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Infrared thermography provides insight into the thermal properties of bird nests

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A B S T R A C T

Thermal properties of nests have been investigated using a variety of techniques. Infrared (IR) thermography has the advantage of being a non-invasive technique allowing the integrity of the nest wall to be retained during measurement. This study investigated the insulative properties of nests of the Eurasian Bullfinch (*Pyrrhula pyrrhula*), the Common Blackbird (*Turdus merula*) and the Song Thrush (*Turdus philomelos*) using IR thermography. Nests were inverted over a heat source and the temperature of the external nest surface was recorded. Bullfinch nests were less insulated than thrush nests. Including foil inside the nest cup decreased the amount of convection through the open walls of Bullfinch nests. Removal of the outer nest and cup lining of thrush nests only slightly decreased the degree of insulation offered by the nest indicating an important insulative role for the substantial 'mud cup' in these nests. The results suggested that the nest wall is not sealed and convection currents may a play a significant role in nest insulation. In conjunction with a steady-state heat source IR thermography is useful in assessing the insulative properties of bird nests.

1. Introduction

Providing protection from prevailing weather conditions, particularly insulation against adverse temperatures, is often considered as a key role for bird nests (Kern and Van Riper, 1984; Sidis et al., 1994; Rohwer and Law, 2010; Crossman et al., 2011; Heenan et al., 2015; Deeming, 2016). The materials that birds use during nest construction are regularly assumed to have a functional value in insulation. For instance, feathers are commonly used in nest linings (Møller, 1984) and the number of feathers in a nest correlates with nest insulation in a variety of species (McGowan et al., 2004; Pinowski et al., 2006; Lombardo et al., 1995; Windsor et al., 2013). Hilton et al. (2004) demonstrated that animal-derived materials, such as feathers and wool, had better insulating characteristics compared to moss and grass (plant-derived materials). Despite this, many species do not use animal-derived materials in their nests. For instance, Common Blackbird (*Turdus merula*) and European Robin (*Erithacus rubecula*) nests rely on dry grasses to provide insulation (Mainwaring et al., 2014; Taberner Cerezo and Deeming, 2016).

The architecture of nests also appears to vary in response to different environmental conditions with colder conditions during nest building leading to heavier nests with thicker cup linings and with better insulatory properties (Rohwer and Law, 2010; Crossman et al., 2011; Deeming et al., 2012; Mainwaring et al., 2012, 2014). The thermal properties of Common Amakihi (*Hemignathus virens virens*) nests also correlate with colder higher altitudes in Hawaii (Kern and van Riper, 1984). Species nesting above the ground have also been shown to produce better insulated nests (Kern, 1984). However, even though temperature seems to be so important in determining nest architecture, there have been relatively few studies that investigate the insulation of bird nests (see review by Deeming and Mainwaring, 2015).

A variety of different methods have been used to investigate the different thermal properties of nests for a variety of different species (see Deeming and Mainwaring, 2015; Smith et al., 2015). These include determining thermal conductance of nest walls using various types of heat sources within the nests, e.g. flasks of hot water (Whittow and Berger, 1977; Walsberg and King, 1978a, 1978b; Skowron and Kern, 1980; Kern and Van Riper, 1984; Kern, 1984; Rodgers et al., 1988;) or heated steel balls (Ar and Sidis, 2002), or electrical heating systems (Heenan and Seymour, 2011, 2012). Small temperature loggers (*i*Buttons®, Maxim.com) that either cool down (e.g. Mainwaring et al., 2012, 2014; Deeming and Gray, 2016a, 2016b; Gray and Deeming, 2017) or warm up (Deeming and Biddle, 2015) within nest materials have proved very popular in recent years (Smith et al., 2015; Deeming and Mainwaring, 2015). Infrared (IR) thermography is a non-invasive and

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non-contact method of measuring temperature (McCafferty, 2013) but only a few studies have used it to study the thermal properties of nests (Lamprecht and Schmolz, 2004; Töpfer and Gedeon, 2012; Deeming and Pike, 2015; Siminov and Matantseva, 2015a, 2015b; Deeming and Gray, 2016a). IR thermography is advantageous in species where the nest would be damaged by a temperature logger being pushed into the wall (Deeming and Gray, 2016a).

In this investigation, IR thermography was used to investigate at the thermal properties of whole nests in the Eurasian Bullfinch (*Pyrrhula pyrrhula*), the Common Blackbird, and the Song Thrush (*Turdus philomelos*). These species were chosen because the Bullfinch builds an open structure of woody stems (Biddle et al., 2017, 2018) whereas the Blackbird builds a more complex structure incorporating an internal mud cup lined with grass (Biddle et al., 2015, 2018). The Song Thrush also builds a substantial nest but has a smooth cup lining comprising dried wood pulp (Biddle et al., 2018). Pushing a temperature logger into the wall of any of these nests is likely to damage the nest and would probably produce inaccurate results.

It was hypothesised that the materials and the construction style of these nests would affect the insulative properties of the structure. Hence it was predicted the open structure of the Bullfinch nest would lose heat to a greater extent than thrush nests. The thermal properties of a Bullfinch nest when it is lined with aluminium foil (cf. Heenan and Seymour, 2011) were also investigated. It was predicted that the foil would significantly reduce convection through the nest wall. Finally, to determine whether the internal structural cup has a substantial role in insulation IR thermography measurements were taken before and after removing the internal cup of thrush nests.

2. Methods

In order to provide a heat source within the nest a brass curtain rod bracket (82 mm height with a 20 mm diameter hole) was placed on an electrically heated hotplate (Stuart, stir-heat CB162) surrounded by layers of expanded polystyrene such that approximately 6 mm or 34 mm of the bracket was exposed for Bullfinch and thrush nests, respectively (Fig. 1). When the hotplate was operational the brass bracket conducted heat and the exposed end increased in temperature, which was recorded by an *i*Button® temperature logger located in the space that would have held the curtain rod. The hotplate was set at a temperature (established through trial and error) that meant that the top of the bracket was at approximately 38 °C. This produced a temperature of around 40–42 °C once the nest was placed over the rod holder, which is comparable to the brood patch temperatures of Passerines (Deeming, 2008; Deeming and du Feu, 2008).

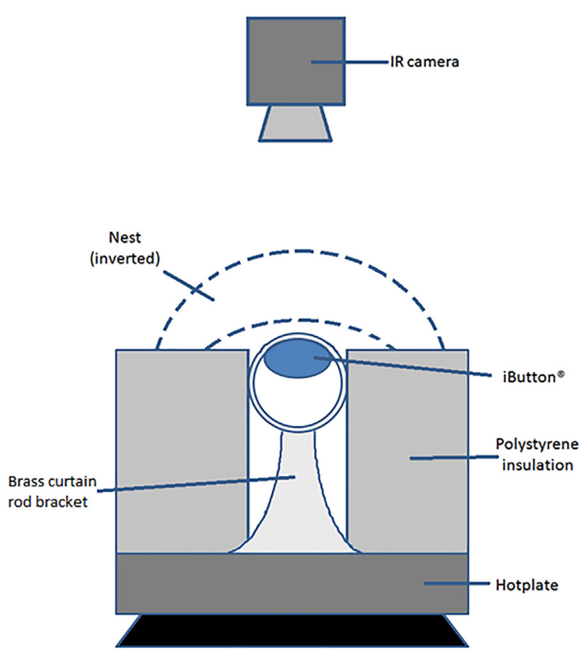

Fig. 1. Diagrammatic representation of the experimental test set up used to measure the outer surface temperature of the nest, which is inverted on polystyrene with the heat source within centre. Arrow indicates 30 cm distance between camera and the upper part of the nest.

Thirteen Eurasian Bullfinch (*Pyrrhula pyrrhula*) nests described by Biddle et al. (2017) were investigated in this study. Eleven Common Blackbird (*Turdus merula*) nests and sixteen Song Thrush (*Turdus philomelos*) nests were also investigated and were part of a sample deconstructed and described by Biddle et al. (2018). Each nest had its linear dimensions measured as described by Biddle et al. (2018).

For temperature recording of the outer nest surface, each nest was placed such that the centre was above the heated brass bracket and were left for 20 min in the case of the Bullfinch, or 45 min for thrush nests, to allow the temperature of the outer nest to reach constant maximum equilibrium. Every minute an Infrared (IR) thermal image of the base of the nest was taken using a FTIR (Fourier Transform Infrared Spectroscopy) i7 thermal camera fixed 30 cm above the nest (Fig. 1).

Each Bullfinch nest was tested three times under two conditions: 1) the inside of the cup was lined with household aluminium foil in order to minimise convective heat loss through the nest wall (as reported by Heenan and Seymour, 2011, 2012); and 2) recordings were repeated without the foil lining. This allowed for determination of the effect of the foil, which would not be present in the wild and hence was a measure of the degree of convection through the nest wall. Pilot data showed that for nests to return to room temperature they had to be removed from the apparatus and left to cool on the bench for 10 min (when not lined with foil), or 15 min (when lined with foil).

Thrush nests were not lined with foil because analysis of Bullfinch nests showed that the foil prevented convective currents through the nest wall, which were deemed important for natural nest function. Each nest was investigated three times for each of two conditions: 1) the complete nest; and 2) with the outer nest and cup lining material removed to reveal just the structural wall of mud/wood pulp. This allowed assessment of the effects of the outer nest and cup lining material, and the 'mud' cup structure. Between trials nests were removed from the apparatus and left to cool for 15 min. All investigations were carried out at room temperature (24.4 °C) and humidity (51.2%).

IR images were transferred to a PC for processing using custom-written MATLAB (Math Works, Natick, MA) functions (Tom Pike, personal communication). These functions extracted a greyscale image from the false-coloured images saved by the thermal camera, in which pixel intensity was linearly related to temperature. A set of sixteen equally spaced radial linear temperature profiles radiating out from the centre of the nest to its edge were created within MatLab (Fig. 2). The average and standard deviation of the temperature was calculated for the first 50 pixels along each radial temperature profile from the central point, which incorporated the radius of the nest. Mean surface temperature of the nest was the mean of these averages and the mean standard deviation of each sample was also calculated. The percentage coefficient of variation was calculated to express the variability of temperature across the outer nest surface.

Statistical analyses were performed in Minitab (Version 17). Species differences were investigated for intact nests (without foil in the case of the Bullfinch) using one-way analysis of variance with Tukey testing for pairwise comparisons where appropriate. Paired *t*-tests were used to compare data from Bullfinch nests when lined and not lined with foil. Similarly, data for thrush nests were compared with paired *t*-tests for the complete nest and when there was just the structural wall present.

3. Results

For complete nests (without foil) Bullfinches were found to have the