Application of Radio Frequency Identification Technology to Study Nesting Behaviour of Tree Swallows

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Abstract

A radio frequency identification (RFID) system was modified for implementation into nest boxes to study the nesting behaviour of Tree Swallows (Tachycineta bicolor) *at Colony Farm Regional Park in Coquitlam, B.C. Ten nest boxes were equipped with RFID technology and monitored for three consecutive breeding seasons (2015-2017). The RFID systems recorded each nest visit made by 39 adult Tree Swallows tagged with passive integrated transponder (PIT) tags, amassing over 20,290h of data and recording 30,482 nest box visits with an investment of approximately 7h of labour per week. Our results indicate that female Tree Swallows play a greater role in provisioning than males by making more frequent and numerous daily nest visits over a greater period of time during the day. The data also revealed interesting nesting behaviour, detecting one case of polygyny in the nest box colony, where one adult male was consistently provisioning for two broods in neighbouring nest boxes. While our sample size was small, the data collected provides an example of the large volume of automated and continuous data that can be collected by integrating RFID technology with nest boxes.*

Tree Swallow Can Stock Studios

Introduction

Application of radio frequency identification (RFID) technology to ornithological research allows for individual birds equipped with passive integrated transponder (PIT) tags to be uniquely identified, and the presence of these individuals at fixed locations to be automatically recorded. Unlike other data loggers and transmitters, PIT tags do not rely on an internal battery. This advantage allows large volumes of data to be collected over long periods of time, such as an entire breeding season, while minimizing labour, cost, and repeated capture and handling. RFID technology has been used to study a wide variety of avian species. Topics of previous studies include presence-absence, movement, physiological characteristics, and nesting behaviour (Bonter and Bridge 2011, Hou et al. 2015). For example, Pied Flycatchers, (*Ficedula hypoleuca)*, were shown to visit conspecific nest sites to collect social information during the breeding season. Larger brood sizes received more visitors, suggesting that the flycatchers are collecting information and assessing the reproductive success of conspecifics. This information can then be used to select high quality nest sites (Schuett et al. 2017).

A nest box represents a fixed location that can be easily fitted with RFID technology for the monitoring of nesting behaviour. RFID-capable nest boxes have been used to study aspects of nesting behaviour in passerines such as parental provisioning (Freitag et al. 2001, Wilkin et al. 2009, Stanton et al. 2016) and fledging (Johnson et al. 2013). In this study, the PIT tags were read by a circular antenna that was incorporated into the nest box, encircling the entrance hole to the box, allowing every visit by a tagged bird to be recorded by the RFID reader.

Tree Swallows (*Tachycineta bicolor*) are secondary cavity nesters that breed throughout North America, including interior and coastal British Columbia (Ryder 2015), and winter in the southern United States, Mexico, Central America, the Caribbean, and northern South America (McCarty 2001, Winkler et al. 2011). Like other aerial insectivores, Tree Swallow abundance has gradually declined in North America over the last few decades (Shutler et al. 2012), particularly in British Columbia (North American Bird Conservation Initiative Canada 2012). Hypothesized causes of decline are reduced flying insect populations due to pesticide use, loss or pollution of wetlands, and loss of natural nesting cavities due to the reduced availability of old trees (Holroyd 1975, Stutchbury and Robertson 1985, Nebel et al. 2010, Ryder 2015). By using RFID technology, Tree Swallow nest boxes can be closely monitored over many breeding seasons and, in association with other research, population changes could be connected with habitat quality or other factors.

Willingness to breed in nest boxes makes the Tree Swallow an ideal candidate species for study for a wide range of behaviors and technologies (Jones 2003), including the use of RFID technology. Typically, Tree Swallows lay one egg per day with clutches ranging from two to seven eggs (McCarty and Secord 1999, Winkler et al. 2011). After 14 to 15 days of incubation by the female, the socially monogamous pair exhibits bi-parental care, sharing the duties of feeding nestlings and removing fecal sacs from the nest cavity (Quinney 1986, McCarty 2001). By fitting nest boxes with RFID capability, the number and timing of nest visits made by individuals throughout the breeding season can be quantified to an extent difficult to achieve using direct observation alone. The absolute and relative provisioning roles of males and females can then be determined, as Tree Swallows are known to feed nestlings during 95-98% of visits to the nest (McCarty 2002, Whittingham et al. 2003).

With the objective of better understanding Tree Swallow nesting behavior and parental provisioning in coastal British Columbia, ten nest boxes in Colony Farm Regional Park were fitted with RFID technology. The purpose of this project was to develop and evaluate RFID capability for continuous and long-term monitoring of nest boxes.

Methods

Study area

The nest box colony was located at the Colony Farm Banding Station (49° 14’ 22.61”N, 122° 47’ 50.78”W) operated by the Vancouver Avian Research Centre (VARC) within Colony Farm Regional Park, Coquitlam, British Columbia. Ten nest boxes were positioned approximately equidistant along a 0.3 km L-shaped transect in an old-field habitat, bordered to the north by riparian mixed woodland.

RFID system

The RFID system consisted of an antenna, RFID reader, data logger, and power source (Figures 1-3). This system was modified from the design of Bridge and Bonter (2011) for implementation into the nest boxes. A complete description of how the system functions can be found in Bridge and Bonter (2011). A 26 American Wire Gauge (AWG) magnet wire was coiled around a plastic spool to allow incorporation of the antenna into the entrance hole of the nest box (Fig. 1 pg. 83). The diameter of the entire coil was 50 mm with an internal diameter of 38 mm for the Tree Swallows to pass through. An optimal antenna inductance of 1.35 mH was achieved by approximately 50 turns of the antenna wire. The reading range of the antenna was approximately 1 cm. We used ITB CompuPhase software Termite 3.1, a standard serial RS232 communication interface, to effect reader communication. The reader operated by initiating a poll for PIT tags, pausing to do a system check, going into a power saving sleep mode, and continuously repeating this cycle. Polling frequency, cycle time, and pause time were set at 0.25, 0.50, and 5 s, respectively. A daily sleep period was set from 23:00 to 04:00 Pacific

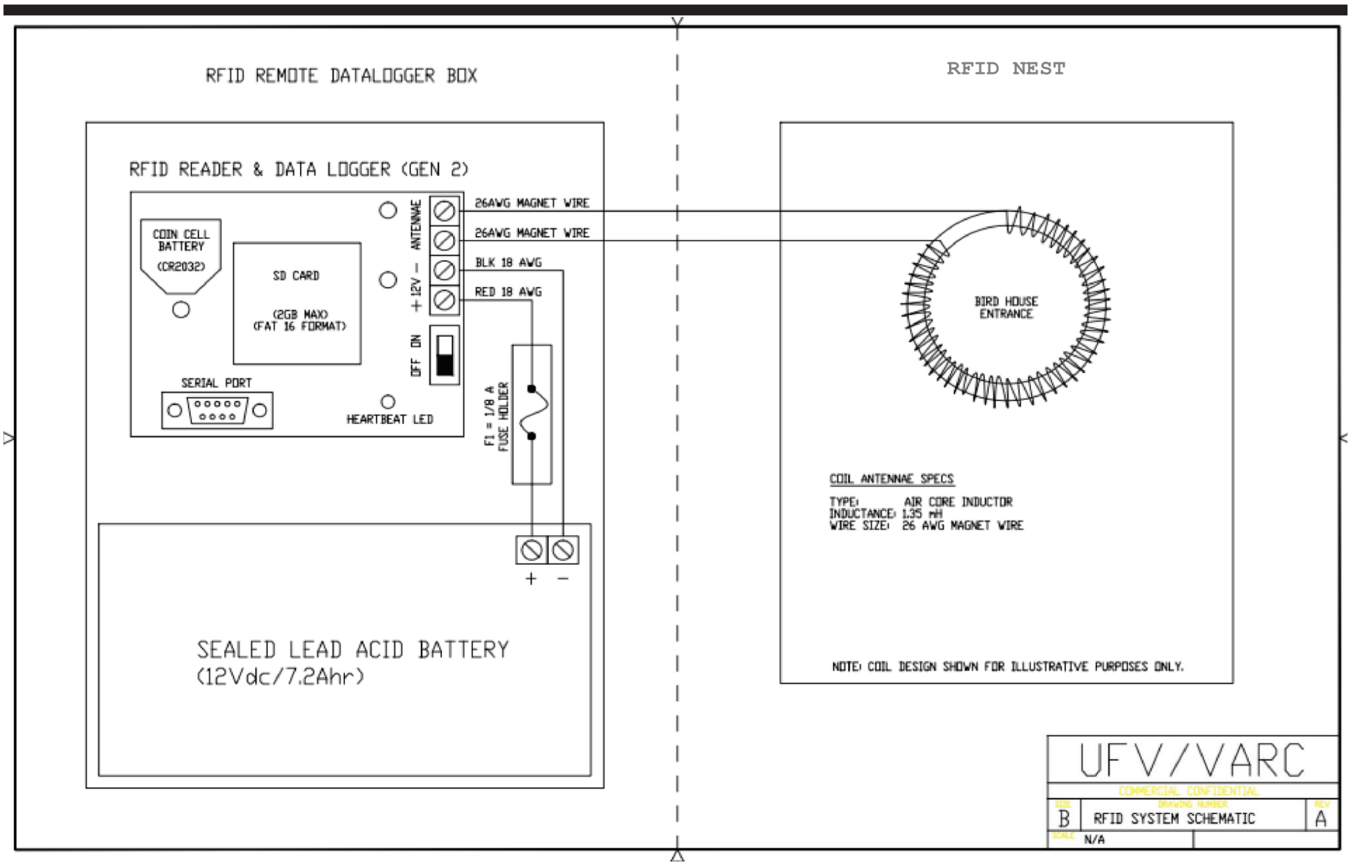

Fig. 1. Electrical schematic of the radio frequency identification datalogger box (left) and nest box (right).

Fig. 2. Radio frequency identification datalogger box (left) and nest box (right) mounted to a 2.4 m length of wooden post. The two units are connected by a 26 American Wire Gauge magnet wire coiled around a plastic spool and inserted into the entrance hole of the nest box. Positioned around the post is a 0.6 m long cylinder made of 26 AWG galvanized steel ducting, functioning as a predator guard.

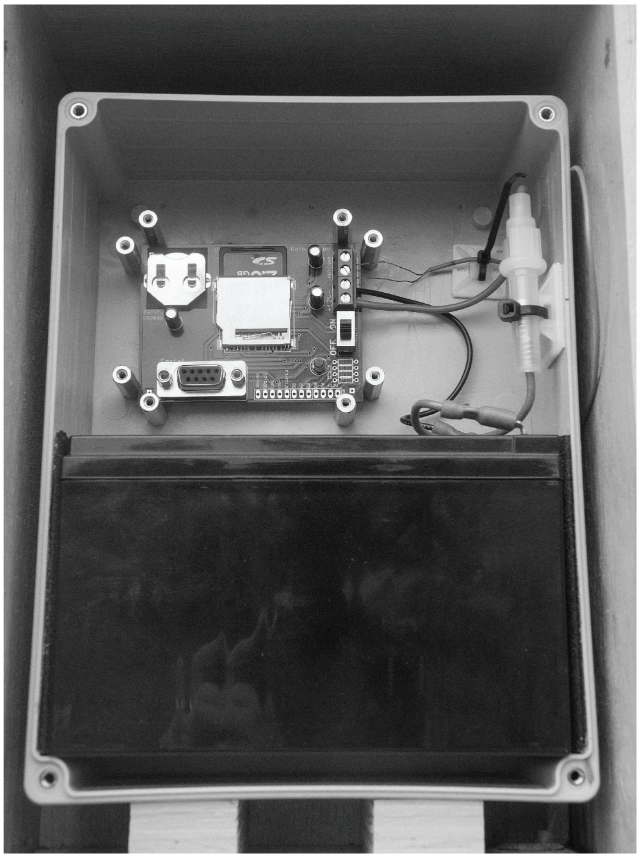

Fig. 3. Radio frequency identification reader and datalogger powered by a sealed lead acid batter inside the RFID datalogger box.

Fig. 4. Cyntag glass passive integrated transponder tag, 2 mm wide and 10 mm long, weighing 0.08 g.

Fig. 5. A passive integrated transponder tag fixed to the back of a Tree Swallow using hypoallergenic nail glue.

Time to save power while the Tree Swallows were inactive. We used 125 kHz Cyntag glass PIT tags that were 2 mm wide and 10 mm long, and weighed 0.80 g (Figure 4). Transponder data were received and read as a line of non-compressed plain text containing the unique RFID code, date and time, and stored to a secure digital (SD) memory card. A 12 V direct-current (DC) sealed lead acid battery with 7.2 amp-hour capacity powered the RFID reader and data logger. Electrical equipment was maintained in the field by changing the batteries once weekly. RFID data were downloaded from the memory cards twice weekly.

Nest boxes were secured approximately 1.5 m above the ground to a 2.4 m length of wooden post. The nest boxes were designed so that the front panel could be opened to remove a tray inside, allowing for ease of access and examination of the nest contents. The base of the tray was approximately the same size as the base of the nest box, and measured 10 cm in height. Each RFID data logger was stored inside a watertight, ABS plastic enclosure and mounted to the back of each post inside a wooden box (Fig. 2). A 0.6 m long cylinder made of 26 AWG galvanized steel ducting was positioned around each post, approximately 0.3 m below the nest box, to prevent predators from climbing up the post and damaging the RFID equipment (Fig. 2).

Nest Box Monitoring

Nest boxes were monitored for three consecutive breeding seasons beginning in 2015. Monitoring began each year in late April to coincide with the start of nest building. During the egg laying period, nest boxes were checked after 09:00 to avoid disturbing female Tree Swallows. Nest boxes were checked two to three times weekly throughout the breeding season. Nest formation, number of eggs and nestlings, and weather conditions were recorded during each nest box check. Hatching and banding dates were anticipated by recording the dates that the first and last eggs were laid. Nest box checks were reduced to twice weekly from 1 to 12 days after the last egg was laid to minimize disruption during incubation. Hatching generally occurred 14 days after the last egg was laid. Nest box checks were then increased to three times weekly until 12 days after hatching, the day nestlings were banded. After banding, nest box checks ceased as not to force premature fledging. Approximately 10 days after banding, nest boxes were checked again to determine the number of fledglings. The number of fledglings was determined by subtracting the number of dead nestlings remaining in the nest from the number banded. Monitoring ended in July each year after all nest boxes were vacated.

Capture and Tagging

Breeding female Tree Swallows were captured in mid to late May each year upon completion of egg laying, in order to minimize the risk of nest abandonment (De Steven 1980, Hussell 1983). Attempts to capture male Tree Swallows began once all eggs had hatched, as they were most likely to be captured while feeding nestlings (Kempenaers *et al*. 2001). A simple wooden trap door was used to capture adult Tree Swallows inside the nest boxes. The door was taped over the entrance of the nest box, propped open with a thin wooden stick and positioned so that it was not visible from the front of the entrance hole. Tree Swallows knocked the stick over as they passed through the entrance hole, thus becoming trapped inside the nest box.

Once removed from the nest box, Tree Swallows were banded on the right leg with a standard size 1 aluminum band, followed by the collection of biometric measurements including wing chord, tail length, and mass. Scores were assigned for fat (0-5), brood patches (0-4), and cloacal protuberances (0-3), according to VARC Banding Station Protocol (VARC n.d.), which is based on the Institute for Bird Populations (IBP) protocol (DeSante *et al*. 2017). Tree Swallows were aged and sexed by breeding characteristics (presence of a brood patch in females or cloacal protuberance in males) and plumage according to criteria outlined by Hussell (1983) and Pyle (1997). The presence of any brown on the head during the breeding season indicated a female, as the upperparts (back, shoulders and head) of males are uniformly blue-green in the spring. Female ages were determined by the percentage of brown plumage on upperparts. Females were aged as second year (SY) if greater than 50% of upperpart plumage was brown and as after second year (ASY) if less than 10% of upperpart plumage was brown. If upperpart plumage was in an intermediate stage, with 50 to 90% iridescent blue-green and the remainder brown or brown-tinged with green, females were aged as after hatch year (AHY). All breeding males with a cloacal protuberance were aged as AHY.

PIT tags were fixed to the downy feathers between the scapulars, halfway down the dorsal surface of the Tree Swallow, using hypoallergenic nail glue (Figure 5). Fixing PIT tags to the downy feathers allowed them to be covered by contour feathers of the back, preventing tag loss by preening or making contact with the nest box entrance hole. All procedures followed requirements outlined by the Canadian Bird Banding Office and Canadian Council on Animal Care.

Data Processing and Analysis

Sections of continuous PIT tag readings resulted when Tree Swallows perched at the entrance hole of the nest boxes. These instances were identified when continuous readings occurred at 6 s intervals, showing that the same individual remained in range of the antenna each time a new poll was initiated. Before determining the number of nest visits by an individual, continuous readings were filtered from compiled data. We acknowledge that this may result in overestimation of the number of daily visits if multiple readings remain that correspond to a single visit. Mean daily start times, end times, and number of visits were compared between females and males using a two-sample *t*-test. Statistical significance was determined with α = 0.01.

Results

Ten RFID-equipped nest boxes recorded 60,989 passages in or out, representing 30,482 nest box visits, between 19 May 2015 and 12 August 2017. Individuals were recorded visiting a nest box up to 247 times in one day. Over the entire study period, the RFID systems amassed over 20,290 hrs of visitation data. Erroneous PIT identification numbers that did not exist in our marked population were identified and discarded, accounting for 2.9% of all post-processed data. Data loss due to battery failure occurred only in the first two weeks of the study period. Once batteries were changed weekly, battery failures no longer occurred. The memory capacities of SD memory cards were never exceeded while data was downloaded twice weekly.

A total of 44 PIT tags were deployed, five of which were replacements for lost tags. Instances of tag loss, possibly due to improper tag placement on the Tree Swallows, resulted in the loss of 10 days of potential data throughout the entire study period. The majority of tag loss occurred in the first season of operation (tag loss rate of 37.5% in 2015). Once the optimal position for tag placement was found, tag and subsequent data loss were minimized (tag loss rates of 6.3% in 2016 and 2017). Six individuals were never again recorded after capture and tagging. These included four adult females, one adult male, and one HY, suspected to be from a nearby colony (800m away) in Colony Farm Regional Park, captured while possibly making extra-nest visits. Tagged Tree Swallows in our nest box colony were recorded making extra-nest visits a total of 292 times, with individuals visiting the same nest up to 58 times in one day.

A total of 39 Tree Swallows were captured in the nest box colony. At the time of capture, 16 (41%) of the Tree Swallows were aged SY, 12 (30.8%) were aged ASY, 12 (30.8%) were aged AHY, and one (2.6%) was a recently fledged hatch year (HY). Captured Tree Swallows included 29 (74.4%) females, 10 (25.6%) males, and two (5.1%) of unknown sex. One adult returned to the nest box colony in all three years of the study period; captured in 2015 as a SY female, she returned to nest in the same nest box in 2016, and a neighboring nest box in 2017.

On average, 77% ± 15% (± SD) out of 10 nest boxes were used each year, with nestlings recorded in 63% ± 12% boxes, and fledglings recorded in 53% ± 15% boxes (Table 1). The mean lay date was 140 ± 6.6 days after the start of the year (20 May), with hatch dates occurring an average of 15.2 ±

1.9 days after the last egg was laid (Table 1). Tree Swallows produced an average of 4.8 ± 1.0 eggs, 4.4 ± 1.2 nestlings, and 3.9 ± 1.0 fledglings per nest (Table 1). Tree Swallows produced fledglings in 73.6% of their first nesting attempts (Table 1). Five nests failed before the eggs hatched: four times due to nest abandonment and once due to death of the female parent (cause unknown). Three nests failed during the nestling stage, in which all nestlings were host to ectoparasites (blowflies, *Protocalliphora* sp., and feather mites, unknown species). One female Tree Swallow attempted nesting a second time after a successful first attempt. The second nesting attempt failed during the nestling stage, and all nestlings were host to ectoparasites. Four new individuals attempted nesting in nest boxes that were vacated by fledglings earlier in the breeding season. All four late nesting attempts were successful in producing fledglings. One male was continuously recorded in two neighbouring nest boxes throughout the nesting period, suggesting that he was provisioning for both broods. During the nesting period, female daily activity began between 03:46 and 15:36 and ceased between 05:45 and 22:58 representing an average of 13.7 ± 3.5 hours of activity per day (Table 2). Male daily activity began between 05:00 and 14:19, and ceased between 05:37 and 21:52, representing an average of 8.2 ± 4.1 hrs of activity per day (Table 2). Mean start times were slightly earlier for females than for males (6:03 ± 1:08 vs. 6:29 ± 1:44, respectively; t = 2.56; df = 136; P = 0.012), and mean end times were significantly later for females than for males (19:40 ± 3:07 vs. 18:57 ± 3:26, respectively; t = 2.81; df = 158; P = 0.006) (Table 2). Generally, females were active for longer periods of the day once hatching occurred, with the longest days of activity occurring when nestlings were 8 to 12 days old (Fig. 6). The shortest period of daily activity occurred the day of fledging, with activity starting approximately 1 hr later and ending approximately 8.5 hrs earlier than the day before fledging (Fig. 6). Average male daily activity fluctuated throughout the nestling period. The shortest period of daily activity occurred the day of fledging (Fig. 6). Although activity started approximately 1.5 hrs earlier than the day before fledging, it ceased approximately 9 hrs earlier than the day before fledging (Fig. 6).

The mean number of daily visits was significantly greater for females than for males (45.6 ± 45.3 vs. 17.0 ± 14.2, respectively; t = 12.26; df = 598; P = <0.001) (Table 2). Average numbers of daily visits made by females increased after the hatch date and generally increased until 6 days before fledging, reaching a maximum when nestlings were 12 days old (27 days after the last egg was laid) (Fig. 7). RFID data show that female and male visits gradually decreased after nestlings reached 10 to 12 days old (25 to 27 days after the last egg was laid), rapidly decreasing by 89.8 and 52.1%, respectively, after the day preceding fledging (Fig. 7). However, Tree Swallows were observed feeding nestlings prior to fledging from outside of the entrance hole, without entering the nest box. Comparing these observations with RFID data showed that the RFID system could not detect feedings from outside of the entrance hole; therefore, the number of visits recorded during the last days before fledging are likely underestimated.

Discussion

Our nest box monitoring results provide an example of the large volume and type of nesting behavior data that can be collected by implementing RFID technology into nest boxes. The data collected allowed us to obtain information on the feeding frequency and provisioning roles of Tree Swallows.

Our results indicate that female Tree Swallows play a significantly greater role in provisioning than males by making more frequent and numerous feeding visits, as found in previous research (Lombardo 1991, McCarty 2002, Whittingham et al. 2003, Ardia 2007, Stanton et al. 2016). Female Tree Swallows have also been shown to remove fecal sacs more frequently than males (Lombardo 1991). Female-biased parental care is often related to foraging conditions, prey abundance, and differing costs and benefits of parental investment between the sexes (Ardia 2007, Stanton et al. 2016). The quality of foraging conditions affects both the frequency and timing of feedings visits. According to Schifferli et al. (2014),

Table 1. Summary of Tree Swallow nest box use and productivity across three breeding seasons (2015-2017) at Colony Farm Regional Park in Coquitlam, BC

Parameter	**Value**
Mean number of nest boxes used (± SD)	7.7 ± 1.5
Mean number of nest boxes with nestlings (± SD)	6.3 ±1.2
Mean number of nest boxes with fledglings (± SD)	5.3 ± 1.5
Mean lay date (days after the start of the year; ± SD)	140 ± 6.6
Mean hatch date (days after the last egg was laid; ± SD)	15.2 ± 1.9
Mean number of eggs per nest (± SD)	4.8 ± 1.0
Mean number of nestlings per nest (± SD)	4.4 ± 1.2
Mean number of fledglings per nest (± SD)	3.9 ± 1.0
Successful first nesting attempts (percentage)	73.6

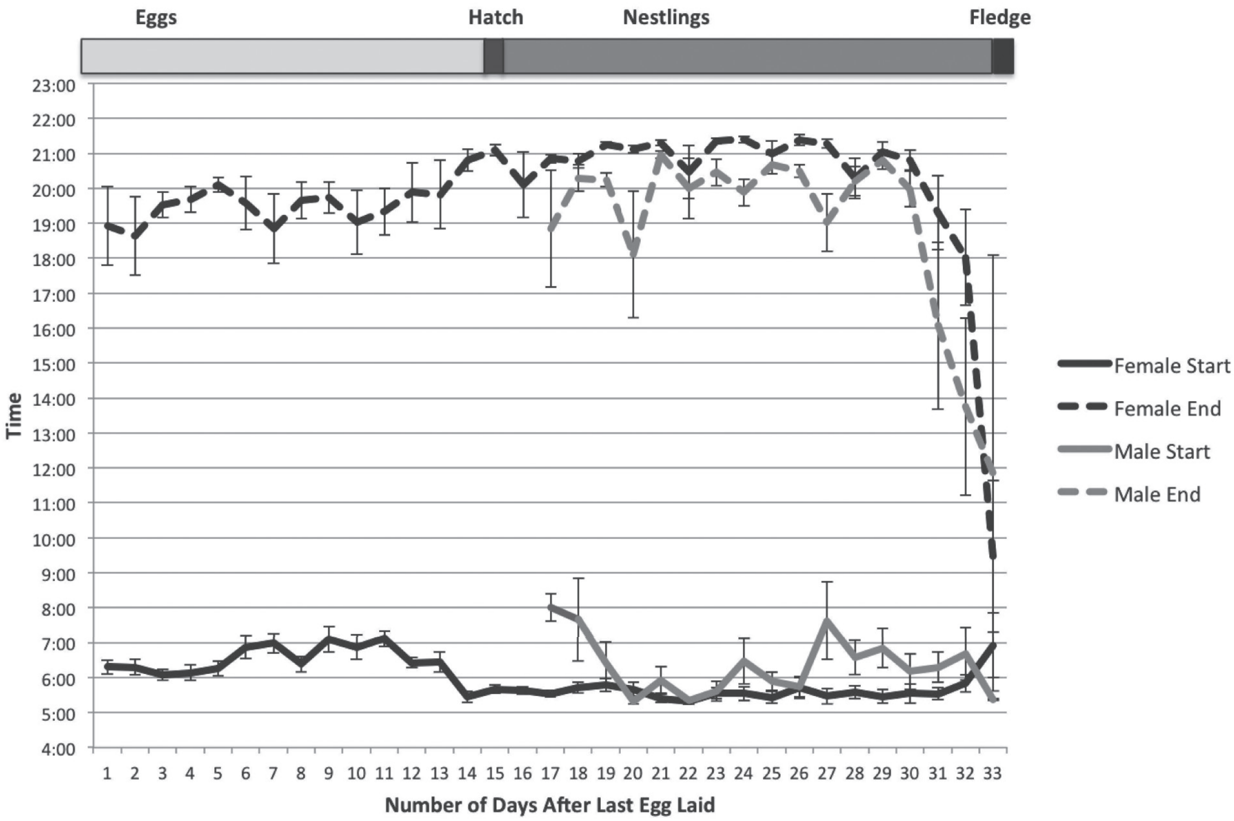

Fig. 6. Average female and male Tree Swallow daily activity start and end times (± SE) from one day after the last egg was laid until the day fledging occurred. Data was pooled from all breeding females and males from 2015-2017.

Table 2. Summary of daily activity and nest visitation data recorded by RFID-equipped nest boxes for female and male Tree Swallows across three breeding seasons (2015-2017) at Colony Farm Regional Park in Coquitlam, BC

Parameter	Female	Male
Mean daily start time (± SD; range)	6:03 ± 1:08 (3:46 – 15:36)	6:29 ± 1:44 (5:00 – 14:19)
Mean daily end time (± SD; range)	19:40 ± 3:07 (5:45 – 22:58)	18:57 ± 3:26 (5:37 – 21:52)
Mean daily activity (hours; ± SD)	13.7 ± 3.5	8.2 ± 4.1
Mean number of daily visits (± SD)	45.6 ± 45.3	17.0 ± 14.2

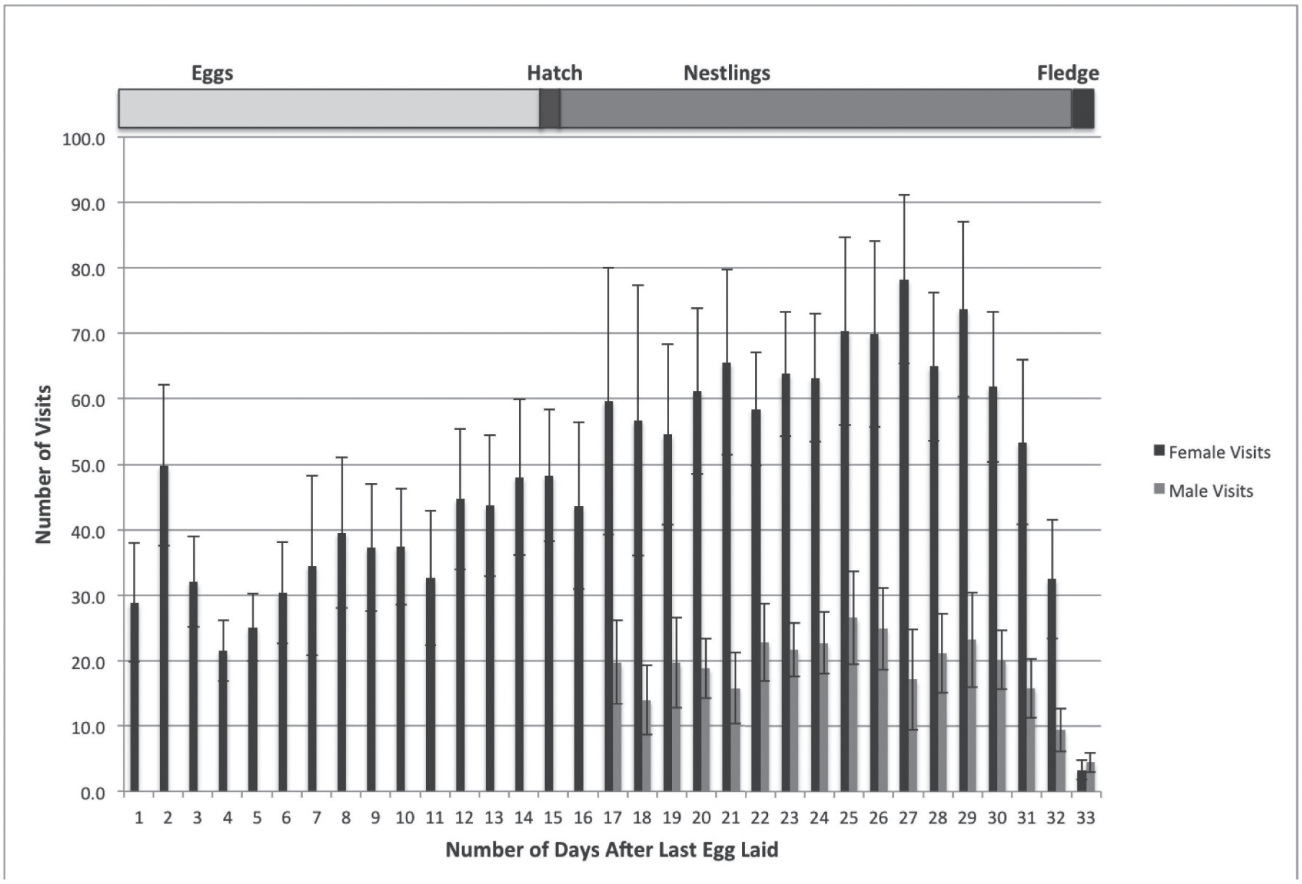

Fig. 7. Average number of daily nest visits (± SE) made by female and male Tree Swallows from one day after the last egg was laid until the day fledging occurred. Data was pooled from all breeding females and males from 2015-2017.

Barn Swallows (*Hirundo rustica*) made more frequent feeding visits under favourable foraging conditions and less frequent feeding visits under poor conditions. Freitag et al. (2001) found that Wrynecks *(Jynx Torquilla)* decreased the number of feeding visits on wet and cold days when prey availability was low. Stanton et al. (2016) suggest that under poor foraging conditions with reduced prey availability, male Tree Swallows may make less feeding visits because they have a greater need to feed themselves, which is supported by the life-history theory that predicts a trade-off between resources allocated to reproduction or body maintenance (McNamara and Houston 1996, Wingfield et al. 1998, Bonier et al. 2009).

The number of feeding visits made by females and males generally increased as nestlings grew and required more frequent feeding, which has previously been documented in Tree Swallows (Whittingham et al. 2003) and other passerines (Gibb 1955, Kluyver 1961, Walsh 1978, Biermann and Sealy 1982). Our results show that for both parents, the number of feeding visits and period of daily activity decrease prior to fledging. Although the number of feeding visits during the last days preceding fledging may be underestimated due to adults feeding outside of the antenna read range, decreased parental feeding visits prior to fledging have been observed in Tree Swallows (Lombardo 1991, Leonard and Horn 1996) as well as other species (Davies 1976, Davies 1978, Bustamante and Hiraldo 1990, Koga and Shiraishi 1994, Gjerdrum 2004, Middleton et al. 2007). Trivers (1974) found parent-offspring conflict can cause parents to manipulate the timing of fledging when nestlings have been in the nest for a period of time longer than optimal. Other tactics to encourage fledging include passing close to the nest or within view of nestlings with food, to cause them to jump out of the nest in order to retrieve it (Meinertzhagen 1954, Rowan 1955, Bustamante and Hiraldo 1990).

RFID recordings also allowed us to detect extra nest visits by one male. This represents a case of social or behavioral polygyny in the nest box colony; without DNA testing to assess paternity it is unknown if genetic polygyny also occurred. While they are socially monogamous, Tree Swallows commonly engage in extra-pair copulations (Quinney 1983, Dunn et al. 1994, Kempenaers et al. 2001) and have one of the highest rates of extra-pair paternity among bird species. Barber et al. (1996) reported 38-69% of Tree Swallow nestlings have extra-pair paternity and Kempenaers et al. (2001) found congruent results Despite the frequency of extra-pair paternity, few researchers have observed male Tree Swallows provisioning broods in multiple nest boxes. De Steven (1980) trapped several individual males provisioning for two different nests, usually at adjacent nest boxes. Kempenaers et al. (2001) observed one male provisioning for two neighboring nest boxes during 2 h of observation time. The male was known to have copulated with the females in both nest boxes but did not father any of the offspring

Our RFID-equipped nest boxes successfully automated and recorded Tree Swallow nesting behavior in Colony Farm Regional Park, yielding over 20,290 h of visitation data from 39 individuals with an expenditure of approximately 7 h of human labor per week (6 h of field work and 1 h of data management) over three consecutive breeding seasons. The use of this system allowed us to obtain a volume of data that would not have been possible by visual observation alone, while minimizing disturbance to nesting Tree Swallows by eliminating the need for repeated capture and handling, at a relatively low cost, and without data lost to weather conditions or predators.

While other researchers have identified high costs of electronic equipment as a limiting factor in the use of RFID technology, we were able to assemble each RFID-equipped nest box, including all RFID system and nest box components for approximately CAD$100 each. PIT tags cost CAD$2 each. In comparison, transceivers used by Brewer et al. (2011) cost approximately USD$2,850 each, and each PIT reader and antenna used by Zangmeister et al. (2009) cost US$2,800.

Design features of this RFID-equipped nest box prevented common causes of data loss in the field. Use of the watertight enclosure prevented any data loss resulting from moisture-caused damage to RFID equipment, which has been identified as a cause of system failure by other researchers using RFID equipment at nest sites (Taylor et al. 2012) and feeders (Bridge and Bonter 2011). Installing the predator guards and housing the RFID data loggers inside wooden boxes mounted securely to wooden posts prevented common predators such as the ermine (*Mustela erminea*), long-tailed weasel (*Mustela frenata*), and American black bear (*Ursus americanus*) from damaging RFID equipment. Prior to this study, American black bears were known to damage or destroy nest boxes in Colony Farm Regional Park. Although a bear scratched the side of a nest box on one occasion during the study period, no damage was done to the RFID system.

While erroneous PIT tag numbers were read at a rate of 2.9%, this error rate is still lower than human observer error rates (5-16%) in visually identifying coloured leg bands on wild birds (Milligan *et al*. 2003). Bridge and Bonter (2011) suggest that erroneous PIT tag readings are a result of data transmission errors associated with the serial communication interface. Although the RFID reader carries out error checking during PIT tag identification, reading errors can still occur.

The method of external tag placement used in this study was advantageous as the procedure was quick, simple, and non-invasive compared with methods of internal tag placement such as subcutaneous and intra-peritoneal implantation. Subcutaneous implantation has been used frequently in ornithological RFID applications in penguins (Ainley et al. 1998; Descamps et al. 2009), passerines (Nicolaus *et al.* 2008), and hummingbirds (Brewer et al. 2011). One advantage of internal tag placement is that the risk of tag loss is negligible (Nicolaus et al. 2008). However, Bridge and Bonter (2011) recommend external tag placement in RFID application with small birds as it maintains the tag in a predictable location and requires fewer wildlife permits. Internally placed PIT tags can shift in position inside the animal (Becker and Wendeln 1997, Gheorghiu *et al*. 2010), which could reduce successful tag detection (Bonter and Bridge 2011) and cause difficulty in optimizing reader antenna configuration (Bridge and Bonter 2011). Subcutaneous and intra-peritoneal implantation have also been known to cause adverse effects in tagged birds (Oswald *et al*. 2018). Externally positioned PIT tags were consistently read by the RFID system, and once the optimal position on the Tree Swallow's dorsal surface was determined, the rate of tag loss was reduced to only once per year in the last two years of the study (6.3%). In a study where tagged individuals are frequently visiting a nest box colony and data is managed weekly, it is easy to detect instances of tag loss early and recapture individuals if necessary. The externally placed PIT tags are known to fall off during molting, eliminating any concerns of long-term adverse effects related to PIT tags, especially those inserted subcutaneously. Tags were not incorporated into the Federal leg band due to the short tibiotarsi of Tree Swallows.

After the first year of operation, two improvements were made to the RFID system to improve data collection. We suspected that some data was lost due to the RFID system missing readings as tagged birds entered or exited the nest boxes. A 28 AWG magnet wire was used in the antenna coil in the first year of operation. We compared visual observations from video recording with RFID readings for a nest box with a 28 AWG magnet wire and a nest box with a 26 AWG magnet wire. The larger gauge wire offering less resistance (26 AWG) had a greater capability to detect tagged birds and was implemented into all nest boxes the following year. Visual observations in the first year of operation were used to find optimal polling settings. Polling cycle time was adjusted from 9 to 5 s so that the polling and pausing cycle occurred at intervals of 6 s (instead of 10 s), thereby reducing the possibility of the RFID system missing the exit of a Tree Swallow visiting the nest box for less than 10 s.

A limitation associated with RFID technology, as identified by other researchers (Freitag *et al*. 2001, Bridge and Bonter 2011, Bonter and Bridge 2011, Lendvai et al. 2015), is that it cannot identify the behaviour occurring during a visit, whether each visit corresponds to feeding, brooding, copulating, or defense. Lendvai et al. (2015) validated that the benefits of RFID technology outweigh this limitation when used to answer particular scientific questions, such as quantifying the feeding rates of nest box breeding birds. Since Tree Swallows are known to feed nestlings during 95-98% of visits to the nest (McCarty 2002, Whittingham et al. 2003), we made the assumption that all nest box visits made by known parents were feeding visits, and acknowledged that the number of feeding visits may be overestimated. In a study on the feeding activity of nesting Wrynecks, Freitag et al. (2001) dealt with this limitation by assuming all recorded visits were feeding visits after eliminating consecutive readings with intervals of less than 60 s for each individual.

The potential exists to combine RFID-equipped nest boxes with other technology and data to address additional scientific questions about the nesting behavior of Tree Swallows at Colony Farm Regional Park in Coquitlam, BC. RFID data providing information on parental provisioning rates could be combined with DNA fingerprinting to determine paternity within the colony and better understand the effects of sexual selection and extra-pair copulation on parental provisioning and reproductive success. Other factors likely influencing parental provisioning rates could also be explored, such as aerial insect abundance and weather conditions throughout the breeding season. The RFID system developed in this study has great potential to be used for other research studies where the individual identification of subjects is required without the necessity of recapturing each bird, or other animal, each time. This greatly reduces any stress placed on the animal and all the effort required to catch individuals more than once. The system is relatively affordable, easy to use and the tags small enough to be used on the smallest of birds or other small animals. It allows large amounts of data to be collected efficiently and economically as long as the test subject returns to a fixed location. In this study, tag placement was temporary, but the tag could, for many birds, be incorporated into a leg band to allow long term data collection, making this system applicable for a diversity of field studies.

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