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A low-cost radio frequency identification device for ornithological research

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ABSTRACT. Radio frequency identification (RFID) technology can be used to implement automated bird-monitoring systems and, therefore, could be of use to field ornithologists. However, the cost of a large-scale RFID network can be prohibitive for those with limited research budgets. We describe a simple RFID reader/data logger that can be constructed for less than $40 (excluding tools and a battery). This device can be mounted on birdfeeders, nest boxes, nests, or any location repeatedly visited by birds fitted with small RFID tags (i.e., passive integrated transponder or PIT tags). To demonstrate the potential of this low-cost RFID reader, we monitored the use of feeders by wintering songbirds in central New York and generated a data set consisting of more than 500,000 feeder visits over 5 mo. These data revealed several interesting behaviors, including high visitation rates by some individuals (>200 visits per day), long-distance movements between feeders (emigration and immigration), and species-specific patterns of feeder use. Although the system performed well in relatively harsh winter conditions, occasional battery failures and water damage led to some loss of data. Nevertheless, we amassed over 8000 h of monitoring by investing approximately 6 h of labor per week. In addition to recording tag numbers and time stamps, the RFID reader can interface with sensors and actuators, permitting the collection of additional data (such as body mass) and allowing control of motors or solenoids to interact with targeted individuals. RFID technology has great potential for use in a variety of ornithological studies, and we hope our device helps make this technology more accessible.

RESUMEN. **Un aparato de identificación de frecuencia (RFID) de bajo costo para la investigación ornitológica**

La tecnología de identificación de radio frecuencia (RFID) puede ser utilizada para implementar sistemas de monitoreo automáticos, y por tanto puede ser de uso para los ornitólogos de campo. Sin embargo, el costo de una red a larga escala de RFID puede ser prohibitivo para aquellos con limitaciones en su presupuesto. Describimos un lector y recopilador de datos RFID que puede ser construido con menos de $40 (incluyendo los instrumentos y la batería). Este aparato puede ser montado en plataformas de alimentación, cajas de anidamiento, nidos o en cualquier localidad que sea visitada con frecuencia por aves a las cuales se les ha montado un pequeño recopilador pasivo integrado (PIT tag). Para demostrar el potencial de este lector RFID de bajo costo, monitoreamos el uso de comederos, por parte de aves canoras invernales en la parte central de Nueva York, y generamos un conjunto de datos que consistió de más de 500,000 visitas a comederos en un periodo de cinco meses. Estos datos revelaron algunos patrones de conducta sumamente interesantes, incluyendo altas tasas de visitas (>200 visitas al día) por algunos individuos, movimientos a larga distancia entre comederos (emigración e inmigración) y patrones específicos de uso por algunas especies. Aunque el sistema trabajo muy bien bajo las condiciones extremas invernales, ocasionalmente las baterías fallaron y hubo daño producidos por el agua que causaron que se perdieran algunos datos. Sin embargo, obtuvimos mas de 8000 horas de monitoreo invirtiendo aproximadamente seis horas de labor/semana. Además de detectar el número del marcador, y periodos de tiempo, el RFID puede hacer interfase con censores, lo que permite tomar datos adicionales (como masa corporal). Esto hace factible el control de motores o solenoides y la interacción con individuos particulares. La tecnología RFID, tiene un gran potencial de uso en una amplia variedad de estudios ornitológicos y esperamos que nuestros aparatos permitan hacer esta tecnología más accesible.

Key words: bird feeder, feeder use, monitoring equipment, passive integrated transponder, PIT tag, RFID

Radio frequency identification (RFID) technology is a simple means of contact-free electromagnetic communication between a reader or interrogator and a transponder that can be attached to an object, person, or animal. RFID systems permit identification of individual tags via transmission of a unique code from the tag to the reader. Because RFID tags can be small (<0.1 g) and have a long operational life (theoretically unlimited), RFID systems can be very useful in studies of wild birds (Nicolaus et al. 2008, Bonter and Bridge 2011). Unfortunately, RFID readers generally cost hundreds or

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thousands of dollars (Becker and Wendeln 1997, Boisvert and Sherry 2000, Jamison et al. 2000), limiting accessibility to RFID systems for some ornithologists. Investigators with limited funds or those who need a large number of readers would benefit greatly from an inexpensive reader suitable for ornithological research.

Here, we describe a small, low-cost RFID reader with data-logging capability as well as some capacity to integrate sensors and actuators. To demonstrate the utility of this device, we describe a large data set generated by seven readers mounted on bird feeders in central New York State. Our objective was to test the low-cost RFID reader as a data collection platform for examining broader questions about the survival, feeding behavior, and caching behavior of wild birds.

We describe the basic functionality of the reader in terms of its capabilities and limitations. For those wishing to build the device, we have generated a schematic, graphic renderings, a parts list, and circuit-board images as online supporting documents (Supporting Figs. S1 and S2, Supporting Table S1). We have also established an open-access website (www.animalmigration.org/RFID/CheapRFID.htm) with further instructions for assembly and operation as well as relevant contact information for vendors and assembly companies. Electronics manufacturers can be contracted to build this device in moderate numbers at a cost of about US$40 per unit. With minor assembly effort on the part of the end user, this cost can be reduced even more.

THE RFID READER

The core components of the reader are an RFID module (UB22270, Atmel Corporation, San Jose, CA), a microprocessor (PIC16F688, Microchip Inc., Chandler, AZ), a memory module (24LC512, Microchip Inc.), and a real-time clock (DS1307, Maxim Integrated Products, Sunnyvale, CA; Fig. 1; Supporting Figs. S1 and S2; Supporting Table S1). The microcontroller communicates with the other major components to create a data-logging scheme where date, time, and RFID code are stored each time a tag enters the read range of the device. More specifically, the microprocessor turns the RFID module on for short periods of time to "probe" for the presence of an RFID tag. If no tag is read, the reader checks the battery level, pauses briefly, and then initiates another probe. If a

Fig. 1. Photo of completed circuit board mounted inside the lid of a waterproof 180-ml container (Lock N Lock, Blacktown NSW, Australia). Circuit board dimensions are approximately 80 mm × 60 mm.

tag is read, then the microprocessor obtains a date and time from the real-time clock and stores a line of compressed data in the memory unit.

User-programmable features allow the device to be customized for a variety of research objectives. Perhaps most important is the ability to adjust the read time (i.e., how long the RFID module probes for a tag) and the pause time (i.e., time between reading attempts). Increasing read time and decreasing pause time makes it less likely that a tag will be missed at the expense of increased power consumption. Hence, careful selection of an appropriate read time and pause time, both of which can vary from about 100 ms to 1 min, allows researchers to strike a balance between reader sensitivity and battery life. Users can also adjust how often the reader records repeated readings of the same tag. This feature is useful for conserving data memory when a single bird tends to remain within read range for an extended period, for example, a bird sitting on a feeder for several minutes or a bird incubating on a nest for several hours. Additionally, those studying diurnal species can schedule a daily "sleep" period to allow the reader to conserve power at night. The reader can also be programmed to shut down when the battery voltage drops below a user-defined threshold. Because the performance of the reader is not well documented at low voltage levels (i.e., below 10 V), it may be preferable to have the unit shut down when a battery is partially depleted rather than remain on and potentially miss an unknown number of tags passing through the normal read range. When a low-voltage shutdown occurs, the reader logs the date and time along with a special ID code ("BFBFBFBFBF") that indicates battery failure.

Our general-purpose RFID reader operates at a low frequency (125 kHz) and, like most other low-frequency systems, has a read range of ≤10 cm using small (2 mm × 12 mm) glass-ampoule RFID tags (i.e., passive integrated transponders or PIT tags). Higher-power systems with greater read ranges are available, but greater range increases the complexity and cost of a reader. Read range will vary greatly depending on the orientation of tags with respect to the reader's antenna and on the size and shape of the reader's antenna coil. Typically, read range is greatest for round antennas with a diameter of about 12 cm and when the long axis of a tag is either parallel or perpendicular to the antenna coil (details in Finkenzeller 1999). However, we tested antennas of various sizes and shapes with the reader, and the effects of size and shape were minimal. Finally, our low-cost system cannot read more than one tag at a time. For a list of the capabilities and limitations of our reader, see Table 1.

The reader requires a power source ranging from 10 to 16 V. A 12-V sealed lead-acid battery with a 5-amp-hour capacity permits up to 2 weeks of logging, depending on user settings (but see Results and Discussion below).

Table 1. Capabilities and limitations of the low-cost RFID reader design.

Capabilities
Modular in terms of housing, battery, and antenna configuration
Can adjust setting to balance reader receptivity and battery life
Serial communication with computers and handheld devices
Can enter a power-saving sleep mode at night
512 Mbit memory (7000 reading events) with some capacity for expansion
Several unused input/output pins for integration with sensors and actuators
Battery-level monitoring, and automatic shutdown when battery voltage is low
Operates on almost any DC power source between 10 and 16 V
Limitations
Read range is ≤10 cm and depends on antenna design and tag orientation; monitoring only possible at locations repeatedly and reliably visited by focal birds
Cannot read tags when more than one is present in the read range
Downloading data can take up to 15 min if memory is nearly full
At present, only compatible with transponders that follow the EM4100 protocol[1]
Antenna cannot be located near large metal objects (metal interferes with RFID communication)

[1]See www.animalmigration.org/RFID/CheapRFID.htm for details about compatible tags and updates on new capabilities.

A battery attached to a solar cell could permit continuous logging for several months (or for as long as memory remains available). In addition to the battery, users must also provide some type of waterproof housing for outdoor use and an antenna coil with an inductance of 1.35 mH (see Finkenzeller 1999). Antennas can be made by tightly coiling enameled wire (magnet wire) until the desired inductance is achieved, or they can be purchased from numerous vendors (e.g., Intersoft Corporation, Tullahoma, TN).

Setting user-defined parameters and downloading data from the reader requires a simple RS232 interface that can be established directly with some computers and hand-held devices or by means of a serial-to-USB cable. By entering one-letter commands and numerical values, users can set the clock, establish reading parameters, schedule the night-time sleep mode, and initiate a memory download. Data stored on the reader are decompressed and transmitted as easily interpreted lines of text, with one line for each reading event that provides the tag ID code and associated date and time. The text output is space-delimited and can easily be read into spreadsheets, databases, or statistical programs.

TESTING

We deployed seven low-cost RFID reader prototypes in Tompkins and Cortland counties, New York, from November 2009 to April 2010. Beginning on 30 October 2009, we captured and attached PIT tags to 70 Black-capped Chickadees (*Poecile atricapillus*), 20 Tufted Titmice (*Baeolophous bicolor*), 13 White-breasted Nuthatches (*Sitta carolinensis*), and 18 House Finches (*Carpodacus mexicanus*). One PIT tag was attached to each bird by wrapping all-weather electrician's tape around the tag and two celluloid leg bands (Fig. 2). A USGS aluminum leg band and a third celluloid leg band were attached to the opposite leg. RFID readers were attached to custom-made bird feeders constructed of PVC pipe and wooden dowel, and the antenna coil was attached to a perch used by birds to access food (Fig. 2). The perch allowed only one bird at a time to take food, helping to ensure that the reader did not encounter multiple tags simultaneously.

Fig. 2. Black-capped Chickadee with an RFID leg band using a feeder equipped with the low-cost RFID reader. The RFID antenna is located on top of two pieces of wooden dowel extending from the PVC feeder housing. The RFID reader and battery (not visible) are housed in a container attached to the bottom of the feeder. Photo, courtesy K. J. McGowan.

Feeders were suspended between trees by a metal cable and raised 2–3 m above ground level to deter pilferage and damage by white-tailed deer (*Odocoileus virginianus*) and squirrels (Sciuridae). Readers were visited twice weekly to refill feeders with seeds and download data. Batteries were changed weekly. Feeders were continuously filled with black oil sunflower seeds.

RESULTS

The seven RFID feeder systems recorded 524,772 visits by tagged birds between 1 November 2009 and 15 April 2010. Individual birds were recorded visiting RFID feeders up to 203 times per day. We occasionally ($<$0.3% of all recorded visits) encountered PIT identification numbers that did not exist in our marked population and do not know if this was due to reader error or data-transfer error during downloading.

Readers were fully operational for 751 of 973 total possible days of operation. Equipment failures were due primarily to battery failure ($N = 70$ d), water damage to circuitry ($N = 35$ d), antenna damage caused by mammals including white-tailed deer and squirrels ($N = 57$ d), and exceeding the memory capacity of the readers ($N = 22$ d). No failures due to memory limitations occurred after capacity of all readers was doubled in late December 2009.

Not all tagged birds were subsequently recorded by an RFID system, with 59 of 70 (84.3%) Black-capped Chickadees, 18 of 20 (90.0%) Tufted Titmice, 9 of 13 (69.2%) White-breasted Nuthatches, and 8 of 18 (44.4%) House Finches recorded at least once 1 d after tagging. Although tag loss was possible, failure to record tags likely meant that those individuals either died or emigrated from the study area. Between November 2009 and April 2010, we recaptured 40 previously tagged birds and detected no tag loss.

Evidence of emigration from study sites was provided by some birds that moved hundreds of meters between RFID systems, usually abandoning the initial banding location altogether. For example, one titmouse moved 990 m between three different feeding stations over 3 mo before apparently leaving the study area. A Black-capped Chickadee was consistently recorded at one RFID station for more than 2 mo before disappearing and reappearing intermittently at a different RFID station located 600 m from the initial banding location.

Despite a few movements by tagged birds between study locations, birds in one small, isolated woodlot containing four RFID readers showed remarkable fidelity to one or two feeding locations. Published winter range size estimates range from 9.5 to 14.6 ha for Black-capped Chickadees (Smith 1993) and 5.8 to 14.6 ha for Tufted Titmice (Grubb and Pravosudov 1994). Our woodlot was 14.7 ha in size, and the maximum distance between feeders was 550 m. Although multiple feeders were likely located within the territory of each winter flock, individuals nearly always visited one feeding location, with fewer visits made to one or two additional locations. Only 8 of 33 tagged birds (24.2%) visited all four feeding locations, suggesting that winter movements by these species were restricted.

Differences in feeder use resulted in species-specific patterns of visitation recorded by the RFID systems. For example, chickadees, titmice, and nuthatches tended to make brief visits ($<$5 s) to feeders, taking seeds, and then leaving to consume or cache them. This behavior resulted in RFID reads with $>$30 s between repeated records of the same individual. In contrast, House Finches tended to remain at feeders for extended periods, resulting in multiple data captures per visit. Most feeder visits (76%) by House Finches lasted more than 30 s.

To determine the biological meaning of a "visit" recorded by an RFID system, observations were conducted at one feeding station over 3 d. These observations revealed that 223 of 275 visits (81.1%) by tagged Black-capped Chickadees resulted in the marked bird leaving the feeder with a seed. Most failed feeding attempts resulted from behavioral interactions (i.e., displacement by another bird) before a seed could be obtained. We obtained no observational data for the other species studied.

DISCUSSION

Performance. Our RFID system generated 8291 h of information about the supplemental feeding behavior of 121 birds in approximately 5 h of field time and 1 h of database management per week. As such, the volume of data generated on a large sample of birds is unparalleled by traditional observational methods. Indeed, managing the volume of data can be one of the challenges and potential drawbacks of such a system.

The few identification errors were likely due to data transmission errors associated with the serial communication interface. Considerable error checking is carried out during tag ID acquisition, making misreads unlikely, but still possible. Despite these errors, the misidentification rate of less than 0.3% is considerably lower than error rates of humans visually identifying colored leg bands (5%–16%; Milligan et al. 2003).

Battery failure led to considerable loss of data during our study and deserves attention in future uses of RFID technology (Cresswell et al. 2003). Our 12-V, 5.5-amp-hour rechargeable, lead-acid batteries often performed well for 7–8 d between charges, but performance deteriorated with battery age and at cold temperatures (temperatures ranged from −22°C to 14°C during testing). Where possible, continuous charging of batteries in the field with photovoltaic devices would be an optimal approach to avoid loss of data due to power failures, and this approach has been used successfully with RFID technology in previous studies (Boarman et al. 1998, Boersma and Rebstock 2009).

Another significant cause of data loss included damage to the RFID circuit boards caused by water infiltrating the component housing. Quite simply, the circuit boards must be kept dry. Investment in high-quality weather-proof housings is advisable and cost effective over time.

We did not attempt to evaluate the optimal balance between read time and pause time. However, knowing the optimal setting for a particular situation is of little use given that circumstances will likely differ among studies. Hence, common sense, observational data, and, perhaps, some trial and error will best guide the selection of appropriate read and pause times.

Tag attachment. We used electrician's tape to attach PIT tags to leg bands. We initially attached tags to celluloid leg bands with Super Glue (Super Glue Corp., Rancho Cucamonga, CA), but this resulted in tag loss and made the bands brittle over time. The glass-ampoule tags that work with the reader can be implanted, and implantation is often used in RFID applications (Ainley et al. 1998, Nicolaus et al. 2008, Descamps et al. 2009). However, we advise against implantation, particularly for small birds, because: (1) external attachment requires fewer wildlife permits (implantation is considered a surgical procedure, whereas attaching RFID leg bands in the United States only requires a banding permit with a provision for supplementary markers), and (2) the position of internal tags may shift in a manner that changes their location or orientation inside a tagged animal (Becker and Wendeln 1997, Gheorghiu et al. 2010, but see Nicolaus et al. 2008). If the location and orientation of the tag is not predictable, then optimizing the reader antenna configuration is difficult. External placement, especially when attached to leg bands, maintains the tag in a predictable location and orientation with respect to a perched bird, making optimal antenna arrangements easier to achieve. Also, with external tags, visually confirming that RFID tags have not been lost is easy.

Subsequent to our field testing, we developed a simple method of preparing RFID leg bands that can be applied to birds of almost any size. The process involves encapsulating an RFID within a short section of 3.2-mm (1/8-inch) PVC heat-shrink tubing (Electro Insulation Corporation, Arlington Heights, IL). Then, a second piece of heat shrink (with an appropriate diameter) is shrunk down to fit a cylindrical template (such as a piece of wire) that corresponds to the desired inner diameter of the leg band. The encapsulated RFID tag is then glued to the other piece of tubing using Weld-on 4784 adhesive (IPS Corporation, Compton, CA). Next, the "band" gets split on the side opposite the RFID tag, and a new split section of leg-band material is glued onto one side of the first, such that the second piece of shrink tubing overlaps the split in the leg band, but does not yet close the loop. After trimming excess heat-shrink material with a razor blade, the tag is ready to deploy by placing it on a bird's leg and gluing the overlapping heat-shrink material (see Fig. 3).

Potential uses. Our results confirm that the RFID reader can be used on bird feeders. Feeders that do not have metal parts (metal interferes with RFID communication) and only allow one bird to perch at a time will be most effective with this or any other RFID system. We believe our low-cost RFID system could also be used on nest boxes to monitor nest attendance, provisioning, and fledging (Freitag et al. 2001, Wilkin et al. 2009). Similar studies are possible

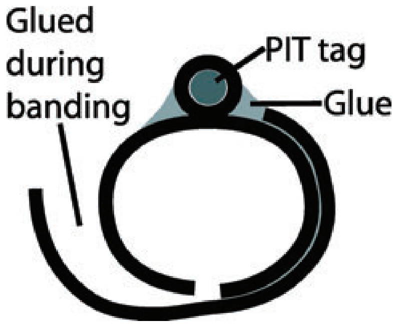

Fig. 3. Cross-sectional drawing of an RFID leg band constructed from heat-shrink tubing and PVC adhesive.

on open-cup nests if there is evidence that the species to be studied will not abandon a nest equipped with an RFID antenna coil.

Because it is possible to integrate external sensors and actuators with the reader's microprocessor, collecting data in addition to dates, times, and RFID codes would be possible. For example, a balance consisting of a strain-gauge array and an instrumentation amplifier (see Poole 1982, Reid 1986) could be constructed to allow the reader to measure the mass of a bird sitting on a perch (e.g., MacLeod and Gosler 2006). Alternatively, output pins from the microprocessor could be exploited to control a motor or solenoid that might dispense food, open a door, or activate some sort of stimulus. By combining inputs and outputs, the reader could be configured to detect an action by a research subject (i.e., depressing a button) and respond by producing a food reward or a startle stimulus. Given this capability to sense and interact with the research environment, we see great potential for our low-cost reader beyond simply monitoring feeding or provisioning rates.

We note that there are several general limitations associated with RFID monitoring. For example, RFID technology alone cannot distinguish death from emigration, and tag detections may only be useful when presence in a particular time and place has meaning, for example, showing feeder use, nest attendance, or association with another individual. Furthermore, RFID data may require certain assumptions. For example, with RFID data collected at a birdfeeder, we might assume that a visit constitutes use of the food resource as opposed to a fortuitous choice of a perching location. Nevertheless, in the right research contexts, RFID technology can generate an unprecedented amount of data with a relatively small investment of labor, and we hope that the versatility and low cost of our reader design will facilitate RFID monitoring in a variety of ornithological investigations.

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LITERATURE CITED

Ainley, D. G., P. R. Wilson, K. J. Barton, G. Ballard, N. Nur, and B. Karl. 1998. Diet and foraging effort of Adélie Penguins in relation to pack-ice conditions in the southern Ross Sea. Polar Biology 20: 311–319.

Becker, P. H., and H. Wendeln. 1997. A new application for transponders in population ecology of the Common Tern. Condor 99: 534–538.

Boarman, W. I., M. L. Beigel, G. C. Goodlett, and M. Sazaki. 1998. A passive integrated transponder system for tracking animal movements. Wildlife Society Bulletin 26: 886–891.

Boersma, P. D., and G. A. Rebstock. 2009. Flipper bands do not affect foraging-trip duration of Magellanic Penguins. Journal of Field Ornithology 80: 408–418.

Boisvert, M. J., and D. F. Sherry. 2000. A system for the automated recording of feeding behavior and body weight. Physiology & Behavior 71: 147–151.

Bonter, D. N., and E. S. Bridge. 2011. Applications of radio frequency identification (RFID) in ornithological research: a review. Journal of Field Ornithology 82: xx–xx.

Cresswell, W., S. Holt, J. M. Reid, D. P. Whitfield, and R. J. Mellanby. 2003. Do energetic demands constrain incubation scheduling in a biparental species? Behavioral Ecology 14: 97–102.

Descamps, S., C. Le Bohec, Y. Le Maho, J. P. Gendner, and M. Gauthier-Clerc. 2009. Relating demographic performance to breeding-site location in the King Penguin. Condor 111: 81–87.

Finkenzeller, K. 1999. RFID handbook: radio-frequency identification fundamentals and applications. Wiley, Chichester, UK.

Freitag, A., A. Martinoli, and J. Urzelai. 2001. Monitoring the feeding activity of nesting birds with an autonomous system: case study of the endangered Wryneck *Jynx torquilla*. Bird Study 48: 102–109.

GHEORGHIU, C., J. HANNA, J. W. SMITH, D. S. SMITH, AND M. P. WILKIE. 2010. Encapsulation and migration of PIT tags implanted in brown trout (*Salmo trutta* L.). Aquaculture 298: 350–353.

GRUBB, T. C., JR., AND V. V. PRAVOSUDOV. 1994. Tufted Titmouse (*Baeolophus bicolor*). In: The Birds of North America Online (A. Poole, ed.). Cornell Lab of Ornithology, Ithaca, NY.

JAMISON, B. E., R. S. BEYER, R. J. ROBEL, AND J. S. PONTIUS. 2000. Passive integrated transponder tags as markers for chicks. Poultry Science 79: 946–948.

MACLEOD, R., AND A. G. GOSLER. 2006. Capture and mass change: perceived predation risk or interrupted foraging? Animal Behaviour 71: 1081–1087.

MILLIGAN, J. L., A. K. DAVIS, AND S. M. ALTIZER. 2003. Errors associated with using colored leg bands to identify wild birds. Journal of Field Ornithology 74: 111–118.

NICOLAUS, M., K. M. BOUWMAN, AND N. J. DINGEMANSE. 2008. Effect of PIT tags on the survival and recruitment of Great Tits *Parus major*. Ardea 96: 286–292.

POOLE, A. 1982. A scale for weighing birds at habitual perches. Journal of Field Ornithology 53: 409–414.

REID, W. V. 1986. An inexpensive electronic balance and data recording system. Journal of Field Ornithology 57: 60–62.

SMITH, S. M. 1993. Black-capped Chickadee (*Poecile atricapillus*). In: The Birds of North America Online (A. Poole, ed.). Cornell Lab of Ornithology, Ithaca, NY.

WILKIN, T. A., L. E. KING, AND B. C. SHELDON. 2009. Habitat quality, nestling diet, and provisioning behaviour in Great Tits *Parus major*. Journal of Avian Biology 40: 135–145.

Supporting Information

The following supporting information is available for this article online:

Fig. S1. Schematic of RFID reader. See parts list for details about each component.

Fig. S2. Three-dimensional renderings of top (left) and bottom (right) sides of the fully assembled RFID circuit board with parts labeled.

Table S1. Complete parts list for RFID reader including optional parts.

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