Nest boxes as microhabitats supporting diverse arthropod communities

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SHORT COMMUNICATION

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Nest boxes as microhabitats supporting diverse arthropod communities

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Abstract

1. Bird nesting boxes are widely used to support cavity-nesting birds but also function as accessible micro-habitats for diverse arthropod communities. This study examined the arthropods inhabiting nesting boxes across eight woodland sites in England and Wales, with a focus on how community structure is influenced by bird nesting activity and whether it impacts breeding success in *Ficedula hypoleuca* (European Pied Flycatcher).
2. Arthropods were sampled from 120 boxes using modified sticky traps (in unoccupied boxes) and NaCl flotation (in occupied nests).
3. A total of 3634 specimens from 82 arthropod families were collected. Nest boxes with bird nests supported significantly higher arthropod abundance, richness and Shannon diversity than unoccupied boxes.
4. Despite changes in community composition between occupied and unoccupied nesting boxes, no functional groups significantly predicted or impacted breeding outcomes.
5. These findings highlight the overlooked conservation value of nest boxes for nidicolous arthropods and call for more frequent consideration of invertebrate communities in nest box design and management.

KEYWORDS
community ecology, invertebrate conservation, micro-habitat, nestboxes, nidicolous arthropods

INTRODUCTION

Arthropods underpin ecosystem function, performing essential roles in decomposition, nutrient cycling and food web dynamics. Yet, global insect populations are in decline due to land-use change, pesticide use and climate change (Wagner et al., 2021). Considering these declines, conservation strategies increasingly include novel habitats such as artificial nest boxes, originally intended for birds or mammals but also valuable to invertebrates (Jaworski et al., 2022).

Bird nests provide sheltered, humid and resource-rich (food) micro-environments ideal for arthropod colonisation (Jaworski et al., 2022); while also improving habitat connectivity by acting as 'stepping-stones' for nidicolous species, allowing them to disperse and persist across fragmented landscapes where natural shelters or cavities are increasingly scarce (Carvallo et al., 2020; Tripet et al., 2002). While much research has focused on ectoparasites and their effects on avian hosts (Tomás et al., 2008; Møller et al., 2009; López-Arrabé et al., 2012), broader nidicolous communities are rarely studied. For instance, detritivores may act as 'nest cleaners' by consuming organic waste and decomposing material, potentially improving nest hygiene and the overall micro-climate for the developing brood. Understanding these interactions is vital, as the broader community, including predators and scavengers, creates a dynamic micro-habitat where both parasitic and beneficial taxa interact. Studies such as Goodenough and Hart (2012) and Jaworski et al. (2022) have documented high invertebrate diversity in nest boxes but few have analysed unoccupied boxes for comparison.

This study investigates the arthropod community composition in occupied vs. unoccupied nest boxes, and whether arthropod community structure affects *Ficedula hypoleuca* (Pallas, 1764) breeding outcomes. The study contributes to filling a knowledge gap on the ecological function of nest boxes beyond avian conservation.

MATERIALS AND METHODS

Study sites

Established avian nest boxes in eight woodland sites in North Wales and South Shropshire were surveyed: Welsh site 1 (*Quercus* dominated broadleaved riparian; 53°18″ N–3°29″ W), Welsh sites 2a/b (lowland mixed deciduous, upper and lower valley; 53°13″ N–3°40″ W), Shropshire site 1 (*Quercus* dominated mixed deciduous; 52°33″ N–2°53″ W) and Shropshire sites 2a/b/c/d (*Alnus* dominated mixed riparian; a = 52°26″ N–3°09″ W, b = 52°26″ N–3°07″ W, c = 52°27″ N–3°07″ W, d = 52°60″ N–2°93″ W). Most sites were bordered by sheep pasture.

Sampling design

A total of 120 wooden nest boxes were sampled at the end of the breeding season in June 2024: 64 occupied by *F. hypoleuca*, and 56 unoccupied. All boxes had previously been cleared of prior season nesting material with then occupied boxes (during 2024) containing nesting material from the current breeding season and all unoccupied boxes being free of fresh nesting material. While nesting material was not weighed, nests generally consisted of dry leaves with smaller proportions of moss or sheep wool, and a basal layer of soil. One exceptional nest (LB40) was noted as significantly larger, having been constructed atop an existing nest and clutch of eggs. All nest boxes maintained consistent internal base dimensions of 10 × 15 cm.

Occupied boxes

Nesting material was collected (into sealable plastic sample bags) within 7 days after fledging or failure and stored without delay at −20°C. Upon warming to room temperature nests were processed twice—once via macro examination and arthropod removal and second using sodium chloride flotation (as per Brandimarte & Anaya, 1998) to extract remaining arthropods.

Unoccupied boxes

Two Vaseline®-coated Petri dish (90 mm ⌀) sticky traps (Fursov et al., 2023) were installed at the time of nest-building and were retrieved after the breeding season at the same time as nest removal. One plate was placed on the floor of the box and the second was affixed to the internal back wall. To match this spatial scope in occupied boxes, the nest was removed, and the remaining internal volume (walls and lid) was thoroughly swabbed for mobile arthropods. Storage of specimens (including those removed from sticky traps) was at −20°C until analysed. Following thawing arthropods were removed following macro examination.

All specimens were identified to the lowest feasible taxonomic level. Where species-level identification was not possible due to specimen condition or taxonomic complexity, individuals were treated as distinct morphospecies within their genus or family to ensure a consistent baseline for diversity calculations. Identification was performed using microscopic examination at up to x300 magnification. This ensured a consistent baseline for calculating species richness and Shannon diversity. Functional group classifications were derived using a rule-based taxonomic approach, assigning dominant ecological roles based on order-, family- or species-level traits. Where taxa exhibit multiple feeding strategies, the most reported or ecologically dominant role was used. Taxa were categorised into detritivores, predators, ectoparasites, necrophages, herbivores, coprophages and saprophages. Parasitoids, fungivores and aquatic invertebrates were also present in minimal numbers.

STATISTICAL ANALYSIS

Arthropod species richness, abundance and Shannon's Diversity Index were calculated per nest box. Generalised linear mixed models (GLMMs; Poisson distribution for richness and abundance, Gaussian for diversity index) tested the effect of occupied boxes on diversity metrics. To test the effect of occupancy status on community metrics, box occupation was included as a fixed effect with 'Occupied Box' set as the reference level within GLMMs, with site used as a random effect throughout. Consequently, the negative estimates reported in our results represent the decrease in diversity and abundance observed in unoccupied boxes relative to those containing nests. Abundance was calculated as the total number of individuals pooled across all taxa per box.

For occupied boxes only, multinomial GLMs tested whether functional group proportions predicted breeding outcomes, with 'Uncertain' outcomes excluded. Model parameters were estimated using L1-regularised maximum likelihood to account for small sample size and collinearity among predictors.

Analyses were conducted in R (version 4.4.2, R Core Team, 2024) using the tidyverse suite for data manipulation and visualisation (Wickham et al., 2019). Community diversity metrics were calculated using the vegan package (Oksanen et al., 2022). Generalised and linear mixed-effects models were fitted using lme4 (Bates et al., 2015) with inference provided by lmerTest (Kuznetsova et al., 2017). Model diagnostics were assessed using performance (Lüdecke et al., 2021) and DHARMa (Hartig, 2022). Estimated marginal means were computed using emmeans (Lenth, 2023). Figures were produced using ggplot2 (Wickham, 2016) and assembled with patchwork (Pedersen, 2020).

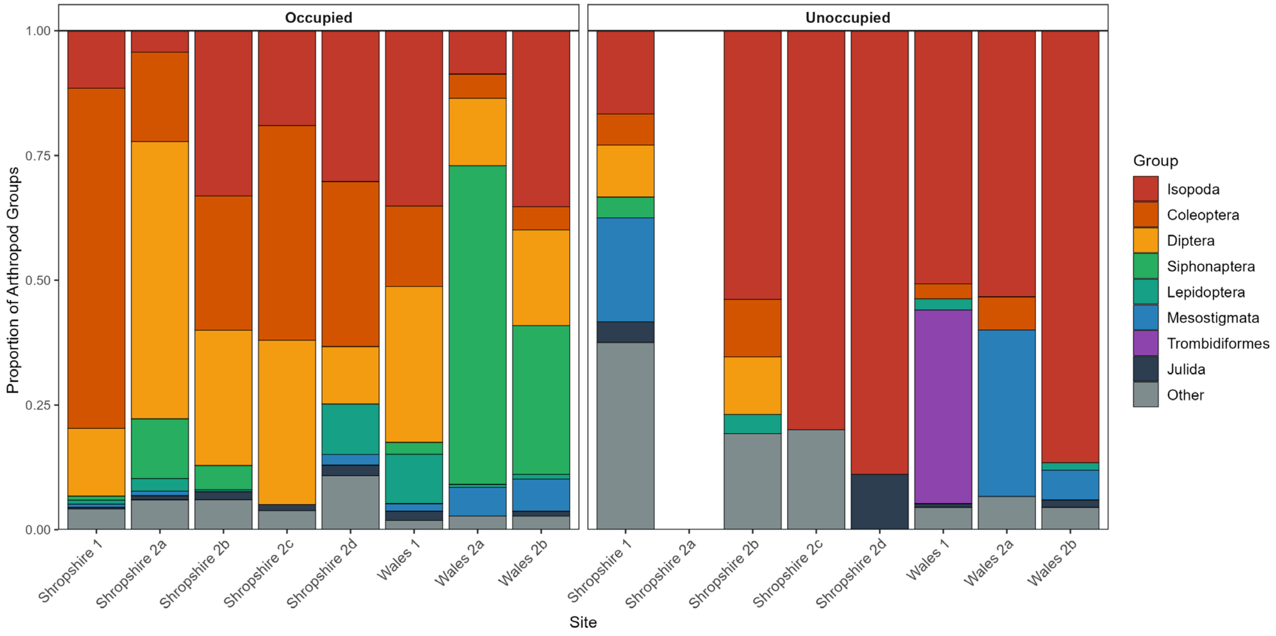

FIGURE 1 Arthropod community composition of eight sites across Shropshire and North Wales, UK. Indicates eight most abundant groups across both occupied (nest sampled) and unoccupied (trap sampled) boxes with the remaining organisms grouped into 'Other', inclusive of (in order of abundance, high to low): Hymenoptera, Araneae, Stylommatophora, Hemiptera, Lithobiomorpha, Entomobryomorpha, Trichoptera, Polydesmida, Ephemeroptera, Opisthopora, Psocodea, Amphipoda, Raphidioptera, Psocoptera, Thysanoptera, Plecoptera. Unoccupied nest boxes in Shropshire Site 2a contained no arthropods.

RESULTS

Arthropod community overview

Across all samples, 3634 individuals were collected representing 22 orders (82 families). Common orders included Isopoda (28%), Coleoptera (23%), Diptera (21%) and Siphonaptera (15%), with the most abundant groups shown in Figure 1. Functional groups were predominantly detritivores, followed by predators, ectoparasites and necrophages. Taxonomic richness (number of different species present in a sample), abundance (number of individuals per species) and Shannon's Diversity Index (a combination of richness and evenness—how individuals are distributed among lowest taxonomic level identified) across all sites can be seen in Figure 2. Model output tables for all analyses can be seen in Tables S1–S4.

There was variation between sites regarding the three community metrics calculated, with no one site peaking with all three. Occupied nest boxes exhibited high arthropod richness (1–34 species), dominated by Coleoptera, Diptera and Siphonaptera, which together accounted for approximately 80% of all individuals. Unoccupied nest boxes contained fewer taxa (1–7 species), with communities dominated by Isopoda (~60%) and Mesostigmata (~25%).

Effects of Nest box occupancy

Arthropod communities differed strongly between occupied and unoccupied nest boxes. Relative to occupied boxes, unoccupied boxes supported substantially lower arthropod species richness (Poisson GLMM: estimate = −1.755 ± 0.098 SE, $z = -17.87$, $p < 0.001$; IRR = 0.173 [95% CI: 0.143–0.210]) and total abundance (Poisson GLMM: estimate = −2.150 ± 0.057 SE, $z = -37.73$, $p < 0.001$; IRR = 0.116 [95% CI: 0.104–0.130]). Shannon diversity was also markedly lower in unoccupied boxes (Gaussian LMM: estimate = −1.198 ± 0.110 SE, $z = -10.89$, $p < 0.001$). The negative model estimates reflect the significant drop in these values for unoccupied boxes when compared to the 'Occupied Box' reference level. Community composition differed from isopod- and mite-dominated (unoccupied) to more taxonomically even communities in occupied boxes, with higher proportions of coleopterans, siphonapterans and dipterans. Functional groups, assigned at as low a taxonomic level as possible for accuracy, revealed similar levels of predators between nest and traps (22% vs. 21%) with unoccupied boxes having more detritivores (58% vs. 33%) and fewer herbivores (15% vs. 26%). Coprophages only occurred in occupied boxes (1.2%).

Breeding outcomes and arthropod functional groups

Occupied boxes with known outcomes provided $n = 22$ observations (Failure = 13, Fledged = 5, Partial Loss = 4). An L1-regularised multinomial GLM (lasso; glmnet) testing whether functional-group proportions predicted outcome showed no retained predictors at λ_1se (all coefficients shrunk to zero; intercept-only). At λ_min, only 'Other' was retained (Fledged: $\beta = 1.188$; Partial Loss: $\beta = -0.424$; Failure: $\beta = -0.765$); all other functional groups were shrunk to zero.

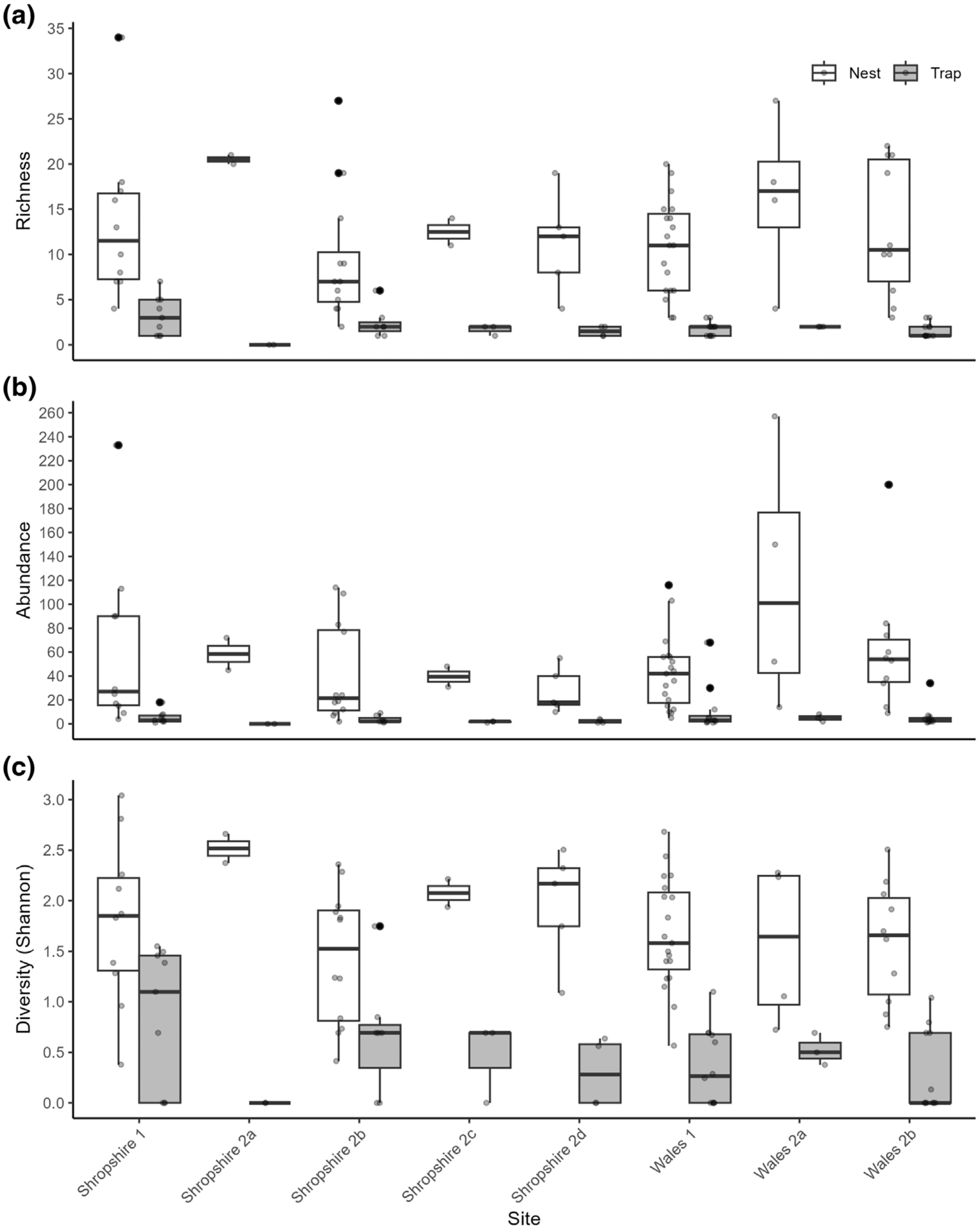

FIGURE 2 (a–c) Species richness (a), abundance (b) and diversity (c), in sampled occupied boxes (nest sampled—white) and unoccupied (trap sampled—grey), across eight sites in Shropshire and North Wales, UK. Data points represent pooled data for sampled traps and nests within nesting boxes across sites, jittered across each boxplot. Nests ($n = 64$ total) and traps ($n = 56$ total) are indicated for comparison. With 'n' for Shropshire sites, nest = (1: 10, 2a: 2, 2b: 12, 2c: 2, 2d: 5), trap = (1: 9, 2a: 0, 2b: 7, 2c: 3, 2d: 4), for Wales sites, nest = (1: 19, 2a: 4, 2b: 10), trap = (1: 12, 2a: 3, 2b: 11). When pooled across sites using GLMMs with site as a random effect, trap (unoccupied) boxes supported significantly lower species richness (IRR [incidence rate ratio] = 0.17, $p < 0.001$) and abundance (IRR = 0.12, $p < 0.001$), and significantly reduced Shannon diversity (Δ [mean difference] = −1.20, $p < 0.001$) relative to nest (occupied) boxes.

Uncertain breeding outcomes occurred in 77% of nests, with successful fledging in 8% and total and partial brood losses the remaining 15%.

DISCUSSION

The findings support prior observations that bird nests host diverse arthropod communities (Roy et al., 2013; López-Rull & Macías Garcia, 2015, p. 82; Jaworski et al., 2022), including taxa overlooked in traditional surveys (Goodenough & Hart, 2012). The strong effect of nesting material on diversity likely stems from structural complexity, food availability and micro-climate (Maziarz et al., 2022); as well as nestling condition (Sauve et al., 2021).

Interestingly, even unoccupied boxes supported arthropods, suggesting value as shelter or incidental refugia. However, community complexity and richness were dramatically enhanced by nest presence. Notably, common detritivores like the Rough Woodlouse, *Porcellio scaber* (Latreille, 1804—Isopoda) and generalist beetles may act as ecosystem engineers, influencing decomposition rates and prey availability within nests (Paoletti & Hassall, 1999).

Despite ecological expectations, no clear link emerged between community structure and breeding outcome, likely reflecting opportunistic colonisation rather than a causal relationship. This may reflect the compensatory behaviours of *F. hypoleuca*, known to increase parental effort under stress (Bauchau, 1997; Cantarero et al., 2013), or the sub-lethal nature of most arthropod interactions observed as high ectoparasite loads did not predict fledging failure. Conversely, nests with successful outcomes tended to have more detritivores, supporting suggestions that these taxa enhance nest hygiene and micro-climate (Maziarz et al., 2017, 2022). Together, these findings reinforce that nest boxes function as dynamic micro-habitats where both beneficial and parasitic taxa interact, and modest adjustments to box management (e.g., delayed cleaning) could further support these invertebrate assemblages. Additionally, the sample size and overall parasite abundance may have been insufficient to elicit strong demographic effects. It should be noted that while box dimensions (10 × 15 cm) were consistent, the sampling method (nest flotation vs. sticky trap) and volume differed and may have impacted numbers. However, each nest box was 'macro-sampled' on collection of traps and nests to additionally sample free-air volume, though the study acknowledges that there is an element of potential bias in surveyor active monitoring here.

The study highlights nest boxes as dual-function conservation tools, supporting both birds and invertebrates. Given the accelerating loss of natural cavities, artificial nest sites may play a larger role in future biodiversity support. Bird nest boxes are not only tools for avian conservation but also valuable micro-habitats for diverse arthropod communities. Nesting material significantly enhances community complexity, though no direct effects on bird breeding success were observed, with multi-year sampling planned to account for uncertainty here and to further evaluate box-use history as a factor in invertebrate diversity. Nest boxes represent underutilised resources for invertebrate monitoring and biodiversity support, meriting more attention in research and conservation planning.

AUTHOR CONTRIBUTIONS

Ailsa M. Miller: Conceptualization; methodology; data curation; investigation; formal analysis; visualization; project administration; writing – original draft; writing – review and editing. **Robert J. Harris:** Conceptualization; methodology; investigation; supervision; project administration; resources; writing – original draft; writing – review and editing. **Julia Casperd:** Supervision; methodology; writing – original draft; writing – review and editing. **Ben J. Clunie:** Data curation; formal analysis; investigation; visualization; supervision; writing – review and editing; project administration.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known financial or non-financial conflicts of interest that could have appeared to influence the work reported in this paper. There are no disputes regarding the ownership of the data presented, and all contributions have been appropriately attributed through co-authorship and acknowledgements.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in dryad at https://doi.org/10.5061/dryad.j6q573nvd (Miller, 2026).

ETHICS STATEMENT

Ethics approval was granted by Harper Adams University, and work was conducted under BTO licence.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Poisson GLMM for arthropod richness (random intercept: Site).

Table S2. Poisson GLMM for arthropod abundance (random intercept: Site).

Table S3. Gaussian LMM for Shannon diversity (random intercept: Site).

Table S4. L1-regularised multinomial GLM (occupied boxes only) predicting breeding outcome from functional-group proportions.

Table S4a. Intercepts.

Table S4b. Non-zero coefficients.

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