Monitoring the feeding activity of nesting birds with an autonomous system: the case study of the endangered Wryneck *Jynx Torquilla*

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This paper describes an original autonomous system based on the Passive Integrated Transponder (PIT) technology for monitoring the feeding activity of small birds at their nest. It is installed on pre-existing nest boxes which were slightly modified for the monitoring purposes. The system operates autonomously for at least 7 days and recorded data can be collected using a simple pocket calculator or a standard laptop. The monitoring capabilities of the system include the arrival times of each adult, tagged with a PIT attached to one leg, and the regular collecting of microclimatic data. In the present study, the internal and external temperatures of the nest were recorded. The autonomous system was validated during two weeks as part of a more extended study on Wryneck (*Jynx torquilla* L.) foraging strategies. Its efficacy was confirmed by comparison with conventional photographs of birds at each feeding and climatic station data. The autonomous system allows researchers to collect good quality and quantities of data with a minimal disturbance of birds' behaviour. Results obtained with this system show that brood size, temperature, precipitation and time of day influence the feeding rate of Wrynecks.

In ornithology, many studies of feeding behaviour or foraging strategies rely on the monitoring of bird activity rhythms (Biermann & Sealy, 1982; Hutto, 1981; Johnson & Best, 1982). The record of feeding frequency during nestling period leads to a greater understanding of the foraging strategies and of the effort made by the parents to raise their young, as well as to a better identification of the factors which might affect birds' activity.

Different methods can be used to monitor activity at the nest: direct observation from a hide (Pfeifer & Keil, 1962), use of a mechanical device (Kluyver, 1961), photography or video recording of feedings (Carere & Alleva, 1998; Royama, 1956), or radiotelemetry (Licht *et al.*, 1989). Some of these methods are very time consuming, involving the permanent presence of an observer in the field, others do not allow individual identification of the birds while, in some cases, disturbance to sensitive species may occur.

The Passive Integrated Transponder (PIT) technology developed in the 1980s offers a novel technique to monitor animals' activity. Although initially developed to speed individual identification of animals (Braude & Ciszek, 1998; Fagerstone & Johns, 1987; Jackson & Bünger, 1993; Schooley *et al*, 1993), its use soon extended to the monitoring of animal activity including vole runways (Harper & Batzli, 1996), nesting sites of colonial birds (Becker & Wendeln, 1997), fish feeding tank (Brännäs, 1998; Burns *et al.*, 1997), fishways (Castro-Santos *et al.*, 1996), or bird feeding sites (Michard *et al.*, 1997). The technique is also suited for the study of feeding activity of cavity-nesting birds: each individual is tagged with a PIT and a reader is placed around the nest entrance.

As part of an extended field study of Wryneck (*Jynx torquilla*, L.) foraging strategies (A. Freitag, unpubl. data), we used the PIT technology to monitor the feeding frequency as an indicator of the parents' activity.

To perform this study, we needed a monitoring system with the following characteristics: (a) low disturbance of bird behaviour and nest invasiveness, (b) good autonomy, both from the energetic and computational point of view, (c) record of nest visits for each bird and regular collection of climatic data.

As none of the PIT systems used in other studies or available met our requirements, we developed a customised Nest Monitoring Autonomous System (NMAS). In addition to visit recording, this system was designed to collect temperature data. This meteorological parameter influences prey availability, namely amount of ants collected at their nests (Freitag, 1996), and thus may affect Wryneck activity.

Here, we first present a technical description of the system, then give some results obtained from the mentioned Wryneck study, and finally, we discuss some advantages and drawbacks of this monitoring technique.

MATERIALS AND METHODS

System description and operation

An NMAS consists of three main modules: the sensor module, the sensor processing and data logging module, and the power unit and user interface module. Figure 1 gives a block diagram of the system and Figure 2 shows an NMAS installed in the field. The sensor module is integrated in a pre-existing nest box door. It is equipped with sensors for measuring the internal and external temperatures of a nest, a modulated optical barrier, and a PIT reading coil, the latter elements being placed around the nest entrance. All components are embedded between two wood layers, so that the modifications to the door are not readily visible. Both adults are tagged with PITs (PFE 10/3L PSU, Ordicam, Paris, France) which contain a code allowing individual identification of each bird. A PIT is attached to the bird's leg using two split plastic rings (Size XB, A.C. Hughes LTD, Hampton Hill, UK), as depicted in Figure 3. Adult tags should not exceed 1% of the weight of Wryneck if attached to a leg. The overall weight of our tag is 0.28 g.

The sensor processing and data logging module is mounted beneath the nest box and represents the kernel of the whole system. It consists of an analog board (CADSC/L/MP, Ordicam) for decoding the PITs and a Motorola® 68HC11 microcontroller-based board.

The power unit and user interface module lies on the ground and is connected to the other two modules by a multiple-wire, coated cable. Splitting the system in this way allows the user to perform battery changing or data collecting operations in an easier way, with a minimal disturbance of Wrynecks. Data can be collected through a standard serial line (wired or infrared) using any type of data logger (e.g. pocket calculators, laptops).

When a Wryneck alights at its nest entrance, it interrupts the optical barrier. This interruption triggers the reading of the bird's corresponding PIT by the coil and a visit is stored in the memory. The optical barrier is placed slightly below the nest entrance to avoid triggering reads when parents leave the nest. With this simple trick, we have implemented a simple “one way” detection barrier and reduced of several order of magnitude the consumption of the system.

Laboratory tests

During two months, three times a day, we simulated ten bird passages by hand in the laboratory, compared the recorded temperatures with industrial thermometer readings, and monitored the state of the battery. All passages were correctly recorded, the measured temperatures were consistent with industrial thermometer readings (± 0.5° C), and the minimal energetic autonomy (battery life) for all the systems tested was 7 days.

Field experience

A field study was conducted in the Rhône plain, canton of Valais, Switzerland. During summer 1998, two nest boxes occupied by Wrynecks were equipped with a NMAS. The installation was performed when nestlings were 5 days old to avoid brood desertion by the parents. The sensor processing and data logging module placed under the nest box was camouflaged with leafy branches. The whole installation of the system took about 15 minutes and the Wrynecks' feeding activity resumed 10-30 minutes later. Uniquely tagging of birds was performed two days later. The birds were caught using a mist nest. Since Wrynecks are not sexualy dimorphic, they were identified as A/B in nest F5 and C/D in nest F9. The mean weight (± sd) of the four Wrynecks was 35.4 ± 1.7 g, the tag representing on average 0.8% of the birds' weight. This method was preferred to subcutaneous implantation (Becker & Wendeln, 1997; Jackson & Bünger, 1993) because the latter method is not suitable for the Wryneck which has a delicate skin.

Visits were recorded uninterruptedly on both nests until fledglings left the nest. In the analysis, each visit was not considered as a feeding. When a Wryneck perched at nest entrance, it could interrupt the optical barrier several times, causing multiple records. Moreover, some visits corresponded to faecal sacs removal after food providing. According to direct observation data (A. Freitag, unpubl. data), the shortest time needed by a Wryneck to collect food was 60 s. Thus, to prevent overestimation of the feeding frequency, consecutive records (for a given bird) exceeding 60 s were only included in the analysis and considered as potential feedings. Previous field observations (A. Freitag, unpubl. data) have shown that more than 99% of the visits to the nest are feedings, at least during the last two weeks of the nestling period.

The efficiency and reliability of NMASs in the field was validated with data collected over two days by direct observation at the same nests. In addition, we have qualitatively compared the collected data with results obtained by timed photography during feedings (Freitag, in press).

Environmental data

Environmental data provided by a federal climatic station situated 20 km away from the study area were integrated and compared with data collected with the NMAS (internal and external nest temperature recorded every 30 minutes). These parameters included air temperature measured every ten minutes, average daily temperature of air (average of the records of 7.00, 13.00 and 19.00, according to de Montmollin, 1993), and precipitation during the day (between 07.00 and 19.00).

The influence of temperature on Wryneck activity was determined by computing a correlation between the number of feedings per hour and the mean temperature of the previous hour. This time-lag of one hour was used because the birds' behaviour is thought to be influenced by prey availability which is in turn dependent on the meteorological conditions (Steiner, 1947).

RESULTS

Two Wryneck broods were studied, having 5 (nest F5) and 9 (nest F9) nestlings. Observations were carried out in June, during 14 days at nest F5 and 9 days at nest F9. In both cases, the 21 days-old fledglings left the nest on the 20 June (i.e. 14 days after the beginning of the experiment).

System efficiency

The two days of feeding monitored by direct observation showed that NMASs correctly recorded each visit to the nest. The temperatures recorded with NMASs were similar to the data delivered by the climatic station (Kendall rank correlation between external temperature at nest F5 and temperature at climatic station: $\tau = 0.74$, $P < 0.001$). Between 07.00 and 16.00, the external temperature recorded by the NMAS was on average 2.4° C higher than the air temperature measured at the climatic station because the nest was exposed to the sun.

Wryneck feeding activity

The NMAS recorded 4043 and 3650 "passages" at nests F5 and F9 respectively, representing 2013 and 1937 potential feedings (see Material and methods for the definition of "potential feeding"). Table 1 summarises the results obtained with the two NMASs.

The Wrynecks perform on average 150 to 190 feedings per day, and feeding effort varies from day to day (Fig. 4A). Both pairs show very similar activity curves: the number of feedings per hour is significantly correlated between the two nests (Pearson correlation: $r = 0.53$, $P < 0.001$). The total number of feedings per day seems to be influenced by air temperature and precipitation (Fig. 4B).

Within a pair, both adults are involved in the feeding activity, but their relative investments are unequal (Table 1). The sharing ratio of the parental investment was constant during the whole nestling development period.

According to the data collected with NMASs, Wrynecks' activity begins between 05.30 and 06.50 and ceases between 20.15 and 21.30. This represents about 14h30 of activity per day. Taken together, the parents perform on average (± sd) 11.7 ± 6.2 feedings/hour, which means one feeding every 5.1 ± 6.2 minutes.

The feeding activity varies according to the time of day (Fig. 5A). The activity is significantly higher during the morning (07.00 to 12.00) than during the afternoon (14.00 to 19.00) (Mann-Whitney U-test: nest F5: $P < 0.001$; nest F9: $P < 0.001$). The influence of temperature during the day on feeding activity is not clearly demonstrated. The number of feedings per hour is negatively and significantly correlated with the mean temperature during the previous hour in the nest F5 (Kendall rank correlation: $\tau = -0.13$, $P < 0.01$) but not in nest F9 (Kendall rank correlation: $\tau = 0.02$, ns).

Timed photography of the feedings was used in 1997 at 3 nests with 5, 6, and 8 nestlings, and 728 feedings were recorded. The mean daily evolution of the feeding activity as revealed by this method (Fig. 5B) is similar to that recorded with NMASs (Kendall rank correlation: $\tau = 0.46$, $P < 0.05$). The interval between two feedings measured with timed photography (median: 3.0 minutes; quartiles range: 2.0-6.0 minutes) does not differ from the one calculated with NAMSs (median: 3.2 minutes (1.7-6.1); Mann-Whitney U-test: ns)

DISCUSSION

Wryneck feeding activity

This first study using the PIT technology to monitor the feeding activity of a nesting bird has generated very promising results. Thanks to the high quality and quantity of the collected data, the NMAS constitutes a very effective tool and although only two broods were placed under survey, the collected data allows us to gain additional, interesting information on Wryneck feeding behaviour.

The factors influencing feeding activity can be divided in two categories: firstly, factors directly related to the Wrynecks themselves such as the brood size and the individual skills of the parents; secondly, external factors such as micro-climatic conditions and prey availability. The formers mainly affect the mean feeding effort while the latter determine the variations of the activity over time (during the day and over the whole nestling period).

To analyse the feeding effort, two factors should be taken into account: the feeding rhythm and the quantity of food brought per feeding. With the NMAS, the quantity of food brought per feeding cannot be assessed. This drawback does not play a crucial role in the case of the Wryneck. When it forages, it exploits only one ant nest at once (Freitag, in press). The quantity of food collected on a foraging trip depends more on ant availability in a given ants' nest than on Wryneck deliberate action. Wrynecks therefore adapt their feeding effort by varying their feeding rhythm rather than collecting more or less ants. The feeding rhythm is thus a good indicator of the feeding effort.

The main factor directly influencing the mean feeding activity is brood size. The larger the brood, the higher the feeding rate of the parents (Bussmann, 1941). In both broods studied, the feeding rate is not linearly proportional to the number of nestlings. In the large brood F9, the nestlings are less often fed than in the small brood F5. Previous observations made on 7 broods with 5 to 9 nestlings (A. Freitag, unpubl. data) have shown that Wrynecks perform at most 210 feedings per day (i.e. on average 14.5 feedings/hour). With 13.6 feedings/hour, the pair F9 is very active and close to capacity.

The feeding activity pattern of Wrynecks over time depends on a number of external factors. The influence of the micro-climatic conditions on the daily number of feedings is obvious. Both pairs studied, nesting 850 m apart and subject to the same climate, show very similar activity curves. The decrease in the number of feedings observed when the meteorological conditions are bad (wet or cold) is in part due to low prey availability. Wrynecks feed exclusively on ants collected directly in ant nests (Freitag, 1996), especially larvae and nymphs placed in the upper part of an anthill to take advantage of the sun’s warming. When it rains or when the air temperature is too low, ants shift their brood deeper in the soil in order to protect it from water or cold (Steiner, 1947).

Similarly, if the prevailing temperature in the upper part of anthill is too high (as during the hottest hours of the afternoon), the ant's brood is also kept deep in the soil to prevent lethal overheating and desiccation. This might explain the reduced feeding activity of Wrynecks during early afternoon and the high activity during the morning, when ants try to take advantage of the sun’s warmth.

Beyond these general considerations, it is very difficult to demonstrate the existence of a significant relationship between temperature and feeding rhythm of Wrynecks. The micro-climatic conditions prevailing in anthills also depend on the solar radiation, the density of the surrounding vegetation, the size and shape of the anthill, and so on. Moreover, ant availability varies from species to species because not all of them have the same tolerance to temperature and dryness in their nest.

System efficiency

With this field experiment, we have demonstrated that autonomous systems such the NMAS can successfully monitor the feeding activity of small nesting birds. The data collected are very accurate and no visit was missed by the NMAS. Compared to other monitoring techniques, this method presents the best ratio between time investment and quality and quantity of collected data. NMASs can be quickly and easily installed in the field, birds resume quickly their normal feeding and foraging activity, and data can be directly imported to a PC for analysis. Furthermore, the NMAS operates autonomously 24 hours a day, requiring only minimal maintenance (battery replacement once a week). This has a great advantage compared to timed photography because this method does not allow continuous monitoring of the birds' activity (limited number of exposures on a film).

Redundant records of single visits and the impossibility of verifying that recorded visits correspond to actual feedings represent the only drawbacks of this system. In the case of the Wryneck study, these problems were solved by eliminating all consecutive visits (of a given bird) with intervals of less than 60 s and by considering all resulting successive visits as feedings. The feeding rate calculated with the corrected data closely matches with the results obtained by photography and by direct observation during two days.

In addition to monitoring of brood provisioning rate, the NMAS can periodically record local environmental variables. In this study, we measured the local nest temperature, but the system is flexible and powerful enough to support any additional sensors (humidity, precipitation, wind speed, and so on) or other devices such as an electronic balance, as used in other studies (Becker & Wendeln, 1997; Michard *et al.*, 1997). This system can be adapted to the study of any animal weighing at least 5 g for aquatic or terrestrial species (Harper & Batzli, 1996; Metcalfe *et al.*, 1999) and at least 15-25 g for flying species (if the same PIT attachment technique is used).

In conclusion, PIT technology combined with autonomous systems offers a large range of applications in the domain of field zoology. We greatly encourage biologists and engineers to collaborate in designing and developing customised systems for animal study.

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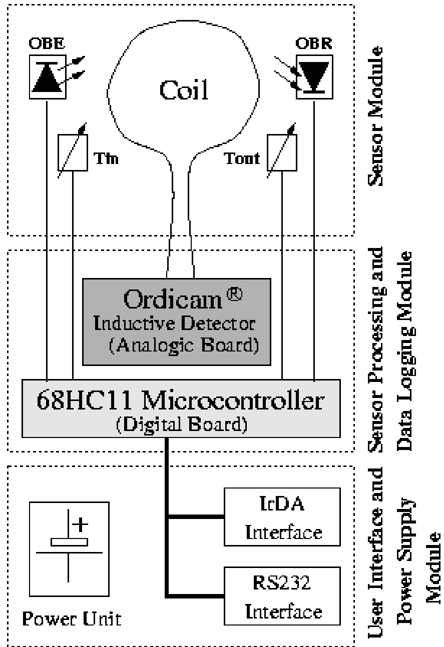

Figure 1. Block diagram of a Nest Monitoring Autonomous System. OBE = optical barrier emitter, OBR = optical barrier receiver, T_{in} = internal temperature sensor, T_{out} = external temperature sensor.

Figure 2. A NMAS installed in the field. (A) Nest box with embedded sensor module (modified door) and sensor processing and data logging module (placed beneath the nest box). (B) Camouflaged with leafy branches. (C) Power unit and user interface at the foot of the tree.

Figure 3. The PIT tag attached to the bird's leg. It consists of a passive transponder and two plastic rings. The three pieces are bound together with cotton wire and glued (scale 1 cm).

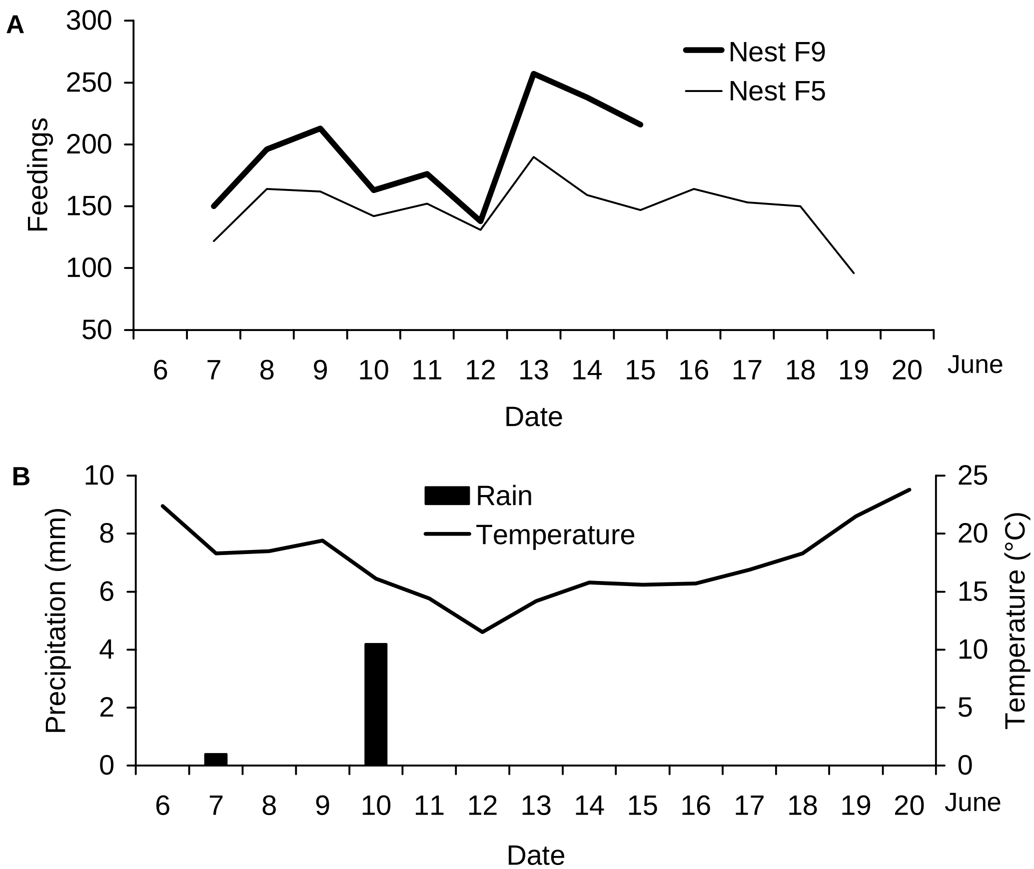

Figure 4. (A) Total number of feedings per day. (B) Micro-climatic conditions prevailing during the whole monitoring period delivered by the climatic station: mean diurnal temperature and precipitation between 07.00 and 19.00.

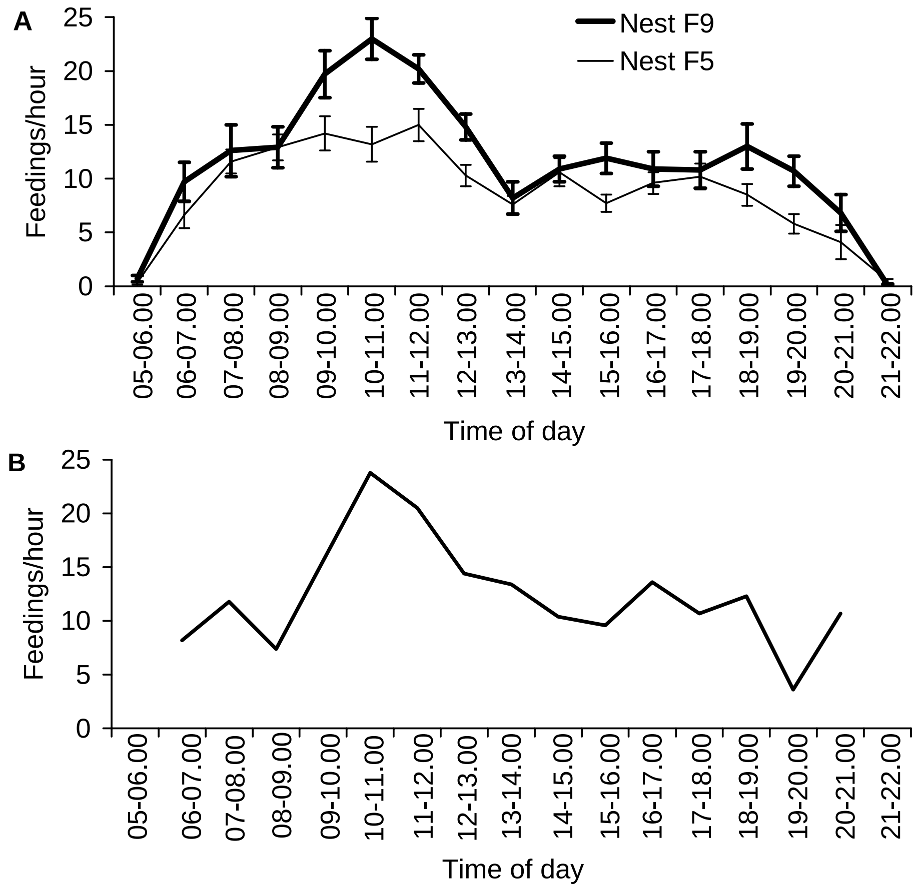

Figure 5. (A) Wryneck feeding rate (mean ± se) according to the time of day. Nest F5: average over 14 days; nest F9: average over 9 days. (B) Daily variations in feeding rate according to the photographic system.

Table 1: Feeding activity of Wrynecks recorded with the NMAS. Comparison of the number of feedings per Wryneck per day (within a pair): Mann-Whitney U-test: *** $P < 0.001$; ns $P > 0.05$. Ind.: individual; QR: quartiles range.

		Nest F5		Nest F9	
Number of feedings (mean ± sd)	- per day	Pair	50 ± 25	Pair	190 ± 40
		Ind. A	90 ± 15	Ind. C	100 ± 25
		Ind. B	60 ± 10	Ind. D	90 ± 15
			***		ns
	- per hour (range)	Pair	10.3 ± 5.1 (0-25)	Pair	13.6 ± 7.0 (2-35)
Interval between 2 feeedings (minutes) (median, QR)		Pair	2.9 (1.5-5.0)	Pair	3.7 (1.8-7.1)
		Ind. A	5.8 (3.5-11.1)	Ind. C	6.0 (3.4-11.6)
		Ind. B	4.9 (2.9-9.2)	Ind. D	8.1 (4.5-16.4)