

Diel activity patterns of urban Woodchucks (*Marmota monax*) revealed by camera traps at burrows in southwestern Ontario, Canada

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Abstract

Animals display a range of diurnal and nocturnal activity patterns and, among mammals, a high proportion of species are crepuscular or nocturnal. Daily activities are often endogenous and oscillate on a light:dark regime. Such cycles are referred to as ‘circadian’ and are generally influenced by biotic and abiotic factors. I investigated the daily activity of urban Woodchucks (*Marmota monax*) by using 24-hour camera traps at backyard burrows in London, Ontario, Canada, in June. Cameras enabled the collection of data that would otherwise have been labour intensive by direct observation. Statistical modelling showed that Woodchucks exhibited a strictly diurnal activity pattern. The unimodal activity pattern started at sunrise and ended before sunset. The general daily activity trend was similar to the pattern described by others who used direct observations and telemetry to monitor Woodchucks in more rural settings. Temperature and wind were not included in the best-fit model. Camera trapping is a non-invasive method that could give insight to diel activity as it can easily monitor extended periods and reduce the effort required by direct observation.

Key words: Burrow; circadian; daily activity; diel activity; trail camera; urban; marmot

Introduction

Most animals exhibit daily activity rhythms (Burger 1976; Daan 1981; Robitaille and Baron 1987; Helfrich-förster *et al.* 1998; Jury *et al.* 2005; Williams *et al.* 2014). Daily activities often originate endogenously and oscillate on a light:dark regime, referred to as ‘circadian’, and are generally influenced by biotic and abiotic factors (Pittendrigh 1981; Aschoff and Tokura 1986). Animals display a range of activity patterns from totally diurnal to totally nocturnal and, among mammals, a high proportion of species are crepuscular or nocturnal (Ashby 1972). Much of an animal’s daily activity budget consists of time spent foraging (e.g., Wauters *et al.* 1992) that may be altered by food availability (e.g., Uttley *et al.* 1994), food quality (e.g., Sæther and Andersen 1990), or competition and the risk of predation (e.g., Hughes *et al.* 1994; Cowlshaw 1997).

For some animals, predation risk and mortality are lower when living in urban areas due to the lack of natural predators, although some are negatively affected by introduced predators that follow urbanisation (Fischer *et al.* 2012). Further, in urban

environments, animals may alter their anti-predator behaviours in response to urban settings, habituating to the absence of specific predators (McCleery 2009), or due to human disturbance (Ditchkoff *et al.* 2006)

Monitoring daily activity in the wild is challenging, particularly 24-hour observations. Traditionally, such data have been collected using very high frequency telemetry and global positioning system data (e.g., Coulombe *et al.* 2006), although non-invasive methods (i.e., no physical capture or handling needed) exist. More recently, non-invasive wildlife monitoring has been accomplished using camera traps (e.g., Heilbrun *et al.* 2006; Rowcliffe *et al.* 2008; Athreya *et al.* 2013; Mohamed *et al.* 2013). As date and time are stored along with imagery, it has been possible to analyse daily activity patterns (Akbaba and Ayaş 2012; Lynam *et al.* 2013; Leuchtenberger *et al.* 2014; Steen and Barmoen 2017). I investigated the presence/absence of urban Woodchuck (*Marmota monax*) at burrows in June 2015 using 24-hour camera traps. I defined activity according to Bronson (1962) as any appearance outside the burrow, although restricted to the camera’s field of view. Woodchucks (order

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Rodentia) feed on a great variety of plant materials, are overall diurnal, dig burrows, and hibernate in winter (Kwiecinski 1998). The burrows serve as protection from predators and locations to breed and hibernate (Howell 1915; Grizzell 1955; Davis 1967; Hayes 1976; Zervanos *et al.* 2014). During winter, the hibernation burrows are often in woody areas, while in summer, burrows are close to feeding areas that provide cover at the burrow entrance (Grizzell 1955). The main predators of Woodchuck are humans, Domestic Dog (*Canis familiaris*), Coyote (*Canis latrans*), Red Fox (*Vulpes vulpes*), Bobcat (*Lynx rufus*), American Black Bear (*Ursus americanus*), and large hawks and owls (Grizzell 1955; Kwiecinski 1998).

Diel activity is an important aspect of an animal's natural history because the circadian rhythm regulates fundamental processes including responses to abiotic and biotic factors (Halle 2000). It is important to document diel activity patterns of animals in urban areas because activity may be altered by artificial light (e.g., Longcore and Rich 2004), changed predation risk (e.g., Watson 2009; Lehrer 2011; Fischer *et al.* 2012), or human disturbance (Ditchkoff *et al.* 2006). I modelled summer diel activity of urban Woodchucks using camera traps and the cosinor method (Nelson *et al.* 1979; Pita *et al.* 2011; Steen 2017). I expected diurnal activity (Bronson 1962; Conrad and Fidura 1970; Hayes 1976; Meier 1985) and wanted to determine if a non-invasive method gives reliable activity estimates as an alternative to more labour-intensive direct observation.

Methods

Study site and camera traps

I placed trail cameras at four Woodchuck burrows in backyards in the City of London, Ontario, Canada (42.995°N, 81.2707°W), 10–25 June 2015. This urban area is surrounded by wooded parks and green spaces that harbour a variety of mammals and birds. The four Woodchuck burrows were in different private gardens, where all had one or two main entrances and were positioned under trees and bushes. One of the burrows was inhabited by a female with two young-of-the-year; the three other burrows were each inhabited by solitary males. At the adult female's burrow, camera captures of any of the three Woodchuck were analyzed. I could not compare behaviour of the family with that of solitary males due to small sample sizes.

I used camouflaged coloured Browning Dark Ops HD cameras (Browning, Birmingham, Alabama, USA). This small trail camera (11.4 × 8.3 × 6.4 cm) is activated by a passive infrared sensor (PIR) that detects movement at any hour (Swann *et al.* 2004) and features a no glow infrared flash to ensure the ani-

mal does not detect the camera. I chose the video recording mode, although still images also would have worked. I mounted the cameras on tree trunks facing the main entrance of the burrows (one at each site) to record activity (Video S1). Each recording was set to last for 10 s, with no delay between each trigger. I only included complete hours of monitoring. I reviewed the videos from the camera traps by using the VideoLAN Client (VLC; Version 2.2.6 Umbrella, free, open source, cross-platform media player). I post-processed the data using R version 3.10.0 (R Core Team 2016), and followed the data processing procedure described in Steen (2017) to create a timeframe for the complete monitoring period for a given hour-block, date, and burrow. Instead of using frequency (number of observations per hour block) in the analysis, I only scored presence or absence of Woodchucks within an hour block (i.e., 'no woodchuck' or 'woodchuck' per observed hour-block; see below). This is a conservative measurement, but is preferred over frequency data because it is likely that not all activity of an individual was recorded (e.g., individuals using an entrance out of view of the camera).

Diel activity and analysis

Statistical analysis was performed using the "lme4" package (R Core Team 2016). The analysis of diel activity rhythms was based on generalized linear mixed-effects regression models (Pinheiro and Bates 2000) in which the periodic component of time series was represented by pairs of sine and cosine functions (Nelson *et al.* 1979; Pita *et al.* 2011; Steen 2017). The response variable was whether there was a Woodchuck observed within an hour-block for each burrow during the 24-h monitoring period each day (Steen and Barmon 2017). Hence, the response variable had two outcomes: 'no woodchuck' or 'woodchuck' per observed hour-block, modelled using binomial distribution logistic regression models (Galyean and Wester 2010). The fixed explanatory variable, time of the day (i.e., 24 hours), was fitted using the cosinor method (Nelson *et al.* 1979; Pita *et al.* 2011; Steen 2017), first with 24 h as the fundamental period and then with one or two harmonics of 12-h and 8-h periodicity to modulate the signal. The cosinor method uses a fundamental function and one or more harmonics to characterize the waveform of the activity rhythm (Nelson *et al.* 1979; Pita *et al.* 2011; Steen 2017). Each added harmonic improves the fit, although too many harmonics could add too much complexity and cause overfitting (Sheather 2009). I included burrow as a random effect to control for repeated measurements at each site, individual variation among Woodchucks inhabiting burrows (in particular for this study female with young versus solitary male), and different sampling effort among burrows.

Different sampling effort was due to time required to locate the burrows and maintain the cameras.

To control for ambient temperature and wind as possible factors influencing diel activity, I used hourly ambient temperature (°C) and wind speed (km/h) from the nearest weather station (London A climate station, distance ~10.0 km; www.climate.weather.gc.ca) as co-variables. The average 24-h temperature during the June monitoring period was 19.3°C (SD 3.7, range 10.8–29.0°) and average wind speed was 12.1 km/h (SD 6.9, range 1–41).

To avoid overfitting the activity curve (i.e., by adding too many harmonics or including unnecessary co-variables), I calculated the small-sample correction AICc for each model (Burnham and Anderson 1998; Burnham 2002; Aho *et al.* 2014). I evaluated each model by assessing the AICc values against the model that included only the random term (M_0). The model with the lowest AICc value was considered the ‘best’. Models in which the difference in AICc relative to $AICc_{min} < 2$ are considered to have substantial support (Burnham and Anderson 1998; Burnham 2002).

I computed the 95% CI of the fitted line by model-based parametric bootstrapping for mixed models (*bootMer* function, 1000 simulations, “lme4” package). I was particularly interested in the global acrophase or time point in the cycle describing an activity

peak in the cosinor model and which part of the day that activity was higher than the average (i.e., mid-line estimating statistic of rhythm, hereafter called MESOR). Global acrophases correspond to the time intervals at which the fitted function had peak value (Pita *et al.* 2011). The time of day that the modelled activity was above MESOR could be defined as the main activity period (Navarro *et al.* 2013).

Results

Only a few observations were recorded at night (range 0059–2220) and I monitored the Woodchucks for a total of 900 h in June 2015 (Table S1); Woodchucks were diurnal (presence/absence at the burrow entrance; raw data, Figure 1). The diurnal activity pattern was confirmed by the best-fitted multi-cosinor model ($AICc = 902.8$ versus $AICc = 1128.8$ for the null model, Table 1; fitted line, Figure 1; Tables S2 and S3). The most parsimonious model was based on the 1st harmonic component (12 h) in addition to the fundamental period (24 h). Adding the 2nd harmonic (8 h), temperature or wind did not improve model fit (Tables 1 and 2). Including wind and temperature (M_{10} and M_6 , respectively) in addition to the time variable in the second and third-best models suggested that wind and temperature had opposite effects (Table S4); the coefficient for wind was positive while temper-

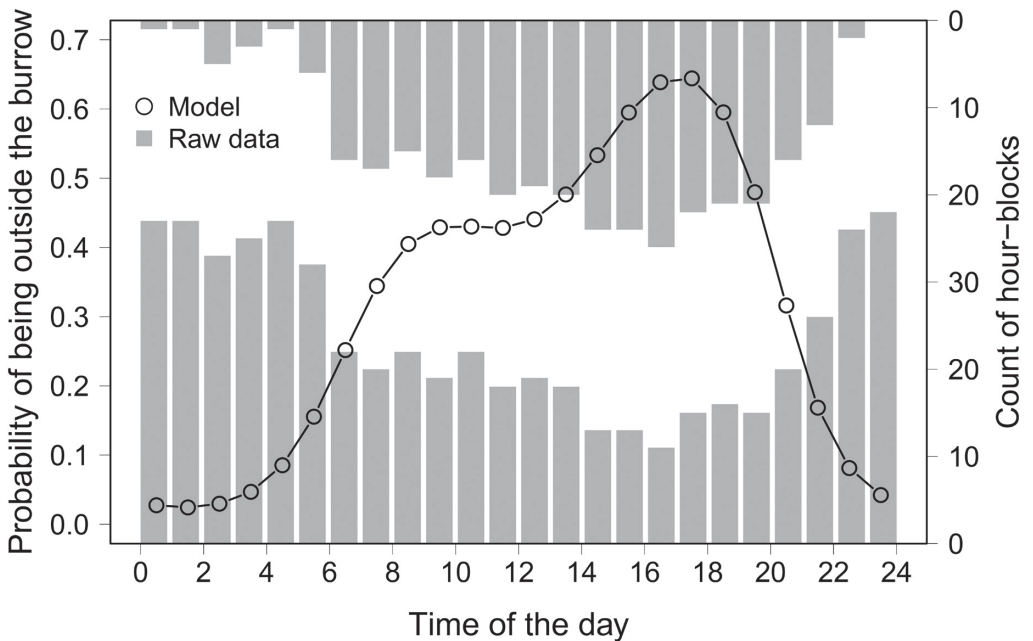


FIGURE 1. Modelled diel activity of Woodchuck (*Marmota monax*), London, Ontario, Canada, June 2015, with the probability of the Woodchuck being outside the burrow in an hour-block (denoted with dot-plot connected with line) and based on the best-fit model (parameter estimates given in Table 1, $n = 900$; random effect = 4). The lower grey bars are the count of hour-blocks with ‘no woodchuck’ ($n = 574$) and upper grey bars are the count of hour-blocks with ‘woodchuck’ ($n = 326$).

TABLE 1. Analysis of diel activity rhythm models for Woodchuck (*Marmota monax*), in June 2015, London, Ontario, Canada. The model with the lowest AICc was considered the 'best'. The five highest ranked models are shown. For full model comparison see Tables S2–S4.

Model	K	AICc	Δ AICc
M ₂	6	902.81	0.00
M ₁₀	7	903.30	0.49
M ₆	7	904.82	2.01
M ₃	8	905.32	2.51
M ₁₁	9	905.49	2.68

ature was negative. This suggests a higher probability of Woodchucks being present at the burrow when it was windy or colder, although these models had low support (Table S3). Further, models only including wind and temperature (M₈ and M₄, respectively) were ranked lowest in comparison to models including the time variable. Thus, there is strong support for Woodchuck activity to oscillate under a light:dark regime with minor influences by abiotic factors such as temperature and wind. The activity pattern at the burrows was unimodal (left skewed) and concentrated in the daylight hours, starting at sunrise and peaking in the afternoon (from 1300–1400 until 1900–2000 hour-blocks, i.e., the global acrophase) and ceasing before sunset (Figure 2). The mean of the modelled activity curve (MESOR) was found to be 0.31 (model M₀, including only intercept and random effect term).

Discussion

I found that Woodchuck had a strictly diurnal activity pattern (presence/absence of the Woodchuck at the burrow entrance) during June as has been found with previous telemetry and direct observation studies (Bronson 1962; Conrad and Fidura 1970; Hayes 1976; Meier 1985). The activity pattern was unimodal, starting with sunrise and ending before sunset. The unimodal pattern corresponds with telemetry data collected during spring and early summer (1–14 June) near the southern range limit of the species (ca. 36° latitude, northern part of Arkansas; Hayes 1976). Although later in June,

July, and August, Hayes (1976) found a transition to a bimodal activity pattern before returning to the unimodal state in October. Using direct observation, Bronson (1962) found a bimodal pattern for general activity during the summer months (May–August) and a unimodal pattern early and late in the year (February–April and September–November, ca. 40° latitude, south-central Pennsylvania). Conrad and Fidura (1970) performed systematic sightings during April–May and found that the activity was characteristically unimodal early in this period with a peak at midday and was bimodal with peaks in early morning and late afternoon later in the period (western New York; ca. 42–43° latitude). Further, the onset and cessation of daily activity agreed with Hayes (1976). I found daily activity at the burrow site was low from activity onset until 0700–0800, similar to Merriam (1966) who found by telemetry that, at the onset of daily activity, the proportion of inter-burrow movements was much lower than the proportion of total activity. Merriam (1966) proposed that morning activity might involve a higher proportion of feeding and related movements.

All of these previous studies monitored Woodchucks in more rural settings: old fields with woodlots (Bronson 1962), cultivated hayfields (Hayes 1976), or land previously farmed with old fields and second growth hardwood forest (Conrad and Fidura 1970). Although comparing my results with those of others is limited to examining general trends due to methodological differences (cameras versus direct observations and telemetry), the urban setting in my study did not appear to result in a change in general activity pattern seen in these more rural areas.

The time of day that Woodchuck activity (presence/absence at the burrow entrance) increased from below the MESOR to above the MESOR (i.e., upward crossing) was from 0700 to 0800 (i.e., switched from lower to higher activity). The time of day that the modelled activity decreased from above the MESOR to below the MESOR was at the end of hour block 1900–2000 (i.e., downward crossing, switched from higher to lower activity). Hence, ~12 hours represent the relative length of the main active period, with

TABLE 2. Analysis of diel activity rhythm models of Woodchuck (*Marmota monax*), in June 2015, London, Ontario, Canada. Parameter estimates from the best-fit model (number of observations: 900; random effect: four burrow sites).

Fixed effects:	Estimate	SE	Z-value	P
(Intercept)	-1.13	0.45	-2.50	0.012
I(cos(2 · pi · Hour/24))	-1.66	0.15	-11.11	<0.001
I(sin(2 · pi · Hour/24))	-0.74	0.12	-6.34	<0.001
I(cos(2 · 2 · pi · Hour/24))	-0.78	0.13	-6.00	<0.001
I(sin(2 · 2 · pi · Hour/24))	-0.19	0.12	-1.52	0.128

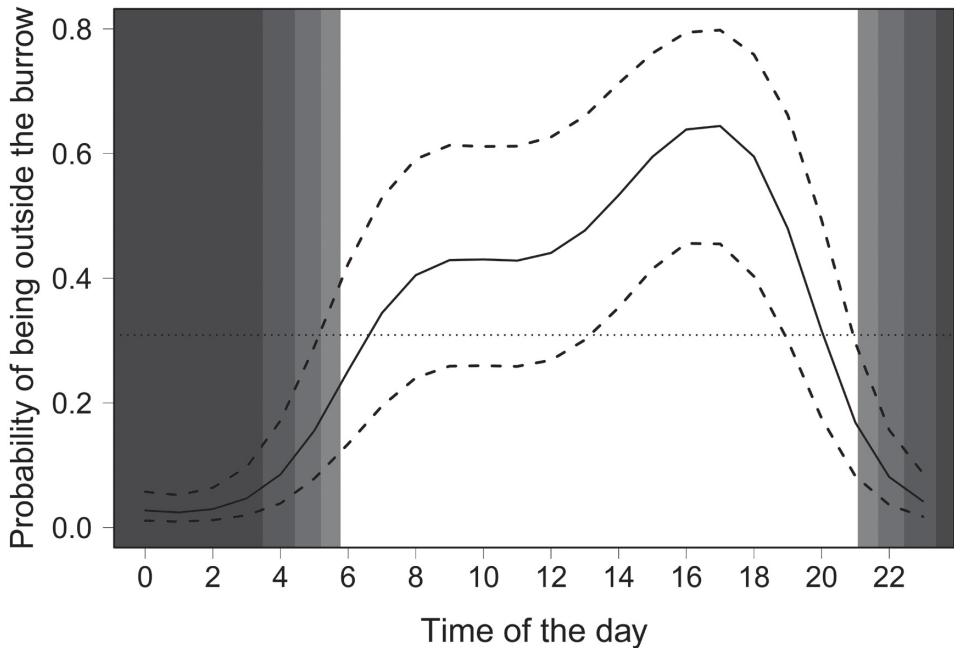


FIGURE 2. Activity plot with grey shading in accordance to the three types of twilight: astronomical, nautical, and civil (dark to light, respectively, with the white area representing daylight). Modelled activity is of the urban Woodchuck (*Marmota monax*), London, Ontario, Canada, June 2015, outside the burrow site (fitted line in solid and upper and lower 95% CI in dashed line). The MESOR (midline estimating statistic of rhythm) is indicated with a dotted line and parameter estimates are given in Table 1 ($n = 900$; random effect = 4).

an afternoon peak. The period from no activity to MESOR was about three to four hours. The period from MESOR to no activity was about two to three hours. Activity was found to be higher in the afternoon (from 1300–1400 to 1900–2000, i.e., the global acrophase), with a peak in the late afternoon (1500–1700). This pattern corresponded well with inter-burrow movements by Woodchucks revealed by telemetry on one adult and three juveniles conducted in New York mainly in August by Merriam (1966). Woodchucks might become satiated after spending more time foraging during the first part of the day and then spend more time resting at the burrow site.

Temperature and wind were not included in the best-fit model. The two models that included wind and temperature, in addition to the time variable, showed a higher probability of Woodchucks being present at the burrows when it was windy and colder. Because wind and, in particular temperature, are dependent on time-of-day (light:dark regime), the effect of these abiotic weather variables on Woodchuck daily activities might only be unravelled under experimental conditions by dissociating time and weather variables. According to the best-fit model that contained only the time variable, I propose that during the early summer, Woodchuck activity oscillates un-

der a light:dark regime with a minor influence of abiotic factors such as temperature and wind. In contrast, annual activity patterns (i.e., initiation and termination of torpor) are likely driven by both photoperiod length and temperature (Zervanos *et al.* 2010). Hayes (1976) compared early and late season with summer activity and found that the activity curves for early and late season were more irregular compared with the relatively smooth activity curve during summer. Hayes (1976) interpreted this as evidence of weather effects on aboveground activity during the early and late season (with more severe weather). However, during summer, Woodchucks were also found to avoid high temperatures during the middle of the diurnal period. Ambient temperature during these periods showed that temperatures above 31°C reduced aboveground activity (Hayes 1976). Such high temperatures were not registered during my monitoring period (maximum temperature was 29°C).

Conclusions

Camera trapping is a non-invasive method that provides insight to diel activity as it easily monitors extended periods and reduces the effort required for direct observation. My camera data revealed a similar diel activity pattern in urban Woodchucks as pre-

viously documented by telemetry and direct observations during summer in more rural settings (Bronson 1962; Hayes 1976; Meier 1985). Adding additional camera traps to monitor foraging activity (e.g., Steen and Barmoen 2017) or combining cameras with telemetry (e.g., Leuchtenberger *et al.* 2014) and extending studies to monitor the complete annual cycle (e.g., Racheva *et al.* 2012) would improve future monitoring.

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Literature Cited

- Aho, K., D. Derryberry, and T. Peterson. 2014. Model selection for ecologists: the worldviews of AIC and BIC. *Ecology* 95: 631–636. <https://doi.org/10.1890/13-1452.1>
- Akbaba, B., and Z. Ayaş. 2012. Camera trap study on inventory and daily activity patterns of large mammals in a mixed forest in north-western Turkey. *Mammalia* 76: 43–48. <https://doi.org/10.1515/mamm.2011.102>
- Aschoff, J., and H. Tokura. 1986. Circadian activity rhythms in squirrel monkeys: entrainment by temperature cycles. *Journal of Biological Rhythms* 1: 91–97. <https://doi.org/10.1177/074873048600100201>
- Asby, K.R. 1972. Patterns of daily activity in mammals. *Mammal Review* 1: 171–185. <https://doi.org/10.1111/j.1365-2907.1972.tb00088.x>
- Athreya, V., M. Odden, J.D.C. Linnell, J. Krishnaswamy, and U. Karanth. 2013. Big cats in our backyards: persistence of large carnivores in a human dominated landscape in India. *PLoS ONE* 8: e57872. <https://doi.org/10.1371/journal.pone.0057872>
- Bronson, F.H. 1962. Daily and seasonal activity patterns in woodchucks. *Journal of Mammalogy* 43: 425–427. <https://doi.org/10.2307/1376964>
- Burger, J. 1976. Daily and seasonal activity patterns in breeding laughing gulls. *Auk* 93: 308–323.
- Burnham, K.P. 2002. Model Selection and Multimodel Inference: a Practical Information-theoretic Approach. Second Edition. Springer, New York, New York, USA.
- Burnham, K.P., and D.R. Anderson. 1998. Model Selection and Inference: a Practical Information-theoretic Approach. Springer, New York, New York, USA. https://doi.org/10.1007/978-1-4757-2917-7_3
- Conrad, K.A., and F.G. Fidura. 1970. An ethological study of diurnal behavior in woodchucks (*Marmota monax monax*) during the vernal period. *Psychological Record* 20: 509–512. <https://doi.org/10.1007/BF03393973>
- Coulombe, M.L., A. Massé, and S.D. Côté. 2006. Quantification and accuracy of activity data measured with VHF and GPS telemetry. *Wildlife Society Bulletin* 34: 81–92. [https://doi.org/10.2193/0091-7648\(2006\)34\[81:qaaoad\]2.0.co;2](https://doi.org/10.2193/0091-7648(2006)34[81:qaaoad]2.0.co;2)
- Cowlishaw, G.U.Y. 1997. Trade-offs between foraging and predation risk determine habitat use in a desert baboon population. *Animal Behaviour* 53: 667–686. <https://doi.org/10.1006/anbe.1996.0298>
- Daan, S. 1981. Adaptive daily strategies in behavior. Pages 275–298 in *Biological Rhythms*. Edited by J. Aschoff. Springer, Boston, Massachusetts, USA. https://doi.org/10.1007/978-1-4615-6552-9_15
- Davis, D.E. 1967. The role of environmental factors in hibernation of woodchucks (*Marmota monax*). *Ecology* 48: 683–689. <https://doi.org/10.2307/1936520>
- Ditchkoff, S.S., S.T. Saalfeld, and C.J. Gibson. 2006. Animal behavior in urban ecosystems: modifications due to human-induced stress. *Urban Ecosystems* 9: 5–12. <https://doi.org/10.1007/s11252-006-3262-3>
- Fischer, J.D., S.H. Cleeton, T.P. Lyons, and J.R. Miller. 2012. Urbanization and the predation paradox: the role of trophic dynamics in structuring vertebrate communities. *Bioscience* 62: 809–818. <https://doi.org/10.1525/bio.2012.62.9.6>
- Galyean, M.L., and D.B. Wester. 2010. Comparison of multinomial and binomial proportion methods for analysis of multinomial count data. *Journal of Animal Science* 88: 3452–3463. <https://doi.org/10.2527/jas.2010-2868>
- Grizzell, R.A. 1955. A study of the Southern Woodchuck, *Marmota monax monax*. *American Midland Naturalist* 53: 257–293. <https://doi.org/10.2307/2422068>
- Halle, S. 2000. Ecological relevance of daily activity patterns. Pages 67–90 in *Activity Patterns in Small Mammals: an Ecological Approach*. Edited by S. Halle and N.C. Stenseth. Springer Berlin Heidelberg, Berlin, Heidelberg, Germany. https://doi.org/10.1007/978-3-642-18264-8_5
- Hayes, S.R. 1976. Daily activity and body temperature of the southern woodchuck, *Marmota monax monax*, in Northwestern Arkansas. *Journal of Mammalogy* 57: 291–299. <https://doi.org/10.2307/1379689>
- Heilbrun, R.D., N.J. Silvy, M.J. Peterson, and M.E. Tewes. 2006. Estimating bobcat abundance using automatically triggered cameras. *Wildlife Society Bulletin* 34: 69–73. [https://doi.org/10.2193/0091-7648\(2006\)34\[69ebaut\]2.0.co;2](https://doi.org/10.2193/0091-7648(2006)34[69ebaut]2.0.co;2)
- Helfrich-förster, C., M. Stengl, and U. Homberg. 1998. Organization of the circadian system in insects. *Chronobiology International* 15: 567–594. <https://doi.org/10.3109/07420529808993195>
- Howell, A.H. 1915. Revision of the American marmots. *North American Fauna* 37: 1–80. <https://doi.org/10.3996/nafa.37.0001>
- Hughes, J.J., D. Ward, and M.R. Perrin. 1994. Predation risk and competition affect habitat selection and activity of Namib Desert gerbils. *Ecology* 75: 1397–1405. <https://doi.org/10.2307/1937463>
- Jury, S.H., C.C. Chabot, and W.H. Watson, III. 2005. Daily and circadian rhythms of locomotor activity in the American lobster, *Homarus americanus*. *Journal of Experimental Marine Biology and Ecology* 318: 61–70. <https://doi.org/10.1016/j.jembe.2004.12.006>

- Kwiecinski, G.G.** 1998. *Marmota monax*. Mammalian Species: 591: 1–8. <https://doi.org/10.2307/3504364>
- Lehrer, E.W., R.L. Schooley, and J.K. Whittington.** 2011. Survival and antipredator behavior of woodchucks (*Marmota monax*) along an urban–agricultural gradient. *Canadian Journal of Zoology* 90: 12–21. <https://doi.org/10.1139/z11-107>
- Leuchtenberger, C., C.A. Zucco, C. Ribas, W. Magnusson, and G. Mourão.** 2014. Activity patterns of giant otters recorded by telemetry and camera traps. *Ethology Ecology & Evolution* 26: 19–28. <https://doi.org/10.1080/03949370.2013.821673>
- Longcore, T., and C. Rich.** 2004. Ecological light pollution. *Frontiers in Ecology and the Environment* 2: 191–198. [https://doi.org/10.1890/1540-9295\(2004\)002\[0191:elp\]2.0.co;2](https://doi.org/10.1890/1540-9295(2004)002[0191:elp]2.0.co;2)
- Lynam, A.J., K.E. Jenks, N. Tantipisanuh, W. Chutipong, D. Ngoprasert, G.A. Gale, R. Steinmetz, R. Sukmasuang, N. Bhumpakphan, L.I. Grassman, P. Cutter, S. Kitamura, D.H. Reed, M.C. Baker, W. McShea, N. Songsasen, and P. Leimgruber.** 2013. Terrestrial activity patterns of wild cats from camera-trapping. *Raffles Bulletin of Zoology* 61: 407–415.
- McCleery, R.A.** 2009. Changes in fox squirrel anti-predator behaviors across the urban–rural gradient. *Landscape Ecology* 24: 483. <https://doi.org/10.1007/s10980-009-9323-2>
- Meier, P.T.** 1985. Behavioral ecology, social organization and mating system of woodchucks (*Marmota monax*) in southeast Ohio. Ph.D. thesis, Ohio University, Athens, Ohio, USA.
- Merriam, H.G.** 1966. Temporal distribution of woodchuck interburrow movements. *Journal of Mammalogy* 47: 103–110. <https://doi.org/10.2307/1378074>
- Mohamed, A., R. Sollmann, H. Bernard, L.N. Ambu, P. Lagan, S. Mannan, H. Hofer, and A. Wilting.** 2013. Density and habitat use of the leopard cat (*Prionailurus bengalensis*) in three commercial forest reserves in Sabah, Malaysian Borneo. *Journal of Mammalogy* 94: 82–89. <https://doi.org/10.1644/11-mamm-a-394.1>
- Navarro, J., S.C. Votier, J. Aguzzi, J.J. Chiesa, M.G. Forero, and R.A. Phillips.** 2013. Ecological segregation in space, time and trophic niche of sympatric planktivorous petrels. *PLoS ONE* 8: e62897. <https://doi.org/10.1371/journal.pone.0062897>
- Nelson, W., Y.L. Tong, J.K. Lee, and F. Halberg.** 1979. Methods for cosinor-rhythmometry. *Chronobiologia* 6: 305–323.
- Pinheiro, J.C., and D.M. Bates.** 2000. *Mixed-effects models in S and S-PLUS*. Springer, New York, New York, USA. <https://doi.org/10.1007/b98882>
- Pita, R., A. Mira, and P. Beja.** 2011. Circadian activity rhythms in relation to season, sex and interspecific interactions in two Mediterranean voles. *Animal Behaviour* 81: 1023–1030. <https://doi.org/10.1016/j.anbehav.2011.02.007>
- Pittendrigh, C.** 1981. Circadian systems: entrainment. Pages 95–124 in *Biological Rhythms*. Edited by J. Aschoff. Springer, Boston, Massachusetts, USA. https://doi.org/10.1007/978-1-4615-6552-9_7
- Racheva, V., D. Zlatanova, D. Peshev, and E. Markova.** 2012. Camera traps recorded use of sett sites by badgers (*Meles meles* L., Mammalia) in different habitats. *Acta Zoologica Bulgarica* 64: 145–150.
- R Core Team.** 2016. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Robitaille, J.F., and G. Baron.** 1987. Seasonal changes in the activity budget of captive ermine, *Mustela erminea* L. *Canadian Journal of Zoology* 65: 2864–2871. <https://doi.org/10.1139/z87-435>
- Rowcliffe, J.M., J. Field, S.T. Turvey, and C. Carbone.** 2008. Estimating animal density using camera traps without the need for individual recognition. *Journal of Applied Ecology* 45: 1228–1236. <https://doi.org/10.1111/j.1365-2664.2008.01473.x>
- Sæther, B.E., and R. Andersen.** 1990. Resource limitation in a generalist herbivore, the moose *Alces alces*: ecological constraints on behavioural decisions. *Canadian Journal of Zoology* 68: 993–999. <https://doi.org/10.1139/z90-143>
- Sheather, S.** 2009. *A Modern Approach to Regression with R*. Springer, New York, New York, USA. <https://doi.org/10.1007/978-0-387-09608-7>
- Steen, R.** 2017. Diel activity, frequency and visit duration of pollinators in focal plants: *in situ* automatic camera monitoring and data processing. *Methods in Ecology and Evolution* 8: 203–213. <https://doi.org/10.1111/2041-210X.12654>
- Steen, R., and M. Barmoen.** 2017. Diel activity of foraging Eurasian red squirrels (*Sciurus vulgaris*) in the winter revealed by camera traps. *Hystrix* 28: 43–47. <https://doi.org/10.4404/hystrix-28.1-11997>
- Swann, D.E., C. C. Hass, D.C. Dalton, and S.A. Wolf.** 2004. Infrared-triggered cameras for detecting wildlife: an evaluation and review. *Wildlife Society Bulletin* 32: 357–365. [https://doi.org/10.2193/0091-7648\(2004\)32\[357:icfdwa\]2.0.co;2](https://doi.org/10.2193/0091-7648(2004)32[357:icfdwa]2.0.co;2)
- Uttley, J.D., P. Walton, P. Monaghan, and G. Austin.** 1994. The effects of food abundance on breeding performance and adult time budgets of Guillemots *Uria aalge*. *Ibis* 136: 205–213. <https://doi.org/10.1111/j.1474-919X.1994.tb01086.x>
- Watson, E.L.** 2009. Effects of urbanization on survival rates, anti-predator behavior, and movements of woodchucks (*Marmota monax*). M.Sc. thesis, University of Illinois, Urbana-Champaign, Illinois, USA.
- Wauters, L., C. Swinnen, and A.A. Dhondt.** 1992. Activity budget and foraging behaviour of red squirrels (*Sciurus vulgaris*) in coniferous and deciduous habitats. *Journal of Zoology* 227: 71–86. <https://doi.org/10.1111/j.1469-7998.1992.tb04345.x>
- Williams, C.T., K. Wilsterman, A.D. Kelley, A.R. Breton, H. Stark, M.M. Humphries, A.G. McAdam, B.M. Barnes, S. Boutin, and C.L. Buck.** 2014. Light loggers reveal weather-driven changes in the daily activity patterns of arboreal and semifossorial rodents. *Journal of Mammalogy* 95: 1230–1239. <https://doi.org/10.1644/14-MAMM-A-062>
- Zervanos, S.M., C.R. Maher, and G.L. Florant.** 2014.

Effect of body mass on hibernation strategies of woodchucks (*Marmota monax*). *Integrative and Comparative Biology* 54: 443–451. <https://doi.org/10.1093/icb/ict100>

Physiological and Biochemical Zoology 83: 135–141. <https://doi.org/10.1086/648736>

Zervanos, S.M., C.R. Maher, J.A. Waldvogel, and G.L. Florant. 2010. Latitudinal differences in the hibernation characteristics of woodchucks (*Marmota monax*).

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SUPPLEMENTARY MATERIALS:

Video S1. Video example of a Woodchuck (*Marmota monax*) revealed by the camera trap. <https://www.canadianfieldnaturalist.ca/index.php/cfn/article/view/2110/2601>.

TABLE S1. Monitoring effort (number of hours monitored) at each Woodchuck (*Marmota monax*) burrow, London, Ontario, Canada, in June 2015.

TABLE S2. Models used to study Woodchuck (*Marmota monax*) activity, in June 2015, London, Ontario, Canada.

TABLE S3. Analysis of diel activity rhythm models for Woodchuck (*Marmota monax*), in June 2015, London, Ontario, Canada.

TABLE S4. Analysis of diel activity rhythm models for Woodchuck (*Marmota monax*), in June 2015, London, Ontario, Canada.