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Roost-site characteristics of the pallid bat (*Antrozous pallidus*) in the Red Hills of Kansas and Oklahoma

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Little is known about roost-site characteristics of the pallid bat (*Antrozous pallidus*) in the Red Hills region of Kansas and Oklahoma. The species is listed as a Species in Need of Conservation within the state of Kansas. We investigated diurnal roost characteristics of the pallid bat during two summers in the Red Hills region of Kansas and Oklahoma. Mist nets were used to capture bats within three 314-ha study sites. Radio transmitters were attached to 10 pallid bats and bats were tracked daily. Physical characteristics of 11 pallid bat roosts were recorded. Two of the 10 pallid bats radioed were females, one of which was tracked to a suspected maternity roost. The largest roost observed was a bachelor colony of 10 individuals. Most roosts (n = 8) were in vertical crevices, but pallid bats also used vertical or horizontal crevices or exfoliated cliff faces. Pallid bats roosted on cliff faces with a westerly aspect (mean = 285° ± 51.3° s). Lengths of roosting crevices ranged from 0.3 m to 3.2 m and approximate widths ranged from 3 cm to 20 cm. Roost heights above talus piles ranged from 0 m to13 m. Most roost sites (n = 8) had no surrounding tree canopy cover. Distances from netting locations to roosts ranged from 120 m to 1200 m. Knowledge of roost sites used by pallid bats in the Red Hills could aid in management to protect habitat for this species as developments (e.g., wind turbines and electrical transmission lines), woody encroachment by eastern red cedar (*Juniperus virginiana*) and related control measures, and other activities intersect this species' habitat.

Introduction

Bats use roosting habitat for shelter, protection from predators, thermoregulation, and social interaction (Twente 1955; Beck and Rudd 1960; Tuttle 1976; Vaughan and O'Shea 1976; Kurta, Kunz and Nagy 1990; Ball 2002; Kunz and Fenton 2003). Roosting sites are critical for hibernation, mating, and the rearing of young, and preferred roost locations vary across circadial and circannual cycles (e.g., winter roosts, summer roosts, diurnal roosts vs. nocturnal roosts, maternity roosts) (Norwak, Kunz and Pierson 1994; Kunz and Fenton 2003). Anthropogenic disturbance of roosting habitat, including spelunking (Tuttle 1979) and mining (Brown and Berry 2000) or adjacent foraging areas for bats could induce greater commutes by bats to foraging sites, decrease survivorship of newly volant young (Ransome 1990; Tuttle 1976), decrease reproductive success (Brigham and Fenton 1986), increase rates of predation from loss of roost fidelity (Lewis 1996), and perhaps lead to abandonment of preferred roost sites (Lacki 2000; Tuttle 1979).

The pallid bat (*Antrozous pallidus*) ranges from central Mexico, pine oak regions of Arizona, and mixed-grass prairies of the central United States, to intermountain regions of the Pacific Northwest (Jones 1965; Hermanson and O'Shea 1983; Rabe et al. 1998; Morrell et al. 1999, Baker et al. 2008, Miller 2011). The pallid bat gleans arthropods from open areas on the ground and in edge vegetation habitat by passively listening to sounds of prey (Hermanson and O'Shea 1983; Bell 1982; Fuzessery et al. 1992). The species roosts within crevices in rocky outcrops, caves, live and dead conifers, and anthropogenic structures, typically roosting singly or in small aggregations (Ball 2002; Orr 1954; Packard and Judd 1968; Vaughan and O'Shea 1976; Baker et al. 2008). However, large aggregations of up to 200 or more individuals have also been reported (Hermanson and O'Shea 1983; Sparks and Choate 2000). Roosting areas near water may be another important characteristic in roost site selection by this species (Hermanson and O'Shea 1983).

Pallid bat maternity roosts are typically horizontal crevices, which might facilitate the retrieval of fallen young and aid in thermoregulation (Vaughan and O'Shea 1976; Hermanson and O'Shea 1983). Pregnant and lactating females have greater energy requirements; thus, roosting habitat that maintains a specific thermal gradient may be preferred (Studier, Lysengen and O'Farrell 1973; Trune and Slobodchikoff 1979; Tuttle 1976; Kurta, Kunz, and Nagy 1990). Vertically oriented rock crevices exhibit greater diel variability in temperature and are used during cooler seasons (Vaughan and O'Shea 1976).

The pallid bat occurs in Kansas at the eastern edge of its range (Vaughan and O'Shea 1976; Sparks and Choate 2000). As of 2011, the pallid bat was listed as a Species In Need of Conservation (SINC) by the Kansas Department of Wildlife, Parks and Tourism (KDWPT) and was only known in Barber and Comanche counties in the Red Hills region (Choate, Schmidt and Taggart 2011). The only known roost in Kansas was a crevice used as a winter hibernaculum in Barber County (Sparks and Choate 2000; Prendergast, Jensen and Roth 2010). Lack of knowledge of the diversity of roosting structures used by pallid bats in this region presents a disadvantage to the successful conservation of the species in Kansas. The Red Hills region of Kansas has a great diversity of geological features that could serve as important roosting sites for pallid bats during the seasons in which this species is actively foraging. The region contains over 400 known caves and numerous crevices that have developed within the soft gypsum and sandstone bedrock (Young and Beard 1993). Within Kansas these caves and crevices serve as roosting sites to the largest number and diversity of cavernaculous bats in the state (Sparks and Choate 2000). With this descriptive note, our objective was to document roost site characteristics of radio-tagged pallid bats during late spring and summer, with an aim to help inform the management of this bat in Kansas and Oklahoma

Materials and Methods

Study area: The Red Hills region of Kansas and Oklahoma is largely composed of mixed-grass prairie, dominated by little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), side oats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*), and woodlands of eastern red cedar (*Juniperus virginiana*), bur oak (*Quercus macrocarpa*), and eastern cottonwood (*Populus deltoids*) occur primarily within lower elevations but variably extend into uplands. The region is geologically defined by tablelands, rocky outcrops, canyons, and cliffs (Young and Beard 1993), and valleys are carved by ephemeral streams that feed the Arkansas River. Geological parent material consists of gypsum, sandstone, and shale with numerous crevices in cliff walls and hundreds of caves (Young and Beard 1993). These geological features serve as important roosting habitat for bats in this region including the pallid bat (Prendergast, Jensen and Roth 2010, Miller 2011). We sampled bats at three locations within the Red Hills of Kansas and Oklahoma. Two sites were located in Barber County, Kansas, and one was in Woods County, Oklahoma. The sites were 2-km diameter circles positioned around known winter roosts of pallid and Townsend's big-eared (*Corynorhinus townsendii*) bats. These sites were located on privately-owned land used primarily for cattle grazing.

Mist netting and tracking: Pallid bats were captured from late May to mid-August in

Figure 1. A pallid bat (*Antrozous pallidus*), freshly equipped with a radio transmitter for telemetric determination of roost locations of the species in the Red Hills of Kansas.

2009 and 2010 using mist-nets placed across pools on ephemeral streams. A total of 44 nights of netting were completed, resulting in approximately two netting attempts per week. Netting locations were systematically chosen by rotating among available pools along stretches of stream within each site during each of the two years of study. A netting station consisted of four independent nets, 2.6 m high and 6, 9, or 12 m long, which were positioned from 16 m to 126 m apart, given pool availability. Thirty-seven netting stations were sampled over 44 nights. A total of 142 independent net locations were used with some locations being visited multiple times over the two-year study. Nets were set for 3 h after sunset, and nets were checked every 45 min in the first summer and every 30 min in the following summer to minimize escapees and damage to nets. After capture, we recorded species (Ch. 1), body length (cm), tail length (cm), ear length (cm), tragus length (cm), forearm length (cm), and mass (g). Additionally, the sex, age, and reproductive statuses of these bats were recorded. Ossification of wing joints was used to determine age (Anthony 1988). Pregnancy was determined by characteristics such as a noticeably distended abdomen, turgid mammaries, and high body mass (Racey 1969).

We attached a 0.3-g radio transmitter (Glue on Transmitter, Model A2414, Advanced Telemetry Systems, Isanti, MN; these were <5% of body weight as suggested by Aldridge and Brigham 1988) to each pallid bat captured by gluing the transmitter between the scapulae using surgical adhesive (Fig. 1). Bats were then released away from—but in the proximity of—nets used for capture. The following morning we returned to the release location and attempted to locate telemetered pallid bats in the vicinity using a Yagi directional antenna and telemetry receiver (3 Element Folding Yagi Antenna, Model 13863 and Scientific Receiver, Model R410, Advanced Telemetry Systems, Isanti, MN). Roosting sites located via telemetry were monitored for visual or audio confirmation for three days after initially locating a bat in 2010. We monitored pallid bat roosts less frequently in 2009. Pallid bats were typically located once in 2009, but bats were located multiple times while tracking other individuals.

Roost characterization: Numbers of individuals occupying roosts were either counted visually or estimated if the roost was inaccessible. If the roost was inaccessible other observations were used to determine if multiple bats were present, including the presence of multiple transmitters in one roost or auditory cues (the latter was only used for single vs. multiple bat determination).

Roost types were identified into two geological categories: crevices or exfoliated rock surfaces. Crevices were cracks within cliff walls that ran perpendicular to the cliff face. These features were then further subdivided into vertical or horizontal crevices based on their predominate angle. Oblique crevices were not identified and were far less common in the region relative to vertical or horizontal crevices (JCM pers observ.). Exfoliated surfaces were hollowed, dome-like structures protruding from—and parallel to—cliff faces. Measurements of crevice length (m) were made at roost locations using a measuring tape.

Height (m) of roost locations was measured from the top of talus piles to the suspected roosting location using a measuring tape. We also measured the distance (m) from the roost site to the top of the cliff escarpment using a measuring tape. If actual roost locations could not be identified then roost height was estimated.

Habitat characteristics of cliff faces where roosts were located were also measured. Directional orientation of cliff faces was measured using a compass bearing (°) perpendicular to—and facing from—the cliff face. Percentage of canopy cover of trees adjacent to cliff faces was averaged across two readings from half of a spherical densiometer. These readings were then taken parallel to the cliffs face. Distance (m) to the closest tree from the roost site was measured in two quadrants of a 180° semi-circle demarcated by a line perpendicular to the cliff face. These distances were measured with a laser rangefinder and included only those trees whose crown height was within line of sight from the top of the talus. Distances (m) of roosts sites from the bat's initial netting location were measured using Garmin Trip and Waypoint Manager (Garmin International, Inc., Olathe, Kansas).

Results

Mist-netting and tracking: Thirteen pallid bats, 11 males and 2 females, were caught over 44 net nights at eight locations. These bats were captured on two of the three study sites: in Barber County, Kansas and Woods County, Oklahoma. In 2009, three bats were captured and radioed in Oklahoma and three of the five bats captured in Kansas were fitted with transmitters. In the first year, telemetered bats in Oklahoma were tracked to four distinct roost sites. In Kansas, two bats were followed to the same roost site and one was never relocated. In 2010 all pallid bat captures occurred in Kansas and four of these five pallid bats were fitted with transmitters, including the only two females we captured. Of these females, one was determined to be gestating.

Bats were tracked to multiple roost sites in 2009 and 2010 (Table 1). However, repeated tracking of bats was not initiated until the 2010 season. In Kansas, one telemetered male pallid bat was tracked to a mound on the ground where the roost was undetermined. In total there were six roost sites in Kansas and four in Oklahoma (Table 1). In 2009 one of two bats in Oklahoma was tracked to two additional

Table 1. Descriptions of roost sites of pallid bats from late-May to mid-August in 2009 and 2010, in Barber County (BR), Kansas, and Woods County (WD), Oklahoma.

Number of individuals [a]	Sex & reproductive status [c]	Distance from net (m)	Roost type	Cliff face bearing (°)	Height of roost (m) [d]	Length of crevice (m) [e]	Roost to escarpment height (m)	Nearest vegetation in each quadrant (m) [f]	Canopy cover (%)
2	AM, AM	120	Vertical	287	3.1-4.2	7.6	3.4	N:20 S:20	0
2	AM, AM	305	Vertical	93	1.1-4.3	5.5	1.2	N:12 S:8	0
6	AM	1200	Exfoliation	325	1.55	2.7	0.8	E:3 W:17	0
1	AM	685	Vertical	220	0-2.1	2.6	0.5	W:31 E:21	0
1	AM	268	Vertical	337	3.5-5.5	5.5	0	W: - E:79	0
10	AM	282	Exfoliation	188	2.3	2.5	0.2	E:5 W:3.5	29.3
2	PF, AM	422	Vertical	278	13.5	14.2	0.7	-	0
M[b]	PF	278	Vertical	246	0.62	1.0	0.48	N:4 S:21	0
1	JF	555	Horizontal	335	0	2.4	0	S:5 N:39	0
6	JF	538	Vertical & Horizontal	308	2.7	4.1	1.4	S:5 N:17	8.3
3	JF	522	Vertical	276	3.8	5.1	1.3	N:6 S:4	2.8

[a] Minimum number of individuals detected.
[b] Multiple individuals of undetermined number were detected aurally.
[c] Only includes the sex of the telemetered bat, not untelemetered roost mates. Adult male (AM), pregnant female (PF), and juvenile female (JF)
[d] Heights of roosts were estimated if location of roosting bats could not be determined.
[e] Length of roosts crevices were estimated if actual location was roosting crevice could not be determined.
[f] Trees at the level of the roost site. A dash (-) indicates absence of vegetation.

roost locations. In 2010, four pallid bats were radioed including the pregnant female that was captured on 17 June and the second female, a juvenile, on 29 July. Three bats were tracked to multiple roosts including both female bats (Table 1). The pregnant female occupied a roost with a radioed male the first morning following attachment. The second and third mornings this female bat was discovered in a single roost shared by other pallid bats of unknown sexes. However, her repeated use of the roost for three days suggested it was a maternity roost. The male bat roosting with this female bat was tracked to this roost site on two different dates. The first roost for this male was in a different location with 10 other individuals. Another female was tracked to three different roosts. Only she occupied the first roost while the other locations were shared by at least two other pallid bats. The largest group of pallid bats visually confirmed in a roost contained at least ten individuals (Table 1), while the smallest group confirmed contained three individuals. Multiple individuals occupied eight of the 11 roost sites that were located. Many of the roosts were inaccessible to visual inspections; therefore, multiple bats could only be determined by the presence of more than one radio in the same roost location or auditory cues. An observation of only one solitary roosting bat was made in the second year. This was the last female discovered roosting alone in a small hole in 2010, but moved by the following morning to a roost with other individuals.

Roost site characterization: Nine roosts were crevices and three roosts were exfoliated rock surfaces (Table 1). Of the nine crevices, seven were vertical, one crevice was horizontal, and one crevice had vertical and horizontal elements. The latter was a hanging boulder nearing separation from the cliff, where two large cracks joined to make a 90° intersection. Pallid bats were using both sides. The pregnant female was located only in vertical crevices.

Most roost locations in our study were inaccessible to observers as they were located well above talus piles within crevices (0 m - 13.5 m). Many roost locations were estimated at >2 m in height (Table 1) from the top of the talus and were often only accessible by scaling or standing on large rocks. Heights of roosts ranged from ground level (mound on a hill break) to a height of 13.5 m above talus slopes. The roost on the small hillside was a horizontal exfoliation measuring 15 cm in diameter. Heights from the top of the suspected roost to escarpments ranged from 0 to 3.4 m.

Seven of the cliff faces (64%) oriented northwesterly between 276° and 337° while three (27%) more southwesterly between 188° and 246° and one remaining roost location faced eastward at 93° (Table 1). The mean bearing and angular deviation of these westerly-facing cliffs was 285° (± 51.3°). Roost crevice lengths were highly variable averaging 4.8 m, (range: 15 cm - 14 m). Crevice widths were estimated to range from 3 cm to 20 cm (visual estimates as crevice widths varied along their lengths and heights of many roosts were inaccessible).

Little tree cover surrounded most roost locations (Table 1). Only 27% had canopy cover nearby and the greatest cover percentage was 29 %. The closest obstructing woody vegetation in front of a roost was at 3 m (deciduous tree, species unknown). The closest obstructing eastern red cedar was 3.5 m away from a roost. The mean distance to an obstructing deciduous tree was 41.2 m (± 48.5 m SD) from the cliff face, while the mean distance to an obstructing cedar tree was 13.4 m (± 10.4 m SD) from the cliff face. Mean distance from roosts to nets where bats were captured was 470 m (± 293 m SD; Range: 120 m - 1200 m). The majority (64%) were < 300 m (Table 1).

Discussion

Prior to our study only two roost locations of pallid bats in natural substrate (not of human construction) had been noted in the Red Hills (Sparks and Choate 2000; Prendergast, Jensen and Roth 2010), with evidence of multiple pallid bats (approximately 200) being reported from one of these (Sparks and Choate 2000). Summer roosting was only documented to have previously occurred in a barn (Twente 1955). Our study documented 11 new summer roosting sites for pallid bats within natural, geological features of the Red Hills, seven of those being within the state of Kansas. The suspected maternity roost would be the first documented maternity roost in a natural rock cavity in Kansas.

Multiple pallid bats were discovered in the same roosts within the Red Hills during the breeding season. This is congruent with previous reports by Twente (1955), Vaughan and O'Shea (1976), Hermanson and O'Shea (1983), and Lewis (1996). A suspected maternity roost was discovered 17 June 2010, when a pregnant female was tracked there and remained for several days, although sexes of all individuals within that roost were not determined. Nearly all roosting colonies of pallid bats that we examined resemble previous documentation of colony sizes described by Vaughan and O'Shea (1976) and Prendergast, Jensen and Roth (2010). However, large aggregations of pallid bats, such as the approximate 200-bat roost reported by Sparks and Choate (2000), were not encountered.

Most roosts were in vertical crevices and exfoliation type geological formations. This has been documented in other areas of the pallid bat range, including California (Orr 1954), Texas (Packard and Judd 1968) and New Mexico (Vaughan and O'Shea 1976). Vertical crevices dominate the region and pallid bats are known to use these features (Ball 2002; Orr 1954; Packard and Judd 1968; Vaughan and O'Shea 1976). Exfoliated crevices are common within the Red Hills and appear to present suitable structures for roosting pallid bats. Both crevices and exfoliations may provide adequate thermoregulation for these roosting bats (Twente 1955; Beck and Rudd 1960; Tuttle 1976; Vaughan and O'Shea 1976; Kunz 1982; Kurta, Kunz and Nagy 1990; Ball 2002). The crevices occupied by the one pregnant female, including a suspected maternity roost, were oriented vertically, which would be contrary to maternity crevices that are typically horizontal for the species (Vaughan and O'Shea 1976; Hermanson and O'Shea 1983).

Roost heights accommodated by the steep cliff faces characteristic of the Red Hills may be important for thermoregulation and predator avoidance (Lausen and Barclay 2002). Steep cliff faces and talus piles are a characteristic feature of the Red Hills. Roost sites situated high on cliffs may benefit thermoregulation by pallid bats, as in other bats (Betts 1998, Ormsbee and McComb 1998). The height of a roost should affect the amount of solar radiation reaching the roost, where higher roosts might be less obstructed by surrounding vegetation and adjacent hills toward evening when warmth may be beneficial for arousal. A similar suggestion was made by Betts (1998) where surrounding trees were distant from silver-haired bat (*Lasionycteris noctivagans*) roosts. Roost sites well above the talus height may also be important in protection from terrestrial predators as suggested by Betts (1998); a similar benefit has been documented for cavity nesting birds (Nilsson 1984; Rendell and Robinson 1990).

Orientation of cliff faces housing pallid bat roosts may also be important for thermoregulation. Cliff face orientation was predominantly westerly with the exception of one roost site facing east. A study on pallid bat roosts by Vaughan and O'Shea (1976) indicated that the warmest pallid bat roosts were warmed late in the day by the sun. A westerly orientation may assist in thermoregulation especially during summer months when daily temperatures are greatest in later daylight hours. Westerly facing roosts might help maintain a gradual warming of temperatures during the day, where cooler temperatures coincide with time periods of torpor and decreased metabolic activity during early morning and midday (Vaughan and O'Shea 1976). Though we did not measure roost temperatures, oxygen consumption by pallid bats is lowest when roosts are maintained at 30°C (Trune and Slobodchikoff 1976). Furthermore, westerly facing roosts become warmest in late afternoons which might aid in arousal before their nightly emergence (Vaughan and O'Shea 1976).

Vegetative characteristics surrounding roosts, such as canopy cover, may affect bats use of available roost sites (Vohnof and Barclay 1996; Betts 1998). Canopy cover in the Red Hills was sparse around the identified roosting locations of pallid bats. If trees were present at roost sites they were distant and not touching cliff faces. This may indicate the use of more open cliff faces or passive selection of available cliff faces; however, we did not assess disproportional avoidance of tree cover by roosting pallid bats. For similar reasons stated above, open cliff faces with no obstructing vegetation might benefit thermoregulation or predator avoidance. Roosts away from trees may increase the amount of protection from terrestrial predators by limiting direct access of terrestrial predators to the roost (Vaughan and O'Shea 1976; Kunz 1982) and allowing quick entrance or exit of these bats to avoid aerial predators (Vohnof and Barclay 1996).

Most roost sites were close to a water sources (within 50 m) (JCM, pers. observ.). Water sources proximate to roosting sites may be an important habitat characteristic for roost selection in bats (Tuttle 1976; Walsh and Harris 1996). Water at our study sites was always associated with the nearby ephemeral creeks. Insect activity is associated with riparian areas and has been identified as key foraging habitat by bats (Walsh and Harris 1996), and survivorship of newly volant young decreases with distance from such foraging areas (Ransome 1990; Tuttle 1976). Warm environments, such as the in the Red Hills of the south-central Great Plains, might also impose evaporative water loss in bats (Kurta et al. 1990; Studier 1970). Therefore, we suspect that proximity to water is also important for roost selection by pallid bats in the Red Hills,

Because of rarity at its range periphery in Kansas, the pallid bat has been described as the most endangered bat in the state (Sparks and Choate 2000). Here we have reported multiple roost locations and descriptions of roosting habitat used by the pallid bat at its range periphery in the Red Hills. We recommend that cliff faces with vertical, horizontal and exfoliated surfaces and nearby streams be maintained, as these are likely important roosting locations for the pallid bats in the Red Hills. Further investigations on the distributional extent of this species and its abundance (including within roost sites) in the region are warranted.

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