at frequencies < 20 kHz), crawling on the floor, and roosting. These four observations per hour were transformed into relative activity proportions, then averaged across seven 1 h time blocks (1000–1700 h). However, we restricted statistical analyses to six blocks between 1000–1600 h (n = 1 set of behavioral observations between 1600–1700 h).

Additional analyses examined bat preferences in feeding (at food cups *vs.* away from food cups; paired t-test) and roosting (in clusters of >7 fruit bats, 5–7 fruit bats, or 2–4 fruit bats; one-way ANOVA) behaviors. All statistical analyses were performed in SYS-

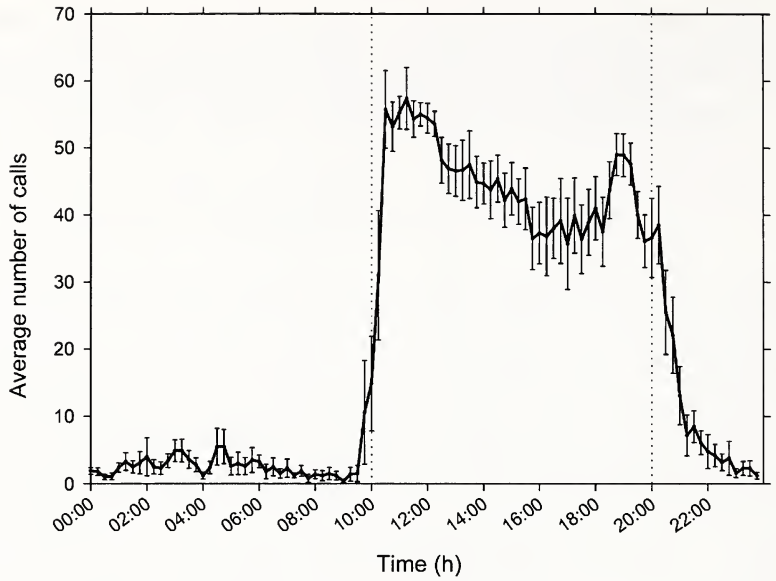

Figure 1.—Anabat echolocation calls for captive Jamaican fruit bat colony, exposed to reverse daylight conditions. Plotted is average number of calls per 15-min interval (with 95% CI) for ten 24-h observation periods from September 2005–January 2006. Time interval between dotted vertical lines indicates approximate hours in which bat enclosure was dark.

TAT 11.0 (Systat, Inc., Point Richmond, California).

RESULTS

We documented 18,509 Jamaican fruit bat echolocation calls during our study, and averaged them across 15-min intervals (Fig. 1). Bat activity was significantly higher in the enclosure during dark hours (1000–2000 h; $\bar{x}$ = 43.2 ± 15.3) than during light hours ($\bar{x}$ = 5.1 ± 10.5; t = 41.4, df = 579, $P < 0.001$). Furthermore, we found that the number of calls per hour differed across the seven time blocks in which bat behavior was recorded (Kruskal-Wallis test, K-W = 13.507, df = 6, $P = 0.036$; Fig. 1).

From 1000–1600 h, we found that bat flying (F = 4.031, df = 5, $P = 0.002$), feeding (F = 4.965, df = 5, $P < 0.001$), and roosting (F = 5.597, df = 5, $P < 0.001$) proportionally differed across time blocks (Fig. 2). Specifically, a Tukey's *post-hoc* test determined that more bats were flying in the 1100 h (i.e., between 1100–1200 h) than the 1200 h (P = 0.021), 1300 h ($P = 0.005$) and 1400 h (P = 0.017) time blocks. Bats fed less often during the 1300 h than at 1100 h ($P = 0.052$) and 1200 h ($P < 0.001$) and showed a trend in feeding less often at 1400 h than at 1300 h (P = 0.117), as well. A similar decline in feeding was observed from the 1300 h to the 1400 h ($P = 0.121$). Additionally, a paired t-test found that more bats were observed to feed away from food cups ($\bar{x}$ = 9.0 individuals per observation) than at cups ($\bar{x}$ = 4.0; t = 6.667, df = 107, $P < 0.001$) across all time intervals.

Finally, bat roosting peaked during the 1400-h time block, which was significantly more than roosting activity during the 1100 h ($P = 0.001$) and 1200 h ($P = 0.001$) time blocks. An ANOVA was used to examine group size in roosting, and found that the three size groups (2–4 individuals, 4–7 individuals, >7 individuals) differed significantly from one another (F = 536.5, df = 2, $P < 0.001$). The smallest grouping occurred more often than the medium (4–7) and large (>7) groups ($P < 0.001$ for both Tukey *post-hoc* comparisons), and individuals in medium groups occurred more often than those in large groups ($P = 0.006$). Crawling (F = 1.694, df = 5, P = 0.143) and vocalizing (F = 0.958, df = 5, P = 0.447) did not differ significantly across any time intervals.

DISCUSSION

As expected, the captive colony of Jamaican fruit bats exhibited a reverse-patterned

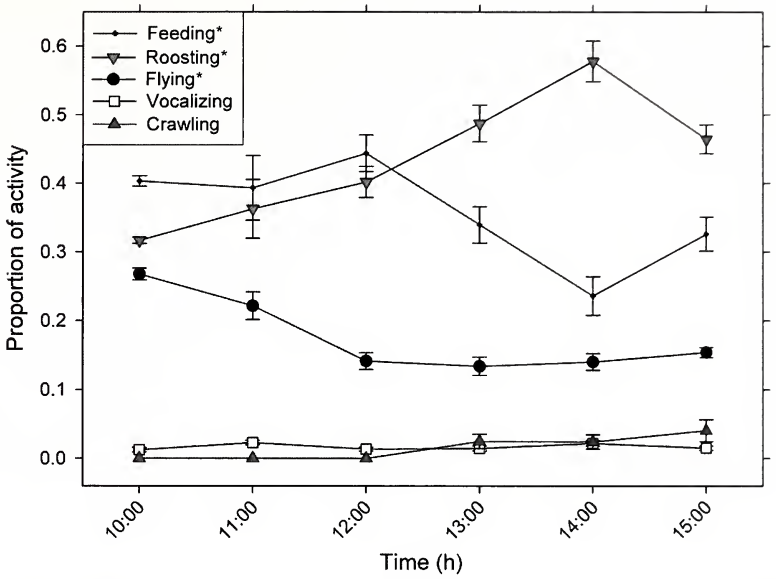

Figure 2.—Proportional bat activity (with 95% CI) for captive Jamaican fruit bat colony, exposed to reverse daylight conditions. Behavioral observations recorded from 1000–1100 h, e.g., are listed as an average at 1000 h. Bats were in darkness during all behavioral observation periods. An asterisk indicates that activity differed significantly across time blocks (see text for details).

circadian cycle complementary to the reverse-daylight pattern utilized in the Jamaican fruit bat exhibit. The Jamaican fruit bats showed significantly more echolocation activity during unlit hours. Their natural nocturnal rhythms, consistent with the hypothesis that the captive colony would adjust their circadian rhythms to the reverse-daylight cycles of the exhibit.

The Jamaican fruit bats exhibited corresponding behavioral changes with respect to the changes in light. Analyses of behavioral data showed there was statistically more feeding and flight activity during the earlier dark hours while roosting increased as the dark hours progressed. However, vocalizing and crawling were not prevalent activities and did not differ significantly across time. The behavioral data also revealed these captive fruit bats to have a tendency to feed away from the feeding cups, supporting the hypothesis that this group would retain wild tendencies. Despite being in a relatively small enclosure, the Jamaican fruit bats still carried their food away from the food source for feeding, continuing their natural role as seed dispersers (Fleming & Heithaus 1981).

However, the roosting groups were generally smaller than what had been found in previous studies of wild populations (Morrison 1978; Gorog 1999). While previous research (e.g., Ortega & Arita 1999) has shown that Jamaican fruit bats tend to form large harem groups for roosting in caves, these bats may display more opportunistic day-roosting behavior, depending on the natural surroundings and availability of resources (Morrison 1979). With few males present, a guaranteed food supply nearby, and multiple perching and roosting sites within the enclosure, several large roosts seem unlikely.

Peaks in flight and foraging activity of the captive colony of Jamaican fruit bats were also consistent with previous studies of wild Jamaican fruit bats. The captive colony presented two peaks of activity during the dark hours: one major peak during the first hour of darkness (0930–1000 h) and a minor peak *ca.* 1900 h (Fig. 1). Jamaican fruit bats in their natural habitats are more active during the first few hours of darkness with a maximum peak generally around midnight (Fenton & Kunz 1977). This peak at midnight might correspond to a peak activity in this captive colony at *ca.* 0930–1130 h.

Because zoo hours did not allow for 24-h

behavioral observations of the captive colony, these data do not represent a full behavioral depiction of a typical captive Jamaican fruit bat. However, we emphasize that they may be useful in determining patterns during hours in which bats are most active. Future experiments might expand to 24-h behavioral observations for a more complete understanding of captive Jamaican fruit bat time budgets. Other experiments may include tagging and monitoring specific bats to better elucidate behavioral trends, and visibly marking the males to determine if a social structure exists within the colony.

These data suggest that captive colonies of Jamaican fruit bats will maintain their natural habits despite unnatural surroundings (i.e., a zoo enclosure and reverse-lighting). Additionally, because all of these Jamaican fruit bats were born in captivity, our data suggest that they have retained innate behaviors even under these unnatural conditions. We, therefore, suggest that captive Jamaican fruit bat behavioral studies may emulate behaviors of natural bat populations. For wildlife biologists and zoologists, further behavioral studies of captive populations, like those suggested, may assist in making management decisions for wild populations of Jamaican fruit bats.

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