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Barred Owl (*Strix varia*) activity and diet recorded with a camera trap at a natural cavity nest in Manitoba, Canada (2016–2017)

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Abstract

Camera trap images (n = 27 092) collected at a natural Barred Owl (*Strix varia*) nest site in Manitoba, Canada, 2016–2019, were used to quantify nesting behaviour and identify prey delivered to the nest. Adult Barred Owl activity increased prior to egg laying and again after incubation. Adults were mostly active at night, but daytime activity increased during the nestling period in 2016 and more so with a larger brood in 2017. Nestlings were active at the nest entrance both day and night for 8–9 days prior to fledging at ≤27–32 d old. Two of three nestling activity peaks (0400 and 2000 Central Daylight Time [CDT]) corresponded to prey delivery activity peaks whereas a third (1200 CDT) did not. Only 31/65 prey were identified to species, but 12 new prey taxa were documented for Barred Owl in Manitoba. Activity at the cavity during the non-breeding season before and after a nest predation event were documented; the nest site was abandoned after an American Black Bear (*Ursus americanus*) visited the nest cavity in May 2018. Factors affecting the quality and quantity of images, and hence data obtained from them, included camera position relative to the nest cavity entrance, light levels, camera trigger speed, non-target species, and the configuration and settings of motion detection sensors. Improved camera traps may overcome these limitations. This is the first published study on this owl species using this increasingly popular technology.

Key words: Barred Owl; *Strix varia*; nesting activity; behaviour; prey provisioning; diet; camera trap; Manitoba; Canada

Introduction

Barred Owl (*Strix varia*) is a large brownish-grey nocturnal owl with dark brown eyes and no ear tufts. Its raucous "Who-cooks-for-you? Who cooks for you all?" call is distinct from other owl species in its range (Duncan 2003). It is found over most of eastern North America and has expanded its range over the last 150 years to central and western parts of the continent due to European settlement of the Great Plains (Livezey 2009a,b). It has a wide distribution in Manitoba (Holland *et al.* 2003; Koes and Artuso 2018) and is detected every year during spring nocturnal owl surveys (Duncan 2021). Despite this, little is known about Barred Owl nesting behaviour or diet in Manitoba (Whiklo 2011).

Observational studies of animal behaviour provide information important to the scientific method. Sometimes a single observation can shed new light on a species' natural history. The accumulation of this information can inform conservation action planning needed to sustain or manage populations of species, especially those that are invasive or of conservation concern. However, many species of wildlife are difficult to observe directly without affecting their behaviour, especially those that are active mainly at night, often hidden from view, and/or sensitive to disturbance, such as nesting Barred Owls.

It is surprising that studies of Barred Owl nesting behaviour have not been published despite the popularity and availability of live streaming nest box video cameras for at least a decade. These cameras (https://www.allaboutbirds.org/cams/barred-owls/) reveal intimate behaviours not otherwise visible; however, the technology to live stream video is expensive and logistically challenging for remote natural cavity nest sites in undisturbed habitats (Balin *et al.* 2022). In contrast, camera traps, also known as trail cameras, are simpler and less expensive. Camera traps are triggered by a motion sensor and/or an infrared sensor. Camera traps are battery powered and do not require

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an internet connection. They have been used to study animal behaviour, population trends, and spatial distribution (Kapfer *et al.* 2011; Duncan and Kerbrat 2022). The methods used to quantify nesting bird behaviour from image files and assessments of the effectiveness of camera traps are still being developed and assessed (Duncan and Kerbrat 2022).

Barred Owl nest cavities are hard to find due to their secretive nature (Frith *et al.* 1997). Prior to 2009, only one nest site had been described in Manitoba. In 2009 and 2010 an additional nine nests were found and documented (Whiklo and Duncan 2014). Between 2011 and 2022 eight more nests were discovered (J.R.D. unpubl. data). The discovery of a new natural active Barred Owl nest cavity in 2015 enabled the use of a camera trap that collected images over the 2016 and 2017 breeding seasons. Additional images were collected until spring 2019. Images were reviewed and analysed to assess the ability of this technology to quantify adult and juvenile behaviour and to identify prey delivered to the nest. This is the first published study of this owl species using this increasingly popular technology.

Methods

Nest site and study area

The study nest was located on 25 April 2015 when a female Barred Owl entered the cavity. The diameter at breast height (DBH) of the nest tree was calculated by measuring the circumference of the tree and then calculating the diameter ($D = C/\pi$). Internal nest cavity height (distance from the lowest point inside the cavity to the highest point inside the cavity), width (distance from the furthest right-hand point inside the cavity to the furthest left-hand point inside the cavity), and depth (distance inside the cavity perpendicular to cavity width) were measured after the young had fledged.

The nest was in relatively undisturbed habitat bisected by a gravel road in southeastern Manitoba (49.68504°N, 96.09040°W). The closest human residences were ~4.5 km from the nest site, which was in a 3630 ha ecologically significant area voluntarily protected since 1992 (Manitoba Natural Resources 1992). A 1-km radius centred on the nest location was used to estimate the 320 ha breeding home range of Barred Owl (Hamer 1988). Forest Resource Inventory (Gill 1955; Natural Resources Manitoba 1996) habitat variables within this home range were summarized and compared with those from similarly estimated home ranges associated with Manitoba Barred Owl spring survey locations (Duncan and Kearns 1997; Tables S1–S4).

Our study area is in the Boreal and Great Lakes–St. Lawrence Forest Regions (Rowe 1972) and the Lake of the Woods Ecoregion (Zoladeski *et al.* 1995; Smith *et al.* 1998). The area contains a variety of soil conditions and habitats resulting from both ground moraine from Pleistocene glaciers and lacustrine deposits of glacial Lake Agassiz (Teller 1984). Typical of boreal forest regions, the area is flat, poorly drained, with the predominant vegetation consisting of Black Spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburg) and Tamarack (*Larix laricina* (Du Roi) K. Koch) interspersed with swamps and meadows (Rowe 1972). Jack Pine (*Pinus banksiana* Lambert) and Trembling Aspen (*Populus tremuloides* Michaux) occur in drier areas.

In this region, prior to 1958, fires burned large areas annually. More recently, logging and smaller, less frequent fires occur. The climate is boreal continental with January and July temperatures, −19.4 ± 0.5°C (SD) and 19.1 ± 0.4°C, respectively; snowfall 128 ± 11.1 cm/year; rainfall 41.1 ± 3.2 cm/year; and total annual precipitation 54 ± 3.9 cm/year of which 24 ± 3.9 cm/year falls as snow (Duncan 1992).

Data collection

We mounted a Reconyx PC900 HyperFire Professional High Output Covert IR Trail Camera (Holmen, Wisconsin, USA) 1 m from the nest cavity opening using a steel angled bracket attached to the nest tree (Figure S1). In 2016, we positioned the camera to point directly into the nest cavity entrance. In 2017, we positioned the camera to point at the side of the nest cavity entrance. A compact aluminum telescoping collapsible ladder carried into the nest site was used to access the camera and nest cavity.

Steen *et al.* (2016) determined that cameras placed <1 m missed behaviours and >1 m made prey identification more difficult. Cameras placed >1 m from nests were triggered excessively by moving branches, wasted limited image memory storage space, and depleted batteries faster (R. Steen pers. comm. 12 February 2015). The camera was custom focussed to 1 m by the manufacturer for our study. The camera was configured with the motion sensor = on; sensitivity = high; pictures per trigger = 3; picture interval = rapid fire; quiet period = no delay; and night mode = fast shutter. Images included an image number, time (hh:mm:ss), date (yyyy-mm-dd), and temperature (°C) stamp. Time was set for the Central Daylight Saving Time (CDT) zone.

The three images/capture/motion setting was a compromise between likelihood of identifying prey to species and limits of memory and battery capacity (R. Steen pers. comm. 12 February 2015). Reducing the frequency of camera memory and battery maintenance also reduced disturbance to the nesting owls (Caravaggi *et al.* 2017). The camera was checked on average every 24 days (range 12–35, $n = 4$) and 15

days (range 8–21, $n = 4$) during the 2016 and 2017 breeding seasons, respectively. On each visit the secure digital card was replaced whereas the batteries were replaced once in 2017. A total of 27 092 images were recorded from March to September 2016 and from March 2017 to May 2019 (Table S5). In 2016, the camera was set up before egg laying and was removed after the young had fledged. In 2017, the camera was set up after the first of three eggs were laid and was removed in May 2019 after the nest cavity remained unoccupied for two subsequent breeding seasons (Table S6).

Reviewing camera trap images

All camera trap images collected were reviewed and behaviours such as prey deliveries were transcribed into a spreadsheet by R.K., and quality controlled by R.K. and J.R.D. This took 172 h on 135 days (average of 1.27 h/day) spread out over a 389 day period from May 2020 to June 2021.

The time, mode (colour/day versus black and white/night), date and number of images with adult or juvenile activity were tabulated to determine activity duration, daily peaks, and changes over time (i.e., associated with pre-egg laying, incubation, and nestling stages). A series of continuous images associated with a behaviour was considered an 'image set'. The times that the camera switched between modes varied depending on light levels affected by cloud cover and vegetation density. In a similar study, this averaged 32 min before sunset and 35 min after sunrise (Duncan and Kerbrat 2022). The sex of adult activity was not noted because Barred Owls exhibit only slight reversed sexual size dimorphism (Mazur and James 2020) and no other sex-specific characteristics (i.e., plumage pattern) were distinguishable on images.

Identification of prey from camera trap images

When possible, prey items delivered to the nest were identified to the finest taxonomic level possible from images by consensus (R.K. and J.R.D.) and using diagnostic characteristics of species expected in this area at the time of the study (Banfield 1974; Godfrey 1986; Naughton 2012). Small mammal prey were identified using a combination of one or more visible features including relative tail or hind leg length, ear and/or eye size, and uniform versus contrasting pelage shading (Figure S2a). Bird prey were identified by bill, head, body, wing, and tail shape and size and plumage appearance to the extent possible. Prey were also identified as needed by consultation with experts with the relevant taxonomic expertise (see Acknowledgements). When poor image quality prevented the identification of prey items to species, they were assigned to one of eight categories: unidentified, unidentified invertebrate, unidentified vertebrate, unidentified mammal, unidentified rodent, unidentified mouse, unidentified vole, or unidentified passerine. No prey species were identified from pellets.

Results

Nest site and habitat

The nest cavity was 3.2 m above ground in a dead Balsam Poplar (*Populus balsamifera* L.) with a 42 cm DBH. The diameter at nest height was 45 cm. The northwest-facing cavity entrance was 32 × 11 cm (height × width). The interior of the nest cavity was 61 × 26 × 30 cm (height × depth × width). The nest stand was dominated by Trembling Aspen, with less than 5% Balsam Poplar, White Spruce (*Picea glauca* (Moench) Voss), Jack Pine, and Balsam Fir (*Abies balsamea* (L.) Miller; J.R.D. unpubl. data).

This pair's estimated breeding home range had more grass/forb, shrub/seedling, and mature forest habitat but less unproductive forest, pole/sapling, and overmature forest habitat (cutting class) than for those reported in Duncan and Kearns (1997); correspondingly, it had relatively more open-crown, less closed-crown forest stands, and an equal mix of softwood and hardwood dominated stands (Tables S1, S2, and S4).

Assessment of the effectiveness of camera traps for this species

Barred Owl activity at the cavity was summarized by the time, date, and number of images taken by the camera trap (Figure 1a). More images were recorded in 2016 (Table S5), when the camera directly faced the nest cavity entrance (Figure S1) because some of the adult and nestling activity inside the cavity also triggered the camera (Figure S2b). However, adult owls visiting the nest in 2016 often had their backs to the camera, thereby partially or completely blocking the view of prey being delivered. To address this issue the camera was repositioned in 2017 to face the side of the nest cavity entrance (Figures 1a, S2c). This enabled more prey items to be identified (Table S7). However, this camera position captured more images either without owls present or with just a small part of the owl visible.

Adult Barred Owl activity

Adult Barred Owl activity at the nest entrance varied daily but showed an activity peak in 2016 about two weeks before egg laying was complete, followed by lower activity during the first half of the incubation period (Figure 2a, Table S6). There was an expected increase in adult activity as nestlings developed and required more food, followed by a decrease corresponding to the fledging of the owlets in both 2016 and 2017 (Figure 2a,b, Table S6). There was a relatively early increase in adult activity during the latter

FIGURE 1. a. Adult Barred Owl (*Strix varia*) at the entrance to its nest cavity and b. Two nestlings inside nest cavity in southeastern Manitoba, Canada. Photos: James Duncan.

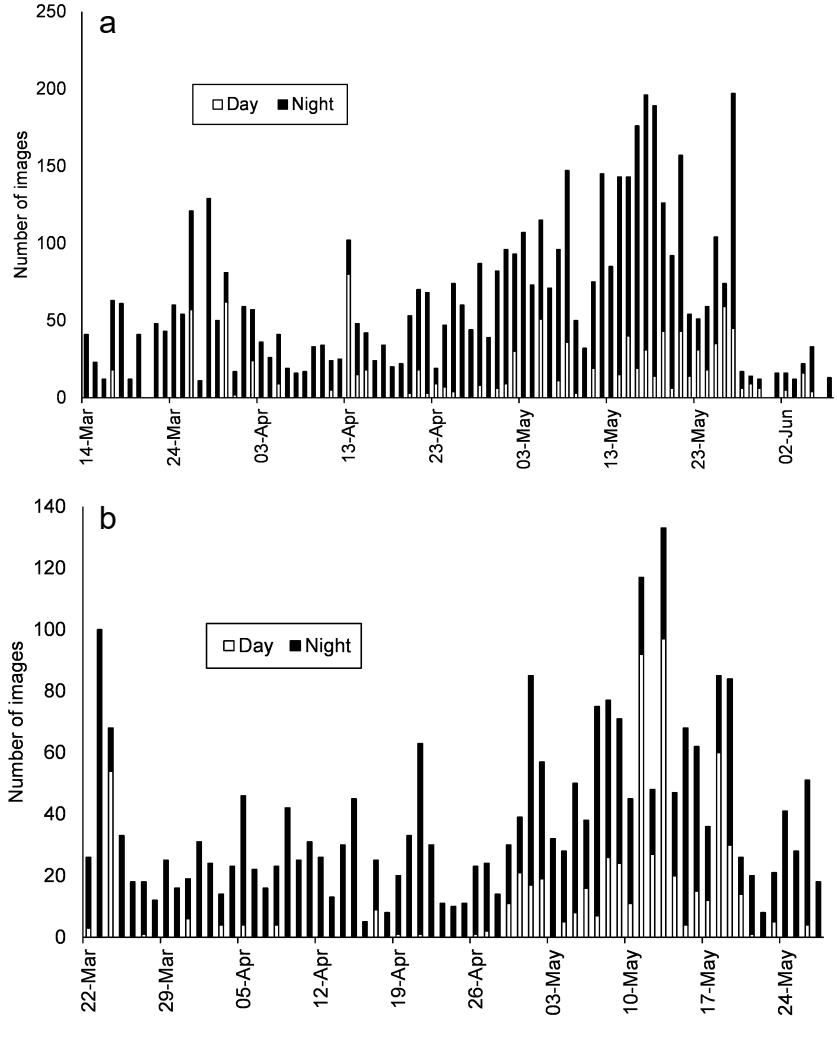

FIGURE 2. Chronology and timing of adult Barred Owl (*Strix varia*) nest activity based on number of images recorded in a. 2016 and b. 2017 during different nesting stages in southeastern Manitoba, Canada.

stage of incubation in 2016 (Figure 2a).

In 2016 and 2017, 80% of 7833 camera images were taken at night suggesting the Barred Owls were mainly nocturnal (Figure 2, Table 1). They were more active during the day in the nestling period (Figure 2, Table 1) when nights were getting shorter as summer equinox approached. The relative increase in daytime activity during the nestling phase was greater in 2017 when three nestlings were present (versus two nestlings in 2016), and the adults had to provide more prey (Table 1).

Nestling activity and fledging

Barred Owls have an asynchronous hatch and are only moderately sexually size dimorphic (Mazur and James 2020). Therefore, we assumed that the oldest nestling would be the largest and would have been readily identifiable in images (Figure 1b). However, it was too difficult to consistently assess nestling relative size based on images, especially when only one was visible (Figure S2c). Nestling Barred Owls developed quickly and climbed up to the nest cavity entrance to observe their surroundings (Figure S2c). Perching on and climbing around the nest cavity also afforded them an opportunity to strengthen their leg and wing muscles before leaving the nest permanently (fledging). We described fledging as occurring when the last image of a nestling was recorded by the camera trap.

In 2016, nestlings were first recorded at the nest entrance at 1931 CDT on 1 June and were last recorded there at 1936 CDT on 7 June. In 2017, the first and last images of nestlings at the nest entrance were at 1305 CDT on 21 May and at 1940 CDT on 28 May, respectively (Figure S3). The earlier fledging in 2017 corresponded to an earlier clutch initiation date (Table S6). The two nestlings were active at the nest entrance and fledged younger (≤27 d old) in 2016 than the three nestlings (≤32 d old) in 2017 (Figure S3, Table S6).

Despite there being two nestlings in 2016 and three in 2017, the number of days the nestlings were recorded at the nest cavity entrance before fledging were similar (8 and 9 days, respectively) in both years (Figure S3). The camera facing directly into the cavity resulted in more nestling activity images being recorded in 2016 versus 2017 (Figure S3), even though there were fewer nestlings present that year.

In contrast with adult Barred Owls, nestlings were equally active at the nest entrance day and night (2016 and 2017, $n = 7259$ images, 51% of which were taken during the day) and for the pooled data there were three evenly spaced activity peaks at 0400, 1200, and 2000 CDT (Figure 3). Two of these peaks (0400 and 2000 CDT) relate to prey delivery activity peaks (Figure 4).

Diet and prey delivery activity

About half (31) of 65 image sets (Table 2, Figure S2a) enabled the identification of prey items delivered to species; the remainder could only be identified to genus (7), subfamily (2), family (3), order (1), class (9), subphylum (4), or kingdom (8). Most prey items identified were vertebrates (52) consisting of 38 mammals, seven birds, two amphibians, and one reptile. The five invertebrates consisted of worms, beetles, bugs, and moths. Star-nosed Mole (*Condylura cristata*) was the most commonly (13) identified prey species (Table 2) and was prominent in both years (Table S7).

Most (~79%) prey deliveries, including all invertebrate and 73% of vertebrate prey, occurred at night (Figure 4) with at least two peaks at 2100 and 0400 CDT; the time between peaks generally corresponded with the time required for nestlings to digest food (Duncan 2003). More prey (63% of 65 prey items) were identified from images with the camera facing the side of the cavity (2017) compared to images with the camera facing directly into the cavity (2016; Table S7).

Barred Owl nest cavity activity outside the nesting season and nest site abandonment

In 2017, after successfully fledging three young, Barred Owls visited the nest cavity entrance five times at night in September and October. On two of these occasions, they entered the cavity and on one occasion two owls were there at the same time. The estimated duration of these visits averaged 2 min and 53 s (range 42 s to 5 min 56 s; Table S8). Barred Owls next visited the nest cavity briefly (24 s) in February 2018, followed by four longer (mean 4 min and 19 s, range 11 s to 22 min and 4 s) visits in each of March and April (Table S8). A 1 min and 18 s owl visit on 14 May 2018 was followed later that day by an American Black Bear (*Ursus americanus*) visit (Figure S4a), after which the owls abandoned the nest cavity and did not nest there in subsequent years (2019–2022). Only five short (<3 s) visits by Barred Owls

TABLE 1. Adult Barred Owl (*Strix varia*) activity at the nest cavity entrance based on number of images recorded in 2016 with two nestlings and in 2017 with three nestlings, southeastern Manitoba, Canada.

Nesting stage	2016		2017	
	Day	Night	Day	Night
Pre-egg laying	173	932	0	0
Incubation	266	1373	86	751
Nestling	528	2018	550	1156
Totals	967	4323	636	1907

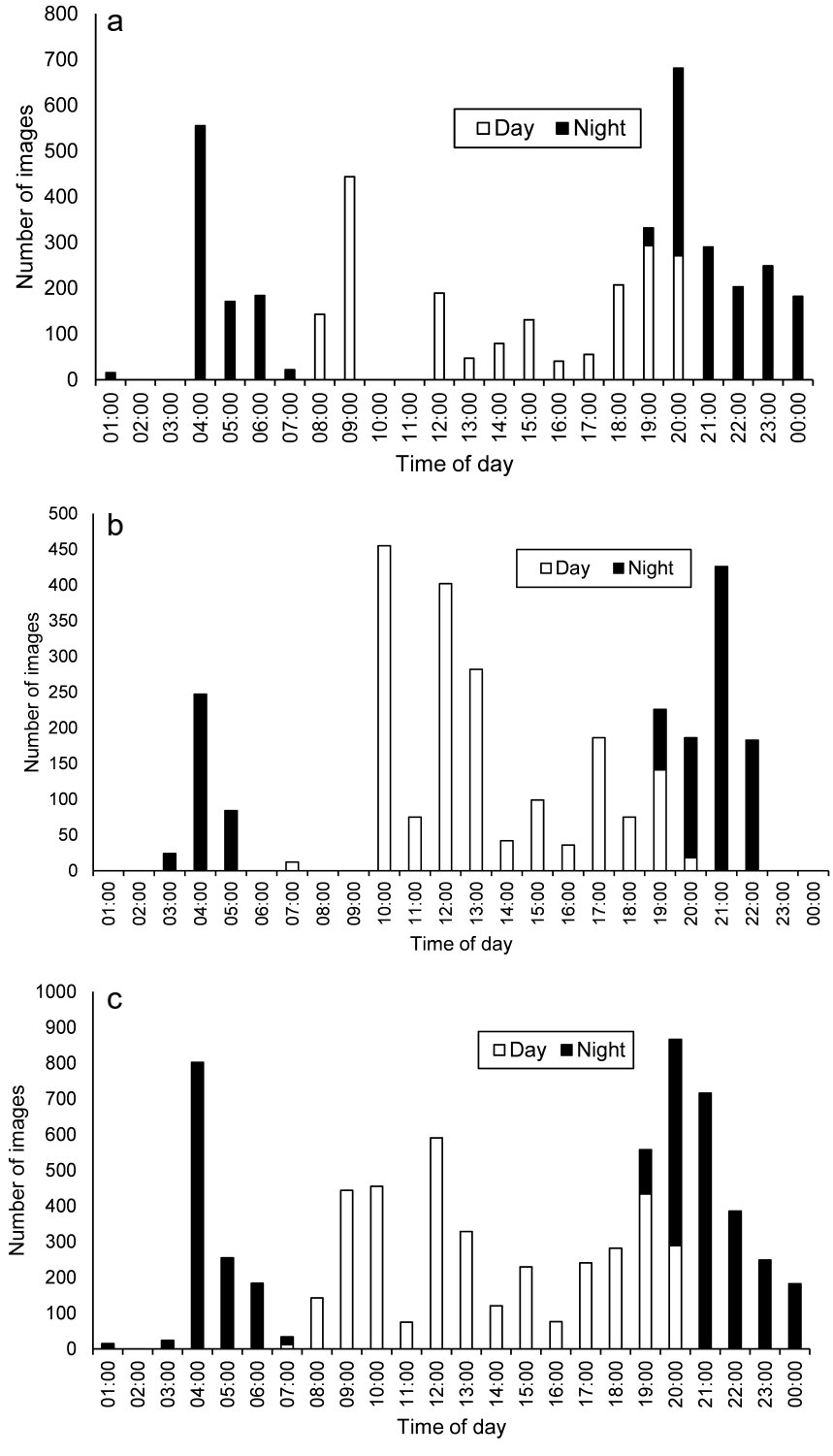

FIGURE 3. Timing of nestling Barred Owl (*Strix varia*) activity at the nest cavity entrance based on images recorded for a. 2016 with two nestlings, b. 2017 with three nestlings, and c. 2016 and 2017 combined in southeastern Manitoba, Canada.

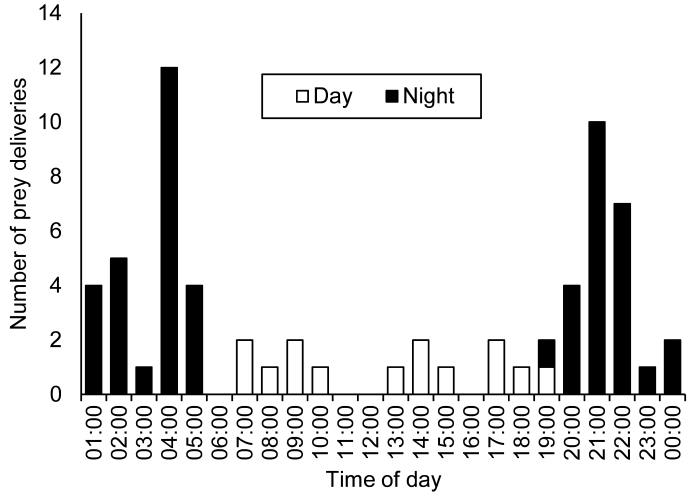

FIGURE 4. Time of Barred Owl (*Strix varia*) prey deliveries to the nest cavity based on 65 image sets recorded in 2016 and 2017 where prey items were visible in southeastern Manitoba, Canada.

TABLE 2. Barred Owl (*Strix varia*) prey identified from images taken by a trail camera at a nest cavity, southeastern Manitoba, Canada (2016–2017).

Number	Common name	Scientific name or taxonomic category
1	*Common Earthworm	*Lumbricus terrestris*
2	*Giant Water Bug	*Lethocerus americanus*
1	*Unidentified sphinx moth	Family: Sphingidae
1	*Unidentified predaceous diving beetle	Genus: *Dytiscus*
1	*Wood Frog	*Lithobates sylvaticus*
1	Unidentified frog (Wood or Leopard Frog)	Genus: *Lithobates*
1	*Unidentified garter snake	Genus: *Thamnophis*
1	American Robin	*Turdus migratorius*
1	*Downy Woodpecker	*Picoides pubescens*
1	Ruffed Grouse	*Bonasa umbellus*
1	*Sora	*Porzana carolina*
1	*Yellow-bellied Sapsucker	*Sphyrapicus varius*
2	Unidentified bird	Class: Aves
1	Deer Mouse	*Peromyscus maniculatus*
3	Meadow Vole	*Microtus pennsylvanicus*
2	*Northern Flying Squirrel	*Glaucomys sabrinus*
3	*Snowshoe Hare	*Lepus americanus*
13	Star-nosed Mole	*Condylura cristata*
3	Jumping Mouse	Genus: *Zapus*
1	*Unidentified weasel	Genus: *Mustela*—likely **Mustela erminea*
1	Unidentified rodent	Family: Cricetidae or Muridae
1	Unidentified squirrel	Family: Sciuridae
2	Unidentified vole	Subfamily: Arvicolinae
1	Unidentified rodent	Order: Rodentia
7	*Unidentified mammals	Class: Mammalia: one likely *Lepus americanus* and one likely **Martes americana*
4	Unidentified vertebrate	Subphylum: Vertebrata
8	Unidentified animal	Kingdom: Animalia

*New prey taxa in Manitoba based on Whiklo (2011). See also Table S7.

occurred in the following months until the camera was removed 25 May 2019 (Table S8).

Other species visiting the nest cavity

The nest camera recorded a variety of other bird and mammal species visiting the nest cavity prior to, during, and after the nesting season including nest predators such as American Marten (*Martes americana*) and American Black Bear (Figures S4, Table S9).

Discussion

Nest site and habitat

The nest cavity's dimensions were within the range of nest cavity dimensions for other Barred Owl nest cavities in Manitoba (Whiklo and Duncan 2014). The forest habitat within the estimated breeding home range was consistent with the characterization of Barred Owls being forest habitat generalists (Whiklo and Duncan 2014; Mazur and James 2020). The reuse of nest sites is well documented in this species (Elderkin 1987; Mazur and James 2020).

Adult activity

The rise and fall of adult Barred Owl activity at the nest before and after egg laying was consistent with that of most birds, which are generally secretive while incubating (Pettingill 1970). The relatively early increase in adult activity during the latter stage of incubation in 2016 seemed unusual. As expected, an increase in recorded adult activity corresponded to nestling growth, followed by a decrease associated with the owlets fledging. Elderkin (1987) reported that an adult female stopped brooding nestlings intensively about two weeks after the first egg hatched and at this time the female started to help with catching prey and feeding nestlings. An inferred similar change in adult female behaviour may explain the timing of the second peak in adult activity at the nest cavity in 2016 and the overall continued general increase in 2017.

Barred Owls are generally considered to be seminocturnal to nocturnal hunters (Mazur and James 2020). Elderkin (1987) documented adults at one nest in Nova Scotia hunted almost exclusively at night. We suggest that the adults we monitored had to also hunt during the day to feed their nestlings because the nights were shorter at our latitude, especially in 2017 when they had more nestlings. This pressure was relaxed in the nonbreeding season when all recorded activity was at night.

Nestling activity

Nestling activity at the nest entrance and fledging dates corresponded to clutch initiation dates and ages (27 to 32 d old) as reported for this species elsewhere (Mazur and James 2020). The larger brood size (two nestlings in 2016 versus three in 2017) only added one extra day (eight versus nine days) to the period when nestlings were active at the nest entrance before fledging. This contrasted with another study where the third hatched nestlings grew slower and took longer to fledge (Elderkin 1987).

Unlike primarily nocturnal adults, nestlings were equally active day and night with three evenly spaced activity peaks at 0400, 1200, and 2000 CDT. Two of these peaks corresponded to prey deliveries. Knowledge of when and how long nestlings are active at the nest cavity entrance can help researchers plan when to capture and band them before they fledge; fledged young typically perched high in tree canopies are harder to find and capture.

Diet and prey deliveries

While Barred Owls are known diet generalists, with small mammals and birds forming the bulk of their diet (Mazur and James 2020), knowledge of their diet in Manitoba is limited. Whiklo (2011) documented 123 prey taxa from nest sites, pellets, and stomach contents. Our camera trap study added 12 new taxa to the known diet of Barred Owls in Manitoba (Table 2). The predominance of Star-nosed Mole as prey suggests that they may be locally abundant. Another study in which camera traps were baited with carcasses documented carrion-feeding by Barred Owls in North Carolina (Kapfer *et al.* 2011).

Barred Owl nest cavity activity outside the nesting season and nest site abandonment

Barred Owls are known to vigorously defend territories year round (Mazur and James 2020) and to prospect potential nest sites as much as a year before use (Elderkin 1987). Our study documents nest cavity inspection behaviour in fall and winter and is evidence of their importance as a scarce or important resource worth the energy expended in defending them from conspecifics. The amount of nonbreeding season activity at the nest cavity in fall 2017 and the following winter was considerable.

An American Black Bear was previously suspected of predating a different Barred Owl nest site in Manitoba (Whiklo 2011) and a female Northern Spotted Owl (*Strix occidentalis caurina*) attacked an American Black Bear to defend its fledged young near its nest site in Washington State, USA (Alston *et al.* 2017). It is likely that Barred Owls had already laid eggs when an American Black Bear visited the nest cavity on 14 May 2018 (Figure S4a) given the clutch initiation dates in the three previous years (Table S6) and the prior increased Barred Owl activity at the nest cavity that spring (Table S8). The absence of eggs or young on two subsequent visits to the nest site (Table S6) suggests that the American Black Bear visit was a nest predation event that caused the owls to abandon

the nest cavity in 2018 and in subsequent years (2019–2022). The significantly reduced nonbreeding activity in fall 2018 and winter 2018–2019, the abandonment of the nest cavity after the predation event, and the use of a Common Raven (*Corvus corax*) stick nest ~100 m to the east in 2021 (Table S6) suggests that resident Barred Owls avoid nest predation involving predators with long-term memory, as noted by Sonerud (1985) for Tengmalm's Owl (*Aegolius funereus*).

Camera trap effectiveness

The use of camera traps to document cavity nesting Barred Owl behaviour, activities, and diet were moderate to poor when compared to the success in using them for studying open-nesting owl species (Duncan and Kerbrat 2022). The camera trap model we used required both motion and temperature variances to trigger. We noticed considerable gaps in image sequences occurred due to a failure of the camera's passive infrared motion sensors to trigger. This likely happened when smaller nestlings were stationary in front of the camera and did not move across more than one detection zone (see red areas in Figure S5); this may have been mitigated by adjusting the camera upward such that both detection zones crossed the nest cavity opening (Figure S5). In addition, dense Barred Owl juvenile plumage, especially on the head and back, may have minimized relative differences between the owl's and the ambient temperatures below the camera's trigger threshold.

Adult Barred Owls often entered or departed the nest tree cavities quickly without lingering at the entrance, likely to avoid detection by predators. This makes finding Barred Owl cavity nests challenging. While Barred Owl flight speed has not been measured, Great Horned Owl (*Bubo virginianus*) can fly at speeds of 65 km/h in level flight (Voous 1988). Other tree cavity nesting species like Wood Duck (*Aix sponsa*) often enter and exit nest tree cavities fast without perching at the entrance to reduce the likelihood of nest predation and/or brood parasitism (M. Dyson pers. comm. 15 June 2022) and fly up to 56 km/h (Stewart 1958). The camera was often unable to trigger fast enough to record images with adult owls in frame or resulted in blurred, distorted, and empty images. This limited the detection of behaviour and prey identification. The resulting time gaps between recorded activities prevented a more detailed analysis of nesting behaviour such as how long the female was in the cavity and how that changed during the incubation and brooding periods.

The camera directly faced the nest cavity entrance in 2016 such that often only the back of the adult owl was visible when it was visiting the nestlings. This limited the number of identifiable prey deliveries and prevented an analysis of changes in prey type as nestlings aged. Conversely more images of young active in the nest cavity prior to fledging were obtained in 2016 versus 2017 even though there were fewer nestlings that year. The opposite occurred in 2017 when the camera was positioned to face the side of the cavity.

Conclusions

Despite the limitations of this camera trap model's technology, new detailed information on the chronology and activity patterns of adult and nestling Barred Owls were documented at a natural nest cavity in a protected area. In addition, an increased number of new Barred Owl prey species were identified in Manitoba (Table 2). These data will assist future research and banding efforts (i.e., when to access nestlings before they fledge). There are few documented Barred Owl nest sites and breeding habitats in Manitoba. The new nest site identified in our study corroborates previous knowledge of the habitat requirements for Barred Owl, which depend on large nest cavities in large trees and a diverse prey base.

Other automated image or video recording systems have demonstrated substantial technological, sample size, and human resource limitations while yielding new behaviours and ecology for species that are logistically challenging to study (Harms 2021; Balin *et al.* 2022; Duncan and Kerbrat 2022). Camera traps are cost effective, but the time required for data processing is large. The use of artificial intelligence, specifically deep learning, to process camera-trap data will make their use more efficient (Vélez *et al.* 2022). Improvements in technology will enhance our knowledge of such species by using less invasive research methods.

Author Contributions

Writing – Original Draft: J.R.D. and R.K.; Writing – Review & Editing: J.R.D., R.K., and T.M.W.; Conceptualization: J.R.D.; Investigation and Methodology: J.R.D. and R.K.; Analysis: J.R.D., R.K., and T.M.W.

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SUPPLEMENTARY MATERIALS:

FIGURE S1. Barred Owl (*Strix varia*) nest cavity with mounted camera trap, southeastern Manitoba, Canada. Photo: James Duncan.

FIGURE S2. Camera trap images of a. adult Barred Owl (*Strix varia*) delivering a Star-nosed Mole (*Condylura cristata*) to its nest cavity, b. nestling peering out of the nest cavity, and c. nestling Barred Owl (*Strix varia*) at the nest cavity entrance before fledging, in southeastern Manitoba, Canada. Photos: James Duncan.

FIGURE S3. Number of nestling Barred Owl (*Strix varia*) images recorded at the nest entrance in a. 2016 with two nestlings present 1–7 June and b. in 2017 with three nestlings present 21–28 May in southeastern Manitoba, Canada.

FIGURE S4. Camera trap images of a. American Black Bear (*Ursus americanus*), b. Red Squirrel (*Sciurus vulgaris*), c. American Marten (*Martes americana*) visiting a Barred Owl (*Strix varia*) nest cavity in southeastern Manitoba, Canada.

FIGURE S5. Camera trap image of Barred Owl (*Strix varia*) nestling at nest cavity entrance in southern Manitoba superimposed with 12 camera motion and relative temperature detection zones (individual red areas bordered by vertical black lines) arranged in upper and lower bands.

TABLE S1. Forest resource inventory habitat cutting class areas (ha) associated with estimated Barred Owl (*Strix varia*) breeding home ranges in southeastern Manitoba, Canada.

TABLE S2. Forest resource inventory habitat crown closure areas (ha) associated with estimated Barred Owl (*Strix varia*) breeding home ranges in southeastern Manitoba, Canada.

TABLE S3. Forest resource inventory habitat species composition areas (ha) associated with estimated Barred Owl (*Strix varia*) breeding home ranges in southeastern Manitoba, Canada.

TABLE S4. Forest cover type associated with a circular 314 ha estimated Barred Owl (*Strix varia*) breeding home range in southeastern Manitoba, Canada.

TABLE S5. Summary of camera trap recorded image files at a Barred Owl (*Strix varia*) nest cavity in southeastern Manitoba, Canada, 2016 to 2019.

Table S6. Chronology of observed and estimated breeding and other select events at a Barred Owl (*Strix varia*) nest cavity in southeastern Manitoba, Canada, 2015 to 2021.

Table S7. Barred Owl (*Strix varia*) prey identified from images taken by a trail camera at a nest cavity in southeastern Manitoba, Canada (2016–2017) in chronological order.

Table S8. Barred Owl (*Strix varia*) non-breeding season visits to a nest cavity in southeastern Manitoba, Canada (2017–2019).

Table S9. Birds and mammals visiting a Barred Owl (*Strix varia*) nest cavity in southeastern Manitoba, Canada, 2016 to 2019.