Literature review of the effects of supplementary feeding on birds and people

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Contents

Executive summary

1. Context: Supplementary feeding (SF) of birds is a common activity undertaken by people around the world. In the United Kingdom (UK) an estimated 12.6 million households (48%) provide supplementary food for birds, with 7.4 million using bird feeders to do this.

2. Context: Whilst many benefits of SF have been recognised for the individual birds and species taking the food, there are growing concerns about potential disbenefits particularly disease transmission risk at feeders and competitive or predation interactions involving species that have benefitted from SF. Specific concerns have been raised about the potential role of bird feeders in facilitating the emergence and spread of finch trichomonosis, caused by *Trichomonas gallinae,* which has driven large and widespread declines of European greenfinch and Eurasian chaffinch across the UK.

3. History: Since the late 1980s the RSPB has encouraged members of the public to undertake year-round SF of birds in residential settings subject to practical advice intended to maintain feeder hygiene, reduce predation risk and minimise any associated pest risks. Similar information has been provided by other NGOs and research organisations although information on adherence to this advice is lacking. Bird feeders have been designed to reduce some of the suspected risks of SF and to allow easy access for cleaning.

4. Evidence review: Due to growing concerns about risks of SF to birds, in 2024, the RSPB decided to undertake a literature review of the benefits and potential disbenefits of SF as typically conducted in residential settings. The aim of this review was to synthesize scientific evidence on the likely pros and cons of SF for both wild birds and for participating people. The review would also consider evidence relating to the efficacy of proposed mitigations for known risks. The information generated by this undertaking would be used by RSPB to review its position relating to its recommended policy and practice for SF in residential settings. This report presents the findings of that evidence review.

5. Approach: Initially we defined a set of research questions that aimed to explore the pros and cons of SF in residential settings for birds and people. Six wildlife-focussed questions considered the likely impacts of SF on the fitness and abundance of wild birds and other wildlife, as well the potential implications for infectious disease risk and interactions between species. We also considered the evidence relating to the efficacy of any potential mitigation measures proposed to reduce any suggested risks of SF. Three people-focussed questions considered the impacts of involvement in SF on human well-being and connection to nature, and their likelihood of engaging in pro-environmental behaviour. Two further people-focussed questions considered people's motivations for feeding and awareness of the potential risks and benefits.

6. Approach: For each of the 11 research questions we conducted searches of the scientific literature using four search engines: Google Scholar, Web of Science, Scopus and PubMed. A standard set of search terms was run through each engine and the top 400 'hits' assessed for relevance based on title and abstract (the limited social science research available on this topic meant this was reduced to 200 'hits' for the people-focussed questions). For the wildlife-focussed questions, studies were only considered relevant if they related to bird orders represented in typical UK residential settings (Passeriformes (songbirds), Piciformes (woodpeckers) or Columbiformes (pigeons and doves)). We then combined relevant studies across search engines and excluded any duplicates. We then checked the full text of each remaining study and extracted details of study design and responses to SF to a spreadsheet in which each individual response metric (such as reproductive success, survival or nature connection) was allocated a single row. We also extracted various context variables such as the type and season of feeding, the study species, design category (e.g. experimental or observational, qualitative or quantitative), geographic location and habitat type (e.g. peri-domestic, woodland, farmland).

7. Approach: For each wildlife question we summarised the composition of the available evidence by key context variables to allow us to assess its relevance to SF as typically conducted in UK residential settings. For questions generating many relevant response metrics we summarised the data in terms of the numbers of positive, neutral and negative responses to SF. For each question we also discussed individual studies that were considered most relevant to SF in UK residential settings. For each people question, the response metrics were categorised as positive, neutral or negative. The limited social science evidence base meant we were able to summarise and discuss all studies.

8. Results - Effects of SF on avian fitness: Most studies of the effects of SF on avian fitness were conducted in Europe or North America, away from residential settings and were biased towards the tit, flycatcher and corvid families. Most studies involved either the provision of animal protein during the breeding season or the provision of seed during either the winter or breeding seasons. Only 10 out of 61 measures of reproductive success or survival were measured in peri-domestic landscapes and 9 of those involved the provision of animal protein rather than seed or fat. Consequently, conclusions relating to the effects of seed or fat provision on avian fitness are derived largely from studies conducted in the wider countryside.

9. Results - Effects of SF on avian fitness: Breeding season animal protein provision had generally positive or neutral impacts on reproductive success and mainly neutral impacts on survival. The average effect size of SF on reproductive output was a 15% increase (n=18 measures). A few negative impacts of animal protein provision may have been a consequence of SF encouraging earlier egg laying resulting in chicks hatching before the seasonal peak in invertebrate prey availability.

10. Results - Effects of SF on avian fitness: Based on studies predominantly conducted away from human habitation, winter seed and/or fat provision was associated with mainly positive or neutral effects on survival and mixed effects on reproductive output. The average impact on survival was large (a 77% increase, n=9 measures) suggesting potentially important implications for wild bird population dynamics.

11. Results - Effects of SF on avian fitness: Only eleven studies assessed the effects of seed or fat provision during April-October on reproductive output or survival, and only three of these involved the provision of just seed or fat. This represents an important limitation of the evidence base. Of the three studies testing only seed and fat provision, two showed positive demographic impacts and one showed no effect. One additional UK woodland study showed that peanut and fat provision before and during breeding led to reduced clutch and brood size in Eurasian blue tits and great tits.

12. Results - Effects of SF on avian fitness: The presence of bird feeders increased nest predation rates for open-cup nesting species within a distance of at least 10m from feeders. The likely mechanism was feeders attracting predators like corvids to feeder locations.

13. Results - Effects of SF on avian abundance and communities: More studies on avian abundance were conducted in peri-domestic landscapes. Most reported effects of SF involved increases in abundance or species richness or no detectable impact of SF with very few reported reductions in abundance or richness. The effect of SF on avian abundance averaged an increase of 40% (n=14 measures) and slightly less (33%, n=19) when measured at mainly small spatial scales in peri-domestic habitats.

14. Results - Effects of SF on avian abundance and communities: There is strong evidence from wider countryside habitats that SF can lead to substantial increases in population size of woodland tits and farmland buntings (both from winter seed provision), woodland nuthatches (autumn seed) and corvids (breeding season protein).

15. Results - Effects of SF on avian abundance and communities: Long-term increases in the amount and types of SF provided in UK gardens are associated with increased bird usage of gardens. Increased access to, and utilisation of, SF probably partly explains population increases of species

whose feeder usage has increased including common wood pigeon, European goldfinch, great spotted woodpecker and wintering Eurasian blackcaps.

16. Results - Effects of SF on avian abundance and communities: Feeders in residential settings attract a larger number and diversity of birds during winter but not summer. Long-term increases in average feeder numbers and food types in British gardens probably explains the increasing diversity of garden bird communities with less dominance of a few common species.

17. Results - Effects of SF on other wildlife: There was some evidence that SF is associated with the local depletion of insect prey around feeders by attracting insectivorous birds to feed in those localities. Several studies showed that squirrel distribution is positively associated with feeder distribution during autumn and winter (suggesting greater nutritional dependence on SF) but not during other seasons. We found no studies that reliably assessed the effects of SF intended for birds on mammal abundance.

18. Results - Effects of SF on pathogen transmission risk and disease: There is clear evidence that SF can increase transmission risks of some pathogens (including *T. gallinae, Salmonella spp.* and *Mycoplasma gallisepticum*) although the relative importance of gardens and other habitats as sources of transmission is unknown and probably differs between pathogens.

19. Results - Effects of SF on pathogen transmission risk and disease: In a UK context, trichomonosis is of significant concern, having driven substantial declines in European greenfinch and Eurasian chaffinch populations. These declines were largely driven by reductions in adult survival, and for both species these reductions in survival were of greater magnitude in peri-domestic areas (where SF intensity is likely to have been higher) than in the wider countryside. Laboratory studies have shown that *T. gallinae* can persist in moist bird feed (up to 5 days) and in water (up to 30 hours). Ongoing research at finch trichomonosis outbreak sites in GB gardens has detected viable *T. gallinae* parasites from supplementary food samples collected from locations accessible to birds within and beneath feeders, and from water baths. Video data collected at trichomonosis outbreak sites show that birds exhibiting clinical signs of disease spend longer at food and water sources and regurgitate food and water that is then readily available to other birds. These observations highlight the potential for indirect transmission of *T. gallinae* via the ingestion of contaminated food and water at feeders and water baths. Outbreaks of finch trichomonosis in GB gardens occur all year round but peak during July-October and are more likely in gardens with larger numbers of European greenfinches and Eurasian chaffinches and in gardens providing multiple types of seed.

20. Results - Effects of SF on pathogen transmission risk and disease: There is strong evidence for an association between SF and the impacts of mycoplasmal conjunctivitis on house finches in the USA. This pathogen is transmitted via contaminated feeder surfaces (referred to as fomites), and two studies suggest that transmission risk increases with feeder density. Although a correlative study found that disease-linked population declines of house finches were greatest in states where SF levels had fallen most, it is unclear whether changes in SF frequency were a likely driver or consequence of increased disease-related mortality.

21. Results - Effects of SF on pathogen transmission risk and disease: No population-level impacts of salmonellosis outbreaks on wild bird populations have been identified in the UK. However, the *Salmonella* bacterium has been detected on bird feeders and tables, and in bird faecal samples collected from feeding sites suggesting the potential for transmission via fomites. Higher prevalence of *Salmonella spp.* has been reported amongst some bird species using supplementary food.

22. Results - Inter-specific interactions involving the beneficiaries of SF: The review data were dominated by studies of interactions involving nest predation (mainly involving corvid and woodpecker species as beneficiaries) and competition (mainly involving great tit, Eurasian blue tit and rose-ringed parakeet as beneficiaries).

23. Results - Inter-specific interactions involving the beneficiaries of SF: Several studies highlight the importance of corvids as predators of passerine nests in peri-domestic settings including higher nest failure rates close to bird feeders. Great spotted woodpecker is an important predator of the nests of the willow tit, a rapidly declining species that is vulnerable to woodpecker predation as it excavates nest sites in soft decaying wood. Eurasian blue tits and great tits are known to evict willow tits from their nesting sites; the rate of nest eviction varied across studies (from 0-67%) and at the highest rate the local willow tit population subsequently went extinct.

24. Results - Inter-specific interactions involving the beneficiaries of SF: Subordinate marsh tits spent more time vigilant and less time feeding in mixed species autumn-winter flocks than dominant Eurasian blue tits and made greater use of the woodland understorey when foraging. Marsh tit survival was lower in years of high reproductive success amongst Eurasian blue tits and great tits suggesting these competitive interactions for food may have important fitness consequences.

25. Results - Inter-specific interactions involving the beneficiaries of SF: It is unlikely that the extent of competition for nesting sites between rose-ringed parakeets or Eurasian nuthatches and other hole-nesting species is sufficient to cause population-level impacts amongst the latter.

26. Results - Potential mitigations for risks associated with SF: Advice to mitigate potential risks associated with SF covers feeder placement, feeder hygiene, feeder density and feeder removal. Empirical tests of mitigation advice were limited in number and scope.

27. Results - Potential mitigations for risks associated with SF: Feeder cleaning was found to reduce pathogen load (3 studies) whilst higher feeder density increased transmission risk associated with *M. gallisepticum* (2 studies). The experimental introduction of SF (1 study) was associated with increased disease prevalence amongst wild birds and improvements in several health parameters including antioxidant levels and innate immune defence. The subsequent removal of feeding restored disease prevalence and health metrics to their pre-feeding levels. We found no studies that tested mitigation measures for *T. gallinae* transmission risk at feeders.

28. Results - Potential mitigations for risks associated with SF: Placing feeders close to woody vegetation increased total bird usage although some species preferred feeders located further from cover (3 studies). Placing feeders close to windows increases bird-window collision risk although risk is reduced very close to windows (2 studies).

29. Results - Effects of involvement in SF on human well-being: Limited evidence suggests that improvements in personal well-being from engagement in SF of birds are likely. One study conducted on nursing home residents measured improvements in mobility, social well-being and cognitive function relating to participation in SF.

30. Results - Effects of involvement in SF on people's connection to nature: Whilst the limited available evidence suggests generally positive associations between engagement in SF activity and nature connection, causality and effect sizes have not been clearly established.

31. Results - Effects of involvement in SF on subsequent engagement in pro-environmental behaviours: A very limited evidence base provided some indication, particularly for children and their teachers, that involvement with SF stimulated longer-term participation in SF and increased interest in related activities like bird surveys and local habitat improvement.

32. Results - Motivations for SF: The most cited motivations for involvement in SF of birds were personal pleasure and interest followed by concern for birds and their survival.

33. Results - Perceptions of risks and benefits of SF: A limited evidence base suggests perceptions amongst SF participants of benefits to birds are greater than perceptions of risks, and people who feed birds are less likely to perceive risks associated with SF than those who do not feed.

34. Knowledge gaps – avian fitness: Most of the available scientific evidence relating to SF has been collected in wider countryside rather than peri-domestic landscapes, and few studies have been conducted in UK residential settings on seed-eating birds that commonly consume supplementary food. A priority research question is therefore what impact does supplementary seed provision have on the fitness (health status, condition, demography) of granivorous species such as finches and sparrows in peri-domestic landscapes. The impacts of seed provision during winter and the breeding season are both priorities for further research.

35. Knowledge gaps – avian nutritional requirements: A further knowledge gap surrounds the nutritional benefits and potential disbenefits to birds of supplementary food consumption. A review is needed into the nutritional requirements of wild birds at different ages and times of year. By mapping these requirements to the nutritional composition of existing supplementary food types it should be possible to assess the extent to which current SF practice provides for the nutritional needs of birds, and how meeting those needs might be improved in future.

36. Knowledge gaps – pathogen transmission risk: An urgent research priority is to improve knowledge of pathogen transmission routes associated with the provision of supplementary food and water, and to develop associated mitigation measures. In a UK context factors affecting transmission risk associated with *T. gallinae* at feeders and water baths is the most urgent priority as this pathogen is causing widespread population declines of feeder using finch species. Some work has begun on this topic, but further research is urgently required. A related requirement is knowledge of pathogen infection prevalence and potential transmission routes away from sources of supplementary food.

37. Knowledge gaps – interactions between the beneficiaries of SF and other species: Little is known about ecological interactions between species that benefit from SF and other species. In a UK context, further work is needed to understand interactions between willow tits and (i) Eurasian blue tits/great tits with respect to nest eviction, and (ii) great spotted woodpeckers with respect to nest predation. Improved understanding is also needed on competition for resources outside of the breeding season between marsh tits and other woodland tit species.

38. Knowledge gaps – benefits for people: This review found only very sparse and variable quality information on the effects of engagement in SF on people's well-being and connection to nature. Further work is needed to understand the impacts of participation in SF on people's well-being and connection to nature, and how such impacts may be moderated by factors including participation duration, socio-economic status, access to private garden space and access to biodiverse local greenspace.

39. Knowledge gaps – wider environmental implications of SF: The large scale of SF in the UK and elsewhere raises questions about the wider environmental implications of SF in residential settings. Key aspects to consider are the environmental impacts and opportunity costs of bird food production, the carbon footprint of bird food production and transportation and the nutrient enrichment of soils and water courses linked to bird feeding.

Section 1: Introduction and Approach

Background

Supplementary feeding (SF) of birds in residential settings is a popular human activity around the world. In the UK an estimated 12.6 million households (48%) provide supplementary food for birds, of which 7.4 million use bird feeders (Davies et al. 2009). The intensity of SF in the UK, as measured by the average number of feeders used per garden, increased from approximately 4.5 in the mid-1970s to approximately 6.5 by 2010, a pattern driven by increased usage of hanging feeders (Plummer et al. 2019). This change followed a large increase in the number and diversity of food types and feeders advertised by the UK bird food industry (Plummer et al. 2019). This growth in SF behaviour led to a general increase in bird feeder usage across the UK and the magnitude of the change in feeder usage was positively correlated across species with national population changes implying that the widespread increase in SF was probably driving population increases for those species showing the greatest increases in feeder usage (Plummer et al. 2019). Those species include common wood pigeon (+152% between 1967-2022; source BTO/JNCC/RSPB Breeding Bird Survey (BBS) combined with Common Birds Census data (Heywood et al 2025)), Eurasian collared dove (+211%), European goldfinch (+129%), Eurasian siskin (+>200%), great spotted woodpecker (+388%) and Eurasian magpie (+102%) (Plummer et al. 2019). Population increases were also recorded for species that maintained a high level of usage of garden bird feeders such as great tit (+82%) and Eurasian blue tit (+25%).

Whilst these population increases are in many ways welcome especially for people providing SF, concerns have been raised in recent years of potential downsides of SF impacts on wild birds. These concerns focus on two main areas: disease transmission linked to SF and negative interactions between species that have benefitted from widespread SF and other species (Jones 2018, Shutt & Lees 2021, Broughton et al. 2022).

Recent research has confirmed earlier work that widespread declines in UK European greenfinch and Eurasian chaffinch populations are caused by an infectious disease called trichomonosis caused by the protozoan parasite *Trichomonas gallinae* (Robinson et al. 2010, Lawson et al. 2012, Hanmer et al. 2022). Finch population declines were largely driven by reductions in adult survival that were larger in peri-domestic landscapes than in the wider countryside which is consistent with a role for SF in the dynamics of the disease (Hanmer et al. 2022). The magnitude of UK finch population declines has been large: abundance declines measured by the BBS for the period 1995-2023 are 66% for European greenfinch, 34% for Eurasian chaffinch and 15% for Eurasian bullfinch (Heywood et al. 2024, although the cause of the bullfinch decline is currently unknown). The decline of European greenfinches in the UK was large enough to merit inclusion of the species on the UK Red List of Birds of Conservation Concern (BoCC; Stanbury et al. 2021).

Concerns have also been raised about potential impacts of two beneficiaries of SF (Eurasian blue tit and great spotted woodpecker) on willow tit which is one of the fastest declining birds in the UK (Shutt & Lees 2021, Broughton et al. 2022). Eurasian blue tits evict willow tits from nesting sites and great spotted woodpeckers predate willow tit nests. There is also growing evidence of competition between declining marsh tits and dominant Eurasian blue tits and great tits during autumn and winter (Broughton et al. 2022).

Due to growing concerns about the risks of SF to birds, in late 2024 the RSPB began an evidence review of the benefits and potential disbenefits of SF as typically conducted in residential settings. The RSPB last reviewed its position on SF in 2008 (Niemann et al. 2008) since when much new evidence has been published on the benefits and likely disbenefits of bird feeding. The aim of the new review was to synthesize scientific evidence on the likely pros and cons of SF for wild birds and other wildlife, and for participating people. The review would also consider evidence relating to the efficacy of proposed mitigations for known risks of SF. The information generated by this undertaking will be used by RSPB to review its position relating to its policy and practice regarding SF in residential settings. This report presents the findings of the evidence review; it does not consider the implications of the review for RSPB's policy and practice, and nor does it make recommendations for any change to that policy.

The specific aims of the literature review are:

1. To assess the ecological benefits and any disbenefits for wild birds of SF as typically conducted in UK residential settings.

2. To assess the effectiveness of current mitigation measures that aim to reduce any negative impacts of SF on wild birds.

3. To assess the benefits and any disbenefits for people who participate in SF as typically conducted in UK residential settings.

4. To identify key knowledge gaps concerning the impacts and consequences of SF as typically conducted in residential settings on wild birds and people.

The literature review was conducted by a core team of RSPB Centre for Conservation Science staff in consultation with a Technical Steering Group (TSG) that included representatives from the Institute of Zoology (IoZ), British Trust for Ornithology (BTO), University of Cambridge and WHM Pet Group.

Approach

The focus is on SF aimed primarily at birds in private gardens and residential settings, but relevant evidence from other contexts is included. SF is a broad and complex issue which intersects ecological, social and environmental domains. The review is therefore structured around multiple specific questions, each aligned with a distinct impact pathway. This structure enables targeted evidence synthesis, acknowledges the diversity of stakeholders, and supports a comprehensive understanding of the multitude of ways in which SF impacts can occur.

The starting point for our evidence review was to define a set of research questions that aimed to explore whether SF has net positive, neutral, or negative effects on bird populations and wider ecological systems in residential settings for birds and people. Six wildlife-focussed questions considered the likely impacts of SF on the fitness and abundance of wild birds and other wildlife as well the potential implications for infectious disease risk and interactions between species. We also considered the evidence relating to the efficacy of any potential mitigation measures proposed to reduce any suggested risks of SF. Three people-focussed questions considered the impacts of involvement in SF on human well-being and connection to nature, and their likelihood of engaging in pro-environmental behaviour. Two further people-focussed questions considered people's motivations for feeding and awareness of the potential risks and benefits. The eleven research questions are listed in Table 1.1. Each question is designed to focus on a clearly defined outcome or mechanism of impact, and search terms are designed accordingly to retrieve and synthesise the most relevant evidence.

Several important topics are not considered by our review for reasons of limited staff time and capacity. These include:

(i) the influence of nutritional quality and composition of supplementary food on bird condition, health and fitness

(ii) the benefits and potential disbenefits of supplementary water provision for birds in residential settings, and any related mitigation measures
(iii) the environmental consequences of SF which might include the land use impacts of the food production, the carbon footprint of the production and transport, as well as any pollution effects such as the nutrient enrichment of soils
(iv) the economic benefits associated with SF such as employment, taxation revenues and income for conservation organisations.

We acknowledge these are important topics and consider these to be priorities for further research and review.

For each of the 11 research questions we conducted searches of the scientific literature using four different search engines: Google Scholar, Web of Science, Scopus and PubMed. A standard set of search terms was run through each engine and the top 400 'hits' assessed for relevance based on title and abstract (the limited social research meant this was reduced to 200 'hits' for the people-focussed questions). Details of the literature search workflow are presented in Appendix A. For the wildlife-focussed questions, studies were only considered relevant if they related to bird orders represented in typical UK residential settings (i.e. Passeriformes (songbirds), Piciformes (woodpeckers) or Columbiformes (pigeons and doves)). We combined relevant studies across search engines, excluded any duplicates and then checked the full text of each remaining study. Details of each study were extracted to a spreadsheet including the type and season of feeding, the study species, details of study design (e.g. experimental, observational, qualitative or quantitative), geographic location (e.g. country, continent), habitat type (e.g. peri-domestic, woodland, farmland) and the key response metrics (e.g. reproductive success, survival rate or nature connection).

For each wildlife-focussed question we summarised the composition of the available evidence by key context variables to allow us to assess its relevance to SF as typically conducted in UK residential settings. For questions generating many response metrics we summarised the data in terms of the numbers of positive, neutral and negative responses to SF. For each question we also discussed individual studies that were considered most relevant to SF in UK residential settings. For each people-focussed question, the response metrics were categorised as positive, neutral or negative, and the limited evidence base meant we were able to summarise and discuss each available study. Further methodological details of the searches and their interpretation are provided in the text relating to each question (section 2 below). A list of common and scientific names of animal species mentioned in the text is provided in Appendix B.

Table 1.1. Research questions addressed by the literature searches.

Research Category	Question	Rationale
Wildlife	W1. What are the effects of SF on the behaviour, physiological status, and demography of bird species that typically utilise supplementary food in residential situations?	To understand whether SF alters survival, reproduction or condition is fundamental to assessing its impact on population viability. This question aims to determine whether SF supports or undermines the fitness of individual birds.
Wildlife	W2. What are the effects of SF (as typically conducted in residential settings) on the abundance, distribution, and structure of wild bird communities?	To understand how SF affects bird populations and communities is essential to identify shifts in species dominance or community composition.

Wildlife	W3. What are the effects on non-avian wildlife of SF aimed at wild birds?	SF may influence broader ecological networks, attracting and affecting non-target species such as mammals, corvids, or invertebrates. This question addresses the extent and nature of these effects.
Wildlife	W4. What are the effects of SF on pathogen transmission risk and disease in wild birds?	To understand whether, and under what circumstances, SF affects disease risk for wild birds
Wildlife	W5. What is the evidence for indirect effects of SF on bird species via ecological interactions with species whose abundance, distribution, or behaviour has changed due to SF as typically conducted in residential settings?	This question investigates whether SF indirectly impacts bird species through altered interactions, such as increased competition or predation. The aim is to assess how changes in one species driven by SF may affect others. Insights will help anticipate unintended cascading effects.
Wildlife	W6. What mitigation measures are available for any negative impacts of SF from W1-5, and how effective are they?	To inform current and future mitigation advice provided for people who participate in SF of wild birds
People	P1. What are the effects of involvement in SF in residential settings on people's well-being?	SF is a widespread public activity that may contribute to mental and emotional wellbeing. This question explores who benefits, in what ways, and to what extent. The evidence will inform the social trade-offs of any proposed changes in feeding practices.
People	P2. What is the relationship between involvement in SF in residential settings and people's connection to nature?	Connection to nature is a key factor in fostering long-term conservation engagement. This question seeks to understand whether SF strengthens that connection. The outcomes will support assessments of SF as a gateway behaviour for pro-environmental values.
People	P3. What are the effects of involvement in SF in residential settings on people's likelihood of engaging in pro-environmental behaviour?	To understand the likely consequences of involvement in SF on people's propensity for pro-environmental behaviour
People	P4. Why do members of the public provide SF for birds in residential settings?	To understand people's motivations for SF and thereby provide information that might inform any future attempts to alter people's SF behaviour
People	P5. What is the extent of public understanding of the risks and/or benefits of SF in residential settings?	To understand the breadth of public understanding of the risks and benefits of SF to inform any future attempts to alter people's SF behaviour

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Section 2: Wildlife-focussed Questions

W1. What are the effects of SF on the behaviour, physiological status, and demography of bird species that typically utilise supplementary food in residential settings?

Rationale

The aim of this question is to summarise the available evidence relating to the effects of SF on the fitness of wild birds. Our primary interest lies in understanding how SF in residential contexts (typically gardens) is likely to affect the population dynamics and abundance of species that regularly consume SF. Thus, we focus primarily on the key demographic fitness traits that have the strongest direct impact on population dynamics: reproductive success and survival. However, for completeness we also summarise the available evidence for other reported fitness traits (behaviour, condition, physiology etc). To aid interpretation and relevance to the UK residential context, we categorised studies according to their location, proximity to human dwellings, supplementary food type and season of provision. As we lacked the time to undertake a formal meta-analysis, we summarised the directional balance of the literature and present average effect sizes for different subsets of the data; we also discuss the findings of individual studies considered most relevant to the UK residential context. A separate question (W2) assessed the evidence relating to the effects of SF in residential contexts on the abundance and community composition of wild birds.

Methods

Literature search procedure

We developed a search string for each question based on key words and phrases from selected relevant studies combined with expert knowledge from TSG members (Appendix W1: Table AW1.1). For each question, we ran the related search string on Google Scholar, Web of Science, Scopus and PubMed. We then used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of twenty studies to quantify the extent to which subject relevance declined with search engine rank. When this decay function declined to zero it is likely that the search had identified a high proportion of relevant studies; if the function failed to reach zero by the 400-study threshold it is likely relevant studies were excluded by our threshold. For question W1, the identification of multiple relevant studies in the 340-400 search engine ranking range implies that some relevant studies were probably missed by our search (Figure AW1.1). After combining the relevant studies from the four search engines we checked for and removed any duplicates and exported the remaining set of studies to a spreadsheet.

Study exclusions

Following amalgamation of selected studies across search engines we inspected full text articles and extracted summary data for each study (and metric) that met each of the following criteria:

1. Study focus: The study considered the effects of SF on one or more fitness traits of wild birds. Fitness traits (hereafter ‘response metrics’) included a variety of measures of reproductive success, survival, condition, physiology, behaviour and phenology (listed in Appendix W1: Table AW1.2). For completeness we included all fitness traits reported in the literature but focused mainly on the primary demographic traits of reproductive success and survival for reasons explained below.

2. Taxonomic selection: We restricted our selection to species in the following taxonomic groups considered to be relevant to UK residential settings: Passeriformes (songbirds), Piciformes (woodpeckers) and Columbiformes (pigeons and doves). SF studies of other taxonomic groups (including raptors, seabirds, waterbirds, gamebirds, hummingbirds) were excluded as not being directly relevant to a UK residential context. We also excluded two passerine families that do not occur in the UK (honeyeaters [Meliphagidae] and stitchbirds [Notiomystidae] both nectivores) and

any species having year-round tropical distributions. We included four studies (providing 10 metrics) of Florida scrub jay (a corvid) which lives in a subtropical zone and is commonly fed by humans in suburban habitats.

3. Study design: The study involved the measurement of response metrics either for fed and control subjects, or across a gradient of the extent of SF provision. Subjects were typically individual birds, pairs, or nests, or different populations or study sites. Studies lacking unfed controls, or a suitable gradient of SF provision, were excluded.

4. Replication: For response metrics measured on individual birds, pairs or nests we excluded any studies with a combined replication (fed plus unfed) of less than 10 subjects. For metrics such as survival, which are typically measured at the site or sub-population scale, we included all studies as some only had a single fed and single unfed study site. In our treatment of the data, we distinguished between metrics having 'high' replication (number of subjects > 20 or number of sites per treatment level >1) from those with 'low' replication (number of subjects >10 but less than 20, number of sites per treatment level=1).

<u>Data extraction - response metrics</u>

We extracted data on the ecological 'response' metrics to SF reported by each study. These included demographic measures (e.g. clutch size, fledging success, adult survival), body condition (e.g. body mass), behaviour (e.g. anti-predator activity), physiology (e.g. blood glucose level), paternity and phenology (e.g. first egg date) as defined in Table AW1.2. Many studies reported multiple response metrics for the same or different study species. Terminology used to describe response metrics varied considerably between studies, and to facilitate interpretation we assigned each metric to a set of hierarchical categories (Table AW1.2). We focused mainly on the effects of SF on two primary demographic response metrics which are likely to directly influence population size and dynamics: reproductive output (RO: the average number of young birds successfully leaving the nest) and survival (SU: of fully-grown birds). Within the category 'reproductive output' we include measures of chick survival, the number or proportion of fledglings raised per nesting attempt and the number of fledglings raised per parent (or pair) per year (sometimes referred to as season-long productivity). Whole-nest survival was excluded from RO as it often excluded early or late-stage nest failures. Most of the bird species included in this review have an altricial life history in which chicks are subject to a period of parental care both before fledging (in the nest) and after fledging (out of the nest). Survival estimates were sub-divided into immature survival (between leaving the nest and age of first reproduction) and adult survival (of breeding age birds).

We determined whether SF was associated with a statistically significant increase or decrease in each response metric or had no significant effect (P>0.05). Hereafter a lack of significant effect is described as a 'neutral' impact of SF. In most cases it was straightforward to infer whether the observed effect of SF on the response metric represented a likely increase or decrease in fitness (e.g. larger clutch size, higher adult or chick survival, likely reflect increases in fitness). However, for some metrics the relationship with fitness was less clear. For example, optimal avian body mass is known to be a trade-off between food supply predictability and predation risk (Lima 1986) which will vary in space and time with ecological conditions, while many physiological metabolites (e.g. blood glucose concentration) have an optimal mid-range value. We followed author interpretations as to whether the observed effect of SF on such metrics was likely to be associated with increased or decreased fitness. For example, Clinchy et al. (2004) considered increased blood glucose relative to a control group to reflect a decline in fitness due to chronic stress, while Knutie (2020) considered reduced blood glucose to reflect reduced fitness caused by blood-sucking parasites. In the few cases where authors' interpretation was uncertain, we coded the response direction as neutral.

Response metrics were extracted to a spreadsheet in which one row was allocated to a single metric meaning that any study reporting multiple metrics contributed multiple rows. Most cases of multiple rows per study reflected multiple metrics reported for the same species (e.g. clutch size, brood size, number of young fledged). A few studies reported response metrics for multiple species, sexes or study sites and each such metric was allocated one row in the spreadsheet. A small minority of studies (3 relating to RO or SU) reported mixed effects of SF across the sexes, or across spatial or temporal replicates of the same experimental treatments. In these cases, we applied rules to derive an overall direction of fitness change associated with SF. We treated cases where there were both significant positive and non-significant (i.e. neutral) effects of SF across sites/years as reflecting an overall positive impact, and cases reporting a mix of significant positive and significant negative effects as reflecting a neutral overall directional impact. For RO and SU combined, 38 out of 47 selected studies contributed a single response metric for a single species. Of the remaining nine studies, seven contributed two metrics and two contributed three metrics. Six studies contributed multiple metrics for a single species (three contributed survival estimates for different ages, two estimates of RO and SU, and one estimate of RO for two habitats), and three contributed metrics for two species (two for RO and one for SU, the latter also providing estimates for one species in two seasons). These subdivisions by sex, season and habitat all reflected significantly different responses to SF.

We summarised the evidence base by tabulating the numbers of positive, neutral and negative response metrics for all the data, and for different subsets of the data based on extent of replication and context variables (described below). It is important to note that the neutral category may have included cases of undetected positive or negative effects of SF (perhaps due to inadequate statistical power or study design limitations), genuine cases where SF failed to affect fitness, and cases of mixed positive and negative impacts in space or time (see above). We could not therefore assume that all neutral cases represented genuinely neutral effects of SF on fitness. We compared the directional balance of different subsets of the response metrics using chi-squared contingency table tests. Where possible we extracted measures of the response metric for fed and unfed birds to calculate average effects sizes. Where this was possible, we calculated a proportional SF effect size as the ratio of the two measures. For example, if the numbers of young fledged from fed nests averaged six, and from unfed nests averaged four, the proportional SF effect size was 1.5. It was not possible to derive effects sizes for all metrics as these were not always reported, especially for studies whose design was based on a SF gradient rather than fed/unfed contrasts. We summarise available effect sizes as medians and ranges.

Data extraction – context variables

For each response metric, we also extracted information on a range of context variables. These allowed us to describe the composition of the extracted data, and to compare and present different subsets of the data particularly those considered most relevant to a UK residential context.

First, we assigned each metric to one of five continents: North America, Europe, Africa, Asia and Australasia based on study locations. Most selected studies were conducted in the temperate zones of Europe, North America and Australasia with a few (n=5) from semi-arid areas subject to marked seasonal temperature variation including sub-zero night-time temperatures (e.g. Texas, USA).

Second, we assigned each metric to a two-level human proximity category: peri-domestic (urban, suburban, rural domestic) and wider countryside (places away from human habitation like farmland, woodland and wetland). Close-proximity SF was considered likely in all habitats classified as peri-domestic but less likely in wider-countryside habitats. Many SF studies were conducted in wider countryside locations aiming to be far enough away from human settlements to minimise the likelihood of consumption of supplementary food that was not part of the experimental design. Most response metrics (86%; see Results) were collected in wider countryside habitats. Given the paucity of studies from peri-domestic habitats, studies from the wider countryside were included with the caveat that the importance of food as a limiting factor may differ between peri-domestic and other habitats and may not necessarily reflect SF use in residential situations as per our study question. Where possible we compared responses between peri-domestic and other habitats to check for differences.

Third, we assigned each metric to one of two study design categories: 'experimental' which includes (i) before-after control-impact (BACI) studies, (ii) reversal studies in which treatment-control allocations were switched for the same experimental units over time or (iii) studies comparing fixed treatment and control experimental units; and 'observational' studies that were typically correlational and compared response metrics across contrasting levels or a gradient of, SF provision. Whilst observational studies can be informative, experimental approaches generally enable stronger inferences to be drawn.

Fourth, we assigned each metric to one of three categories combining the type of supplementary food and the season of provision. Initially, we identified five categories of food: (i) animal proteins (mainly mealworms, wax worms and chicken eggs); (ii) seeds, including sunflowers, millets, nyjer, mixes, and peanuts; (iii) fat, suet, tallow; (iv) food mixtures (e.g. fat plus seed); (v) undefined (i.e. subjects reported as being supplementary fed but food type not described, for example from surveys of residential areas where only feeder presence is recorded). Our selected studies included many that provided animal protein-rich foods, seeds or mixtures but rather few that provided only fat (Table W1.1). As studies providing animal protein were largely restricted to the breeding season, and studies presenting seed, fat or food mixtures tended to occur either during the breeding or winter seasons (Table W1.1) we assigned each response metric to one or more of the following food-type-season categories:

A: Animal protein provision during the breeding season included any study which fed animal-based protein during the breeding season (March-August in the northern hemisphere). Animal protein-rich foods are listed in Table W1.1 and include foodstuffs for which protein-content is expected to exceed fat content (e.g. mealworms: 100g wet mass contains 19.1g protein /9.1g fat, Peach et al. 2015; a single raw chicken egg: 12.6g protein /9.0g fat; Farron-Wilson 2012). Some studies providing bespoke food types did not provide details of nutritional composition and we allocated such cases based on comments in the papers (e.g. 'meat-based dog food' was assigned to animal protein-rich) as shown in Table W1.1. Where food mixtures specified a component known to be rich in animal proteins the study was included in this category.

B: Seeds and/or fat provided during winter included any seeds, peanuts, fat or low-protein mixtures provided during winter (November to February in the northern hemisphere). Fat levels in this group generally exceed protein levels (e.g. peanuts: 28.7% protein /44.5% fat; sunflower seeds 18.0% protein /44.4% fat; sunflower hearts 21.4% protein /58.0% fat, Harrison et al. 2010).

C: Seeds and/or fat provided outside the winter period included any studies providing seeds, peanuts, fat or low-protein mixtures outside of winter (March to October in the northern hemisphere).

The intention with these categories was to distinguish between studies that aimed to test the limiting effect of protein availability on avian reproduction (when chicks of many species are fed invertebrates or other animal dietary items), and the potentially limiting effect of nutritional energy (e.g. during winter when many birds in temperate regions rely on a predominantly vegetarian diet). These food-type-season categories are not mutually exclusive as some studies provided multiple food types within or across seasons. For example, a study providing mealworms and seed during the breeding season was assigned to both categories A and C.

Results

Literature composition

Our literature search generated 129 different studies reporting the consequences of SF on 42 different response metric types (n=459 individual metrics; median metrics per study=3, range=1-12).

The range of these metrics and contributing species composition is summarised in Appendix W1, Tables AW1.3 and AW1.4. The 459 individual metrics are comprised of 234 (from 80 studies) relating to avian reproduction, 11 (7 studies) juvenile survival, 18 (14 studies) adult survival, 51 (30 studies) condition of fully-grown birds, 21 (9 studies) physiology of fully-grown birds, 59 (34 studies) behaviour, one (1 study) ectoparasite load, five (2 studies) brood parasitism, three (2 studies) paternity and 56 (39 studies) phenology (Table AW1.3). Our search identified 38 metrics (from 35 studies) that measured the effect of SF on RO, 23 metrics (from 16 studies) that measured the effect of SF on SU, and 61 metrics (from 46 studies) that measured the effect of SF on either RO or SU (Table W1.3). Six of the 29 survival metrics were not included in the SU category because they entailed measures of local recruitment that may have confounded survival and local settlement behaviour.

Most metrics relate to animal protein (40%) or seed/mixed food (53%) provision with only a small number of fat-only related metrics (Table W1.1). Most animal protein provision studies (accounting for 92% of such response metrics) were conducted during the pre-breeding and breeding season while most seed provision studies (accounting for 75% of such metrics) were conducted during winter and/or the pre-breeding and breeding seasons (Table W1.1). Most metrics were collected as part of experimental (89%) rather than observational studies, and in the wider countryside away from human habitation (86% typically in woodland or farmland; Tables W1.2a & d). Most studies providing breeding season animal protein were experimental but a higher proportion of studies providing winter seed or fat were observational (Table W1.2b). Nearly half of the peri-domestic metrics (49%) involved the provision of animal protein; only 12 involved the provision of seed and seven the provision of food mixtures reflecting a major limitation of the evidence base to address the question focus on residential settings (Table W1.2d).

The species composition of the data was dominated by North American and European passerines particularly the Paridae, Muscicapidae and Corvidae (Table AW1.4). The primary demographic response data include metrics relating to several species that frequently take food in UK residential settings (including house sparrow (n=1 RO, n=2 SU), great tit (6, 2), Eurasian blue tit (5, 1), common starling (2, 0), great spotted woodpecker (1, 0), western jackdaw (2, 0) and carrion crow (2, 2)), but notably lack any studies of finches, European robin, European thrushes (other than ring ouzel) and Columbidae (other than European turtle dove).

Given the relative lack of data from peri-domestic habitats we compared the directional balance, and average effect size, of the effects of SF on RO and SU between peri-domestic and wider countryside habitats to assess the extent to which data from the latter may inform questions about the former. Comparisons of directional balance considered the relative proportions of positive, neutral and negative responses to SF (contingency table tests) using data in Table W1.3. We conducted similar comparisons for data from different continents and food-type-seasons. There was no significant difference in the directional balance of effects of SF on either RO or SU between studies conducted in North America and Europe (RO: χ^2_2=2.92, P=0.23; SU: χ^2_2 = 3.10, P=0.21). The directional balance of responses to SF was also similar across food-type-season categories (RO: χ^2_4 = 4.23, P=0.38; SU: χ^2_4=2.75, P=0.60) although there was a higher proportion of positive effects of winter seed/fat provision on SU than for other food-type-season categories (Table W1.3). There was weak evidence (not statistically significant) that the directional response balance differed between peri-domestic and wider countryside habitats (RO: χ^2_2=5.36, P=0.069; SU: χ^2_2 = 4.49, P=0.109) in which the effects of SF in peri-domestic habitats were more positive for RO than in the wider countryside (6 positive, 0 neutral, 1 negative vs 13, 14, 4) and more neutral for SU (0, 3, 0 vs 11, 7, 2) although peri-domestic sample sizes were modest and two of the three peri-domestic SU studies had important design weaknesses (see below). Median effect sizes for RO and SU were similar for Europe, the wider countryside and for breeding season animal protein provision, and for SU for winter food provision (Table W1.3). However, there was evidence that the median RO effect size was more positive in peri-domestic studies than in the wider countryside (+91% vs +10%; Mann-Whitney

U test: W=62, P<0.01). The sample of 10 peri-domestic RO/SU metrics comprised five collected on corvids (3 RO & 2 SU measures; 4 from Switzerland, 1 from Canada) all involving breeding season animal protein provision. The remaining five peri-domestic metrics were collected on great tits (n=2, Hungary & France), house sparrows (2, both England) and eastern bluebird (1, Canada), of which four involved breeding season animal protein provision and one (on house sparrow) year-round seed. The small peri-domestic RO/SU sample is therefore dominated by studies feeding animal protein, with only four metrics collected on species commonly targeted at UK feeders (great tit & house sparrow). There is considerable uncertainty therefore whether the available data provide a representative assessment of the effects of SF on bird fitness in peri-domestic settings. Although the peri-domestic RO metrics were more positive than those collected in the wider countryside this might reflect the dominance of animal protein provision in that sample, or perhaps the species composition.

Effects of SF on avian fitness

Of the primary demographic metrics (RO and SU) the majority reported positive (30) or neutral (24) effects of SF on fitness while seven reported negative impacts (Table W1.3). The impact of SF on RO was mainly positive (19) or neutral (14) with some negative cases (5), and the median effect size was +17%. For SU, the responses to SF were similarly positively skewed (11 positive, 10 neutral, 2 negative) and the median effect size was +55% (Table W1.3). Excluding the low replication metrics had little effect on the directional balance of RO or SU, and a modest positive effect on the average SU effect size (Table W1.3). The average effect sizes suggest that SF is having a large positive impact on survival rates (mostly measured year-round or during winter) that may be ecologically important and a more modest positive impact on reproductive output.

A variety of other fitness metrics were reported in the literature and the topics receiving most attention were phenology, behaviour and individual condition (Table AW1.3). All phenology studies were focused on reproduction and the metrics reflected mainly earlier nesting (n=29, 52%) or a neutral effect (n=23, 41%). Half of the behavioural responses (n=30/59) entailed likely increases in avian fitness particularly increased anti-predator behaviour, the construction of larger/heavier nests and the devotion of more time to vocalisations like singing (Table AW1.3). Most studies of individual condition (of fully grown birds) reported what are likely to have been changes associated with increases in fitness (n=24 positive, n=2 negative metrics; 47% and 4%) such as increased body mass/fat reserves although there is a well-known trade-off between body mass/condition and predation risk (Lima 1986, Gentle & Gosler 2001, Creswell et al. 2009). The metric category physiology (of fully grown birds) included a wide range of responses such as stress hormones, oxidative damage/antioxidants and physiological indicators of nutritional status; this category provided a mix of positive (n=8), neutral (n=8) and negative (n=5) impacts on response metrics (Table AW1.3).

Seasonal patterns of SF provision

(A) Animal protein provision during the breeding season: The effects of breeding season animal protein provision on RO metrics were mostly positive or neutral (17 positive, 10 neutral, 4 negative), whilst the effects on survival were predominantly neutral (2, 5, 1) (Table W1.3). The median effect size was +15% for RO and +48% for SU.

Two notable studies involved the experimental provision of mealworms in suburban areas which increased clutch size, chick survival and fledging success (by 55%) amongst house sparrows (Peach et al 2014) and increased chick body size and chick survival in great tits (Seress et al. 2020). Breeding season protein provision in peri-domestic settings also increased fledgling success amongst black-billed magpies in Canada (Dhindsa & Boag 1990), and nestling survival amongst western jackdaws in Switzerland (Meyrier et al. 2017). In the wider countryside (farmland), breeding season animal protein provision increased fledgling success amongst carrion crows in Scotland (Yom-Tov 1974), western jackdaws in Spain (Soler & Soler 1996), and common starlings in Sweden (Granbom & Smith

2006). These and other studies strongly suggest that the availability of suitable dietary protein (especially invertebrate prey) limits the reproductive success of some bird species in both peri-domestic (Chamberlain et al. 2009) and farmland habitats (Newton 2004).

We found five cases of reduced fitness associated with breeding season animal protein provision (4 RO, 1 SU; Table W1.3). In four of these cases (all in wider countryside habitats) the authors suggested that the observed negative effects of protein provision on RO (3 cases involving Eurasian blue tit, common starling and red-winged blackbird) and SU (1 case involving Eurasian blue tit) were a consequence of SF causing earlier laying and thereby exposing chicks (and provisioning adults) to lower levels of natural food than would otherwise have been the case (i.e. phenological mismatch). In one of these four studies SF was only provided pre-breeding up until the first egg was laid, whilst in the others SF was maintained throughout the nesting period. The fifth study in peri-domestic France reported reduced survival of supplementary fed great tit chicks when animal protein was only provided after eggs had hatched and therefore had no effect on laying date (Demeyrier et al. 2017).

(B) Seeds/fat provided during winter: The provision of seed/fat during winter had mainly positive impacts on survival (8 positive, 5 neutral, 1 negative) with less research on RO (1, 2, 2; Table W1.3). The average effect size was +77% for SU and -8% for RO. The positive effect of winter seed/fat provision on survival is large enough to have had ecologically significant implications for the population dynamics of the species involved.

One of the most conclusive studies of SF of birds was conducted by Brittingham & Temple (1988) who showed experimentally that SF with sunflower seeds over three winters in North American temperate woodland (latitude 43°N) increased annual survival of individual black-capped chickadees from 37% to 69% (as well as increasing body mass). The SF was considered to have buffered the birds against high energy demands associated with cold winter weather (most mortality amongst unfed birds occurred during months having more than 5 days with minimum temperature less than -18°C). The magnitude of the effect of SF on chickadee survival is large enough to have had a strong effect on population dynamics. A second North American study (Spellmeyer et al. 2020; latitude 37°N) reported a similarly large positive impact of SF on the over-winter resighting rates of dark-eyed juncos averaging 84% for SF birds and 32% for controls over three winters when January-February temperatures averaged 1.8°C and total snowfall averaged 40.3 cm. For comparison, average UK minimum/maximum monthly temperatures (for the period 1991-2020) are 1.2/6.7°C in January and 1.1/7.2°C in February (https://www.metoffice.gov.uk/research/climate/maps-and-data/location-specific-long-term-averages/gcpsvg3nc). Although these studies were conducted away from peri-domestic habitats, both black-capped chickadees and dark-eyed juncos are common visitors to garden feeders in the USA. A study conducted in Swedish coniferous woodland in which seeds and protein-enriched fat were provided during November-March recorded large positive effects of feeding on the survival rates of willow tits and crested tits (45%/82% and 39%/76% unfed/fed respectively; Jansson et al. 1981). Mean monthly temperatures in this part of Sweden are -2.3/1.6 in January and -2.7/2.1 in February (https://en.climate-data.org/europe/sweden/vaestra-goetalands-laen/gothenburg-197/).

In contrast, two UK studies found no effect of increased SF on survival. An observational study on woodland great tits and Eurasian blue tits found no difference in the recruitment rates (a proxy for first-year survival) of individuals having contrasting usage of supplementary seed in winter (Crates et al. 2016), whilst the provision of unlimited seed (in addition to that already provided by residents) had no effect on the survival rates of house sparrows in suburban London (Peach et al. 2018). It is important to note that both of these studies had relatively weak designs (observational, all birds had access to supplementary food) compared to the US/Swedish studies described above, and both were conducted during winters for which temperatures were close to local long-term averages. The one study reporting a negative effect of winter SF on apparent survival (Krama et al. 2023) compared irregular (ca 4 hours per week) and continuous seed provision in Latvia where average December temperatures ranged between 0 and -5°C. Although this study was restricted to just two woodland patches (1 per treatment, albeit over 5 winters) it found that adult male great tits maintained higher body weights under continuous feeding, and had slower take off speeds, higher susceptibility to Eurasian sparrowhawk attacks at feeders and lower survival. This suggests that supplementary fed birds may not always be able to trade-off the risks of starvation and predation as suggested by several previous studies (Lima 1986, Gentle & Gosler 2001, Creswell et al. 2009) and can incur negative overall fitness costs from SF.

Of five metrics that tested for carry-over effects of winter SF on subsequent reproduction, one reported a positive effect, two reported neutral effects and two negative effects (Table W1.3). The positive effect involved winter peanut provision and Eurasian blue tit fledging success (13% more fledglings; Robb et al. 2008), whilst the two neutral effects involved a gradient of winter seed provision and great/Eurasian blue tit fledging success (Crates et al. 2016). The two negative effects involved winter fat provision and Eurasian blue tit nestling survival (8% fewer fledglings; Plummer et al. 2013a) and winter seed and fat provision and Eurasian blue tit fledging success (52% fewer fledglings; Clamens & Isenmann 1989). In the latter study SF was associated with an earlier laying date which may have exposed chicks to periods of reduced natural food levels. A separate study reported high levels of linoleic acid in European greenfinches and hawfinches having access to supplementary sunflower seeds, and a positive correlation between blood linoleic acid and sperm abnormalities (Støstad et al. 2019). Linoleic acid occurs at high concentrations in sunflower seeds and is associated with oxidative stress and can damage sperm cell membranes.

A potential concern with SF is that provisioned individuals become reliant or dependent on the supplementary food and therefore vulnerable to its removal. Brittingham & Temple (1992) compared the survival rates of chickadees during a winter with no SF for black-capped chickadees with and without access to sunflower hearts during the preceding 25 winters (October-April). The two groups had identical survival in the absence of SF which suggests the birds with previous long-term access to winter feeding had not become dependent on that food source.

(C) Seeds/fat provided outside the winter period: Provision of seed/fat outside of the winter period (April-October but mostly during the breeding season, Table W1.1) was associated with mainly positive impacts on RO (5 positive, 1 neutral, 2 negative) and there was very little evidence relating to survival (1, 2, 0) (Table W1.3). Median effect sizes, albeit based on small samples, were larger for RO (+34%, n=4) than for SU (+20%, n=3). It is important to note that a high proportion of the studies included in this food-type-season category (8 out of 11) involved the provision of animal protein-rich foods as well as seed and/or fat meaning that we cannot confidently ascribe the measured responses to the provision of either individual food type. Of the three studies that provided only seed or fat (and not animal protein) one showed a positive effect and one a neutral effect on RO (for great spotted woodpecker and Eurasian blue tit respectively, both conducted in the UK), and the other a positive effect on SU (for varied tit in Japan). The lack of studies providing only seed or only fat outside of winter is a major limitation of the evidence base.

Notable examples of studies showing positive effects of SF include pre-breeding fat provision doubling the RO of great spotted woodpeckers in English woodland (Smith & Smith 2013) and pre-breeding feeding of sunflower seed increasing adult survival and pair bond maintenance in woodland varied tits in Japan (Nakamura & Kubota 1998). Autumn seed (and protein) provision increased the survival rates of willow tits in Swedish woodland although the magnitude of the effect was smaller than for winter feeding (74%/89% unfed/fed cf. above; Jansson et al. 1981). In contrast provision of peanuts and fat from pre-breeding throughout the breeding season led to a reduction in clutch size and post-hatching brood size in Eurasian blue tits and great tits in English woodland (Harrison et al. 2010; not included in Table W1.3 because RO at fledging was not measured). The mechanism was unclear but may have reflected lack of protein in the supplementary food or the females laying reduced clutch sizes to facilitate earlier laying. Given the sparsity of studies of seed/fat provision outside of winter, and the mixed directional findings of those studies, it is difficult to draw any general conclusions about the impacts of such provision.

Three different studies have recorded higher nest predation rates close to feeders providing peanuts/seed, the likely mechanism being the attraction of nest predators to those feeders. These studies reported higher rates of nest predation (caused by American crows) close to feeders for American robins (but not northern cardinals) in Ohio gardens (Malpass et al. 2017), for artificial nests predated by corvids and grey squirrels in English gardens (Hanmer et al. 2017) and for dusky flycatcher nests in Californian montane meadows (Borgmann et al. 2013).

Summary

- The available literature on the effects of SF on avian fitness is dominated by studies conducted in the wider countryside (mainly woodland and farmland) on tits, corvids and flycatchers. We found only 10 measures of the effects of SF on RO or SU in peri-domestic settings and nine of these involved the provision of animal protein during the breeding season. The evidence base does not therefore provide an adequate assessment of the effects of seed and fat provision on birds in peri-domestic settings.
- The directional impacts of SF on RO and SU were broadly similar for North America and Europe, and for different types and seasons of provision. There was some evidence that responses of RO to SF were more positive in peri-domestic settings, but that might reflect the dominance of breeding season protein or the taxonomic composition of the peri-domestic sample.
- Breeding season provision of animal protein had generally positive or neutral impacts on RO and mainly neutral impacts on SU. Most of the reported negative impacts of animal protein provision may have been a consequence of SF encouraging earlier egg laying resulting in chicks hatching before the seasonal peak in invertebrate prey availability.
- Based on the wider sample of studies mainly conducted away from human habitation, winter seed and/or fat provision was associated with mainly positive or neutral effects on SU and mixed effects on RO. The average impact of winter seed or fat provision on SU was large (+77%, n=9) suggesting potentially important implications for population dynamics. One study of great tits in Latvian woodland documented reduced survival probably caused by higher Eurasian sparrowhawk predation at feeders linked to increased body mass and slower take-off speeds of the great tits.
- Only three studies measured the effects of only seed or fat provision during spring, summer or autumn on RO or SU. This represents an important limitation of the evidence base.
- The primary research need is to assess the fitness impacts of seed and fat provision for a wider range of passerines and Columbidae in peri-domestic habitats. The impacts of seed and/or fat provision outside of winter is also a major gap. Other topics meriting further consideration are the effects of supplementary food on nest predation and the effects of the nutritional composition of supplementary food on RO and SU.

Table W1.1 The numbers of response metrics associated with different food types and seasons of provision. Note some (n=23) studies provided supplementary food in multiple seasons so contribute to multiple columns.

Food type and sub-type	Pre-breeding (Mar)	Breeding (Apr-Jul)	Post-breeding (Aug)	Autumn (Sep-Oct)	Winter (Nov-Feb)
Fat	**4**	**4**	**0**	**0**	**9**
Fat[1]	4	4	0	0	9
Mixed	**50**	**81**	**7**	**8**	**30**
Bread & eggs	4	4	4	4	4
Chicken food	0	3	0	0	0
Custom made[2]	2	0	0	0	0
Fat + seed	22	37	0	0	21
Fat + sugar	0	5	0	0	0
Human food	0	3	0	1	1
Pet food[3]	15	13	3	3	4
Pet food + seed	7	16	0	0	0
Protein	**22**	**218**	**9**	**0**	**11**
Eggs	5	8	0	0	0
Insects[4]	4	179	9	0	0
Insects + fat	0	1	0	0	0
Insects + fat + seed	9	9	0	0	9
Insects + seed	0	4	0	0	2
Insects or seed + fat[5]	4	4	0	0	0
Meat	0	3	0	0	0
Meat + eggs	0	10	0	0	0
Seed	**24**	**33**	**18**	**22**	**66**
Seed[6]	24	33	18	22	66
Undefined/presence only	**12**	**11**	**0**	**1**	**5**
Undefined SF	9	9	0	0	0
SF presence only	3	2	0	1	5
Total	**112**	**347**	**34**	**31**	**121**

[1] Predominantly described as animal fat (e.g. tallow) but in one case was margarine.

[2] 35% protein 19% fat.

[3] Typically dry pelleted food (occasionally wet food) with protein content markedly greater than fat.

[4] Insects consisted of larval stages of one of the following: mealworms (*Tenebrio sp.*), wax worms (e.g. *Galleria sp.*) or blow flies (*Calliphora sp.*) presented live or occasionally dehydrated.

[5] Factorial experiment comparing two SF diets alongside control, this diet combination presented separately from others for clarity.

[6] All types of whole seed typically fed to wild birds but predominantly sunflower seed and peanuts.

Table W1.2a. The numbers of response metrics presented by supplementary food type and study design (experimental vs. observational).

Food type	Experimental	Observational	**Total**
Fat	13	0	**13**
Mixed	106	6	**112**
Protein	221	4	**225**
Seed	68	22	**90**
Undefined/presence only	4	15	**19**
Total	**412**	**47**	**459**

Table W1.2b. The numbers of response metrics presented by food-type-season (as defined in methods) and study design (experimental vs. observational). The food-type-season categories are non-exclusive as feeding was often carried out with multiple food types and across multiple seasons.

Type and season of SF provision	Experimental	Observational	Total
Breeding animal protein	265	4	**269**
Winter seed/fat	86	19	**105**
Pre-breeding-Autumn seed/fat	119	9	**128**
Total	**470**	**32**	**502**

Table W1.2c. The numbers of response metrics presented by food-type-season and food category. The food-type-season categories are non-exclusive as feeding was often carried out using multiple food types and across multiple seasons.

Type and season of SF provision	Fat	Mixed	Protein	Seed	Total
Breeding animal protein	0	49	220	0	**269**
Winter seed/fat	9	21	11	64	**105**
Pre-breeding-Autumn seed/fat	4	67	10	44	**125**
Total	**13**	**137**	**241**	**108**	**499**

Table W1.2d. The numbers of response metrics presented by food category and proximity to human habitats (peri-domestic vs. wider countryside).

SF type	Peri-domestic	Wider Countryside	Total
Fat	0	13	**13**
Mixed	7	105	**112**
Animal protein	31	194	**225**
Seed	12	78	**90**
Undefined/presence only	13	6	**19**
Total	**63**	**396**	**459**

Table W1.2e. The numbers of response metrics presented by continent and proximity to human habitats (peri-domestic vs. wider countryside).

Continent	Peri-domestic	Wider Countryside	Total
Africa	3	0	**3**
Asia	0	7	**7**
Australasia	0	10	**10**
Europe	35	232	**267**
North America[1]	25	147	**172**
Total	**63**	**396**	**459**

[1] 13 metrics (3 peri-domestic, 10 wider countryside) come from a sub-tropical zone (from 5 studies conducted in Florida, USA).

Table W1.3. Effects of SF on reproductive output (RO) and survival (SU). Numbers of positive, neutral and negative response metrics (and the sum) are shown, along with the number of studies (sub-divided by the numbers of metrics contributed per study) and the number of, and the median effect size and range, for different sub-divisions of the data. Higher replication metrics were those derived from 20 or more subjects (RO) or more than one study sites per treatment level (SU).

Data division	Number positive	Number neutral	Number negative	Sum of metrics	Number studies (number contributing 1, 2, 3 metrics)	Median effect size (n)	Range
All RO/SU metrics							
Reproductive output	19	14	5	38	35 (32,3,0)	17.1 (21)	-52-250
Survival	11	10	2	23	16 (11,3,2)	54.8 (16)	-30-618
Sum	30	24	7				
Higher replication RO/SU metrics only							
Reproductive output	19	10	5	34	32 (30,2,0)	22.0 (18)	-52-250
Survival	7	8	1	16	12 (9,2,1)	72.0 (10)	-1-618
Sum	26	18	6				
Europe only							
Reproductive output	10	11	4	25	23 (21,2,0)	17.1 (15)	-52-250
Survival	5	8	2	15	9 (5,2,2)	72.0 (10)	-30-618
Sum	16	19	6				
Peri-domestic only							
Reproductive output	6	0	1	7	7 (7,0,0)	91.4 (4)	55-250
Survival	0	3	0	3	2(1,1,0)	6.5 (2)	-1-14
Sum	6	3	1				
Wider Countryside only							
Reproductive output	13	14	4	31	29 (27,2,0)	10.0 (17)	-52-100
Survival	11	7	2	20	14 (10,2,2)	72.0 (14)	-30-618
Sum	24	21	6				
Breeding season protein							
Reproductive output	17	10	4	31	29 (27,2,0)	15.0 (18)	-52-250
Survival	2	5	1	8	5 (3,1,1)	47.5 (6)	-1-618
Sum	19	15	5				
Winter seeds/fat							
Reproductive output	1	2	2	5	4 (3,1,0)	-8.0 (3)	-52-22
Survival	8	5	1	14	10 (7,2,1)	77.2 (9)	-30-162
Sum	9	7	3				
Breeding season/autumn seed/fat							
Reproductive output	5	1	2	8	8 (8,0,0)	34.2 (4)	-52-100
Survival	1	2	0	3	3 (3,0,0)	20.3 (3)	20-43
Sum	6	3	2				

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W1 Appendix

Table AW1.1 Search term used for the W1 literature search separated into three component parts by 'AND' statements.

Part-1	Part-2	Part-3
(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "food addition" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")	AND ("breeding success" OR "reproductive success" OR productivity OR "nest success" OR "nesting success" OR "laying date" OR "clutch size" OR "brood size" OR survival OR mortality OR predation OR condition OR mass OR weight OR physiol* OR immun* OR trauma OR toxin)

Figure AW1.1 Changes in the relevance 'hit rate' of studies selected by four search engines for question W1. The numbers plotted are the number of studies we considered to be relevant out of each batch of 20 studies ('hit rate') across the 400 studies as ranked in relevance order by each of the search engines (1-20=ranked most relevant, 400 = ranked least relevant). A hit rate declining to zero implies most relevant studies have been identified, but higher hit rates up to the 400 threshold, as in this case, implies some relevant studies may have been missed.

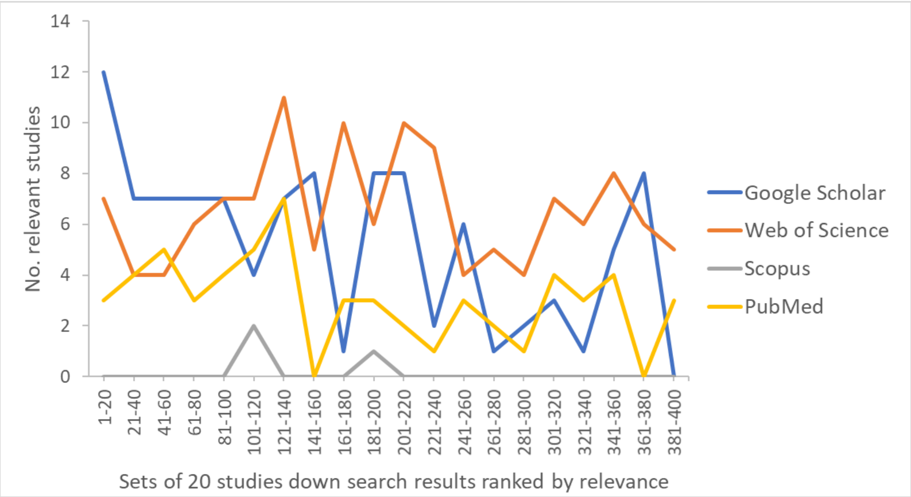

Table AW1.2. Metric types and their definitions as used to categorise data extracted for question W1. Most metrics were measured on individual birds, nests or pairs, while some (like survival) were measured on different sub-populations or study areas. Those metrics that contribute to reproductive output (RO) and survival (SU) are indicated.

Metric type	Definition	Contributing to primary demographic rates: RO or SU
1. Reproduction		
Age ratio	Number of juveniles divided by number of adults as an index of breeding performance	
Brood size	Number chicks in nest (often maximum)	
Chick biometrics	External chick body dimensions and mass	
Chick physiology	Variety of chick physiological measures (e.g. white blood cell count, blood glucose)	
Chick survival	Survival rate of individual chicks within the nest	**Chick survival/fledging success/productivity (RO)**
Clutch size	Number of eggs in completed clutches	
Egg biometrics	Egg dimensions, shape, coloration	
Egg laying	Interval between laying consecutive eggs	
Egg physiology	Measures of egg physiology and composition (e.g. yolk size)	
Fertility	Aspects of reproductive health (e.g. sperm motility)	
Fledging success	Number or proportion of chicks fledged per nest	**Chick survival/fledging success/productivity (RO)**
Hatch success	Number or proportion of eggs hatched per nest	
Incubation	Aspects of incubation (e.g. total duration, time spent incubating, length of incubation bouts)	
Nest success	Proportion of monitored nests that fledged at least one chick (whole nest survival)	
Nesting attempts	The average number of nesting attempts (measured across multiple pairs)	
Productivity	Number of fledged young per pair per year	**Chick survival/fledging success/productivity (RO)**
2. Juvenile survival		
Post-fledging survival	Survival from fledging to independence	**Survival – immature (SU)**
To maturity	Survival from fledging to sexual maturity/recruitment	**Survival – immature (SU)**
3. Adult survival		

Metric type	Definition	Contributing to primary demographic rates: RO or SU
Adult survival	Survival of breeding age adults	**Survival – adult (SU)**
4. Fully-grown condition		
Fully-grown biometrics	External body dimensions and mass of fully-grown birds (i.e. after fledging)	
Growth & development	External aspects of adult nutritional status indicated by feather replacement capacity (e.g. ptilochronology)	
5. Fully-grown physiology	**NB: Fully grown = all birds after they have left the nest**	
Fully-grown antioxidants	Levels of antioxidants (e.g. reactive oxygen metabolites, carotenoids, vitamin-E, malondialdehyde)	
Fully-grown hormones	Levels of hormones (e.g. reproductive hormones, dehydroepiandrosterone hormone precursor)	
Fully-grown immunity	Immunological status and response capacity (e.g. immunoglobulin, basophils, phytohemagglutinin, inflammatory response to overnight lipopolysaccharide challenge)	
Fully-grown nutrition	Nutritional status markers (e.g. total plasma protein, cholesterol, haematocrit)	
Fully-grown stress	Levels of stress markers (e.g. corticosterone, cortisol, heterophil to lymphocyte ratio)	
6. Behaviour		
Aggression	Time invested in aggression toward conspecifics	
Anti-predator	Range of direct / indirect metrics including: investment in vigilance, take-off speed, nest defence, willingness to cross gaps and response to predators	
Begging	Time chicks spent begging for food	
Feeding	Time spent foraging	
Incubation	Time spent incubating	
Interspecific mixing	Composition of winter flocks	
Movement (e.g. range-size, dispersal)	Propensity to join same or mixed species winter flocks	
Nest construction	Nest size, time to build, and propensity to build additional display nests	
Pair-bond	Metrics of investment in mate guarding and propensity to change mate	

Metric type	Definition	Contributing to primary demographic rates: RO or SU
Provisioning	Rate of, or time invested in, feeding chicks	
Social	Site fidelity, flock size, dominance, and social networks	
Vocalisation	Time invested in singing	
7. Brood Parasitism		
Brood parasitism	Aspects of brood parasitism (e.g. brown-headed cowbird laying eggs in nests of other species)	
8. **Ectoparasites**		
Ectoparasite Load	Parasite Load (e.g. flea abundance in the nest)	
9. Paternity		
Paternity	Proportion of young with a different parent to the nest builders	
10. Phenology		
Phenology	Change in timing of breeding activities (e.g. at nest building, egg laying). Positive values reflect earlier nesting	

Table AW1.3. The numbers (and percentages) of metrics showing positive (increased fitness), neutral (no effect on fitness) and negative (decreased fitness) responses to SF for different response categories. Also presented are the number of studies for which effect sizes could be extracted, the mean, maximum and minimum effect size, and the number of contributing studies. Metric statistics and effect sizes are averaged within, but not across (n/a bottom row of table), major response categories. Some studies contributed metrics on multiple species and so the total is not informative.

Response categories	n (metrics)	n (increased fitness)	n (neutral)	n (decreased fitness)	% increase	% neutral	% decline	n (metrics with effect size)	Mean effect size	Max effect size	Min effect size	n (studies)
1. Reproduction	**234**	**86**	**123**	**25**	**37**	**53**	**11**	**86**	**18**	**250**	**-52**	**80**
Age ratio	**4**	4	0	0	100	0	0	4	42	62	20	**3**
Brood size	**10**	3	4	3	30	40	30	4	7	21	-11	**8**
Chick biometrics	**59**	20	32	7	34	54	12	24	6	75	-6	**37**
Chick physiology	**13**	9	3	1	69	23	8	4	10	27	2	**9**
Chick survival	**9**	4	3	2	44	33	22	4	36	83	2	**8**
Clutch size	**38**	5	30	3	13	79	8	15	5	19	-6	**31**
Egg biometrics	**19**	7	12	0	37	63	0	3	5	8	4	**16**
Egg laying	**2**	0	2	0	0	100	0	0	0	0	0	**2**
Egg physiology	**8**	6	2	0	75	25	0	1	1	1	1	**5**
Fertility	**4**	0	2	2	0	50	50	0	0	0	0	**1**
Fledging success	**27**	13	12	2	48	44	7	15	41	250	-52	**25**
Hatch success	**15**	1	13	1	6.7	87	7	5	-1	7	-9	**12**
Incubation	**3**	3	0	0	100	0	0	0	0	0	0	**2**
Nest success	**16**	4	8	4	25	50	25	5	45	156	1	**13**
Nesting attempts	**5**	5	0	0	100	0	0	0	0	0	0	**4**
Productivity	**2**	2	0	0	100	0	0	2	31	46	17	**2**
2. Juvenile survival	**11**	**3**	**8**	**0**	**27**	**73**	**0**	**6**	**152**	**618**	**-1**	**7**
Post-fledging survival	**5**	2	3	0	40	60	**0**	3	215	618	-1	**5**
To maturity	**6**	1	5	0	17	83	0	3	89	161	40	**4**
3. Fully-grown survival	**18**	**9**	**6**	**3**	**50**	**33**	**17**	**13**	**58**	**162**	**-30**	**14**
Fully-grown survival	**18**	9	6	3	50	33	17	13	58	162	-30	**14**
4. Fully-grown condition	**51**	**24**	**25**	**2**	**47**	**49**	**4**	**11**	**7**	**44**	**-1**	**30**
Fully-grown biometrics	**41**	20	19	2	49	46	**5**	11	7	44	-1	**27**
Growth & development	**10**	4	6	0	40	60	0	0	0	0	0	**4**
5. Fully-grown physiology	**21**	**8**	**8**	**5**	**38**	**38**	**24**	**2**	**7**	**13**	**0**	**9**
Fully-grown antioxidents	**3**	1	0	2	33	0	67	0	0	0	0	**2**
Fully-grown hormones	**2**	0	2	0	0	100	0	0	0	0	0	**2**
Fully-grown immunity	**4**	2	2	0	50	50	0	1	0	0	0	**3**
Fully-grown nutrition	**2**	0	0	2	0	0	100	0	0	0	0	**1**
Fully-grown stress	**10**	5	4	1	50	40	10	1	13	13	13	**8**
6. Behaviour	**59**	**30**	**21**	**8**	**51**	**36**	**14**	**18**	**39**	**529**	**-100**	**34**

Aggression	**2**	1	1	0	**50**	**50**	**0**	0	0	0	0	**1**
Anti-predator	**8**	4	2	2	50	25	25	2	-54	-9	-100	**8**
Begging	**1**	0	1	0	0	100	0	0	0	0	0	**1**
Feeding	**6**	2	3	1	33	50	17	1	-64	-64	-64	**5**
Incubation	**2**	2	0	0	100	0	0	1	12	12	12	**2**
Interspecific mixing	**3**	2	1	0	67	33	0	0	0	0	0	**1**
Movement	**6**	5	1	0	83	17	0	1	529	529	529	**5**
Nest construction	**12**	5	6	1	42	50	8	10	8	134	-21	**4**
Pair-bond	**2**	1	1	0	50	50	0	0	0	0	0	**2**
Provisioning	**6**	2	1	3	33	17	50	2	-17	-8	-26	**4**
Social	**4**	2	2	0	50	50	0	0	0	0	0	**3**
Vocalisation	**7**	4	2	1	57	29	14	1	284	284	284	**5**
7. Brood parasitism	**5**	**1**	**1**	**3**	**20**	**20**	**60**	**4**	**6**	**65**	**-60**	**2**
Brood parasitism	**5**	1	1	3	**20**	**20**	**60**	4	6	65	-60	**2**
8. Ectoparasitism	**1**	**1**	**0**	**0**	**100**	**0**	**0**	**1**	**--77**	**-65**	**--77**	**1**
Ectoparasitism	**1**	1	0	0	100	0	0	1	-77	-77	-77	**1**
9. Paternity	**3**	**1**	**1**	**1**	**33**	**33**	**33**	**1**	**100**	**100**	**100**	**2**
Paternity	**3**	1	1	1	33	33	33	1	100	100	100	**2**
10. Phenology	**56**	**29**	**23**	**4**	**52**	**41**	**7**	**33**	**-6**	**9**	**-26**	**39**
Phenology	**56**	29	23	4	52	41	7	33	-6	9	-26	**39**
Total	**459**	**192**	**216**	**51**	**42**	**47**	**11**	**n/a**	**n/a**	**n/a**	**n/a**	**131**

Table AW1.4. Bird species contributing response metrics to the reproductive output and survival categories (in peri-domestic and wider countryside habitats), and to all other metrics (as listed in Table AW1.3). Table entries show the numbers of different response metrics associated with each species. Also indicated is whether the species occurs in Europe (Yes/No) and is a regular user of garden feeders (Yes/No) both based on literature and expert opinion. Sixteen species contributing metrics were regular garden users in Europe. Some studies contributed metrics on multiple species and so the aggregate total number of studies across families is not informative.

			Peri-domestic		Wider countryside			
Family and species	Europe	Garden SF user	Reproductive output	Survival	Reproductive output	Survival	All other metrics	No. studies
Acrocephalidae			**0**	**0**	**0**	**0**	**13**	**4**
Australian reed warbler	N	N	0	0	0	0	7	2
Common reed warbler	Y	N	0	0	0	0	6	2
Cardinalidae			**0**	**0**	**0**	**0**	**9**	**3**
Indigo bunting	N	Y	0	0	0	0	5	1
Northern cardinal	N	Y	0	0	0	0	4	2
Columbidae			**0**	**0**	**0**	**0**	**5**	**2**
European turtle dove	Y	N	0	0	0	0	5	2
Corvidae			**3**	**2**	**4**	**1**	**42**	**16**
American crow	N	Y	0	0	0	0	3	1
Black-billed magpie	N	Y	1	0	1	0	2	1
Canada/Grey jay	N	Y	0	0	0	0	7	3
Carrion crow	Y	Y	1	2	1	0	6	2
Florida scrub jay	N	Y	0	0	1	1	8	4
Western jackdaw	Y	Y	1	0	1	0	5	2
Eurasian magpie	Y	Y	0	0	0	0	11	3
Fringillidae			**0**	**0**	**0**	**0**	**9**	**2**
European greenfinch	Y	Y	0	0	0	0	3	1
Hawfinch	Y	Y	0	0	0	0	3	1
House finch	N	Y	0	0	0	0	3	1
Icteridae			**0**	**0**	**1**	**0**	**7**	**3**
American robin	N	Y	0	0	0	0	1	1
Red-winged blackbird	N	N	0	0	1	0	3	1
Yellow-headed blackbird	N	N	0	0	0	0	3	1
Muscicapidae			**0**	**0**	**4**	**3**	**46**	**19**
Black redstart	Y	Y	0	0	1	0	4	2
Collared flycatcher	Y	N	0	0	0	0	1	1
Pied flycatcher	Y	N	0	0	2	3	32	8
Northern wheatear	Y	N	0	0	1	0	9	2
Paradoxornithidae			**0**	**0**	**0**	**0**	**3**	**1**
Wrentit	N	Y	0	0	0	0	3	1
Paridae			**2**	**0**	**10**	**9**	**154**	**54**
Black-capped chickadee	N	Y	0	0	1	2	13	8
Eurasian blue tit	Y	Y	0	0	5	1	58	15
Carolina chickadee	N	Y	0	0	0	0	5	3
Crested tit	Y	Y	0	0	0	1	4	2
Great tit	Y	Y	2	0	4	2	56	19
Long-tailed tit	Y	Y	0	0	0	0	1	1
Mountain chickadee	N	Y	0	0	0	0	3	1
Tufted titmouse	N	Y	0	0	0	0	2	2
Varied tit	N	Y	0	0	0	1	4	2
Willow tit	Y	Y	0	0	0	2	8	3

Family and species	Europe	Garden SF user	Peri-domestic: Reproductive output	Peri-domestic: Survival	Wider countryside: Reproductive output	Wider countryside: Survival	All other metrics	No. studies
Parulidae			**0**	**0**	**3**	**0**	**10**	**3**
Black-throated blue warbler	N	N	0	0	2	0	5	2
American yellow warbler	N	N	0	0	1	0	5	1
Passerellidae			**0**	**0**	**2**	**4**	**28**	**11**
Dark-eyed junco	N	Y	0	0	0	1	3	1
Song sparrow	N	Y	0	0	2	2	24	8
Swamp sparrow	N	N	0	0	0	1	1	2
Passeridae			**1**	**1**	**0**	**1**	**8**	**5**
House sparrow	Y	Y	1	1	0	1	8	5
Picidae			**0**	**0**	**1**	**0**	**5**	**3**
Downy woodpecker	N	N	0	0	0	0	2	2
Great spotted woodpecker	Y	Y	0	0	1	0	3	1
Prunellidae			**0**	**0**	**0**	**0**	**2**	**1**
Alpine accentor	Y	N	0	0	0	0	2	1
Sittidae			**0**	**0**	**0**	**0**	**3**	**3**
Eurasian nuthatch	Y	Y	0	0	0	0	1	1
White-breasted nuthatch	N	Y	0	0	0	0	2	2
Sturnidae			**0**	**0**	**2**	**0**	**7**	**4**
Red-winged starling	N	Y	0	0	0	0	3	2
Common starling	Y	Y	0	0	2	0	4	2
Sylviidae			**0**	**0**	**0**	**0**	**1**	**1**
Eurasian blackcap	Y	Y	0	0	0	0	1	1
Troglodytidae			**0**	**0**	**0**	**0**	**5**	**2**
House wren	N	Y	0	0	0	0	5	2
Turdidae			**1**	**0**	**3**	**1**	**26**	**11**
Eastern bluebird	N	Y	1	0	2	0	21	7
Mountain bluebird	N	Y	0	0	0	0	3	2
Ring ouzel	Y	N	0	0	1	1	1	1
Western bluebird	N	Y	0	0	0	0	1	1
Tyrannidae			**0**	**0**	**0**	**0**	**1**	**1**
Dusky flycatcher	N	N	0	0	0	0	1	1
Vireonidae			**0**	**0**	**1**	**1**	**3**	**1**
Red-eyed Vireo	N	Y	0	0	1	1	3	1
Zosteropidae			**0**	**0**	**0**	**0**	**3**	**1**
Silvereye	N	Y	0	0	0	0	3	1
Not sp. specific			**0**	**0**	**0**	**0**	**11**	**4**
Artificial nests	-	-	0	0	0	0	1	1
Multiple sp.	-	-	0	0	0	0	10	3
Total	**Y=23 N=32**	**Y=39 N=16**	**7**	**3**	**31**	**20**	**398**	**n/a**

W2. What are the effects of SF, as typically conducted in residential settings, on the abundance, distribution, and structure of wild bird communities?

Rationale

The aim of this question is to summarise the available evidence relating to the effects of SF on the abundance and community composition of wild birds. Our primary interest lies in understanding how SF in residential settings is likely to affect the abundance and distribution of species that regularly consume SF in those settings and the consequent impact on bird communities. To aid interpretation and relevance to the UK residential context, we categorise studies according to their geographic location and proximity to human dwellings. We also distinguish between studies conducted at spatial scales considered adequate to infer genuine changes in avian abundance from those conducted at more local scales (such as individual gardens) that are more likely to measure behavioural responses to SF such as aggregation around feeders.

Methods

Literature search procedure

We developed a search string for each question based on key words and phrases from selected relevant studies combined with expert knowledge (Appendix W2: Table AW2.1). For each question, we ran the related search string on Google Scholar, Web of Science, Scopus and PubMed. We then used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of ten to quantify the extent to which relevance declined with search engine rank. When this decay function declines to zero it is likely that the search has identified a high proportion of relevant studies; if it fails to reach zero by the 400-study threshold it is likely relevant studies were excluded. We checked for and removed duplicates across search engines and exported the remaining set of studies to a spreadsheet.

Study exclusions

Following amalgamation of selected studies across search engines we inspected full text articles and extracted summary data for each study (and metric) that satisfied all the following criteria:

1. Study focus: The study considered the effects of supplementary food provision on one or more of the following metrics relating to wild birds: abundance, abundance change over time, community species richness, community diversity.

2. Taxonomic selection: The species studied fell within one of the following taxonomic groups considered to be relevant to UK garden birds: Passeriformes (songbirds), Piciformes (woodpeckers) and Columbiformes (pigeons and doves). SF studies of other taxonomic groups (including raptors, seabirds, waterbirds, gamebirds, hummingbirds) were excluded as not being directly relevant to a UK residential context. We also excluded two nectivorous passerine families that do not occur in the UK (honeyeaters (Meliphagridae) and stitchbirds (Notiomystidae)) and any species having year-round tropical distributions.

3. Study design: The study involved the measurement of response metrics either for fed and control subjects, or across some form of gradient of SF provision (e.g. across space, time or species). Subjects were typically defined as study areas (e.g. gardens, sites, regions, countries). Studies lacking unfed controls, or a suitable gradient of SF provision, were excluded.

4. Replication: As most response metrics were measured at the scale of the entire study area, we included any studies having at least one fed and one unfed study area. For correlative studies where SF was not manipulated, we excluded any studies having fewer than 10 replicates in space or time or across species.

Data extraction – response metrics

The reported response metrics comprised measures of avian abundance, abundance change, distribution, community diversity and/or species richness and we summarised the available data under these headings. For each study we determined whether SF was associated with increased or decreased levels of the response metric or had no significant ($P>0.05$) impact. We labelled these categories positive, negative and neutral responses respectively. Where studies reported responses for multiple individual species, or for different species groupings (e.g. native vs. introduced species), each species or grouping contributed a single metric to our analysis (one row in the extraction spreadsheet) although we avoided including duplicate aggregate metrics. For example, if a study presented abundance metrics for multiple individual species as well as for the same set of species aggregated, we only included the former species-level data.

For abundance and distribution metrics, a 'positive' response refers to a significant increase in the total number of birds recorded or the number of locations occupied. This does not imply ecological or social benefit, which may depend on species identity, conservation status, or public perception. For abundance change, a 'positive' response refers to a statistically significant increase in bird numbers over time, across a defined SF contrast (e.g. fed vs unfed treatments or across a gradient of SF provision). This may suggest a population-level effect or local redistribution, but interpretation depends on study design and spatial scale. For example, increases in counts measured at the garden scale may reflect the local aggregation of birds around feeders rather than any underlying increase in local abundance or population size.

For studies of community structure, a 'positive' species richness response indicates a statistically significant increase in the number of species present. However, the ecological and conservation implications of increased richness depend on the identity and particular traits of the species complement - for example, whether they are non-native, generalist, or competitively dominant species. For diversity, a 'positive' response refers to a statistically significant increase in diversity index values (e.g. Shannon, Simpson), which typically capture both species richness (i.e. the number of species) and evenness (i.e. how equally the abundance of individual species is distributed across species). Higher diversity does not necessarily imply ecological benefit, as it may reflect increased occurrence or abundance of generalist, non-native, or feeder-associated species.

In this review interpretation of all community-level responses is necessarily generalised. Effects may be non-linear, scale-dependent, and shaped by the baseline used for comparison, which varies across studies and may not always reflect an ecologically desirable reference state. Responses are also influenced by contextual and conservation values. Our assignment of 'positive', 'negative' and 'neutral' responses is based entirely on the direction and statistical significance of response metric changes as reported in the literature, while recognising that their ecological interpretation depends on species, setting, spatial scale and assumptions about what constitutes enhancement or deterioration of ecological communities.

Where possible we extracted reported effect sizes for fed and unfed subjects/study areas and calculated a proportional SF effect size as the ratio of the two measures. For example, if the numbers of species counted in fed areas averaged ten and the number in unfed areas eight, the proportional SF effect size would be 1.25. It was not possible to derive effect sizes for all metrics as these were not always reported, especially for studies whose design was based on a SF gradient rather than fed/unfed contrasts. We did not attempt to extract effect sizes from figures or regression equations. We summarise available effect sizes as medians and ranges.

Data extraction – context variables

For each extracted response metric, we also extracted information on a range of context variables. These allowed us to describe the composition of the extracted data, and to compare and present different subsets of the data particularly those considered most relevant to a UK residential context.

First, we assigned each metric to one of four continents: North America, Europe, Asia and Australasia based on study locations. Second, we assigned each metric to a two-level human proximity category: peri-domestic (urban, suburban, rural domestic) and wider countryside away from human habitation (farmland, woodland, wetland etc). Close-proximity SF was considered likely in all habitats classified as peri-domestic but less likely in wider countryside habitats. Many SF research studies are conducted in wider countryside locations far enough away from human settlements to substantially reduce the likelihood of consumption of supplementary food by wild birds that is not part of the study design. Third, we assigned each metric to one of two study design categories: 'experimental' which included (i) before-after control-impact (BACI) studies and (ii) comparisons of fixed treatment and control experimental units (like sites); and 'observational' or correlational studies that typically compared response metrics across contrasting levels, or a gradient of, SF provision. Whilst observational studies can be informative, experimental approaches generally enable stronger inferences to be drawn so greater emphasis was placed on their interpretation.

Fourth, we identified studies of limited spatial scale for the response metric being measured. For example, as most birds occupy ranges larger than a typical single suburban garden, surveys conducted at the garden scale cannot provide reliable information on variation in avian population size or community composition. Surveys conducted at the garden scale are likely to reflect local scale behavioural responses to feeding such as local redistribution close to feeders. We adopted a sampling unit area threshold to distinguish studies capable of measuring abundance or community composition from those more likely to be measuring local redistribution or behavioural responses to feeding. The threshold we adopted was 25 ha and any study having a sampling unit area less than this was considered 'smaller scale' and more likely to have measured behavioural responses to SF rather than genuine abundance or distributional responses. A study area of 25 hectares (ha) has the potential to support at least 10 individual adults (or 5 breeding pairs) of most species commonly encountered in peri-domestic settings (Tratalos et al. 2007), whilst garden-scale studies will typically support no more than 2-3 pairs of most species, and many encounters measured at the garden scale will reflect garden usage by birds ranging over much larger areas (Hanmer et al. 2022). For context the area surveyed for birds within 100 m of the 2-km transect line within a typical Breeding Bird Survey (BBS) square is approximately 40 ha. We summarise the findings of larger and smaller-scale studies separately. One distributional study conducted at the garden scale (Plummer et al. 2015) was categorised as a larger-scale study because it carried high spatial and temporal replication (data from 3,800 gardens over 12 years) and was therefore likely to have reflected broad-scale patterns of avian distribution.

Fifth, we assigned each metric to one of three measurement season categories: breeding season (March-August), winter (November-February) and year-round (the latter involved measurement during multiple seasons). Avian abundance and community metrics are most reliably measured during the breeding season when many species are territorial and relatively conspicuous and therefore most likely to be detected. At other times of year many species are dispersive and flocking and less easy to detect and count.

The information available describing the type and seasonal timing of SF provision was less detailed than for question W1 and it was not possible to assign many studies to the same three food-type-season categories (i.e. breeding-season protein, winter seed/fat, breeding-autumn seed/fat). For example, of the 85 selected metrics from 34 studies, the type of SF provided was not specified in 29 cases. Most studies involved either seed provision (particularly during winter and/or pre-breeding) or the food type was unknown (Table W2.1a). For those studies where food type was known each metric was allocated to one of the three food-type-season categories used in W1 (Table W2.1b).

Results

Literature composition

After excluding any studies lacking appropriate controls or replication, 85 metrics were available from 34 studies (1971-2025). Of these, 43 metrics from 21 studies were conducted at a scale considered large enough to measure abundance or distribution rather than behavioural responses to feeding (Table W2.2a). Most metrics describe the effects of SF on abundance (48/85) or abundance change (19/85), with smaller numbers of community metrics (8 diversity, 9 species richness) (Table W2.2a). The majority of metrics were collected in Europe (56/85) with the remainder in North America (15), Australasia (13) and Asia (1; Table W2.2b). Most metrics were collected entirely or partly in peri-domestic habitats (52/85) (Table W2.2c) and were measured either during the breeding (39/85) or winter (31/85) seasons (Table W2.2d). Eight of the 21 large-scale studies, and 7 of the 13 small-scale studies, contributed multiple metrics all involving multiple species (see Table W2.3a footnote). The taxonomic composition of the selected metrics, broken down by proximity to human habitation, is summarised in Appendix W2 Table AW2.2. All selected studies were conducted in temperate regions except one on urban bird communities in a subtropical zone (Texas, USA).

The size of the evidence base relating to the effects of SF on avian abundance and community composition is smaller than for fitness impacts (question W1) probably because it is more difficult to design studies to reliably measure the effects of SF on abundance/community structure. Strong study designs for population level impacts require multiple treatment and control study areas with limited scope for between-area avian dispersal. Our sample comprised a similar number of experimental and observational studies, each of which included a similar proportion conducted at large and smaller spatial scales (experimental: 12 and 7; observational: 9 and 6; χ^2_1 = 0.04, P=0.85; Table W2.2e).

We tested whether the directional balance of the effects of SF on bird abundance and community composition differed between metric categories (abundance/abundance change vs diversity/species richness), scale of metric measurement (smaller vs larger), season of metric measurement (breeding vs winter vs year-round), proximity of human habitation (peri-domestic vs wider countryside) and continent (North America vs Europe vs Australasia). To allow these comparisons across groups one metric from a highly replicated distributional study (% occupation, Plummer et al. 2015) was included in the abundance category. The proportion of positive/neutral/negative responses to SF did not differ significantly between metric categories (Table W2.3a; χ^2_2 = 1.65, P=0.44), large vs smaller measurement scales (Table W2.3a; χ^2_2 = 4.77, P=0.09), peri-domestic vs other habitats (Table W2.3b: χ^2_2 = 4.46, P=0.11) or between continents (North America vs Europe vs Australasia: Table W2.3c: χ^2_4 = 7.03, P=0.13). Although there was some evidence that the directional balance of SF impacts differed between measurement seasons (χ^2_4 = 10.36, P=0.034) this was associated with two negative effects generated by a single year-round New Zealand study (Table W2.3c). The balance of positive and neutral effects did not differ between measurements collected during the breeding and winter seasons (χ^2_1 = 0.61, P=0.44). The selected response metrics are therefore homogenous with respect to the directional balance of SF effects across metric categories, measurement scales, proximity to human habitation, continent and between breeding and winter seasons.

Effects of SF on avian abundance and community structure (large scale studies)

Studies conducted at a spatial scale considered large enough to reliably measure avian abundance and/or community composition reported either positive (n=26) or neutral (n=17) impacts, and there were no reported negative impacts (Table W2.3a). Most of the available effect sizes relate to abundance and averaged 1.40 (40% increase) for large scale studies and 1.60 (60% increase) for smaller scale studies (Table W2.3a). Combining larger and smaller-scale studies, abundance effect sizes were similar for peri-domestic and wider countryside studies (median [n, range] = 1.33 [19, 0.23 – 6.61] and 1.60 [14, 1.00 – 3.75] respectively), although most small-scale effect sizes (17/19) were measured in peri-domestic settings and most large-scale effect sizes (12/14) were measured in the wider countryside.

(A) Impacts of SF on abundance: Four experimental studies provide clear evidence that winter seed provision can lead to large increases in the size of woodland tit populations. Provision of winter seed in Oxfordshire woodland led to a 40% increase in Eurasian blue tit breeding density but had no effect on great tit numbers (Krebs 1971). Winter seed provision in the Netherlands increased great tit breeding densities by an average of approximately 40% over 5 years (compared to a control site) with effects of SF much greater in years of low beech mast (van Balen 1980). Provision of seed and fat in two Swedish woodlands over a single winter resulted in a 39% increase in great tit numbers compared to a 13% loss in three unfed areas (Kallander 1981). Provision of seed and protein at a single Swedish woodland site over a single winter led to a 14% increase in willow tits (compared to a 48% loss in a control area) and a 3% loss in crested tits compared to a 56% loss in an unfed area (Jansson et al. 1981). These two Swedish studies measured increased survival, local recruitment and settlement as likely demographic drivers of the observed abundance changes.

A well replicated observational study conducted in Scottish woodland found that nest box occupancy by Eurasian blue tits was positively correlated with the prevalence of supplementary food (mainly peanuts and sunflower seed) in the diet of adult birds as detected in faeces using metabarcoding (Shutt et al. 2021). The effect of SF was large with nest box occupancy of 20% in areas with no supplementary food in the diet, rising to 75% when all the faecal samples contained supplementary food, suggesting that Eurasian blue tit breeding density may be limited by access to anthropogenic food. Supplementary food was found in faeces (collected during mid-March to early April) from nest boxes up to 1.4 km from the nearest human habitation.

An experimental study of territorial Eurasian nuthatches in Swedish woodland showed that autumn territory density increased by 85% following seed provision during June to November (Enoksson 1990). The author concluded that seed provision encouraged nuthatches to accept smaller territories prior to the main period of food shortage in winter, rather than any food shortage during autumn. A well-replicated experimental study conducted on English farmland showed that winter seed provision increased breeding abundance of several (though not all) small passerines including yellowhammer and corn bunting (Siriwardena et al. 2007). However, two other well-replicated studies found no effect of seed provision on house sparrow abundance in suburban London (Peach et al. 2018) or on Swedish farmland (Von Post et al. 2013), although the former study lacked a ‘no feeding’ control so only tested the effect of SF provision in addition to background suburban levels.

Two experimental studies providing breeding season protein to corvids have measured increases in breeding density. A natural experiment involving black-billed magpies breeding close to a cattle carcass (which provided abundant blowfly larvae) recorded a doubling of breeding adult magpie numbers compared to no change at nearby control colonies (Knight 1988). Feeding chicken eggs to breeding western jackdaws in Spain was associated with a combined increase (across two fed colonies) in nest site occupancy of 62% (Soler & Soler 1996).

A national scale correlative study across GB showed that species showing the greatest increases in feeder usage between 1973 and 2012 (like European goldfinch, common wood pigeon and great-spotted woodpecker) also showed the greatest proportional increase in population size over the same period (Plummer et al. 2019). Moreover, in peri-domestic areas (though not in the wider countryside) the abundance of feeder-using species increased whilst the abundance of species that do not use feeders remained stable. These findings are consistent with the hypothesis that pronounced increases in garden feeder usage by some species has led to increased peri-domestic populations of those species in Britain (Plummer et al. 2019). Although it is not certain that increased exploitation of supplementary food has caused these population increases in feeder-using species (abundance may have increased for some other reason), this seems the most likely explanation given the increases are largely restricted to feeder-using species.

One correlative study based on a large sample of garden-scale feeder counts over 12 years concluded that the spread of wintering Eurasian blackcaps across Britain has been driven both by the increase in SF in residential settings and by milder winter conditions (Plummer et al. 2015). Eurasian blackcaps were more likely to be recorded in gardens where supplementary seed or suet was provided during a high proportion of the winter, and the strength of this relationship increased over the course of the study suggesting this species was adapting behaviourally (and possibly genetically) to the widespread increase in SF across Britain.

(B) Impacts of SF on species richness and diversity: There were three larger scale studies considering the effects of SF on bird communities, one of which provided metrics on both richness and diversity (Table W2.2a). Two well-replicated correlational studies from Europe showed that species diversity and the total abundance of wintering birds was positively related to the numbers of food sources (which included bird feeders) in Poland (Ciach & Frohlich 2017), while winter (but not summer) diversity was higher in localities having feeders (Ibanez-Alamo et al. 2020). Long-term extensive feeder usage data from across Britain indicate that both diversity and species richness have increased over time at the garden-scale, while diversity but not richness has increased at the national scale (Plummer et al. 2019). Thus, while the national 'pool' of feeder-using species has remained stable, a larger number and diversity of species are now recorded in individual gardens a pattern that is probably driven by coincident increases in average feeder numbers and food types. Bird communities using feeders in GB have become more 'even' over time (i.e. less numerically dominated by a few relatively abundant species; Plummer et al. 2019).

<u>Local scale effects of SF on avian distribution and activity</u>

Studies conducted at relatively small spatial scales can usually only provide information on factors affecting the local distribution and activity of birds. Our review identified 42 metrics recorded at a smaller spatial scale of which 17 reported positive local effects of SF (mainly on local abundance), 23 reported neutral effects and 2 reported negative effects (Table W2.3a).

Several correlative studies report positive smaller-scale relationships between feeder presence or density and avian abundance and/or species richness. One study in Sheffield (England) found a positive correlation between aggregate avian abundance (counts summed across species) in summer and local feeder density but no relationship involving species richness (Fuller et al. 2008). Another study in Sheffield reported a weak positive association between the presence of a feeder and both avian species richness and aggregate abundance during summer but not winter (Bonnington et al. 2014). A winter study of urban habitats in the Czech Republic reported higher numbers of Eurasian blue tits and Eurasian tree sparrows at locations with feeders especially in industrial and new residential areas (Salek et al. 2025). A garden-scale study in New Zealand showed that SF was associated with higher abundance and species richness of introduced species but lower richness of native species and lower abundance of one native species (Galbraith et al. 2015). This latter study accounted for both of the negative responses to SF that we encountered for this question (Table W2.3a).

<u>Summary</u>

- The directional balance of numerical and community responses of birds to SF was similar across peri-domestic and wider countryside habitats, measurement scales and study geographic location. The effects of SF were comprised of similar proportions of positive (higher abundance or species richness) and neutral (no change) outcomes, with very few reported negative outcomes. The effect of SF on avian abundance averaged an increase of 40% although this was slightly less (33%) in peri-domestic habitats.
- There is strong experimental evidence that SF can lead to substantial increases in population size of woodland tits and farmland buntings (both from winter seed), of woodland Eurasian nuthatches (autumn seed) and of corvids (breeding season protein).
- Many studies report no effect of SF on abundance. These outcomes are difficult to interpret with certainty as they could reflect that local natural food supplies were adequate to meet the needs of the studied bird populations, or they could reflect some limitation of study

design such as a compromised fed/unfed contrast, inadequate supplementary food provision or lack of statistical power.

- Long-term increases in the amount and types of supplementary food provided in GB gardens are associated with increased bird usage of gardens. Increased access to, and utilisation of, SF probably at least partly explains population increases of species whose feeder usage has increased including common wood pigeon, European goldfinch and great-spotted woodpecker. The expansion of the winter distribution of Eurasian blackcaps across Britain has probably been driven by a combination of milder winter conditions and increasing utilisation of supplementary food in gardens.
- Feeders in residential settings attract a larger total number and diversity of birds during winter but not summer. Long-term increases in average feeder numbers and food types in British gardens probably explain the increasing diversity of garden bird communities with less dominance of a few common species.
- One negative finding involved fewer native species, and individuals of one native species, visiting supplementary fed gardens in New Zealand possibly as a consequence of increased feeder usage by introduced species.
- As with question W1, the evidence base lacks strong experimental studies conducted in peri-domestic landscapes (where experiments are logistically difficult to establish) and taxonomic relevance to some key UK bird groups (such as finches, pigeons and doves).

Table W2.1a. The number of response metrics associated with different types and seasons of supplementary food provision. Food sub-type is as described by the study and is grouped into five broader categories (SF types). Seasons are (in the northern hemisphere) pre-breeding (March), breeding (April-June), post-breeding (July), autumn (Aug-Oct) and winter (Nov-Feb). Table entries are numbers of response metrics; a single metric can contribute to multiple rows if feeding occurs during more than one season. Bold font indicates food type metric sums.

Food type and sub-type	Pre-breeding (Mar)	Breeding (Apr-Jul)	Post-breed (Aug-Sep)	Autumn (Sep-Oct)	Winter (Nov-Feb)
Fat	**0**	**0**	**0**	**0**	**0**
Fat[1]	0	0	0	0	0
Mixed	**4**	**1**	**0**	**3**	**7**
Fat + seed	2	0	0	2	2
Fat + protein + seed	1	0	0	1	1
Pet food[2]	0	0	0	0	4
Protein + bread	1	1	0	0	0
Protein	**1**	**2**	**1**	**1**	**2**
Insects[3]	0	1	0	0	0
Insects + seed	1	1	1	1	2
Seed	**30**	**13**	**14**	**16**	**39**
Seed[4]	17	0	1	3	26
Seed + bread	13	13	13	13	13
Undefined/presence only	**4**	**2**	**1**	**1**	**29**
Presence only	0	0	0	0	3
Undefined	4	2	1	1	26
Total	**39**	**18**	**16**	**21**	**77**

[1] Predominantly described as animal fat (e.g. tallow) but in one case was margarine.
[2] Typically dry pelleted food (occasionally wet food) with protein content markedly greater than fat.
[3] Insects consisted of larval stages of one of the following: mealworms (*Tenebrio sp.*), wax worms (e.g. *Galleria sp.*) or blow flies (*Calliphora sp.*) presented live or occasionally dehydrated.
[4] All types of whole seed typically fed to wild birds but predominantly sunflower seed and peanuts.

Table W2.1b. The numbers of response metrics generated by our literature searches subdivided by food-type-season and food type. The three food-type-seasons are non-exclusive as SF was sometimes carried out using multiple food types and across multiple seasons.

Type and season of SF provision	Fat	Mixed	Protein	Seed	Total
Breeding protein	0	1	2	0	**3**
Winter seed/fat	0	6	2	39	**47**
Pre-breeding-Autumn seed/fat	0	2	1	32	**35**
Total	**0**	**9**	**5**	**71**	**85**

Table W2.2a. The numbers of response metrics and studies generated by our literature searches subdivided by metric type and larger vs smaller study spatial scales (larger: average study unit area > 25 ha; smaller: <=25 ha). 'Studies' columns do not sum to totals as some studies contribute to multiple metric types.

	Metrics			Studies		
Metric type	Larger	Smaller	Total	Larger	Smaller	Total
Abundance	17	31	**48**	14	11	**25**
Abundance change	19	0	**19**	6	0	**6**
Distribution	1	0	**1**	1	0	**1**
Diversity	5	3	**8**	3	2	**5**
Species richness	1	8	**9**	1	6	**7**
Total	**43**	**42**	**85**	**21**	**13**	**34**

Table W2.2b. The numbers of response metrics and studies for each metric category in each continent, for different sized studies (large: average study unit area > 25 ha; small: <=25 ha). 'Studies' columns do not sum to totals as some studies contribute to multiple metric types. Bold font indicates metric type sums.

	Metrics			Studies		
Metric type by continent	Larger	Smaller	Total	Larger	Smaller	Total
Abundance	**17**	**31**	**48**	**14**	**11**	**25**
N. America	5	7	**12**	5	5	**10**
Asia	1	0	**1**	1	0	**1**
Australasia	0	11	**11**	0	1	**1**
Europe	11	13	**24**	8	5	**13**
Abundance change	**19**	**0**	**19**	**6**	**0**	**6**
N. America	1	0	**1**	1	0	**1**
Europe	18	0	**18**	5	0	**5**
Distribution	**1**	**0**	**1**	**1**	**0**	**1**
Europe	1	0	**1**	1	0	**1**
Diversity	**5**	**3**	**8**	**3**	**2**	**5**
N. America	0	1	**1**	0	1	**1**
Europe	5	2	**7**	3	1	**4**
Species richness	**1**	**8**	**9**	**1**	**6**	**7**
N. America	0	1	**1**	0	1	**1**
Australasia	0	2	**2**	0	1	**1**
Europe	1	5	**6**	1	5	**6**
Total	**43**	**42**	**85**	**21**	**13**	**34**

Table W2.2c. The numbers of response metrics and studies for each metric type subdivided into studies having larger and smaller study areas (larger: average study unit area > 25 ha; smaller: <=25 ha) in peri-domestic (PD) and wider countryside (WC) habitats. 'Studies' columns do not sum to totals as some studies contribute to multiple metric types. Bold font indicates metric type sums. One study that combined PD and WC data is included in WC.

	Metrics			Studies		
Metric type	Peri-domestic	WC	Total	Peri-domestic	WC	Total
Abundance	**31**	**17**	48	**13**	**12**	25
Larger	5	12	17	5	9	14
Smaller	26	5	31	8	3	11
Abundance change	**4**	**15**	19	**5**	**1**	6
Larger	4	15	19	5	1	6
Smaller	0	0	0	0	0	0
Distribution	**1**	**0**	1	**1**	**0**	1
Larger	1	0	1	1	0	1
Smaller	0	0	0	0	0	0
Diversity	**8**	**0**	8	**5**	**0**	5
Larger	5	0	5	3	0	3
Smaller	3	0	3	2	0	2
Species richness	**8**	**1**	9	**6**	**1**	7
Larger	1	0	1	1	0	1
Smaller	7	1	8	5	1	6
Total	**52**	**33**	**85**	**21**	**13**	**34**

Table W2.2d. The numbers of response metrics and studies for each metric category, subdivided by measurement period and proximity to human habitation (peri-domestic (PD) vs. wider countryside (WC)). 'Studies' columns do not sum to totals as some studies contribute to multiple metric types. Bold font indicates metric type sums. One study that combined PD and WC data is included in WC. One mixed study was included in the WC category because most the underlaying data are from wider countryside (UK national BBS data).

	Metrics			Studies		
Metric type by measurement season	Peri-domestic	WC	Total	Peri-domestic	WC	Total
Abundance	**31**	**17**	**48**	**13**	**12**	**25**
All Year	11	0	**11**	1	0	**1**
Breeding	5	11	**16**	5	9	**14**
Winter	15	6	**21**	8	3	**11**
Abundance change	**4**	**15**	**19**	**5**	**1**	**6**
All-year	0	0	**0**	0	0	**0**
Breeding	3	15	**18**	4	1	**5**
Winter	1	0	**1**	1	0	**1**
Distribution	**1**	**0**	**1**	**1**	**0**	**1**
All-year	0	0	**0**	0	0	**0**
Breeding	0	0	**0**	0	0	**0**
Winter	1	0	**1**	1	0	**1**
Diversity	**8**	**0**	**8**	**5**	**0**	**5**
All Year	1	0	**1**	1	0	**1**
Breeding	2	0	**2**	2	0	**2**
Winter	5	0	**5**	4	0	**4**
Species richness	**8**	**1**	**9**	**6**	**1**	**7**
All Year	3	0	**3**	2	0	**2**
Breeding	3	0	**3**	2	0	**2**
Winter	2	1	**3**	2	1	**3**
Total	**52**	**33**	**85**	**21**	**13**	**34**

Table W2.2e. The numbers of response metrics and studies for each metric category, subdivided by spatial scale (larger/smaller) and study design (experimental vs observational studies). 'Studies' columns do not sum to totals as some studies contribute to multiple metric types. Bold font indicates metric type sums.

	Metrics			Studies		
Metric type by spatial scale	Expt.	Obs.	Total	Expt.	Obs.	Total
Abundance	**31**	**17**	**48**	**17**	**8**	**25**
Larger	11	6	17	9	5	14
Smaller	20	11	31	8	3	11
Abundance change	**17**	**2**	**19**	**5**	**1**	**6**
Larger	17	2	19	5	1	6
Smaller	0	**0**	**0**	0	0	0
Distribution		**1**	**1**	**0**	**1**	**1**
Larger	0	1	1	0	1	1
Smaller	0	0	0	0	0	0
Diversity	**1**	**7**	**8**	**1**	**4**	**5**
Larger		5	5	0	3	3
Smaller	1	2	3	1	1	2
Species richness	**3**	**6**	**9**	**2**	**5**	**7**
Larger		1	1	0	1	1
Smaller	3	5	8	2	4	6
Total	**52**	**33**	**85**	**21**	**13**	**34**

Table W2.3a. Effects of SF on abundance, abundance change, diversity and species richness, subdivided by study spatial scale (large vs small). Table entries are the numbers of positive, neutral and negative response metrics, along with the number of contributing studies. Also listed is the number of metrics for which effect sizes were available, the median effect size and range. The 'No. Studies' column does not sum to totals as some studies contribute to multiple metric types. A single large scale distribution study providing one metric (% occupancy) is included in the abundance category. Bold font indicates metric type sums.

	Effect direction						
Metric type by spatial scale	Positive	Neutral	Negative	No. studies	No. effect size	Median	Range
Abundance	**29**	**19**	**1**				
Larger	15	3	0	15	11	1.59	1.00 – 3.75
Smaller	14	16	1	10	17	1.60	0.23 - 6.61
Abundance change	**7**	**12**	**0**				
Larger	7	12	0	6	3	1.05	1.03 – 1.18
Diversity	**4**	**4**	**0**				
Larger	3	2	0	3	0	-	-
Smaller	1	2	0	2	1	1.54	-
Species richness	**3**	**5**	**1**				
Larger	1	0	0	1	0	-	-
Smaller	2	5	1	6	1	1.02	-
Total	**43**	**40**	**2**	**34**	**33**		
Total larger	26	17	0	21[1]	14	1.40	1.00 – 3.75
Total smaller	17	23	2	13[2]	19	1.60	0.23 – 6.61

Footnote:

1. Of the 21 larger-scale studies, 13 contributed a single metric, 5 contributed two metrics, 2 contributed three metrics and 1 contributed fourteen metrics (Siriwardena et al. 2007). All multi-metric studies related to multiple species.
2. Of the 13 smaller-scale studies, 6 contributed a single metric, 3 contributed two metrics, 2 contributed 4 metrics, 1 contributed 9 metrics (Salek et al. 2025) and 1 contributed 13 metrics (Galbraith et al. 2015). All multi-metric studies related to multiple species

Table W2.3b. Effects of SF on abundance, abundance change, diversity and species richness, subdivided by spatial scale of study (larger vs smaller) and proximity to human habitation (peri-domestic vs wider countryside). Table entries are the numbers of positive, neutral and negative response metrics, the total number of metrics and the number of contributing studies. The 'No. Studies' column does not sum to 'Total' as some studies contribute to multiple metric types. A single large-scale distribution study providing one metric (% occupancy) is included in the abundance category. Bold font indicates metric type sums. One mixed study was included in the WC category because most the underlaying data are from wider countryside (UK national BBS data).

	Peri-domestic			Wider countryside				
Metric type by spatial scale	Increase	No effect	Decrease	Increase	No effect	Decrease	No. metrics	No. studies
Abundance	**15**	**15**	**1**	**14**	**4**	**0**	**49**	**26**
Large	5	0	0	10	3	0	**18**	**15**
Small	10	15	1	4	1	0	**31**	**11**
Abundance change	**1**	**2**	**0**	**6**	**10**	**0**	**19**	**6**
Large	1	2	0	6	10	0	**19**	**6**
Small	0	0	0	0	0	0	**0**	**0**
Diversity	**3**	**4**	**0**	**1**	**0**	**0**	**8**	**5**
Large	2	2	0	1	0	0	**5**	**3**
Small	1	2	0	0	0	0	**3**	**2**
Sp. richness	**1**	**5**	**1**	**2**	**0**	**0**	**9**	**7**
Large	0	0	0	1	0	0	**1**	**1**
Small	1	5	1	1	0	0	**8**	**6**
Total	**20**	**26**	**2**	**23**	**14**	**0**	**85**	**34**
Total large	8	4	0	18	13	0	**43**	**21**
Total small	12	22	2	5	1	0	**42**	**13**

Table W2.3c. Effects of SF on abundance, abundance change, diversity and species richness subdivided by study spatial scale (large vs small) and continent of study. Table entries are the numbers of positive, neutral and negative response metrics, along with the number of contributing studies. The 'No. Studies' column does not sum to 'Total' as some studies contribute to multiple metric types. A single large scale distribution study providing one metric (% occupancy) is included in the abundance category. Bold font indicates metric type sums.

	Metrics													
	Increased				No change				Decreased					
Metric type by spatial scale	N. America	Asia	Australasia	Europe	N. America	Asia	Australasia	Europe	N. America	Asia	Australasia	Europe	No. metrics	No. studies
Abundance	**9**	**1**	**3**	**16**	**3**	**0**	**7**	**9**	**0**	**0**	**1**	**0**	**49**	**26**
Large	4	1	0	10	1	0	0	2	0	0	0	0	**18**	**15**
Small	5	0	3	6	2	0	7	7	0	0	1	0	**31**	**11**
Abundance change	**1**	**0**	**0**	**6**	**0**	**0**	**0**	**12**	**0**	**0**	**0**	**0**	**19**	**6**
Large	1	0	0	6	0	0	0	12	0	0	0	0	**19**	**6**
Small	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
Diversity	**0**	**0**	**0**	**4**	**1**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**8**	**5**
Large	**0**	**0**	**0**	3	**0**	**0**	**0**	2	**0**	**0**	**0**	**0**	**5**	**3**
Small	0	0	0	1	1	0	0	1	0	0	0	0	**3**	**2**
Sp. richness	**0**	**0**	**1**	**2**	**1**	**0**	**0**	**4**	**0**	**0**	**1**	**0**	**9**	**7**
Large	**0**	**0**	**0**	1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Small	0	0	1	1	1	0	0	4	0	0	1	0	**8**	**6**
Total	**10**	**1**	**4**	**28**	**5**	**0**	**7**	**28**	**0**	**0**	**2**	**0**	**85**	**34**
Large	5	1	0	20	1	0	0	16	0	0	0	0	**43**	**21**
Small	5	0	4	8	4	0	7	12	0	0	2	0	**42**	**13**

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W2 Appendix

Table AW2.1. Search terms used for the W2 literature searches separated into three component parts by 'AND' statements.

Part-1	Part-2	Part-3
(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "food addition" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")	AND (abundance OR density OR range OR distribution OR migration OR assemblage* OR "community structure" OR "community composition" OR richness OR diversity OR simplification OR evenness OR homogenisation)

Figure AW2.1 Changes in the relevance 'hit rate' of studies selected by four search engines for question W2. The numbers plotted are the number of studies we considered to be relevant out of each batch of 20 studies ('hit rate') across the 400 studies as ranked in relevance order by each of the search engines (1-20=ranked most relevant, 381-400 = ranked least relevant). A hit rate declining to zero implies most relevant studies have been identified. Our rates approach zero at the 400 threshold implies most relevant studies were found.

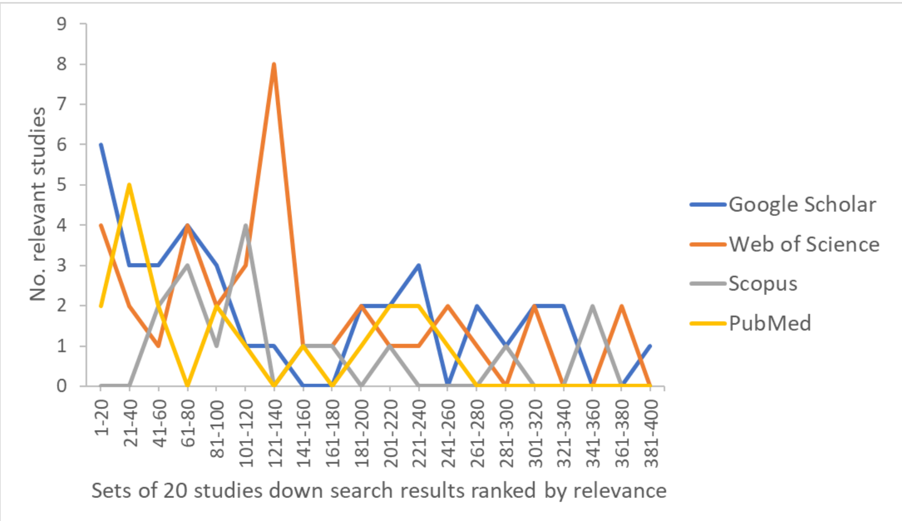

Table AW2.2. Taxonomic composition of metrics and studies included in our selection for question W2. Some studies included metrics for multiple species (such as species richness or diversity). The 'Total studies' column does not sum to 'Total' as some studies contribute to multiple metric types.

	Peri-domestic					Wider countryside				
Family and species	Abundance	Abundance change	Distribution	Diversity	Sp. richness	Abundance	Abundance change	Sp. richness	Total metrics	Total studies
Acanthizidae	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Gray gerygone	1	0	0	0	0	0	0	0	1	1
Columbidae	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**3**
Eurasian collared dove	1	0	0	0	0	0	0	0	1	1
Feral pigeon	1	0	0	0	0	0	0	0	1	1
Spotted dove	1	0	0	0	0	0	0	0	1	1
Corvidae	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**3**	**3**
Western jackdaw	0	0	0	0	0	1	0	0	1	1
Eurasian magpie	1	0	0	0	0	1	0	0	2	2
Emberizidae	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**	**4**	**1**
Corn bunting	0	0	0	0	0	0	1	0	1	1
Common reed bunting	0	0	0	0	0	0	1	0	1	1
Yellowhammer	0	0	0	0	0	0	2	0	2	1
Fringillidae	**4**	**1**	**0**	**0**	**0**	**0**	**3**	**0**	**8**	**6**
Eurasian chaffinch	1	0	0	0	0	0	1	0	2	2
European goldfinch	0	0	0	0	0	0	1	0	1	1
European greenfinch	1	0	0	0	0	0	1	0	2	2
House finch	2	1	0	0	0	0	0	0	3	3
Meliphagidae	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Tui	1	0	0	0	0	0	0	0	1	1
Muscicapidae	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**
Eurasian robin	0	0	0	0	0	0	1	0	1	1
Paridae	**2**	**0**	**0**	**0**	**0**	**10**	**2**	**0**	**14**	**9**
Black-capped chickadee	0	0	0	0	0	2	0	0	2	2
Eurasian blue tit	1	0	0	0	0	3	1	0	5	5
Crested tit	0	0	0	0	0	1	0	0	1	1
Great tit	1	0	0	0	0	3	1	0	5	5
Willow tit	0	0	0	0	0	1	0	0	1	1
Passerellidae	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	**2**
Song sparrow	0	0	0	0	0	1	0	0	1	1
Swamp sparrow	0	0	0	0	0	1	0	0	1	1
Passeridae	**3**	**2**	**0**	**0**	**0**	**0**	**3**	**0**	**8**	**6**
House sparrow	2	2	0	0	0	0	2	0	6	6
Eurasian tree sparrow	1	0	0	0	0	0	1	0	2	2
Prunellidae	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**

Family and species	Peri-domestic					Wider countryside				
	Abundance	Abundance change	Distribution	Diversity	Sp. richness	Abundance	Abundance change	Sp. richness	Total metrics	Total studies
Dunnock	0	0	0	0	0	0	1	0	1	1
Rhipiduridae	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
New Zealand fantail	1	0	0	0	0	0	0	0	1	1
Sittidae	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**
Eurasian nuthatch	0	0	0	0	0	1	0	0	1	1
Sturnidae	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**1**
Common myna	1	0	0	0	0	0	0	0	1	1
Common starling	1	0	0	0	0	0	0	0	1	1
Sylviidae	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Eurasian blackcap	0	0	1	0	0	0	0	0	1	1
Troglodytidae	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Carolina wren	1	0	0	0	0	0	0	0	1	1
Turdidae	**3**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**4**	**3**
Common blackbird	2	0	0	0	0	0	1	0	3	3
Song thrush	1	0	0	0	0	0	0	0	1	1
Zosteropidae	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Silvereye	1	0	0	0	0	0	0	0	1	1
Metrics based on multiple sp.	**8**	**1**	**0**	**8**	**8**	**2**	**0**	**1**	**28**	**20**
Multiple	8	1	0	8	6	2	0	1	26	19
Multiple - introduced	0	0	0	0	1	0	0	0	1	1
Multiple - native	0	0	0	0	1	0	0	0	1	1
Total	**31**	**4**	**1**	**8**	**8**	**17**	**15**	**1**	**85**	**44**

W3. What are the effects on non-avian wildlife of SF aimed at wild birds?

Rationale

SF in residential settings provides a concentrated and predictable food resource that can influence a wide range of non-avian taxa through both direct and indirect pathways. Users of SF (like grey squirrels, rats, small mammals) may gain nutritional benefits and change their foraging behaviour or local distribution. There may also be indirect effects of feeding as birds respond to the utilisation of food by other taxonomic groups. For example, increases in predator or competitor species at feeders could affect other garden wildlife through increased predation pressure, disturbance, or competition for food resources and refuge sites. The accumulation of spilt food may also support commensal or nuisance species and elevate local parasite or pathogen loads (e.g. ticks, rodents). Understanding these non-avian responses is important because they can (i) alter local biodiversity and ecological functioning, (ii) contribute to human-wildlife conflict or disease risk, and (iii) influence public perceptions of feeding and willingness to follow guidance. Assessing the strength, direction and scale of these effects will help us to identify and explain the wider ecological and social risks of feeding birds, and to provide clear, evidence-based advice and mitigation options for the public.

Methods

Literature search procedure

As with the other questions in this review, we developed a search string based on key words and phrases from selected relevant studies combined with expert knowledge. The search string comprised three parts: terms relating to bird feeding (to identify studies where supplementary food was provided for birds), a list of SF-related terms, and a set of terms specifying candidate non-avian taxonomic groups and species (Appendix W3: Table AW3.1).

We ran the searches on Google Scholar, Web of Science, Scopus, and PubMed search engines, and used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of 20 studies to quantify the extent to which relevance declined with search engine rank. When this decay function declines to zero it is likely that the search has identified a high proportion of relevant studies; if it fails to reach zero by the 400-study threshold it is likely relevant studies were excluded by our threshold. For this question, the decay in study relevance beyond the highest ranked 150 studies suggests we located most of the relevant studies (Appendix W3: Figure AW3.1). After combining the relevant studies from the four search engines we checked for and removed duplicates and exported the remaining set of studies to a spreadsheet. We added two additional relevant studies that we encountered whilst extracting data from the relevant search engine studies.

Study exclusions

Following amalgamation of selected studies across search engines we inspected full text articles and, where studies remained relevant, we extracted summary data for each study as described below. We focused on studies of impacts of SF on non-avian species across a broad range of taxa and excluded any studies of limited relevance to UK residential settings (e.g. one study related to snakes in Arizona, USA). The selection included a range of studies on mammals as well as a few on invertebrates.

Data extraction – response metrics

For each selected study we recorded the primary response metric(s) to SF which included measures of abundance, distribution and community composition, as well as measures of activity, feeder usage and supplementary food consumption. For reporting purposes, we grouped these studies and response metrics into three groups:

(i) studies adequate to infer effects of SF on local animal abundance were defined as those with replicated fed and unfed treatments where the subjects were unlikely to move between experimental units. Only three studies satisfied this criterion all of these were on insects, two involving situations where the insects could not move and one on ground beetles where the spacing between fed and unfed sampling areas was considered large enough (4-15m apart) for dispersal to have been minimal. This group accounted for 4 metrics from 3 studies.

(ii) studies of animal distribution, feeder usage or diet conducted either without unfed control locations or at a spatial scale that would allow individual animals to readily move between fed and unfed localities. This group accounted for 18 metrics from 12 studies.

(iii) studies relating to ectoparasite ecology measuring parasite abundance, host parasite load and human serosurveillance for tick-borne pathogens. All these studies related to ticks (order Ioxdida) or to human exposure to ticks. This group accounted for 9 metrics from 7 studies. We did not include these studies in question W4 on avian disease because their focus was on the parasites outside the host and on risks to human health rather than health impacts on the avian hosts.

Statistically significant effects were assigned directions of change irrespective of potential human perceptions or risks. For example, increases in non-native species and parasites were always scored as positive.

Data extraction – context variables

For each response metric, we also extracted a range of context variables. These allowed us to describe the composition of the extracted data, and to compare different data subsets. First, we assigned each response metric to a continent (North America, Europe). Second, we assigned each metric to one of three human proximity categories according to the landscape in which the study was conducted: peri-domestic (urban, suburban, rural domestic), wider countryside away from human habitation (usually woodland or farmland), or a mixture of the two. Third, we assigned each metric to one of two study design categories: experimental which included the imposition of at least one treatment with a suitable control, or observational describing taxon associations involving SF. The subject(s) of each study were also assigned to an appropriate taxonomic group. The type of supplementary food provided was specified in 36% of North American studies and 60% of European studies and was predominantly seed.

We summarise the findings of our literature search first by describing the composition of the extracted response metrics and selected studies, and second, for each response category, we describe the directional balance of the reported associations between SF and non-avian taxa (positive, neutral, negative), where positive indicates a significant increase in the response metric and vice versa.

Results

Literature composition

We extracted data relating to 31 metrics from 21 studies (Table W3.1). Most studies (21 metrics from 13 studies) were conducted in North America, with the remainder conducted in Europe (10 metrics from 8 studies; Table W3.1). All studies of parasites were conducted in North America. Most studies of mammalian mesopredators (medium sized carnivores and omnivores of the families Canidae, Mustelidae, Procyonidae and Felidae) were conducted in North America (8 of 9 metrics, 5 of 6 studies), while most rodent studies (mainly squirrels and rats) were conducted in Europe (6 of 7 metrics and studies). Arthropods accounted for 13 metrics from 10 studies with ticks making up 9 metrics from 7 studies (Table W3.1). Studies of insects (aphids, mealworms, beetles) took place in both Europe (2) and North America (1).

Most studies were conducted in peri-domestic landscapes (19 metrics from 13 studies) with fewer from wider countryside (8 metrics from 4 studies) and mixed localities (4 metrics from 4 studies).

The data comprised a mix of experimental and observational designs (14 vs. 17 metrics, 8 vs. 13 studies). All studies of local abundance/community were experimental, all but one parasite exposure studies were observational, while distribution/activity/usage studies were an equal mix of the two designs (Table W3.2).

The W3 evidence base is dominated by North American observational studies, with relatively few experimental or UK-based examples. This limits the strength of causal inference and the applicability of findings to UK residential contexts.

<u>Directional balance of the impacts of SF</u>

The directional balance of responses to SF was mostly positive for measures of animal distribution, activity and feeder usage (all mammals), mostly negative for measures of local abundance (all insects) and either positive or neutral for measures of parasite exposure (entirely ticks in North America) (Table W3.3).

(a) Effects of SF on non-avian species on local abundance and community composition. Only three studies were found that measured abundance on a scale where the effect of SF on true abundance (rather than distribution or feeder usage) could be considered to have been tested. All three were conducted on insects and considered whether elevated levels of bird activity close to feeders resulted in the depletion of local insect abundance:

- A winter field experiment conducted in Michigan, USA, evaluated the impact of predation by small passerine birds on invertebrate prey provided at increasing distances from bird feeders in gardens (Martinson et al. 2003). Mealworms were used as a surrogate for overwintering bark-dwelling arthropods which feed on trees. The rate of mealworm depletion over a 60-day period was higher (by 10% and 30% at two different sites) up to 20 m from bird feeders compared to control locations further away from feeders.
- A similar UK breeding season study deployed laboratory-reared pea aphid colonies as surrogate natural prey in 38 gardens (Orros et al. 2012). In each garden some colonies were protected from bird predation by mesh cages and others not. After three weeks of exposure to foraging birds, aphid numbers were significantly more depleted, and with lower colony survival, in unprotected locations in gardens with bird feeders but not in gardens without feeders.
- The third study considered the effects of feeder presence on the local abundance and species richness of ground beetles (Carabidae) during late summer in UK city gardens. Sampling was conducted under bird feeders and at matched ‘control’ locations 4-15 m away from feeders (Orros et al. 2015). Significantly fewer carabids were captured under bird feeders compared with control locations, and video evidence suggested garden birds were responsible for this depletion as they spent more time ground feeding under feeders than at control sites. There was no effect on beetle species richness although the authors acknowledge limited statistical power.

These three studies show that by attracting birds to gardens, SF can cause reductions in the local abundance of invertebrate prey. Although these effects are localised, they indicate that high densities of feeders can influence nearby invertebrate populations, but the ecological consequences remain uncertain. Some depletion may represent a beneficial ecosystem service if birds reduce pest species yet impacts on non-target or beneficial taxa could contribute to local homogenisation of urban invertebrate assemblages. The evidence is limited and largely experimental, so further work is needed to assess whether such effects are transient or ecologically significant in UK garden settings.

(b) Impacts of SF on non-avian species distribution, activity and diet. Eleven studies considered the effects of bird feeders on mammal distribution, activity or diet. Four such studies focussed on rodents:

- Building on their ground beetle experiment, Orros et al. (2015) also collected data on small mammal abundance across a sample of 36 UK gardens during late summer. They found no evidence that small rodent numbers (predominantly wood mice) differed between fed and un-fed gardens. Based on a single trapping occasion at the garden scale, we categorised this conservatively as testing for a distributional rather than an abundance impact of SF.
- Jokimäki et al. (2017) analysed winter data on red squirrel (*Sciurus vulgaris*) encounter rates from 355 10-km transects in Finland in relation to a set of covariates, one of which was abundance of 'winter feeding sites for birds'. The number of recorded squirrels significantly increased with the abundance of feeding sites, with the highest squirrel numbers in urban areas and rural settlements. However, because of the scope for squirrels to disperse and aggregate around feeders in gardens, we did not consider this effect a true abundance response.
- In another correlational study, of non-native grey squirrels in the city of Sheffield UK, Bonnington et al. (2014) used a point sampling method to measure adult squirrel occurrence and estimate density across 140 sites that varied in the extent of green space. The local density of bird feeders significantly increased the likelihood of squirrel occurrence during winter but not during other seasons, and feeder density had no detectable influence on squirrel density. The study demonstrated that bird feeders weakly influence squirrel distribution in peri-domestic settings during winter.
- An experimental study in New York state, USA used camera traps during autumn and winter to compare the usage of bird feeder locations with control sites (Reed et al. 2018). Their two-year study consisted of six locations 50 m apart along a rural forest edge, switching location-level feeding status between years. Grey squirrels were recorded on 94% of sampling days, and significantly more often and in larger group sizes at locations with feeders.

Despite the wide spacing of sampling units in the first two squirrel studies, we consider all three studies to be measuring distributional rather than abundance responses to SF partly due to the small spatial scale of the encounters and partly due the correlational study designs.

Several North American studies have used camera traps to assess visits to localities with bird feeders by nocturnal mammals, although the consumption of food from seed feeders directly or indirectly (e.g. spilt seed) was not formally measured:

- Reed et al. (2018) reported that woodland locations with bird feeders in New York state USA were more likely to attract racoon, white-tailed deer and a suite of carnivores (red fox, grey fox, fisher) than locations lacking feeders, resulting in higher species richness at fed sites. The study did not quantify whether bird food was consumed by these species.
- In relation to concerns about rabies outbreaks in Arizona, USA, Theimer et al. (2015) used camera traps to measure visit rates of urban mesocarnivores to peri-domestic bird feeders. Racoons, domestic cats and striped skunks were attracted to spilt seed beneath feeders and visit rates increased following the introduction of cat food. In a follow up study bird feeders were tested as locations for uptake of oral rabies vaccine baits (Theimer et al. 2017) from which significantly more (54%) placebo baits were removed by striped skunks than at paired, non-feeder locations (19%).
- A camera trapping study showed eight mammalian mesopredator species visiting 43 gardens in Arkansas, USA (Johansson et al. 2024). Mesopredator diversity, but not species richness, was positively correlated with the number of bird feeders present. Racoons and Virginnia opossums were reported eating supplementary food from or below feeders, and the authors speculated that coyote and red fox may have been attracted to gardens by SF attracting small mammals.

We found two studies of brown rat usage of supplementary food both conducted in the UK and both in relation to game bird feeders in the wider countryside:

- Brown rat usage of hopper-style game bird feeders was significantly higher adjacent to hedgerows with new feeder locations being discovered within 2-4 days (Sanchez-Garcia et al. 2015).
- Brown rat encounters on Northumberland farmland decreased with distance from game bird feeders and increased during cold and wet weather, and when feeders contained more supplementary food (Saad et al. 2021).

Two large-scale studies of mammalian mesopredator diet provide information regarding the consumption of bird food:

- Murray et al. (2015) found bird seed in 12% of coyote scats from urban-living coyotes compared to 0% for those living in the wider countryside of Alberta, USA. Over 1000 scats were collected monthly from a combination of opportunistic and standardised searches.
- Contesse et al. (2003) found that the stomachs of 84% of suburban red foxes shot in suburban Zurich, Switzerland, contained anthropogenic food (mainly scavenged meat) while 9% of 402 stomachs contained bird seed which accounted for 3.7% of all food by volume. The study did not consider differential digestibility of the 12 food categories it assessed.

These studies show that SF sites are regularly used by a range of non-avian species particularly mammals such as squirrels, rats, foxes and mesocarnivores which are attracted to spilt seed or food residues. However, the extent to which these observations represent genuine local abundance increases, rather than localised foraging or behavioural responses, remains unclear. Most evidence derives from small-scale or camera-trap studies in North America and northern Europe and largely reflects urban or peri-domestic settings. While some interactions may be neutral or even beneficial – for example, providing food resources that support urban wildlife – others could exacerbate human-wildlife conflict, disease risk, or competition with native species. Overall, SF appears to alter patterns of mammal activity around feeders, but the ecological and management implications of these changes remain uncertain and warrant further investigation in a UK context.

(c) Associations between SF and ectoparasites. Studies of ectoparasite ecology associated with SF focus mainly on ticks and are treated separately from those addressing avian disease (question W4), as their emphasis is on parasite abundance in the environment and potential implications for human or mammalian exposure rather than bird health. All identified studies were observational and conducted in North America. These studies were all focused on *Ixodes scapularis* as a potential source of tick-borne infections in humans, notably Lyme disease caused by *Borrelia* bacteria. The proposed mechanism was the attraction of mammal hosts like deer and rodents to bird feeder locations. The equivalent Lyme disease vector in the UK, *Ixodes ricinus*, acts in a similar way, with successive life stages feeding on small passerines, small mammals and deer, but our literature search located no studies directly addressing this species in relation to bird feeding.

Four North American studies measured the abundance or distribution of ticks in relation to bird feeder distribution in residential gardens:

- Bird feeder presence had no effect on tick abundance (all life stages), or on the prevalence of *Borrelia* spp. infection in nymphs, based on sampling of multiple habitats within randomly selected gardens in areas of New York state, USA having high Lyme disease incidence (Townsend et al. 2003).
- Similarly, bird feeder presence had no effect on either nymph abundance or small rodent tick burden in 143 gardens in New York state (Fischhoff et al. 2019).
- In an evaluation of landscaping and vegetation management that aimed to suppress host-seeking nymphs at 42 properties in Connecticut, nymph abundance did not differ between bird feeder locations and nearby grass (Linske et al. 2024).

- In a study of nine bird feeders in a single Massachusetts garden, tick occurrence was significantly higher on grass lawns directly beneath bird feeders compared to that 6 m away from feeders (Kowalczyk et al. 2008).

A second group of correlative studies from North America tested whether garden bird feeders were associated with increased human exposure to ticks or Lyme disease:

- A questionnaire survey conducted in Northern California found that the presence of a bird feeder in participant's gardens was the only significant (positive) predictor of antibody presence for three tick-borne infections in human blood (Pascoe et al. 2019).
- A questionnaire study conducted in suburban Connecticut asked participants from 471 households to record tick detections on themselves along with detailed activity logs during a week-long monitoring period in June. Participants that recorded at least one tick on their body were more likely to have a bird feeder in their garden than those recording no ticks (Mead et al. 2018). This was one of several significant risk factors. The authors conclude that most tick exposures in the study area occurred in private gardens.
- Finally, an age-matched case-control study of 51 participants in New Jersey found that the presence of a garden bird feeder was a significant positive risk factor for confirmed Lyme disease cases along with several other factors (Orloski et al. 1998).

These findings indicate a plausible association between bird feeding and localised increases in tick abundance, but the strength, persistence and ecological significance of this relationship remain uncertain. Further investigation is needed to determine whether similar patterns occur in UK gardens and whether they present any material implications for wildlife management or public health.

<u>Summary</u>

- The available evidence relating to the effects of SF in residential settings on the abundance of non-avian wildlife is limited largely to small-scale studies of local abundance and patch usage. Apart from three experimental studies conducted on insect depletion close to feeders, we found no replicated experimental studies testing whether SF affects the true abundance of non-avian taxa.
- Three experimental studies on insects provide consistent evidence that bird feeders are associated with increased local depletion of insect prey within the immediate vicinity of feeders. The likely mechanism for this effect is that bird feeders concentrate the foraging activities of wild birds within the vicinity of feeder locations. The distance over which feeders enhanced insect depletion varied between studies from 4 m to 20 m.
- Three studies (including one in the UK) have demonstrated that autumn-winter squirrel distribution is positively (but weakly) related to the distribution of bird feeders, but there is no evidence of any such relationship during other seasons. This may reflect a greater reliance of squirrels on bird feeders during winter as a source of nutrition. Three North American studies have demonstrated similar positive relationships between the distributions of bird feeders and various mammals including raccoons, opossums, carnivores, deer and domestic cats. Dietary studies confirmed consumption of supplementary bird seed by red fox and coyotes in North America.
- Two studies of brown rats conducted on UK farmland showed that rat distribution was positively related to the distribution of game feeders and hedges next to game bird feeders.
- Several North American studies have investigated potential links between ticks and bird feeding. Although only one of four studies directly measured higher tick densities close to feeders, three indirect correlative studies report evidence of higher apparent exposure risk of humans to ticks in households where birds are fed. No similar studies from Europe were identified.

- A key evidence gap is the effect of widespread SF in residential settings on the abundance of species like grey squirrel and brown rat that regularly consume food provided for birds in the UK.

Table W3.1. Numbers of metrics and studies relevant to question W3 subdivided by species/taxonomic group, study location (Europe, North America) and study design (experimental, observational).

	Metrics					Studies				
	North America		Europe			North America		Europe		
Taxon group	Expt.	Obs.	Expt.	Obs.	Total	Expt.	Obs.	Expt.	Obs.	Total
Arthropod	**2**	**8**	**3**	**0**	**13**	**2**	**6**	**2**	**0**	**10**
Aphid	0	0	1	0	**1**	0	0	1	0	**1**
Tick	1	8	0	0	**9**	1	6	0	0	**7**
Mealworm	1	0	0	0	**1**	1	0	0	0	**1**
Beetle	0	0	2	0	**2**	0	0	1	0	**1**
Mammal large herbivore	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**
White-tailed deer	1	0	0	0	**1**	1	0	0	0	**1**
Mammal mesopredator	**3**	**5**	**0**	**1**	**9**	**2**	**3**	**0**	**1**	**6**
Coyote	0	1	0	0	**1**	0	1	0	0	**1**
Raccoon	1	1	0	0	**2**	1	1	0	0	**2**
Red fox	0	0	0	1	**1**	0	0	0	1	**1**
Striped skunk	1	1	0	0	**2**	1	1	0	0	**2**
Red fox & Coyote	1	0	0	0	**1**	1	0	0	0	**1**
Domestic cat	0	1	0	0	**1**	0	1	0	0	**1**
Mesopredators	0	1	0	0	**1**	0	1	0	0	**1**
Mammal spp. richness	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**
Mammal spp. richness	1	0	0	0	**1**	1	0	0	0	**1**
Rodent	**1**	**0**	**3**	**3**	**7**	**1**	**0**	**3**	**3**	**7**
Brown rat	0	0	1	1	**2**	0	0	1	1	**2**
Grey squirrel	1	0	1	1	**3**	1	0	1	1	**3**
Red squirrel	0	0	0	1	**1**	0	0	0	1	**1**
Mice & Voles	0	0	1	0	**1**	0	0	1	0	**1**
Total	**8**	**13**	**6**	**4**	**31**	**4**	**9**	**4**	**4**	**21**

Table W3.2. Numbers of metrics and studies relevant to question W3 subdivided by response metric category (see methods), individual response metric and study design (experimental, observational).

Response metric category, and metric	Experimental	Observational	Total	n (studies)
Local abundance/community	**4**	**0**	**4**	**3**
Aphid predation	1	0	1	**1**
Beetle abundance index	1	0	1	**1**
Beetle species diversity	1	0	1	**1**
Mealworm predation	1	0	1	**1**
Distribution/activity/usage	**9**	**9**	**18**	**12**
Bait removal	1	0	1	**1**
Bird food as % by vol stomach content	0	1	1	**1**
Mammal detections at camera	4	0	4	**1**
Mammal mesopredator diversity	0	1	1	**1**
Mammal species richness at camera	1	0	1	**1**
Mammal visits per night	0	3	3	**1**
Prevalence of bird seed in scats	0	1	1	**1**
Rat detections at camera	1	0	1	**1**
Rat occurrence at tracking plates	0	1	1	**1**
Small rodent abundance index	1	0	1	**1**
Squirrel density	0	1	1	**1**
Squirrel encounter rate	0	1	1	**1**
Squirrel visit duration	1	0	1	**1**
Exposure to parasites	**1**	**8**	**9**	**7**
Tick abundance index	1	5	6	**5**
Tick burden on small mammals	0	1	1	**1**
Tick-borne disease antibody seroprevalence	0	2	2	**2**
Total	**14**	**17**	**31**	**21**

Table W3.3. Directional responses to SF (numbers, percentages) for metrics relevant to question W3 subdivided by response metric category (see methods), and individual response metrics. Numbers of contributing studies are also shown. Numbers of metrics for individual response metrics were too few to calculate meaningful percentages.

Response metric categories	Positive	Neutral	Negative	% positive	% neutral	% negative	n (metrics)	n (studies)
Local abundance/community	**0**	**1**	**3**	**0**	**25**	**75**	**4**	**3**
Aphid predation	0	0	1				1	1
Beetle abundance index	0	0	1				1	1
Beetle species diversity	0	1	0				1	1
Mealworm predation	0	0	1				1	1
Distribution/activity/usage	**16**	**2**	**0**	**89**	**11**	**0**	**18**	**12**
Bait removal	1	0	0				1	1
Bird food as % of stomach content	1	0	0				1	1
Mammal detections at camera	3	1	0				4	1
Mammal mesopredator diversity	1	0	0				1	1
Mammal species richness at camera	1	0	0				1	1
Mammal visits per night	3	0	0				3	1
Prevalence of bird seed in scats	1	0	0				1	1
Rat detections at camera	1	0	0				1	1
Rat occurrence at tracking plates	1	0	0				1	1
Small rodent abundance index	0	1	0				1	1
Squirrel density	1	0	0				1	1
Squirrel encounter rate	1	0	0				1	1
Squirrel visit duration	1	0	0				1	1
Exposure to parasites	**4**	**5**	**0**	**44**	**56**	**0**	**9**	**7**
Tick abundance index	2	4	0				6	5
Tick burden on small mammals	0	1	0				1	1
Tick-borne disease antibody level	2	0	0				2	2
Total	**20**	**8**	**3**	**65**	**26**	**10**	**31**	**21**

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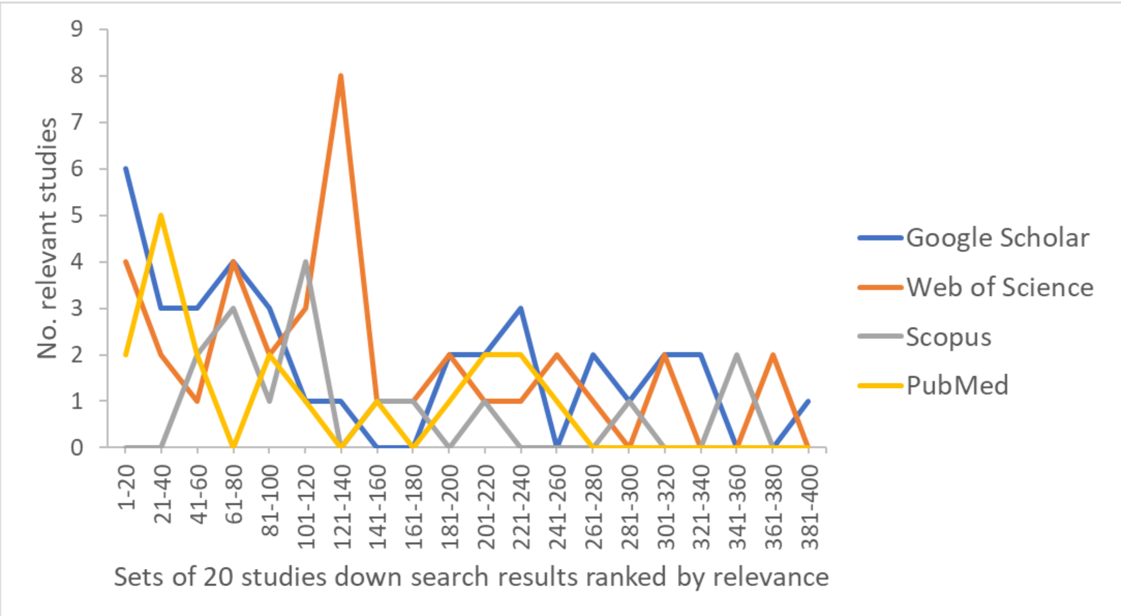
W3 Appendix

Table AW3.1. Question W3 search string.

Part-1	Part-2	Part-3
(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")	AND ("non-target animals" OR rat* OR "brown rat"* OR "rattus norvegicus" OR rodent* OR rodentia OR "small mammals" OR squirrel OR Sciuridae OR Sciurus OR fox OR "Vulpes vulpes" OR cat OR "felis domesticus" OR opossum OR possum OR deer OR mesopredator* OR mammal OR "bark dwelling" OR "bird prey" OR tick* OR beetle* OR aphid* OR plant* OR invertebrate* OR insect* OR arthropod*)

Figure AW3.1. Changes in the relevance 'hit rate' of studies selected by four search engines for question W3. The numbers plotted are the number of studies we considered to be relevant out of each batch of 20 studies ('hit rate') across the 400 studies ranked in relevance order by each search engine (1-20=ranked most relevant, 381-400 = ranked least relevant). A hit rate declining to zero implies most relevant studies have been identified, but higher hit rates up to the 400 threshold implies some relevant studies may have been missed.



W4. What are the effects of SF on pathogen transmission risk and disease in wild birds?

Rationale

The aim of this question is to summarise the available evidence on the effects of SF in a residential context on pathogen transmission risk, and host health, within wild bird populations. The primary area of concern is whether SF increases pathogen transmission within wild bird populations due to aggregation at feeding sites leading to more frequent direct contact between individuals, increased indirect transmission (e.g. via fomites on feeder surfaces, or contaminated food or water sources), and/or through increased inter-species interactions which predispose to pathogen spillover. Here, the evidence for interactions between SF and transmission are considered separately for each pathogen (or pathogen group) identified. To aid interpretation, we present background information on each of the key pathogens and the diseases they cause, including transmission routes and whether there is evidence of disease-mediated population impacts in wild birds. We do not estimate effect sizes for impacts of SF on pathogen transmission due to the wide range of response metrics in the papers identified, and the need for pathogen-specific context for interpretation. In addition to pathogen transmission, we also review the available literature on additional effects of SF on host health. Effects of SF on host response to infection are considered (e.g. due to nutritional effects on immune response), and evidence for contaminants present in wild bird feed with potential to cause adverse health impacts.

Methods

Literature search procedure

We developed a search string for each question based on key words and phrases from selected relevant studies, combined with expert knowledge (Appendix W4: Table AW4.1). General disease-related search terms were used (e.g. parasite, epidemic, health), in addition to specific search terms for pathogens relevant to UK garden bird populations, to ensure key conditions relevant to a UK context were included. These were informed by the disease factsheet library and peer-reviewed publication outputs listed on the Garden Wildlife Health website (as of 20/03/2025). For each question, we ran the related search string on Google Scholar, Web of Science, Scopus and PubMed. We then used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of twenty studies to quantify the extent to which relevance declined with search engine rank. When this decay function declines to zero it is likely that the search has identified a high proportion of relevant studies; if it fails to reach zero by the 400-study threshold it is likely relevant studies were excluded by the threshold. We then checked for and removed duplicates across search engines and exported the remaining set of studies to a spreadsheet.

The 'relevance' decay function indicates the hit rate declined to a stable, low level after approximately 160 studies (Fig. AW4.1). However, to ensure our assessment included all relevant literature we also incorporated unpublished research where this is of relevance to the question, including dissertations and preliminary findings from two on-going research projects.

Study exclusions

Following amalgamation of selected studies across search engines we inspected full text articles and extracted summary data for each study that met each of the following criteria:

1. Avian health hazard focus: The study considered one or more pathogens, or contaminants present in wild bird feed, with potential to cause adverse health effects in wild birds. Studies focusing on human health risks from exposure to zoonotic pathogens present in wild bird populations were

excluded (and are addressed in section 5 of this report – Other Topics).

2. Study design: Studies were included that met one or more of the following criteria:

(i) SF contrast studies considered the effects of SF either in comparison to a no-SF control, or across a gradient of SF provision, on one or more of the following metrics relating to wild bird health status: infection and/or disease status, infection risk (e.g. contact rates or environmental pathogen loads relevant to transmission risk), condition, fitness, physiology or survival. For condition, fitness, physiology and survival metrics, these were only retained if effects of SF on these responses were linked to infection or immunological status, as direct effects of SF on these metrics are covered under W1. Subjects were typically defined as individual birds or groups of birds occurring within defined study areas (e.g. gardens, sites, habitat types). Experimental studies in captive populations were included if they manipulated SF (including nutritional value) or measured responses to SF relevant to pathogen transmission.

(ii) Descriptive studies provided additional context or information on SF effects on pathogen transmission or wild bird health but did not include a fed control or contrast. These studies encompassed those that (i) reported disease occurrence in proximity to feeding stations (i.e. pathological investigation of morbidity and mortality incidents), (ii) measured pathogen prevalence in garden birds in proximity to feeding stations (i.e. active surveillance with random sampling of live birds), (iii) conducted environmental sampling for pathogens present on, or in proximity to, feeding sites, (iv) screened supplementary food for contaminants with potential to impact bird health, or (v) measured bird behaviour relevant to understanding transmission risk at feeders.

3. Taxonomic selection: The species studied fell within one of the following taxonomic groups considered to be relevant to UK garden birds: Passeriformes (songbirds), Piciformes (woodpeckers), Columbiformes (pigeons and doves) and Psittaciformes (included due to potential for pathogen transmission amongst non-native parakeet species within UK residential contexts). SF studies of other taxonomic groups (including raptors, seabirds, waterbirds, gamebirds, hummingbirds) were excluded as not being directly relevant to a UK residential context. Studies on species relevant to UK gardens, but in the context of SF via gamebird feeders were included, as the effects of aggregation at a feeding-site may be comparable to garden bird-feeding.

Studies that considered potential mitigation measures aimed at reducing disease risk associated with SF are considered under review question W6 and were therefore excluded from consideration under this question.

<u>Data extraction- response metrics</u>
For each selected study we identified the presence/absence of a SF control or contrast. These studies, hereafter collectively referred to as 'SF contrast studies', were then assigned to the following categories based on the comparison included in the study: (i) SF present or absent (SF vs. no SF), (ii) SF gradient (e.g. density of feeders or individual level of feeder use), (iii) SF species surrogate (e.g. species regularly using feeders vs. those that rarely use feeders), (iv) SF habitat surrogate (habitat type used as a proxy for likely intensity of SF e.g. peri-domestic vs wider countryside areas), (v) transmission route (indirect transmission via feeders vs direct transmission between birds), and (vi) supplementary food nutritional value. For each selected study, key findings defining the effect of the SF contrast on pathogen transmission or host health were extracted. Where findings were reported for multiple individual bird species or pathogens within a single study, each of these contributed a single metric to our evidence review (one row in the extraction spreadsheet) although we avoided including duplicate aggregate metrics. For example, if a study

presented effects of SF for multiple species as well as for the same species aggregated, we only included the former.

For descriptive studies it should be noted that as non-fed controls were not available, the causative effects of SF on transmission cannot be confidently identified. For example, although a number of studies reported disease outbreaks in proximity to SF stations, the effects of observer bias (birds are more likely to be observed at feeding stations relative to the wider environment) cannot be separated from the potential effects of increased transmission at feeding sites. Limited disease surveillance of birds in the wider environment also means there is a lack of baseline data to compare with information from gardens where SF occurs. Therefore, key findings were extracted from these descriptive studies to provide additional insight, but firm conclusions as to the relative importance of SF as a driver of population-wide pathogen transmission risk could not usually be drawn. Findings from SF contrast studies and descriptive studies are summarized for each pathogen.

Data extraction – context variables

For each response metric across all included studies, we also extracted information on a range of context variables. These allowed us to describe the composition of the extracted data, and to compare and present different subsets of the data.

First, we extracted information on study settings. Studies were defined as field studies, captive studies (birds kept in aviaries) or laboratory studies (primarily feeder or water pathogen contamination comparisons that did not involve live birds). Geographic information was also extracted. This included the country and continent the study was conducted in, and for field studies information on the habitat type. Where available, we also extracted information on the type of supplementary food provided, and/or the feeder types used.

Second, studies were assigned to design categories. SF contrast studies were defined as either 'experimental' studies (experimental manipulation of SF e.g. by introduction of feeding sites, or modification of SF practice), and 'observational' studies that typically compared response metrics across existing levels, or a gradient of SF provision.

Third, the bird species subject(s) of the study was extracted. For each species, we also noted whether it occurs in the wild in the UK.

Fourth, we extracted the pathogen species (or contaminant where applicable) and where relevant the strain or type (e.g. for *Salmonella* spp.). Each pathogen was also categorized into broader taxonomic groups (i.e. bacterial, viral, endoparasites and ectoparasites) and by transmission routes (i.e. aerosol, contact, saliva, faecal-oral and vector-borne). We also extracted the diagnostic method used to identify the pathogen, and whether the study considered infection (detection of the pathogen only), disease (impacts on host health e.g. clinical signs, pathological abnormalities), detection of environmental pathogen presence or load, or a measure of supplementary food contamination.

Results

Literature composition

The literature search generated 76 studies in total. Of these, 29 were categorised as SF contrast studies and measured a response relevant to pathogen transmission or host health and provided 97 response metrics. Of these studies, the most common SF contrast was 'SF vs no SF' (n=11) followed by comparison across a SF gradient (n=7) (Table W4.1). Four studies used habitat as a surrogate for SF intensity, and three used species as a surrogate (whether species regularly use feeding sites or not). Interpretation of studies using surrogate measures of SF requires caution, as other factors which vary across habitats and species could confound interpretation of SF effects. Two studies considered how the nutritional value of supplementary food influences disease impacts, and one study compared transmission routes (via feeders vs. via direct transmission).

A further 47 descriptive studies (contributing 54 metrics) were selected which contained relevant information on (i) disease occurrence in garden birds in proximity to feeding sites (n=23 studies contributing 26 metrics), (ii) pathogen prevalence in garden birds (n=6 studies contributing 8 metrics), (iii) indirect transmission of pathogens via fomites on feeders, or in proximity to feeding sites (n=12 studies contributing 13 metrics), (iv) contaminants of supplementary food (n=4 studies contributing 5 metrics) or (v) bird behaviour relevant to transmission risk (n=2 studies contributing 2 metrics) (Table W4.2).

A similar number of studies were conducted in Europe (n=40) and North America (n=33), in contrast to only single studies from each of Asia, Africa and Australasia (Table AW4.2). Most studies identified were field studies (n=60, 25 with a SF contrast), followed by laboratory studies (n=10, none with a SF contrast) and captive studies (n=6, 4 with a SF contrast) (Table AW4.3). Of the field studies, most were conducted in human-modified habitats (e.g. gardens, urban parks; 37/60), while 13 were carried out in wider countryside habitats (e.g. woodland, farmland) and ten involved multiple habitat types (including sampling along rural-urban gradients, n=3). Most studies did not specify the type of supplementary food provided or the feeder type used (n= 46). Of those which did, seed provision was most common (n=12), followed by mixed food types (n=6) and studies on contamination of water sources (n=3) (Table AW4.5). For SF contrast studies, most studies were observational (n=19), while only 10 were experimental (of which 5 focused on *Mycoplasma gallisepticum* (*MG*) and were conducted in North America).

Taxonomic composition was dominated by multi-species studies (n=28), followed by house finch (n=12; 10 of which related to *MG*) and European greenfinch (n=5; 3 of which related to trichomonosis) (Table AW4.4). The multi-species studies were mostly descriptive (e.g. reporting a disease outbreak affecting multiple species at a feeding site, n=16) or observational (e.g. screening multiple species for pathogens across an existing gradient of SF, n=10). Of the 76 contributing studies, 43% (32/76) considered bird species that are present in the UK, 42% (32/76) considered species absent in the UK, while 16% (12/76) did not focus on a bird species (e.g. laboratory pathogen persistence studies).

Pathogen composition was biased towards a small number of species/genera (Table W4.1). Of the SF contrast studies, eleven focused on *MG,* four on *Trichomonas gallinae,* four on *Salmonella spp.,* and three each on avipoxvirus, coccidia and a tick species (*Ixodes scapularis,* not native to the UK). Pathogens considered were primarily those transmitted via direct contact, or indirectly via fomite transmission or contaminated food or water sources. No relevant studies were identified which considered vector-borne pathogens other than avipoxvirus which can also be directly transmitted. A total of 23 different pathogen species or groups (i.e. helminths not identified to species level) were reported across all studies. Of these, 40 studies across 10 pathogens (Bacterial: *Chlamydia psittaci, Escherichia albertii, Mycoplasma gallisepticum, Salmonella spp., Suttonella ornithocola*; Viral: *Avipoxvirus, Beak and feather disease virus;* Protozoan: *Trichomonas gallinae*; Arthropods: *Protocalliphora sialia*; Viral/ Arthropods: *Cnemidocoptes* spp. and/or *Fringilla* papillomavirus) measured disease (i.e. adverse impacts on host health), while for other pathogens only infection or environmental load were measured (Table AW4.4).

Evidence for effects of SF on pathogen transmission

(A) Bacterial pathogens

1. *Mycoplasma gallisepticum (MG)*

Route of transmission: Direct contact or fomite transmission

Background: Mycoplasmal conjunctivitis is a bacterial disease caused by *Mycoplasma gallisepticum* (*MG*), which in passerines has primarily been reported in house finches in North America. Infected birds develop swollen eyelids and conjunctiva, and severe infection can impact sight, leading to reduced survival through increased risk of predation or starvation (Faustino et al. 2004; Adelman et al. 2017). Transmission occurs through ocular discharge, either via direct transmission between birds, or indirectly via fomite transmission. In North America, *MG* has been linked to large declines in house finch populations (Hochachka & Dhondt 2000). While *Mycoplasma spp.* are present in the UK (Pennycott et al. 2005b), to date there has not been substantial disease occurrence reported in UK garden bird populations.

Evidence for SF effects: MG has been the subject of concerted research effort in North America, leading to a higher number of SF contrast studies, and experimental work, than for any of the other pathogens identified (9 studies, 24 metrics of which 13 are experimental, 11 observational). The available evidence supports an association between SF and *MG* transmission within house finch populations. In an experimental study, the potential for *MG* to be transmitted via fomite exposure from feeders has been demonstrated in the absence of direct contact between birds (Dhondt et al. 2007). Comparison of fed and unfed sites showed that *MG* exposure, measured via seroprevalence, was more than twice as high at sites with feeders (Vana et al. 2018), and individual birds with higher feeder use were more likely to transmit and be exposed to the pathogen (Adelman et al. 2015). An observational field study found that use of tube feeders was a significant risk factor for occurrence of mycoplasmal conjunctivitis in house finches (Hartup et al. 1998). However, an observational field study screening other North American wild bird species for *MG* (via PCR and rapid plate agglutination to test for antibodies) found that while there was evidence of exposure in 27 other species, clinical disease was rare, and infection prevalence was not higher in species regularly using feeders (Dhondt et al. 2014). This suggests that the impacts of *MG* are primarily on house finch populations.

Research on *MG* has also considered the effects of the density of feeder provision on *MG* transmission, with results indicating complex interactions. In a field trial, higher feeder density was found to increase measures that might enhance risk of *MG* transmission, such as house finch abundance, feeding bout duration and time spent on feeders. However, no effect was found of feeder density on *MG* seroprevalence, which was attributed to low overall seroprevalence and therefore low statistical power to detect effects (Aberle et al. 2020). In a captive study, higher transmission rates were found when more feeders were available (Moyers et al. 2018). However, at lower feeder densities, birds in this study had higher *MG* antibody levels which authors suggested might be due to subclinical exposure to low doses of pathogen on feeders. A further study characterized wild bird feeding practice across 22 states in the USA using household surveys and explored how the reported level of SF related to house finch densities through the epizootic of mycoplasmal conjunctivitis. Study results found that higher house finch densities were associated with higher supplementary food availability, both during and after the epizootic, although this relationship was weaker immediately following the epidemic and the relationship levelled off above densities of approximately 40 people feeding birds/km^2 (Fischer et al. 2015). This finding suggests that although SF is likely to contribute to *MG* transmission in house finches, densities remained higher where SF provision was higher at a broad regional scale. This finding suggests that although SF is likely to contribute to *MG* transmission in house finches, densities remained higher where SF provision was higher at a broad regional scale. Results also suggested that where levels of SF declined most as a response to the epizootic (reductions occurred of between 1-7 people feeding birds/km2), greater declines in house finch numbers occurred. Interpretation of this relationship is hindered by its correlational nature. One potential interpretation is that higher levels of SF reduced the impact of the disease on house finch mortality, and another is that more people gave up feeding birds in areas having high levels of disease.

Descriptive studies: Three additional descriptive studies on *MG* were identified, two captive studies and one field study. Adelman et al. (2013) found that *MG* deposition onto feeders in a captive house finch population was linked to the severity of infection but was not affected by changes in finch behaviour caused by reduced ambient temperatures. However, once on feeders, Teemer et al. (2024) found that the pathogen remained viable for up to one week at cold temperatures and was significantly more pathogenic following incubation at cold temperatures compared to warm temperatures, suggesting winter is a higher risk period for *MG* transmission through feeder use. A further study found higher *MG* seroprevalence in house finches captured on poultry farms compared to garden feeder sites, which were used as controls, showing that *MG* circulation can also occur outside of garden feeding sites (Luttrell et al. 2001).

2. *Salmonella* spp.
Route of transmission: Faeco-oral.

Background: Of the diversity of *Salmonella* species known to exist, only some types have been linked to disease occurrence in wild birds (Wigley 2024). *Salmonella enterica* serovar Typhimurium *(S.* Typhimurium) definitive phage type (DT) 40, DT56 variant(v), and DT160 have been associated with mortality events due to salmonellosis in garden birds within the UK (Lawson et al. 2010). These strains of the bacterium show evidence of host adaptation, and the passerine species affected by the disease act as the reservoir of infection in apparently healthy carrier individuals (Mather et al. 2016). The bacterium can persist in the environment for an extended period (e.g. up to 291 days reported in dried faecal material [Oni et al. 2015] and up to 168 days in soil [Underthun et al. 2018]), and transmission occurs via the faecal-oral route through contaminated food or water sources. Sporadic outbreaks of salmonellosis have been reported in passerines, typically in winter, with seed-eating and gregarious species such as European greenfinch and house sparrow primarily affected in the UK. However, the number of outbreaks identified per annum within the UK has declined markedly since 2008 (Garden Wildlife Health 2023).

Evidence for SF effects: Four SF contrast studies were identified which measured *Salmonella spp.* association with SF. A study in New Zealand comparing fed and control gardens, found low prevalence of *Salmonella* spp. in cloacal swabs from house sparrows in both garden types despite environmental samples of feeding stations (swabs of feeding tables and food containers) testing positive for *S.* Typhimurium on 6.8% (3/44) of occasions (Galbraith et al. 2017). At a species-level, two studies (Krawiec et al. 2015 across 40 species in Poland, and Brobey et al. 2017 across 24 species in the USA) found higher prevalences of *Salmonella spp.* in species which frequented bird feeders, compared to species that rarely used feeders. Differences in species susceptibility, or ecology linked to exposure rates, may explain these differences without necessarily inferring any causal link to SF. A comparison of two gardens in Scotland with contrasting levels of SF found endemic circulation of *S.* Typhimurium DT56 (variant) at the site with high levels of SF compared to only a single detection at a site with low SF provision (Pennycott et al. 2002). The strength of inference from this study is limited by the modest garden-scale replication.

Descriptive studies: Eleven additional descriptive studies were identified on *Salmonella spp*. Three of these studies tested environmental samples from feeding stations. In a field study monitoring a single garden bird table in Scotland, *S.* Typhimurium DT56(v) was detected in faecal samples across three years (Pennycott et al 2005a). However, no *Salmonella* was isolated in studies screening faecal samples and food remnants from feeders in Poland (Fratczak et al. 2021) or from feed contaminated with faeces from feeders in Ontario, Canada (Prescott et al. 2000). Salmonellosis incidents-have been diagnosed through post-mortem and microbiological examination of passerine carcasses found in proximity to SF stations in studies conducted in the UK (seven species with European greenfinch and house sparrow most frequently affected; Lawson et al. 2010), Scotland (primarily house sparrows, Eurasian chaffinch and European greenfinch; Pennycott et al. 2005a), Japan (Eurasian tree sparrows; Fukui et al. 2014), Poland (Eurasian siskin and European greenfinch; Krawiec et al. 2014), Sweden (Eurasian bullfinch, Eurasian siskin and redpoll; Söderlund et al. 2019) and Switzerland (primarily Eurasian siskins; Giovannini et al. 2013). However, as the detectability of sick birds may be higher at feeding sites than in the wider countryside, these studies do not imply higher pathogen transmission rates at SF sites than at natural feeding sites.

3. Chlamydia psittaci
Route of transmission: Direct contact, inhalation of contaminated dust or aerosols, or through ingestion of secretions from infected birds.

Background: Chlamydia psittaci is a bacterial pathogen which can infect a range of wild bird species, including Psittaciformes, Passeriformes and Columbiformes. Infection may cause the disease avian chlamydiosis but can also occur in apparently healthy carrier birds. Sporadic cases of chlamydiosis have been reported in garden birds within the UK (Beckmann et al. 2014), however the pathogen is not thought to cause substantial population impacts.

Evidence for SF effects: Galbraith et al. (2017*)* tested cloacal, choanal and conjunctival swabs from Columbiformes for *C. psittaci* across SF and control sites in New Zealand. No positive detections were found from screening of healthy birds and only a single case from post-mortem examination (PME) of a dead spotted dove found closed to a SF station, and therefore no conclusions can be drawn on the contribution of SF to transmission.

Descriptive studies: In the UK, garden bird disease surveillance has led to sporadic diagnoses of mortality due to chlamydiosis in species including dunnock, great tit, Eurasian blue tit, Eurasian collared dove and European robin (Simpson & Bevan 1989, Beckmann et al. 2014). *C. psittaci* genotype A was also detected at low incidence in garden birds in Sweden with indications of disease in some infected birds (Sporndly-Nees et al. 2023; Herrmann et al. 2024). In Arizona, USA, Dusek et al. (2018) reported a mortality event caused by chlamydiosis affecting non-native, rosy-faced lovebirds. Active sampling of birds caught at backyard bird feeders showed high prevalence (43/46 or 93%) of *C. psittaci* (genotype A) detected by PCR from choanal and cloacal swabs in healthy lovebirds, and lower infection levels amongst other species (14/142 or 10%) with highest rates in rock doves (same species as feral pigeon). Environmental samples taken from the surfaces of bird feeders, perches, and edges of bird baths also tested PCR positive (14/18) leading these authors to suggest SF may have facilitated *C. psittaci* transmission.

4. *Escherichia albertii*
Route of transmission: Faeco-oral

Background: Escherichia albertii (previously known as *E. coli* serotype O86) is a bacterium which has caused sporadic mortality in garden birds, primarily Eurasian siskins, European greenfinch and Eurasian chaffinch in the UK but may also be an incidental infection (Bengtsson et al. 2023). Transmission is via the faeco-oral route, and the bacterium is likely to persist for an extended period in the environment, with persistence times of days to weeks found in meat products and water (Hirose et al. 2024). This bacterium is not known to cause substantial avian population impacts.

Evidence for SF effects: No SF contrast studies were identified for *E. albertii.*
Descriptive studies: In the UK, *E. albertii* has been isolated during PME of birds found in close proximity to garden feeders, and infection was associated with adverse impacts on host health in multiple species including Eurasian bullfinch, Eurasian chaffinch, European greenfinch, Eurasian siskin, house sparrow and a Eurasian blue tit (Bengtsson et al. 2023). However, direct effects of SF in increasing transmission were not evaluated.

5. *Suttonella ornithocola*
Route of transmission: Not well established, likely aerosol.

Background: Suttonella ornithocola is a bacterial pathogen which primarily causes disease in Paridae species, most commonly Eurasian blue tit. First identified in the UK in 1996, mortality incidents associated with the bacterium have occurred across the UK on a sporadic basis consistent with an endemic disease with peak seasonality in spring (Lawson et al. 2011). However, no population-level impacts have been identified.

Evidence for SF effects: No SF contrast studies were identified on *S. ornithocola.*

Descriptive studies: S. ornithocola has been detected in tit species in proximity to feeders, with mortality occurring around feeder stations in Germany (Merbach et al. 2019) and in the UK amongst Paridae and Aegithalidae species (Lawson et al. 2011). However, levels of infection in wider countryside habitats lacking SF have not been established. A large-scale regional epidemic of tit mortality associated with *S. ornithocola* infection occurred in spring 2020 in Germany, with citizen scientists reporting mortality of thousands of sick and dead Eurasian blue tits, however no link to SF was reported (Fischer et al. 2021).

6. Other bacterial pathogens
Background: In addition to the bacterial species having known adverse host health impacts described above, wild birds can carry a range of species which are commensal or with unknown health effects. Studies which screened for bacterial species of uncertain pathogenicity in wild birds, and without describing disease occurrence, are presented below.

Evidence for SF effects: In black-capped chickadee in the USA, comparison of birds caught at three fed sites compared to two unfed sites found significantly lower infection prevalence of both *E. coli* and *Streptococcus spp*. (based on culture of cloacal swabs) at the fed sites, however this was attributed to additional sources of bacterial contamination at the unfed sites and probably unrelated to feeding status (Brittingham et al. 1988). Two studies comparing urban and rural sites found higher prevalence of bacterial species at rural sites where SF provision was presumed to be lower (*Campylobacter* spp. from great tits in Poland, and *Listeria* spp. in multiple species in Texas, USA). In both cases, cloacal swabs were tested using PCR (Tryjanowski et al. 2020; Brobey et al. 2017). However, these bacteria are expected to be primarily commensals, causing no or limited impacts on host health. Direct supplementation of eastern bluebird nests with mealworms had no effect on the abundance of a range of potentially pathogenic bacterial species with one exception of *Clostridium.* Despite being more abundant at fed nests this was not associated with negative health impacts (Knutie 2020).

(B) Endoparasites
1. *Trichomonas gallinae*
Route of transmission: Oral transmission, both direct (e.g. through regurgitation of food to chicks or during courtship) and indirect (e.g. via consumption of seed or water sources contaminated with

saliva containing viable parasites). Infection of predatory species can also occur via scavenging or predation of infected prey.

Background: Trichomonas gallinae is a protozoan parasite which most commonly affects Columbiformes; a variety of parasite strains infect these birds which may act as apparently healthy carriers or succumb to disease (Chi et al. 2013). However, severe population declines in European greenfinch and Eurasian chaffinch populations across the UK have been linked to the emergence of finch trichomonosis in 2005, caused by a clonal strain of *T. gallinae* (Robinson et al. 2010, Hanmer et al. 2022). The UK epidemic was first identified through a pronounced change in the seasonal pattern of garden bird fatalities reported to a passive garden wildlife health surveillance scheme with a pronounced peak in finch mortality and trichomonosis cases during September to November (Robinson et al. 2010, Fig. 1). Subsequent reports described year-round finch trichomonosis cases with a late summer peak during August to September (Lawson et al. 2018b). In the UK, the European greenfinch population has declined by 66% since 1995 leading to the species being moved to the UK BoCC Red List, with Eurasian chaffinch declining by 39% between 2013-23 (Heywood et al. 2025). The throat and gullet are typically affected by the disease, causing lesions that can obstruct feeding, drinking and breathing, which leads to mortality in severely affected individuals.

A study of Accipiter hawks in northern Germany found high rates of *T. gallinae* infection amongst both Eurasian goshawk (n=542, 42%) and Eurasian sparrowhawk (n=165, 21%) chicks from mainly rural study areas (Merling de Chapa et al. 2021). Of the infected birds, 6% and 37% respectively showed clinical signs of trichomonosis. The finch epidemic A1 strain was the commonest strain affecting sparrowhawks and the second commonest affecting goshawks. Infection transmission is likely to have occurred via the hawks' avian prey.

Evidence for SF effects: Three SF contrast studies were identified which tested for associations between SF and *T. gallinae* transmission. Hanmer et al. (2022) considered national disease surveillance for garden birds using data for Great Britain (2005-2013) and constructed integrated population models for European greenfinch and Eurasian chaffinch incorporating ring recovery, nest record and breeding bird survey data. This study found that declines in European greenfinch and Eurasian chaffinch populations in Great Britain were largely driven by reductions in adult survival, and that for both species those reductions in adult survival were greater in magnitude in peri-domestic than in wider countryside habitats (Hanmer et al. 2022). The authors suggested that the greater reductions in survival in peri-domestic habitats may have been caused by higher levels of SF in those habitats, where feeding may increase opportunities for *T. gallinae* transmission amongst birds.

A further study compared infection rates between farms in four columbid species within the East of England (60 individuals sampled across 12 sites over a 3 month period in 2011: 7 Eurasian collared dove, 14 European turtle dove, 5 stock dove and 34 common wood pigeon), and found that infection rates were significantly higher at sites providing supplementary grain for gamebirds (65% prevalence across 6 fed sites compared to 50% from 6 un-fed sites; Lennon et al. 2013).

A study considering *T. gallinae* infection in multiple species (116 individuals from 24 species across 5 sites) across an urban-rural gradient in Texas, USA found that feeder-using species (which included white-winged dove, mourning dove, Inca dove, house finch and American goldfinch) had higher *T. gallinae* infection rates than non-feeder using species (Brobey et al. 2017). However, a wide taxonomic range was included (e.g. including chimney swift, ruby-throated hummingbird as non-feeder using species) and differential susceptibility, or differences in other aspects of species' ecology that might affect exposure (e.g. gregariousness), may alternatively explain inter-specific differences in *T. gallinae* infection.

Evidence from ongoing studies: Preliminary findings from two ongoing studies conducted by the RSPB, ZSL's Institute of Zoology (IoZ) and the British Trust for Ornithology (BTO) are summarised here as they are relevant to the potential influence of SF on the likelihood of finch trichomonosis outbreaks and *T. gallinae* transmission in residential settings.

The first is a retrospective analysis of observational data of wild bird populations gathered through the BTO's Garden BirdWatch project combined with scanning disease surveillance data from the Garden Wildlife Health (www.gardenwildlifehealth.org) project across Great Britain during the period 2013-2022 inclusive. These projects collect weekly maximum bird counts in gardens along with weekly reports of clinical signs of sick or dead wild birds in garden settings. Descriptions of clinical signs and species affected, combined with PME findings when available, allowed the authors to identify suspected finch trichomonosis outbreaks (n=350 from 248 different gardens) which they compared statistically against a sample of non-outbreak periods matched for land cover, space and time (n=1,050 from 310 gardens). Factors associated with the probability of a suspected finch trichomonosis outbreak were Eurasian chaffinch and European greenfinch abundance (non-linear positive effects, especially strong for European greenfinch during July-October), season (higher risk during July-October) and the number of different seed types presented in gardens (positive linear relationship). The latter provides a crude measure of SF intensity and exhibited a relatively weak positive relationship with the probability of a finch trichomonosis outbreak.

The second project aims to assess the risk of direct and indirect transmission of *T. gallinae* at shared food and water resources in gardens. This field study involves measuring bird behaviour (using video cameras) and testing for viable *T. gallinae* parasites (using culture, microscopy and molecular methods) on bird feeders and associated supplementary food and water sources in 15 gardens having suspected active outbreaks of finch trichomonosis, and 5 control gardens. Finches displaying clinical signs of trichomonosis spent significantly longer at feeders, had a lower peck rate, consumed fewer food items and dropped more food items. Sick birds frequently struggled to swallow food and regurgitated food back into feeder trays or onto the ground where that food would have been available for other birds to consume. Live viable *T. gallinae* associated with feeders was detected at four different gardens and was confirmed via PCR detection at one additional garden. At feeding locations, viable *T. gallinae* was only detected on food samples, including from three base trays beneath feeders and from one food sample from within a feeder. At gardens where sick birds were observed, overall viable *T. gallinae* was detected on 23% (3/13) of feeder base trays and on 1% (1/78) of food samples collected from locations on feeders accessible to birds. Additional positive PCR detections (which could have involved non-viable *T. gallinae*) were made from two additional food samples, one from a feeder and one collected from the ground beneath a feeder. Notably, there were no positive detections of *T. gallinae* from surface swab samples collected from 79 different feeders. In the same study and at gardens where sick birds were observed, viable *T. gallinae* was detected from 23% of water baths (6/26). These data demonstrate that viable *T. gallinae* parasites survive outside of the host at shared food and water sources in gardens and therefore pose an indirect pathogen transmission risk associated with the provision of supplementary food and water. More data of this sort are needed to assess the relative transmission risk of different types of shared feeders, food and water resources.

Relevant descriptive studies:
(i) Trichomonosis outbreak reports at sites with SF
Multiple descriptive studies were identified which reported detection of trichomonosis outbreaks in finches at sites with SF in countries other than the UK. In mainland Europe, this includes outbreaks in Germany (mortality in European greenfinch and hawfinch, Peters et al. 2009), Austria (mortality primarily in European greenfinch, Brunthaler et al. 2022) and France (in European greenfinch and European goldfinch, Chavatte et al. 2019). There have also been reports of finch trichomonosis from

North America involving mortality affecting purple finch and American goldfinch in the maritime provinces of Canada (Forzán et al. 2010, McBurney et al. 2015). In Canada there was a significant association between detected cases of trichomonosis and SF sites, with 56% (5/9) of dead finches found at feeder sites testing positive for *T. gallinae* compared to none of the dead birds found away from feeder sites (0/6) (Forzán et al. 2010).

In the context of infection in Columbiformes, an outbreak of trichomonosis occurred in common wood pigeons in Spain, leading to mortality of approximately 2,600 individuals, which was anecdotally linked to aggregation at gamebird feeders. No mortality occurred after treatment of the feeders with dimetridazole (Höfle et al. 2004).

(ii) Inter-species transmission linked to SF
T. gallinae can infect and cause disease in a wide range of passerine species. From surveillance data for Great Britain (See supplementary material from Hanmer et al. 2022), species diagnosed with trichomonosis from PME encompass common blackbird, brambling, Eurasian bullfinch, Eurasian chaffinch, dunnock, European goldfinch, great tit, European greenfinch, hawfinch, house sparrow, redpoll, European robin, Eurasian siskin and yellowhammer. Of these, European greenfinch, hawfinch, house sparrow, redpoll and yellowhammer are on the BoCC red list. Spill-over of the pathogen into species of conservation concern risks exacerbating population declines, however there is limited evidence on the importance of such additive causes of decline. Both direct and indirect opportunities for interspecific *T. gallinae* transmission may be increased in residential settings where SF is practiced, as compared with wider rural habitats, where a variety of passerines and columbids utilize a range of supplementary food types often presented in close proximity to one another.

Trichomonosis has been considered as a potential cause of population decline for UK hawfinches. In this species, an MSc study found high prevalence of *T. gallinae* in oral swabs from live birds (32/83 tested PCR-positive; Benwell 2025). None of the live birds sampled showed clinical signs of trichomonosis on examination, however four of five dead hawfinches found at nearby ringing sites showed oral lesions on PME and tested positive for *T. gallinae*. Sequencing showed a diversity of *T. gallinae* strains were present and the author suggested variation in pathogenicity between strains may explain the lack of clinical signs observed in the infected live birds. The author also suggested that this diversity of strains may indicate that spill-over into hawfinch may occur from multiple species. Analysis of camera trap footage at feeders found hawfinch often co-occur with Eurasian chaffinch at SF sites, which was suggested to be one potential route of exposure. Further UK hawfinch studies have shown that 31% of winter GPS tracking locations were close to anthropogenic food sources (Kirby et al. 2025), and 31% of faecal samples were found to contain sunflower seed DNA implying substantial use of supplementary food (Stenhouse et al. 2025). Further work is needed to establish whether trichomonosis is a driver of hawfinch population declines, and if so, whether SF is contributing to this problem. It should be noted that Eurasian bullfinch, a species amber-listed on the UK BoCC that is known to be susceptible to trichomonosis, is currently experiencing a rapid population decline in England (Heywood et al. 2025).

Outside of the UK, a further study reported an outbreak of trichomonosis in the white-winged snowfinch, an alpine specialist species in Switzerland, with more than 20 dead individuals reported. Spill-over into this previously unaffected species was assumed to have occurred at SF sites within mountain villages with trichomonosis previously diagnosed in European greenfinch in nearby regions and therefore suggested as a potential source of *T. gallinae* spillover (Dirren et al. 2022).

(iii) Studies of T. gallinae detection and persistence in food and water
In a laboratory study, *T. gallinae* was shown to survive for up to 48 hours at 37°C in moist, but not dry, birdseed (McBurney et al. 2017) indicating that this could act as a source of viable parasite exposure under typical garden conditions. Comparison of strains isolated from infected columbids showed substantial variation in persistence between food types, with the longest survival times in sorghum and buckwheat (120 hours at 35°C). Cooler temperatures (10°C and 25°C) reduced persistence by 48 hours (Kocan 1969). In a further laboratory trial, the parasite persisted for up to 5 days in wheat but only at higher temperatures and where there was high water content within the food (Thomas 2017).

Bird baths are also a potential source of exposure to *T. gallinae*. In water sources, maximum parasite persistence times have been reported as 16 hours (at 37°C, Purple & Gerhold 2015) and 30 hours (at artificially reduced oxygen concentration at 37°C, Purple et al. 2019). Persistence of *T. gallinae* in water has been shown to be enhanced by the presence of organic material (via a reduction in reduced dissolved oxygen concentration) and reduced by the addition of chlorine (Gerhold et al. 2013; Purple & Gerhold 2015; Purple et al. 2019).

These findings confirm the potential for the *T. gallinae* parasite to survive outside of the avian host on supplementary food and water in a manner that is likely to increase transmission in residential settings. Warmer conditions (e.g. persistence was greater at 35°C than at 10-25°C), high moisture levels in food, and low oxygen and chlorine levels in water are suggested to pose the greatest risk.

2. Gastrointestinal endoparasites (excluding *T. gallinae)*

Route of transmission: Varies between specific parasite species and includes faeco-oral and via intermediate hosts

Background: Gastrointestinal (GI) parasites in wild birds include a range of protozoa (e.g. coccidia) and metazoa (e.g. acanthocephalans, cestodes, nematodes, trematodes). These parasites do not typically cause obvious clinical signs in infected hosts. However, with higher parasite burdens sub-clinical impacts on survival or reproduction, or clinical disease, may occur.

Evidence for SF effects: Four studies considered effects of SF on GI endoparasite infection in wild birds including studies on helminth, coccidian spp. and a measure of burden with multiple protozoan and helminth parasites. In all cases parasite infection was measured via faecal egg counts but clinical signs were not measured. In the UK, Parsa et al. (2023) measured faecal egg counts for multiple GI parasites (comprising gregarines, coccidia, nematodes and trematodes) across 38 passerine species from 18 families (755 individual birds) and compared sites with and without SF. They found that SF had no effect on parasite prevalence but was associated with a significant increase in parasite load, with infection intensity (eggs per gram) in faecal samples more than doubling at fed sites.

A study in New Zealand found that the effects of SF on GI parasites varied depending on both the host and parasite species. In house sparrows, SF had no impact on helminth prevalence. However, silvereyes at fed sites had lower helminth loads, while common blackbirds at fed sites showed higher helminth loads. For coccidia, SF had no effect across all three species (Galbraith et al. 2017). By contrast, an experimental field study on house finches in the USA found that the introduction of feeders, when left uncleaned, increased coccidia infection severity (faecal oocyst load) over time in males at a rural site but had no such effect on females or on either sex at an urban site (Schaper et al. 2021). This study design, which compared cleaned and un-cleaned feeders, also provides evidence for the role of pathogen transmission via fomite surfaces on feeders rather than through some other mechanism. In a separate USA study, severity of coccidian infection in house finches was found to be higher in urban than in rural areas, which could be linked to SF but might also be driven by other aspects of urbanization (Giraudeau et al. 2014).

Overall, research findings support the hypothesis that GI parasite burdens are higher at SF sites particularly if feeders are not cleaned. However, the consequences of this for host health or for population-level impacts are unknown.

Relevant descriptive studies: No additional descriptive studies were identified for GI parasites.

(C) Ectoparasites

1. Arthropod ectoparasites
Route of transmission: Method of movement of ectoparasites between hosts will depend on the species, and may require close contact between individuals, or may occur via the environment (e.g. at nesting or feeding sites).

Background: Ectoparasites infecting wild bird species include tick, lice, mite and parasitic fly species (e.g. hippoboscidae). These parasites can have direct impacts on hosts through factors such as blood loss and feather damage or can cause impacts through transmission of vector-borne disease.

Evidence for SF effects: Four studies were identified which considered interactions between SF and ectoparasite transmission. Considering parasite prevalence only, comparing fed and un-fed sites in New Zealand, Galbraith et al. (2017) found that lice were significantly more abundant (but not more prevalent) on house sparrows at fed sites, but no effect of feeding was found on lice prevalence or abundance in common blackbirds or silvereyes. No effect of feeding was found across any of these three bird species for mite prevalence or abundance.

Two North American studies considered environmental tick (*Ixodes scapularis*) densities in relation to the presence of feeders. This tick species is primarily associated with deer but can also parasitize birds. Neither study found an association between tick abundance and SF (Townsend et al. 2003, Linske et al. 2024). A further study considered *I. scapularis* prevalence on birds along a rural-urban gradient and only found infestation at a single site that was less urban preventing any conclusions to be drawn on the potential effects of SF (Hamer *et al.* 2012).

*Descriptive studies***:** No additional descriptive studies were identified for ectoparasites.

(D) Ectoparasites/ Viral pathogens

1. Leg abnormalities (Infection with *Cnemidocoptes* spp. and/or *Fringilla* papillomavirus)
Route of transmission: Direct contact or fomite transmission.

Background: Proliferative skin lesions on the legs (hereafter leg abnormalities) are commonly reported signs of ill health in garden birds in the UK and primarily affect finch species (Lawson et al. 2018a). These lesions have two primary causes, infection with *Cnemidocoptes* sp. mites (causing the disease cnemidocoptosis) and infection with *Fringilla* papillomavirus (causing the disease papillomatosis), with co-infection also occurring (Lawson et al. 2018a). In both cases, transmission can occur through direct contact, or via fomite transmission (e.g. shared perches). Lesions vary in severity and do not typically cause mortality but may impact movement, lead to entanglement and increase potential for predation. However, no adverse population impacts are known to have occurred in UK garden bird species.

Evidence for SF effects: A single study was identified which considered the effects of SF on leg abnormalities. Norman (2021) compared the prevalence of leg abnormalities in Eurasian chaffinch (2,282 individuals) during ringing activities across habitat types. No statistical analysis was conducted, and a relatively small number of sites were considered (7 sites across 4 habitat types). However, substantially higher prevalence of leg abnormalities was found at feeding stations (15.6%, 29/186) compared to farmland sites (1.7%, 13/754), woodland roosts (3.1%, 34/1109) and the author's own garden where SF was conducted but feeder hygiene was considered to be high (6.1%, 10/165).

Descriptive studies: Two additional descriptive studies were found. In the UK, leg abnormalities were reported frequently both amongst living birds and from PME. A survey of approximately 3,000 monitored sites with Eurasian chaffinch reported 3-4% of sites as having observed at least one bird with leg lesions each week. Of 1,066 wild finch carcasses examined post-mortem over a 10-year period (April 2005–December 2015), 16% of Eurasian chaffinches, 9% of Eurasian bullfinches, 1% of European goldfinches and 0.2% of European greenfinches had proliferative leg skin lesions (Lawson et al. 2018a). However, concurrent disease (e.g. trichomonosis) was considered the likely cause of death in the majority (62%, 28/45) of cases. Sporadic cases of atypical, severe cnemidocoptosis have also been diagnosed in dunnocks found dead in garden habitats in England (Seilern-Moy et al. 2021). In Portugal, only two cases of cnemidocoptosis were detected, in a Eurasian blue tit and a great tit, from 32,500 birds of 156 species screened in Portugal (Martinho et al. 2017). Although the authors linked these cases to SF the number of detections is too small to infer any effect of feeding.

(E) Viral pathogens

1. Avipoxvirus

Route of transmission: Direct contact, fomite, or vector-borne transmission.

Background: Avipoxvirus is a pathogen that can be transmitted via direct contact, indirect fomite transmission or via insect vectors like mosquitoes. Presentation varies by species, with affected wild birds typically developing proliferative skin lesions and the 'dry' or cutaneous form of the disease, with lesions often on the head or legs. Severe skin lesions may impact vision and mobility, leading to effects on condition and survival. A range of avipoxvirus species/strains are known to affect a diverse range of bird species, with impacts varying between species. In the UK, sporadic, endemic avian pox has been reported in various species for several decades including garden birds such as dunnock, house sparrow, common wood pigeon and common starling (Edwards 1955, Blackmore & Keymer 1969, Lawson et al. 2012). In 2006, a severe form of this disease, primarily affecting Paridae species (especially great tits), was first detected in south-east England. Cases of this disease, called Paridae pox, peaked in August and September (Lawson et al. 2012) and subsequently spread across much of Great Britain including southern Scotland. This emerging disease caused reduced survival, particularly amongst juveniles. Although age structured model predications based on observed prevalence did not predict disease-mediated population declines, the disease had the potential to reduce resilience of great tit populations to other environmental factors (Lachish et al. 2012a).

Evidence for SF effects: Four SF contrast studies were identified which compared avian pox prevalence in relation to SF. Wilcoxen et al. (2015) compared prevalence of clinical signs of ill health from multiple bird species captured across six forested sites in the USA, with SF introduced at three sites (three fed and three unfed sites). Laboratory confirmation of disease was not conducted in this study and most clinical signs cases (81%) involved skin lesions consistent with avian pox. There was a higher likelihood of birds with clinical signs of disease at sites with feeders across two of the three years of the study. Disease signs were also associated with negative impacts on physiological measures including reduced microbial killing ability (innate immune defense) and reduced body condition. However, other health measures (including antioxidant levels, heterophil-to-lymphocyte ratio, innate immune defense and the speed of feather growth) were generally improved at SF sites.

A follow up study used blood samples taken during capture to assess how seroprevalence of antibodies against avipoxvirus varied between fed and unfed sites, with no significant difference found in exposure between the treatments (Vana et al. 2018). The authors suggested that the increase in birds showing clinical signs of avian pox at fed sites, but not increased exposure measured via seroprevalence, may have been a consequence of sick birds making greater use of supplementary food rather than higher pathogen transmission at fed sites (Vana et al. 2018).

Prevalence of avian pox in house finches sampled at a series of sites along an urban-rural gradient in the USA increased with urbanization (Giraudeau et al. 2014). The authors suggested this relationship might be a consequence of higher levels of SF in urban areas but acknowledged that other factors linked to urbanization could have been causal. A further study compared presence of clinical signs of avian pox from multiple bird species from fed and un-fed properties in New Zealand and found no association with SF provision (Galbraith et al. 2017).

Descriptive studies: Two additional descriptive studies described the patterns of avian pox in Paridae species in Great Britain. In the first study, the majority of incidents (94%) were reported from gardens having feeding stations, a pattern that could have been driven either by higher pathogen transmission in gardens or higher detectability of sick birds in gardens (Lawson et al. 2012). The second study involved surveillance of an avian pox outbreak affecting populations of great tit and Eurasian blue tit in woodland habitat and confirmed occurrence of the disease in non-garden habitats (Lachish et al. 2012b).

2. Beak and feather disease virus (BFDV)

Route of transmission: Direct or indirect transmission through contaminated feather dust, faeces or oral secretions. The virus can persist in the environment for several months (Martens et al. 2020).

Background: BFDV causes Psittacine Beak and Feather Disease (PBFD). This virus primarily affects psittacines (parrot species) although infection (with uncertain health implications) has been detected in other taxa on rare occasions, primarily raptors (MacColl et al. 2024). In the UK, PBFD has been diagnosed in a small number of rose-ringed parakeets (Sa et al. 2014). Disease can cause feather loss, beak abnormalities and in severe cases can lead to mortality.

Evidence for SF effects: Only a single relevant study was identified on BFDV and the context of which differed substantially from a UK residential situation. The study considered BFDV infection of reintroduced echo parakeets in Mauritius (Tollington et al. 2015). The disease was associated with a short-lived reduction in hatching success which was more pronounced amongst breeding pairs that took supplementary food.

Relevant descriptive studies: No additional descriptive studies were identified for BFDV.

(F) Undefined pathogens

Evidence for SF effects: One correlative study compared the daily food volume associated with reported mortality incidents affecting wild birds in British gardens (Kirkwood 1998). Of 50 records involving infectious disease of feeder-using species the average daily supplementary food provision was significantly higher than at gardens where the mortality was probably caused by factors unrelated to infectious disease (e.g. trauma). The proportion of mortality incidents apparently caused by infectious disease was 95% at gardens with higher rates of food provisioning compared to 55% at gardens having lower levels of provisioning (the difference being statistically significant). Although a correlative study with modest sample sizes, these findings are consistent with increased risk of infectious disease amongst wild birds at gardens having higher rates of supplementary food provision.

Effects of SF on host response to infection

In addition to effects on pathogen transmission, SF may influence disease impacts in wild birds through changes in host response once exposed to pathogens, either through effects on host resistance (ability to prevent or reduce infection by a pathogen) or host tolerance (ability to maintain host health in the presence of the pathogen). Only five studies were identified with relevance to understanding SF effects on host response to infection.

Wilcoxen et al. (2015) tested how introduction of SF at three study sites in the USA (feeders with seed mix replenished 2-3 times each week) affected innate immunity across 11 species, relative to birds caught at a similar unfed site. Three different microbial killing assays were combined into a single metric of innate immunity, and this metric was found to be higher for birds using fed sites in two of the three study years (there was no difference in the other year). Birds at the fed sites also had higher blood antioxidant levels, reduced stress (heterophil-to-lymphocyte ratio) and more rapid feather growth (Wilcoxen et al. 2015). In a study on eastern bluebirds in the USA, provision of individual nests with mealworms was associated with higher antibody levels (IgY antibodies, equivalent to IgG in mammals) in nestlings, which correlated with a lower abundance of parasitic nest flies (Knutie et al. 2020). However, this effect was limited to early in the season when resource availability was lower.

A further study was identified which compared the levels of bacterial contamination in blood samples in male European greenfinch infected with *T. gallinae* between a regularly fed and irregularly fed site (Krama et al. 2025). This study found that bacterial contamination of the blood was not detected prior to the trichomonosis outbreak, but during the outbreak bacterial alpha diversity was higher in infected birds caught at the regularly fed site. The authors hypothesized that while birds at both sites were infected, birds at sites with permanent access to supplementary food may have experienced more severe disease, leading to higher translocation of gut or other commensal micro-organisms into the bloodstream through lesions. However, the implications of this study are unclear as sample sizes were small (18 and 17 individual birds per site) and only a single site was subject to each treatment; the observed differences may therefore reflect site rather than treatment effects.

The nutritional value of supplementary food sources may also influence host responses to infection; however we found only limited evidence of such effects. Perrine et al. (2025) found that in experimental infection of canaries (used as a model for house finches) with *MG,* individuals fed a high-lipid diet showed more severe clinical signs of conjunctivitis, and a longer recovery period, compared to birds fed a high-protein diet. These findings were used to parameterize a transmission model which suggested that provision of lower nutritional quality food could result in larger epidemics, leading to greater population declines, compared to higher-quality food. Analysis of bird seed sales in Arkansas, USA indicated that purchases were skewed towards food types with a low protein to lipid ratio (Sauer et al. 2025), leading the authors to suggest that poor nutritional value from SF could have contributed to the population declines in house finch from the mycoplasma conjunctivitis epidemic. It should be noted that there are other potential physiological impacts of poor nutrition in supplementary food which are beyond the scope of question W4 as they are not directly related to disease (e.g. Støstad et al. 2019, discussed in W1).

Contaminants in SF with potential health impacts

Four descriptive studies were identified which considered a link between contaminants and wild bird health, with a potential link to SF. Three of these looked at mycotoxin levels, of which two were UK-based studies. Mycotoxins are substances produced by mould (fungi) which can grow on foodstuffs.

These toxins can cause a variety of acute and chronic adverse health impacts including immunosuppression. Lawson et al. (2006) reported aflatoxin residues above detectable thresholds in four of 22 house sparrows and seven of 13 European greenfinches from samples of liver tissue collection post-mortem. The source of these residues was unknown, since exposure could occur through consumption of natural food sources as well as via supplementary food. While the sample size in the study was small, it was noted that residues were only detected in birds that had died of infectious disease (salmonellosis), and not in birds dying of non-infectious causes (i.e. predation/trauma). Testing of wild bird food products purchased in the UK for aflatoxin and ochratoxin residues showed that while the majority of samples had no detectable levels, residues were present in a subset of products, with 10% of 98 peanut samples at point of sale having limits which exceeded the maximum permitted limit for aflatoxin B_1, highlighting SF as a potential source of exposure for wild birds (Lawson et al. 2020). Aflatoxin residues greater than 100 g/kg were also detected in 17% of 142 bird seed products tested, which were sourced from a range of suppliers in Texas, USA (Henke et al. 2001).

A recent study screened 74 UK retail bird seed samples for contamination by a suite of more than 400 pesticides and associated residues. The detection method was multiresidue gas and liquid chromatography. The 74 samples contained residues from between 2 and 7 different pesticide types (no sample was pesticide free). In total residues were detected from 15 different pesticide types, six of which are not approved for use in the UK or EU (Tank 2023). The most frequently detected pesticide (diphenylamine - an insecticide, fungicide and plant growth regulator) was present in 89% of samples. Two of the pesticides detected (DDT in 1% of samples and malathion in 3% of samples) are banned for use in the UK and have been shown to adversely impact host health in birds (Moreau et al. 2022), while, for others, toxicity studies are required to understand their impacts. Residue concentrations varied between food sources, with mixed seed having the highest levels followed by maize and sunflower seeds (Tank 2023).

It should be noted that neither of these studies on pesticides and mycotoxins were able to conclude whether these contaminants were consumed at a level that would result in negative health impacts on wild birds.

<u>Research gaps</u>

The literature review identified multiple research gaps around the effects of SF on disease occurrence and host-health. Currently, there is a substantial body of literature where outbreak investigation or pathogen surveillance has been conducted in proximity to bird feeding stations. However, these are the sites where observer effort tends to be highest, and sick birds may congregate at available feeding sites. As a result, the occurrence of disease at these sites is not conclusive evidence of a direct effect of SF on pathogen transmission. Relatively few studies were identified which contrasted infection prevalence or disease occurrence at SF sites compared to wider habitat, and these were limited to a small number of pathogens and bird species. Further resources for this type of study and surveillance activity are needed within the UK, to characterize infection prevalence and disease impacts across a wider set of species and habitat types relative to sites with SF.

Additional topics that require further research include:

- The importance of SF, and water provision, in promoting the transmission of pathogens between birds in residential settings. Better understanding is needed of exactly how SF and water provision affect the avian transmission risk of key pathogens like *T. gallinae* in residential settings. Are the key transmission routes direct or indirect and how exactly are pathogens transmitted? Such knowledge is likely to be valuable for the development of future mitigation measures.
- Experimental studies on the effectiveness of feeder cleaning, feeder removal, changes to feeder design and changes to feeding practice (e.g. food types provided, or times of year

birds are fed) to mitigate pathogen transmission. The need to evaluate existing and new mitigation measures is discussed further under question W6.
- The influence of SF on the responses of wild birds to infection. Specifically, how do contaminants in supplementary food (like pesticides and mycotoxins), and the nutritional value of that food, affect host health, immune function and overall host fitness (e.g. survival, reproductive output).
- Sub-clinical effects of infection and associations with SF. Several studies measured higher infection prevalence or parasite load (e.g. for gastrointestinal parasites) at sites where supplementary food was provided but did not relate this to clinical signs or avian fitness. Further work is needed to characterise whether these increased infection levels are associated with adverse host health and fitness impacts.
- Effects of SF on potential for inter-species transmission of disease. SF sites have been suggested to increase potential for spillover of pathogens between species, however only circumstantial evidence was identified, for example disease diagnosis in infrequently affected species found dead in gardens assumed to be due to spill-over at feeding stations. Research to characterize inter-species contact rates at SF sites compared to those in natural habitats, combined with active surveillance to determine infection rates in apparently healthy birds, could inform whether SF increases potential for disease spill-over relative to background rates. Field studies in wild bird populations to improve understanding of disease ecology and dynamics for key pathogens, such as transmission routes (e.g. relative importance of direct vs indirect transmission), survival rates, infectious periods, and host immune responses to infection. These studies would be beneficial to inform modelling approaches to test how proposed disease mitigation changes altering SF could affect populations in the longer-term.
- The potential role of trichomonosis as a cause of population decline for hawfinch and Eurasian bullfinch in the UK, and the influence of SF on disease dynamics.

<u>Summary</u>

- Disease outbreaks are regularly reported in wild birds at feeding sites in gardens; however, the extent to which this is a consequence of higher observer effort in peri-domestic habitats, rather than higher disease prevalence, is often unclear. We therefore focused on findings from studies that include a SF control, or contrast, to isolate the effects of feeding.
- The literature provides clear evidence that SF can increase transmission risks of some pathogens including *T. gallinae, Salmonella* spp. and *MG.* However, the extent to which SF raises transmission risk above that experienced by birds feeding on natural food sources is largely unknown and may differ between pathogens. The impacts of disease on host population dynamics also varies markedly between pathogens, with evidence of trichomonosis and mycoplasmal conjunctivitis having caused large and widespread avian population declines, with other avian diseases having uncertain or no known adverse impacts at a population level.
- In the UK context, trichomonosis is of particular concern as it has driven substantial declines in European greenfinch and Eurasian chaffinch populations. There is strong evidence that SF in residential settings increases transmission of *T. gallinae*. In peri-domestic areas, greater declines in the survival of adult Eurasian chaffinch and European greenfinch have occurred, consistent with an effect of higher supplementary food provision in this habitat. Laboratory studies have shown that *T. gallinae* can persist in moist bird feed (up to 5 days) and in water sources (up to 30 hours). Ongoing research at finch trichomonosis outbreak sites in GB has shown that sick birds spend longer at shared food and water sources where they regurgitate food and water that is then available for other birds to consume. Viable *T. gallinae* parasites have been detected on bird food at access points of feeders and from feeder base trays (although not on feeder surfaces) and from the edges and contents of water baths,

indicating potential for indirect transmission. Analysis of UK gardens where finch trichomonosis outbreaks have occurred (relative to disease-free sites) indicates a strong seasonal pattern of disease (highest during July-October) and an increased probability of outbreaks in gardens where multiple seed types are provided.

- There is strong evidence for an association between SF and the impacts of mycoplasmal conjunctivitis on house finches in the USA*.* While *MG* is not currently known to cause disease on a similar scale in passerines in the UK, the in-depth research that has been conducted on this pathogen provides useful insights. Research has shown that *MG* transmits via indirect contact with feeder surfaces and individual birds with higher feeder usage are more likely to transmit and be exposed to the pathogen. Higher feeder densities are associated with higher rates of disease transmission, higher local abundance, and more time spent on feeders.
- Salmonellosis outbreaks have also been regularly reported at feeding sites in multiple countries including the UK. Detection of *Salmonella* on feeding tables and food containers, and in bird faeces collected from feeding sites, suggests the potential for fomite transmission, and higher prevalences of *Salmonella spp.* have been reported in species using supplementary food. However, lack of comparisons to non-fed sites means that the causative influence of SF (e.g. extent to which SF may increase pathogen transmission rates, as compared with those in wider habitats) is unclear. No population-level impacts of salmonellosis outbreaks on wild bird populations have been identified in the UK.
- There was limited evidence for effects of SF on disease impacts from other pathogens. SF was found to increase gastrointestinal parasite load in some circumstances, including in a study of UK bird species, which could have sub-clinical effects on wild bird health. A single small-scale study also found higher prevalence of leg lesions (infection with *Cnemidocoptes* spp. and/or Fringilla papillomavirus) at SF sites relative to other habitats. For avian pox, introduction of feeders at woodland sites in the USA increased the prevalence of birds caught with clinical signs of disease but not the proportion with antibodies to avipoxvirus. The authors suggested that sick birds might spend more time at feeders rather than feeders increasing the transmission of the virus. For ectoparasites (e.g. mites, lice and ticks), and for bacterial pathogens other than Salmonella, although infections were found in garden birds, no strong evidence was found for a link with SF. For these pathogens, while effects of SF cannot be ruled out, further research is required to understand any influence of SF on pathogen transmission and disease risk.
- There was limited evidence of effects of SF on host response to disease. While there was evidence for the presence of contaminants, both mycotoxins and pesticide residues, in wild bird food sources for sale in the UK, the significance of the contaminant levels for wild bird health remains unclear. Recent research has indicated the potential for negative effects of SF of low nutritional quality on avian responses to infection. For example, an experimental study in captive birds showed more severe *MG* infection in birds fed low-protein diets.

Table W4.1. Numbers of SF contrast studies by pathogen, host species and SF contrast category. Bird species present in the UK are shown in red. Many studies included multiple pathogens.

Pathogen group, sub-group and host species	SF vs. no SF	SF gradient	SF spp. Surrogate	SF habitat	SF nutritional	Transmission route	Total
Bacteria	**4**	**6**	**3**	**0**	**2**	**1**	**16**
Chlamydia psittaci	**1**	**0**	0	0	0	0	**1**
Common blackbird	1	0	0	0	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
Escherichia albertii	**0**	**1**	**0**	0	0	0	**1**
Multiple[1]	0	1	0	0	0	0	**1**
Escherichia coli	**1**	**0**	0	0	0	0	**1**
Black-capped chickadee	1	0	0	0	0	0	**1**
Listeria monocytogenes	**0**	0	**1**	**0**	0	0	**1**
Multiple[2]	0	0	1	0	0	0	**1**
Multiple bacterial species	**2**	**0**	0	0	0	0	**2**
Black-capped chickadee	1	0	0	0	0	0	**1**
Eastern bluebird	1	0	0	0	0	0	**1**
Mycoplasma gallisepticum	**1**	**5**	**1**	**0**	**2**	**1**	**10**
Domestic canary	0	0	0	0	1	0	**1**
House finch	0	5	0	0	1	1	**7**
Multiple[3,4]	1	0	1	0	0	0	**2**
***Pseudomonas* spp.**	**1**	**0**	0	0	0	0	**1**
Black-capped chickadee	1	0	0	0	0	0	**1**
***Salmonella enterica* serovar Typhimurium**	**1**	**1**	**0**	0	0	0	**2**
Common blackbird	1	0	0	0	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Multiple[1]	0	1	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
***Salmonella* spp.**	**0**	0	**2**	**0**	0	0	**2**
Multiple[2,5]	0	0	2	0	0	0	**2**
***Staphylococcus* spp.**	**1**	**0**	0	0	0	0	**1**
Black-capped chickadee	1	0	0	0	0	0	**1**
***Streptococcus* spp.**	**1**	**0**	0	0	0	0	**1**
Black-capped chickadee	1	0	0	0	0	0	**1**
***Yersinia* spp.**	**1**	**0**	0	0	0	0	**1**
Black-capped chickadee	1	0	0	0	0	0	**1**
Ectoparasite	**4**	**0**	0	**1**	**0**	0	**5**
Ixodes scapularis	**2**	**0**	0	**1**	**0**	0	**3**
Multiple[6]	0	0	0	1	0	0	**1**
not species specific	2	0	0	0	0	0	**2**
Louse spp.	**1**	**0**	0	0	0	0	**1**
Common blackbird	1	0	0	0	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
Mite spp.	**1**	**0**	0	0	0	0	**1**
Common blackbird	1	0	0	0	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**

Pathogen group, sub-group and host species	SF vs. no SF	SF gradient	SF spp. Surrogate	SF habitat	SF nutritional	Transmission route	Total
***Protocalliphora sialia* (Parasitic nest fly)**	**1**	**0**	0	0	0	0	**1**
Eastern bluebird	1	0	0	0	0	0	**1**
Ectoparasite/Virus	**1**	**0**	0	0	0	0	**1**
Leg lesions	**1**	**0**	0	0	0	0	**1**
Eurasian chaffinch	1	0	0	0	0	0	**1**
Endoparasite	**3**	**1**	**1**	**3**	**0**	0	**8**
Coccidia spp.	**1**	**0**	0	**2**	**0**	0	**3**
Common blackbird	1	0	0	0	0	0	**1**
House finch	0	0	0	2	0	0	**2**
House sparrow	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
Helminth spp.	**1**	**0**	0	0	0	0	**1**
Common blackbird	1	0	0	0	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
Multiple gastrointestinal parasites	**1**	**0**	0	0	0	0	**1**
Multiple[7]	1	0	0	0	0	0	**1**
Trichomonas gallinae	**1**	**1**	**1**	**1**	**0**	0	**4**
Eurasian chaffinch	0	0	0	1	0	0	**1**
European greenfinch	0	1	0	1	0	0	**2**
Multiple[2,8]	1	0	1	0	0	0	**2**
Multiple groups	**1**	**0**	0	0	0	0	**1**
Multiple diseases (conjunctivitis, avian pox,	**1**	**0**	0	0	0	0	**1**
Multiple[9]	1	0	0	0	0	0	**1**
Virus	**3**	**0**	0	**1**	**0**	0	**4**
Avipoxvirus	**2**	**0**	0	**1**	**0**	0	**3**
Common blackbird	1	0	0	0	0	0	**1**
House finch	0	0	0	1	0	0	**1**
House sparrow	1	0	0	0	0	0	**1**
Multiple[10]	1	0	0	0	0	0	**1**
Silvereye	1	0	0	0	0	0	**1**
Beak and feather disease virus	**1**	**0**	0	0	0	0	**1**
Mauritius parakeet	1	0	0	0	0	0	**1**
Total	**11**	**7**	**3**	**4**	**2**	**1**	**28**

Footnotes: [1]Composite faeces screened from two UK garden sites (range of garden bird species present, primarily house sparrow and Eurasian chaffinch). *E. coli* O86 screened for, now classified as *E. albertii.* [2]24 wild bird species screened in Texas, USA. [3] 9 different host species in Illinois, USA. [4] 53 different species screened in USA. [5]40 different species in varied habitats in Poland. [6]34 species screened from Illinois, USA. [7]38 different species from varied UK habitats. [8]Four columbid species from UK (stock dove, European turtle dove, common wood pigeon, Eurasian collared dove).[9]Diagnosis was by clinical signs only, therefore pathogen type not confirmed. 11 different species considered from Illinois, USA. [10]10 different species screened from Illinois, USA.

Table W4.2. Numbers of descriptive studies by pathogen type and the study focus. Bird species present in the UK are shown in red.

Pathogen group, sub-group and host species	Disease occurrence	Pathogen prevalence	Environmental measure	SF contamination	Bird behaviour	Total
Bacteria	**14**	**3**	**6**	**0**	0	**23**
Chlamydia psittaci	**4**	**1**	**0**	0	0	**5**
Multiple[1,2,3]	4	1	0	0	0	**5**
Escherichia albertii	**1**	**0**	0	0	0	**1**
Multiple[4]	1	0	0	0	0	**1**
Escherichia coli	**0**	0	**1**	**0**	0	**1**
Multiple[5]	0	0	1	0	0	**1**
Mycoplasma gallisepticum	**0**	**1**	**2**	**0**	0	**3**
House finch	0	0	2	0	0	**2**
Multiple[6]	0	1	0	0	0	**1**
***Salmonella enterica* serovar Typhimurium**	**6**	**1**	**2**	**0**	0	**9**
European greenfinch	0	1	0	0	0	**1**
Multiple	4	0	0	0	0	**4**
Not species specific	0	0	2	0	0	**2**
Eurasian siskin	0	1	0	0	0	**1**
Eurasian tree sparrow	1	0	0	0	0	**1**
***Salmonella* spp.**	**0**	0	**2**	**0**	0	**2**
Multiple[5]	0	0	1	0	0	**1**
Not species specific	0	0	1	0	0	**1**
Suttonella ornithocola	**3**	**0**	0	0	0	**3**
Eurasian blue tit	1	0	0	0	0	**1**
Coal tit	1	0	0	0	0	**1**
Great tit	1	0	0	0	0	**1**
Multiple[7]	2	0	0	0	0	**2**
Ectoparasite	**1**	**1**	**0**	0	0	**2**
Cnemidocoptes mites	**1**	**1**	**0**	0	0	**2**
Eurasian blue tit	0	1	0	0	0	**1**
Dunnock	1	0	0	0	0	**1**
Great tit	0	1	0	0	0	**1**
Ectoparasite/Virus	**1**	**0**	0	0	0	**1**
Leg lesions	**1**	**0**	0	0	0	**1**
Multiple[8]	1	0	0	0	0	**1**
Endoparasite	**5**	**2**	**6**	**0**	0	**13**
Trichomonas gallinae	**5**	**2**	**6**	**0**	0	**13**
European goldfinch	1	0	0	0	0	**1**
European greenfinch	1	0	0	0	0	**1**
Hawfinch	0	1	0	0	0	**1**
Multiple[8,9,10]	2	1	0	0	0	**3**
Not species specific	0	0	6	0	0	**6**

Pathogen group, sub-group and host species	Disease occurrence	Pathogen prevalence	Environmental measure	SF contamination	Bird behaviour	Total
White-winged snowfinch	1	0	0	0	0	**1**
Common wood pigeon	1	0	0	0	0	**1**
Not pathogen specific	**0**	0	0	0	**2**	**2**
Not pathogen specific[11]	**0**	0	0	0	**2**	**2**
Hawfinch	0	0	0	0	2	**2**
Toxin exposure/contamination	**0**	0	0	**4**	**0**	**4**
Mycotoxin	**0**	0	0	**3**	**0**	**3**
European greenfinch	0	0	0	1	0	**1**
House sparrow	0	0	0	1	0	**1**
Not species specific[12]	0	0	0	2	0	**2**
Pesticide	**0**	0	0	**1**	**0**	**1**
Not species specific[12]	0	0	0	1	0	**1**
Virus	**2**	**0**	0	0	0	**2**
Avipoxvirus	**2**	**0**	0	0	0	**2**
Great tit	2	0	0	0	0	**2**
Total	**23**	**6**	**12**	**4**	**2**	**47**

Foot notes: [1]16 species in Arizona, USA with focus on non-native rosy-faced lovebirds. [2]Detection in dunnock, great tit, Eurasian blue tit, Eurasian collared dove and European robin from UK. [3]Detection in great tits, feral pigeon and common wood pigeon in Sweden. [4] Detection from PME in range of UK species, primarily Fringillidae. [5]Composite faeces screened from UK garden site. *E. coli* O86 screened for, now classified as *E. albertii.* [6]36 species screened at farms and feeding sites in USA. [7]Isolation from PME of Paridae and Aegithalidae species in UK. [8]Eurasian chaffinch, European greenfinch, Eurasian bullfinch and European goldfinch in the UK. [9]3 species (purple finch, American goldfinch and rock dove/feral pigeon) in Canada. [10]Passive surveillance with detection in species from Austria. [11]European greenfinch and hawfinch in Northern Germany. [11]These studies considered use of SF by hawfinch, which poses a risk for *T. gallinae* transmission, however the studies themselves did not test for specific pathogens. [12]Studies which tested for contaminants in supplementary food sources but did not consider implications for any specific bird species.

W4 References

Studies in bold indicate contributed metrics.

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W4 Appendix

Table AW4.1. W4 search string.

Part-1	Part-2	Part-3
(bird* OR finch* OR paridae OR tits OR sparrow* OR passerine OR avian OR pigeon* OR dove*)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision" OR feeder* OR "aggregation" OR "garden bird")	AND (fomite* OR vector* OR parasite* OR health OR disease OR epidemic OR trichomonosis OR "trichomonas gallinae" OR "mycoplasmal conjunctivitis" OR "mycoplasma gallisepticum" OR "avian malaria" OR plasmodium OR "newcastle disease" OR paramyxovirus OR "beak and feather disease" OR circovirus OR "usutu virus" OR flavivirus OR "paridae pox" OR "avipoxvirus" OR psittacosis OR ornithosis OR chlamydiosis OR "chlamydia psittaci" OR "escherichia albertii" OR "escherichia coli" OR papillomatosis OR papillomavirus OR knemidocoptes OR cnemidocoptes OR salmonellosis OR "salmonella typhimurium" OR "suttonella ornithocola" OR mycotoxin* OR aflatoxin OR ochratoxin)

Figure AW4.1. Relevance rate decay function. For each group of 20 studies, the number deemed relevant to the evidence review was recorded. Once this curve reaches close to zero, it suggests the majority of the relevant literature has been identified.

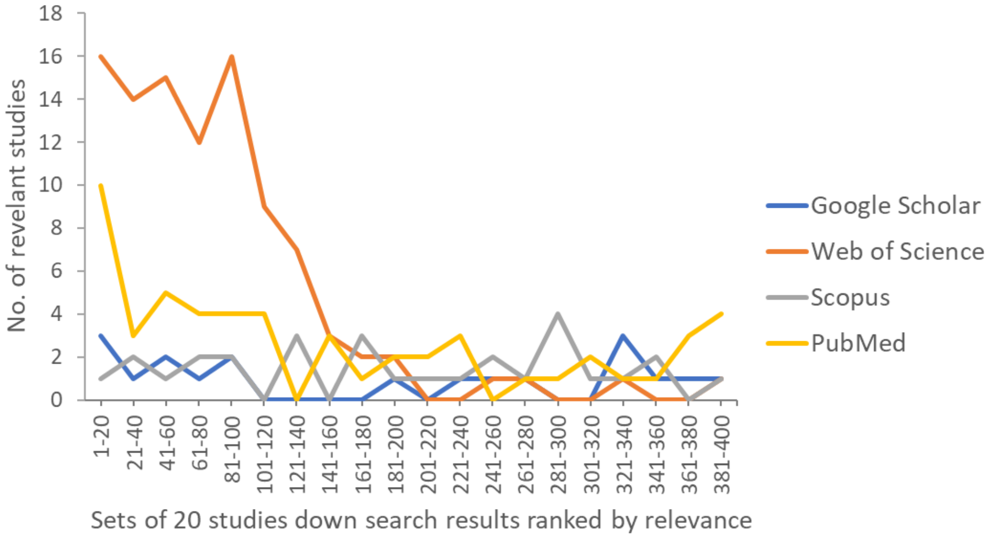

Table AW4.2. Study frequency by pathogen group and sub-group, and continent across all studies included (SF contrast and descriptive).

Pathogen group and sub-group	Africa	Asia	Australasia	Europe	North America	Total
Bacteria						
Chlamydia psittaci	0	0	1	4	1	**6**
Escherichia albertii	0	0	0	2	0	**2**
Escherichia coli	0	0	0	1	1	**2**
Listeria monocytogenes	0	0	0	0	1	**1**
Multiple bacterial species	0	0	0	0	2	**2**
Mycoplasma gallisepticum	0	0	0	0	14	**14**
Pseudomonas spp.	0	0	0	0	1	**1**
Salmonella enterica serovar Typhimurium	0	1	1	7	2	**11**
Salmonella spp.	0	0	0	3	1	**4**
Staphylococcus spp.	0	0	0	0	1	**1**
Streptococcus spp.	0	0	0	0	1	**1**
Suttonella ornithocola	0	0	0	3	0	**3**
Yersinia spp.	0	0	0	0	1	**1**
Ectoparasite						
Cnemidocoptes spp. mites	0	0	0	2	0	**2**
Ixodes scapularis	0	0	0	0	3	**3**
Louse spp.	0	0	1	0	0	**1**
Mite spp.	0	0	1	0	0	**1**
Protocalliphora sialia (Parasitic nest fly)	0	0	0	0	1	**1**
Ectoparasite/Virus						
Leg lesions	0	0	0	2	0	**2**
Endoparasite						
Coccidia spp.	0	0	1	0	2	**3**
Helminth spp.	0	0	1	0	0	**1**
Multiple gastrointestinal parasites	0	0	0	1	0	**1**
Trichomonas gallinae	0	0	0	10	7	**17**
Multiple groups						
Multiple diseases (conjunctivitis, avian pox, fungal skin disease, cloacal infections)[1]	0	0	0	0	1	**1**
Not pathogen specific						
Not disease specific	0	0	0	2	0	**2**
Toxin exposure						
Mycotoxin exposure	0	0	0	2	1	**3**
Pesticide exposure	0	0	0	1	0	**1**
Virus						
Avipoxvirus	0	0	1	2	2	**5**
Beak and feather disease virus	1	0	0	0	0	**1**
Total						

Table AW4.3. Study frequency by pathogen group and sub-group, and study setting (Laboratory/Field/Captive) across all studies included (SF contrast and descriptive).

Pathogen group and sub-group	Field	Laborator	Captive	Model	Total
Bacteria					
Chlamydia psittaci	6	0	0	0	**6**
Escherichia albertii	2	0	0	0	**2**
Escherichia coli	2	0	0	0	**2**
Listeria monocytogenes	1	0	0	0	**1**
Multiple bacterial species	2	0	0	0	**2**
Mycoplasma gallisepticum	8	0	6	1	**15**
Pseudomonas spp.	1	0	0	0	**1**
Salmonella enterica serovar Typhimurium	10	1	0	0	**11**
Salmonella spp.	4	0	0	0	**4**
Staphylococcus spp.	1	0	0	0	**1**
Streptococcus spp.	1	0	0	0	**1**
Suttonella ornithocola	3	0	0	0	**3**
Yersinia spp.	1	0	0	0	**1**
Ectoparasite					
Cnemidokoptes spp.	2	0	0	0	**2**
Ixodes scapularis	3	0	0	0	**3**
Louse spp.	1	0	0	0	**1**
Mite spp.	1	0	0	0	**1**
Protocalliphora sialia (Parasitic nest fly)	1	0	0	0	**1**
Ectoparasite/Virus					
Leg lesions	2	0	0	0	**2**
Endoparasite					
Coccidia spp.	3	0	0	0	**3**
Helminth spp.	1	0	0	0	**1**
Multiple gastrointestinal parasites	1	0	0	0	**1**
Trichomonas gallinae	11	6	0	0	**17**
Multiple groups					
Multiple diseases (conjunctivitis, avian pox, fungal skin disease, cloacal infections)	1	0	0	0	**1**
Not pathogen specific					
Not disease specific	2	0	0	0	**2**
Toxin exposure/contamination					
Mycotoxin	1	2	0	0	**3**
Pesticide	0	1	0	0	**1**
Virus					
Avipoxvirus	5	0	0	0	**5**
Beak and feather disease virus	1	0	0	0	**1**
Total	**60**	**10**	**6**	**1**	**76**

Table AW4.4: Study frequency by pathogen group and sub-group across all studies included (SF contrast and descriptive) Also included is whether the study measured infection (e.g. by PCR in apparently healthy birds), disease (clinical signs in living birds or abnormalities detected on post-mortem examination), a measure of contamination of supplementary food, or an environmental measure (e.g. pathogen detection in water/food).

Pathogen group and subgroup	Infection only	Both infection and clinical signs	Clinical signs only	Contaminant measure	Environment al measure	Inter-species transmission risk	Model	Other	**Total**
Bacteria	**11**	**21**	**2**	**0**	**3**	**0**	**1**	**1**	**39**
Chlamydia psittaci	3	3	0	0	0	0	0	0	**6**
Escherichia albertii	0	2	0	0	0	0	0	0	**2**
Escherichia coli	1	1	0	0	0	0	0	0	**2**
Listeria monocytogenes	1	0	0	0	0	0	0	0	**1**
Multiple bacterial species	2	0	0	0	0	0	0	0	**2**
Mycoplasma gallisepticum	2	8	2	0	0	0	1	1	**14**
Pseudomonas spp.	1	0	0	0	0	0	0	0	**1**
Salmonella enterica serovar	3	6	0	0	2	0	0	0	**11**
Salmonella spp.	2	1	0	0	1	0	0	0	**4**
Staphylococcus spp.	1	0	0	0	0	0	0	0	**1**
Streptococcus spp.	1	0	0	0	0	0	0	0	**1**
Suttonella ornithocola	0	3	0	0	0	0	0	0	**3**
Yersinia spp.	1	0	0	0	0	0	0	0	**1**
Ectoparasite	**3**	**2**	**0**	0	**2**	**0**	0	0	**7**
Cnemidocoptes spp.	1	1	0	0	0	0	0	0	**2**
Ixodes scapularis	1	0	0	0	2	0	0	0	**3**
Louse spp.	1	0	0	0	0	0	0	0	**1**
Mite spp.	1	0	0	0	0	0	0	0	**1**
Protocalliphora sialia (Parasitic nest	0	1	0	0	0	0	0	0	**1**
Ectoparasite/Virus	**0**	**1**	**1**	**0**	0	0	0	0	**2**
Leg lesions	0	1	1	0	0	0	0	0	**2**
Endoparasite	**8**	**7**	**0**	0	**6**	**0**	0	0	**21**
Coccidia spp.	3	0	0	0	0	0	0	0	**3**
Helminth spp.	1	0	0	0	0	0	0	0	**1**
Multiple gastrointestinal parasites	1	0	0	0	0	0	0	0	**1**
Trichomonas gallinae	4	7	0	0	6	0	0	0	**17**
Multiple groups	**0**	0	**1**	**0**	0	0	0	0	**1**
Multiple diseases (conjunctivitis,	0	0	1	0	0	0	0	0	**1**
Not pathogen specific	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**2**
Not disease specific	0	0	0	0	0	1	0	1	**2**
Toxin exposure/contamination	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**4**
Mycotoxin	0	0	0	3	0	0	0	0	**3**
Pesticide	0	0	0	1	0	0	0	0	**1**
Virus	**1**	**2**	**3**	**0**	**0**	**0**	**0**	**0**	**6**
Avipoxvirus	1	1	3	0	0	0	0	0	**5**
Beak and feather disease virus	0	1	0	0	0	0	0	0	**1**
Total	**19**	**34**	**7**	**4**	**11**	**1**	**1**	**2**	**76**

Table AW4.5: Frequency breakdown of description of supplementary food or water provided, or method of provision (feeder type) across all studies included (SF contrast and descriptive).

Food/ water type provided	Frequency
Bread + seed	1
Gamebird feeder	2
Mealworms	1
Mixed	6
Multiple feeder types	2
No supplementary food	1
Not specified	46
Peanuts	1
Seed	12
Water source	3
Total	**76**

W5. What is the evidence for indirect effects of SF on bird species via ecological interactions with species whose abundance, distribution, or behaviour has changed due to SF as typically conducted in residential settings?

Rationale

The aim of this question is to summarise the available evidence relating to interactions between wild bird species that have benefitted from SF in UK residential settings and other species of wild birds. Some beneficiaries of SF have increased in abundance or experienced changes in distribution or behaviour, and this may increase the likelihood of interactions with other species including species that do not routinely take SF in residential settings. While such interactions could be beneficial for one or both interacting species, they might also entail negative impacts for one or other party. Several recent UK studies have highlighted the potential for negative interactions, such as increased competition or predation pressure from SF beneficiary species (e.g. Shutt & Lees 2021, Broughton et al. 2022). The aim of this question is to summarise the evidence and potential for such interactions with a particular focus on UK wild bird species.

Methods

Literature search procedure

As with the other questions in this review, we first developed a search string based on key words and phrases from selected relevant studies combined with expert knowledge. As many relevant interactions between species will carry no or little mention of SF this aspect was excluded from our search terms. Our search string comprised three components: a list of potential interspecific interaction types (competition, predation, parasitism etc), a list of species that may have benefitted from SF in residential settings, and a list of species that may have experienced negative interactions with one or more of those beneficiaries (Appendix W5: Table AW5.1). To ensure a focus in the searches on interspecific interactions involving species of relevance to the UK, we identified a list of nominate SF 'beneficiary' species that are known or suspected to have benefitted from SF in UK residential settings, and a list of species that are known or suggested to have experienced negative interactions with suspected beneficiary species in the UK. We acknowledge that the beneficiary/negative interaction status allocated to a particular species may depend on the assumed temporal or spatial context. Some species may have benefitted from SF during one time period and not another, while negative interspecific interactions experienced by another species might be restricted to particular habitats or parts of their range. Our approach was to allocate beneficiary/negative interaction status based primarily on the period since the late 1990s, and to consider any negative interactions irrespective of spatial scale.

The list of suspected beneficiary species was derived by combining information from four sources:

1. high or increasing feeder usage in the UK during the period 1973-2012 (from Figure 3 in Plummer et al 2019)
2. increasing abundance in the UK especially in urban/suburban areas (from the BTO Trends Explorer web site: https://data.bto.org/trends_explorer/)
3. evidence from this review that fitness or abundance is affected by SF (questions W1 and W2)
4. commentary suggesting that UK population changes may be linked to SF in residential locations (from BTO (2025)).

Species were considered 'likely' beneficiaries of residential SF if feeder usage was high or had significantly increased over time, and abundance had increased since the 1970s (particularly in urban-suburban areas) and either: there was evidence from this review that food availability limits fitness or abundance or a suggestion at BTO Bird Facts (2025) that SF was a potential driver of population change (Table W5.1). Species were considered 'plausible' beneficiaries of residential SF if feeder usage was high or had increased, and abundance had increased but there was no evidence from the review or suggestion at BTO Bird Facts that SF had driven abundance change. Species that failed to meet these criteria were considered ‘unlikely’ beneficiaries of SF. Further details of the criteria underpinning these categorisations are given in Table W5.1. Although we categorise urban/suburban Eurasian sparrowhawk abundance as having been plausibly affected by the increase in SF in residential settings (Table W5.1), we only include interaction studies conducted in peri-domestic landscapes as SF is not a likely driver of Eurasian sparrowhawk abundance change in the wider UK countryside (BTO 2025). For completeness we added rose-ringed parakeet and grey squirrel to the list of potential beneficiaries as there is evidence for both of interactions with birds at feeders (Peck et al. 2014, Hanmer et al 2018).

Our list of species that may have experienced negative interactions with beneficiary species was informed by recent commentaries (e.g. marsh tit, willow tit, lesser spotted woodpecker: Shutt & Lees 2021, Broughton et al 2022) and included several species whose abundance and feeder usage has declined significantly in the UK (e.g. song thrush, house sparrow and common starling; Table W5.1). The latter group of species are included in the candidate negative interactions group because their abundance and feeder usage in urban-suburban areas of the UK have declined, but not due to prior knowledge of negative interspecific interactions with beneficiary species. Although our search prioritised these named species, we included in the review any interactions involving UK species at least one of which was categorised as a ‘likely’ or ‘plausible’ beneficiary of residential SF. It is important to note that the main function of our *a priori* species-specific beneficiary/negative interaction allocations was to focus the literature searches on species that might plausibly be involved in interspecific interactions. But the extracted direction of any reported interaction was as described in the literature. Therefore, any species initially classified as a nominate beneficiary could be recorded as experiencing negative interactions and vice versa.

We ran the search string on Google Scholar, Web of Science, Scopus and PubMed and used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of ten studies to quantify the extent to which relevance declined with search engine rank. When this decay function declines to zero it is likely that the search has identified a high proportion of relevant studies; if it fails to reach zero by the 400-study threshold it is likely relevant studies were excluded by our threshold. For this question, the strong decay in the search function beyond approximately 300 studies suggests we located most relevant studies (Appendix W5: Figure AW5.1). After combining the relevant studies from the four search engines we checked for and removed duplicates and exported the remaining set of studies to a spreadsheet.

Study exclusions

Following amalgamation of selected studies across search engines we inspected full text articles and extracted summary data for each study (and metric) that satisfied both of the following criteria:

1. Interspecific interaction focus: The study provided clear empirical evidence relating to an ecological interspecific interaction involving at least one of the species categorised as a ‘likely’ or ‘plausible’ beneficiary of residential SF (as listed in Table W5.1). Our search terms identified many studies documenting interactions between pairs of potential beneficiary species and between beneficiary species and a species not on either of our lists, and these were all included in our selection and review. We only included studies that specified an interspecific interaction as a stated aim. We excluded studies whose authors proposed (usually post-hoc) interspecific interactions as a candidate (but not exclusive) interpretation or explanation for their findings. We only included student theses if the information was not included in selected journal papers. We included studies irrespective of geographic location as long as they met the species-related criteria above.

2. Interactions involving fitness costs or benefits: We excluded any studies that did not report potential fitness or abundance consequences of interspecific interactions. Common interactions in the selected studies involved abundance changes, breeding success, mortality, nest predation, nest

defence behaviour and access to food. We included several studies of breeding season territory settlement patterns as these could have had direct fitness implications linked to habitat quality or competition for nest sites or food. We excluded studies whose primary focus was on explaining adaptive patterns of co-existence or interactions in bird communities such as niche partitioning.

Descriptive studies of predation, mortality or nest eviction often documented the number (and proportion) of nests or individual birds affected and associated causes (e.g. predation or competition). Our selection is therefore more likely to find studies that report observations of predation/combatants as interactions, than those where interactions were not specifically identified (e.g. changes in nest failure rates with no cause identified). We tried to reduce the impact of this potential bias by including any secondary studies referred to by the selected studies or that were known to us.

<u>Data extraction – response metrics</u>

We extracted a wide variety of response metrics which were grouped into seven categories: avian abundance, breeding success, nest predation, nest defence, mortality of fully-grown birds, territory settlement and access to food. Some studies reported multiple response metrics for the same or different study species. For each study we identified all interspecific interactions that met our selection criteria (above), and for each interaction we identified *a priori* the expected or nominate beneficiary and nominate disadvantaged species. We then defined a set of broad inter-specific interaction categories (commensal, competition, predation) and recorded the direction of the reported outcome for both the nominate disadvantaged species (positive, neutral or negative) and for the nominate beneficiary species (positive, neutral, negative or unmeasured). An example of an unmeasured outcome is when a corvid beneficiary depredates nests of disadvantaged species but the impact of this on corvid breeding success was not measured. We did not attempt to extract effect sizes because the response metrics were diverse and, unlike studies summarised in previous questions in this review, there was no attempt to quantify the effect of SF on birds. Where comparable effect sizes were available, we summarise these in our narrative synthesis. Literature reviews did not contribute metrics but were described where relevant.

<u>Data extraction – context variables</u>

For each response metric, we also extracted information on a range of context variables. These allowed us to describe the composition of the extracted data, and to compare different subsets of the data.

First, we assigned each response metric to one of two continents (Europe or Asia) and one of three time periods (breeding, winter, year-round). Second, we assigned each metric to one of three-level human proximity categories according to the landscape in which the study was conducted: peri-domestic, wider countryside away from human habitation (usually woodland or farmland) and a mixture of the two. Unlike previous questions in this review, we are interested in interspecific interactions in any habitats as most bird species that consume supplementary food in residential settings are sufficiently mobile and SF sufficiently ubiquitous across the UK to expect interactions in most habitats at least in the lowlands (Shutt et al. 2021). Third, we assigned each metric to one of three study design categories: (i) experimental which included the imposition of at least one treatment with a suitable control; (ii) observational which tested for relationships (correlations or associations) across space and/or time to infer interspecific interactions and (iii) descriptive which measured an interspecific interaction without treatments/controls or variation in space and/or time. Several of the observational studies involved testing for correlations in space and/or time between species that might be competitors or predators of one another. Such studies often utilise species counts from extensive monitoring programmes which may not provide data of sufficient quality, scope or variation to provide reliable measures of local predation pressure and therefore tests of species interactions (Nichol & Norris 2010). Whilst experimental studies usually provide more powerful and conclusive findings, manipulating species interactions in the field is often difficult or impractical to achieve and consequently experimental data comprised only 26% of the extracted metrics. Fourth, we assigned each metric to a six-level ecological guild category reflecting a combination of nest type and migration status (hole nesting resident or migrant, open nesting resident or migrant, multi-species mixed, artificial nest). Finally, to facilitate summary of the taxonomic composition of the literature search and of the type and direction of interactions, we grouped potentially disadvantaged species into the largely taxonomic groups listed in Table AW5.2.

We summarise the findings of this literature search first by describing the composition of the selected metrics and studies in relation to taxonomy and various context variables, and then we describe the directionality of the interactions between nominate beneficiary and disadvantaged species. Finally, for each interaction category in turn (nest predation, wider predation, competition, commensalism/parasitism), we consider the evidence that SF has been a driver of population increase amongst the key beneficiary species and then the directional balance and nature of the selected findings for the numerically dominant beneficiary and disadvantaged species.

Results

Literature composition

Our search and extraction identified 145 interaction metrics from 67 studies, of which 106 metrics were measured in the UK (from 40 studies), 36 from the rest of Europe (25 studies) and 3 from Asia (Israel, 2 studies) (Table AW5.2.) The taxonomic composition of the response metrics shows that tits (n=51 metrics, 40 studies), small insectivores such as flycatchers (28, 19) and Turdidae/common starling (25, 12) dominate the nominate disadvantaged species data, while tits (42, 31), corvids (31, 10) and woodpeckers (23, 18) dominate the nominate beneficiary data (Table W5.2a). The nominate disadvantaged species are dominated by hole-nesting residents (mainly tits) and open-nesting resident species (Table W5.2b).

The sample of metrics comprised 78 measured in wider countryside habitats (57 from woodland, 14 farmland), with 23 in peri-domestic habitats and 44 from across an urban-rural gradient (Table W5.2c). The interaction metrics were dominated by measures of nest predation (n=78), competition for nest sites (n=36) and competition for food (n=13) (Table W5.2d). The predation interaction metrics derived from mainly correlative (n=36/86) or descriptive (n=28/86) studies, the competition interactions came were from mainly descriptive (24/51) or correlative (15/51) studies, and the commensalism interactions (n=8/8) were entirely from experimental studies (Table W5.2e).

Overview of interactions between nominate beneficiary and disadvantaged species

As might be expected based upon our *a priori* assessments of the predicted benefits/disbenefits of different interspecific interactions, the directional balance of response metrics was strongly negative for nominate disadvantaged species (76 negative, 59 neutral, 10 positive; Table W5.3a) and strongly positive for nominate beneficiary species (5, 11, 62 and 67 unmeasured; Table W5.3b). The 10 interactions reported as positive for nominate disadvantaged species (Table W5.3a) comprised 4 correlations involving extensive predator-prey abundance data (some of which may have spurious or due to an unidentified confounding factor) and 6 cases of heterospecific attraction whereby territory settlement amongst migratory species (such as flycatchers) was positively associated with the local distribution of earlier nesting resident species (such as tits; see commensal interactions below). All 5 interactions reported as negative for nominate beneficiary species involved negative interspecific competition effects on great tits (three involving Eurasian blue tits and two involving European pied flycatchers).

Interactions involving nest predation

Population changes amongst the key nominate beneficiary species: The main potential nest predators whose fitness and/or abundance might have been influenced by the increasing availability of supplementary food in UK residential settings are great spotted woodpecker, Eurasian magpie, western jackdaw and carrion crow (Table W5.1). All four species show increased usage of SF in residential settings particularly great-spotted woodpecker and Eurasian magpie (Plummer et al.

2019). Several factors have probably combined to cause UK populations of these four species to increase. For all three corvids a widespread reduction in gamekeeper activity is likely to have been beneficial (Gregory & Marchant 1996) along with a widespread increase in breeding success perhaps linked to these species omnivorous diets and ability to exploit ephemeral food sources (BTO Bird Facts). SF has been shown to increase breeding success in urban black-billed magpies and western jackdaws (see W1, page 17) suggesting that widespread residential feeding may have been one factor driving wider population increases amongst corvids. The nearly four-fold increase in the UK great spotted woodpecker population has been attributed to a combination of reduced competition for nest sites with common starlings, a milder winter climate and possibly increased exploitation of SF in residential settings (Smith 2005, 2006). Experimental provision of fat during spring doubled the reproductive output of woodpeckers in English woodland (Smith & Smith 2013). Thus, for each of these potential nest predators it is plausible that residential SF has contributed to their observed population increases especially in peri-domestic habitats. Eurasian jay has shown a smaller increase in feeder usage and although its UK population has increased since 1997, abundance was similar in 2022 to that in the early 1970s (Table W5.1). Eurasian jays are also strongly associated with woodland rather than peri-domestic habitats. For these reasons Eurasian jay was considered an unlikely beneficiary of SF in residential settings and any interactions involving this species were therefore excluded from this review.

Potential predation interactions involving nominate SF beneficial species: A recent review of the effects of corvid predation on avian prey populations (Madden et al. 2015) concluded that although corvid predation can depress breeding success there are relatively few examples where that predation translates into population limitation. Madden et al. reported 4 negative, 13 neutral and no positive effects of experimental corvid removal on passerine reproductive success, and 2 negative, 13 neutral and no positive effects on passerine abundance. A review of avian reproduction in urban landscapes found no consistent difference in nest survival rates between urban and wider countryside habitats (Chamberlain et al. 2009) which might have been expected if SF-enhanced corvid densities were impacting avian reproduction in peri-domestic settings.

Our data on nest predation comprised 77 metrics (from 33 studies) of which 47 (from 13 studies) related to corvids, 23 (from 18 studies) to great spotted woodpecker and 7 (from 3 studies) to grey squirrel as the nominate nest predator. Of the 47 **corvid** metrics, 20 documented negative impacts on the prey species (from 10 studies), 25 neutral (6 studies) and 2 positive (1 study). Eleven of the 20 negative impacts came from two field studies conducted at the same mixed farmland site in rural Leicestershire where removal of a range of predators including corvids and grey squirrels resulting in higher nest survival (5 out of 7 species) and local breeding abundance (6 out of 7 species; Stoate & Szczur 2001, 2006). The strong effect of predator removal on open-nesting passerines at this mixed farmland site contrasts with experience on a lowland arable farm in Cambridgeshire where large increases in open-nesting passerines were achieved without predator removal (Aebischer et al. 2016). A possible explanation for this difference between study sites is the higher densities of corvids in the mixed farmland site (Aebischer et al. 2016).

Several studies report high nest predation rates affecting some open-nesting species in peri-domestic habitats. A study of common blackbirds in Manchester parks (UK) found that fewer than 5% of nests produced fledged young with most known cause failures being Eurasian magpie predation (Groom 1993). Failure rates of common blackbird nests in Sheffield were high following experimental exposure to a dummy domestic cat which initiated a strong anti-predator response from parent common blackbirds, which was thought to have attracted nest predators like corvids to the nest (Bonnington et al. 2013). A further study in the same area suggested that high predator densities created an ecological trap for common blackbirds which did not adjust their nest location or clutch size to avoid predation pressure but did experience slightly higher nest failure rates when nesting close to corvids or in areas of high corvid activity (Bonnington et al. 2015). A study of artificial nests in suburban Reading (UK) found that nest predation rates were higher closer to filled bird feeders which were shown to attract nest predators like corvids and grey squirrels (Hanmer et al. 2017). Thus, SF may be having an indirect negative impact on the reproductive output of open-nesting birds in peri-domestic settings by increasing the local abundance and/or activity of nest predators. While most analyses of extensive UK site-based abundance data report few significant negative correlations between corvid and passerine abundance or breeding success (Gooch et al. 1991, Thomson et al. 1998, Newson et al. 2010) our search identified three examples of such effects (from two studies). One of these involved common starling and carrion crow abundance (Newson et al. 2010) and the other involved nest survival and local corvid abundance for both common blackbird and song thrush (Paradis et al. 2000). Both positive associations involving nominate disadvantaged species and corvids came from the same extensive correlational study (Newson et al. 2010) and might have been spurious.

Of the 23 **great spotted woodpecker** metrics, 15 involved negative impacts (from 12 studies), 8 neutral (6 studies) and 0 positive (a similar directional balance to that for corvid nest predation: χ^2_2 =3.68, P=0.16). Of the 15 negative effects, 7 involved willow tit (6 field studies, 1 abundance correlation based on national survey data). All six field studies reported predation by great spotted woodpeckers as the main cause of nest failure and four UK studies reported between 17-28% of all nests being destroyed by woodpeckers (Lewis et al 2009, Stewart 2010, Rustell 2015, Parry et al. 2018). Willow tits excavate nest holes in decaying soft wood in dead tree stumps or branches where they are relatively vulnerable to attack by woodpeckers. The correlational study involved a negative relationship between willow tit and great spotted woodpecker abundance on UK farmland but there was no such relationship in the more important woodland habitat (Siriwardena 2004). Two studies reported lower woodpecker nest predation rates for marsh tits whose nests in harder living wood are generally less vulnerable to woodpeckers than those of willow tits (Broughton 2024). Other studies document lower rates of predation by great spotted woodpeckers on nests of great and Eurasian blue tits, Eurasian blackcap, Eurasian chaffinch, wood warbler and spotted flycatcher (all single studies).

Of the 7 **grey squirrel** nest predation metrics, four came from a review of impacts on European birds and found no clear evidence of population level impacts (for great tit, Eurasian blue tit, great spotted woodpecker & wood warbler; Broughton 2020). A correlational field study in Sheffield found no evidence that squirrel presence affected spatial variation in avian species richness or abundance during the breeding season other than a weak interaction in which squirrels reduced the positive association with woodland cover (Bonnington et al. 2014). A correlative study based on extensive UK monitoring data identified negative associations between the abundance of grey squirrels and the egg-stage nest failure rates of common blackbird and Eurasian collared dove (Newson et al. 2010).

<u>Interactions involving predation of fully-grown birds.</u>

Eight metrics from 4 studies related to possible predation impacts on fully-grown birds, all of which related to Eurasian sparrowhawk as the nominate beneficiary species. Two studies reported negative correlations between Eurasian sparrowhawk presence and abundance changes in individual gardens for three species measured at the garden scale (Bell et al. 2010 for house sparrow; Swallow et al. 2019 for house sparrow, common starling and Eurasian blue tit). Interpreting these relationships is hindered by the small spatial scale of the data collection; they could reflect genuine local population impacts linked to hawk predation or a behavioural response in which the songbirds avoid gardens subject to regular hunting by hawks. When a similar correlative analysis was conducted for survey data collected at a much large spatial scale (farms within the BTO Common Birds Census sample) there was no equivalent correlation for house sparrow, and significant positive correlations for Eurasian blue tit and common starling (Bell 2020).

Two field studies considered the effects of hawks on their urban prey. An experimental study of feeder usage in Poland found that feeders attract both hawks and their songbird prey with the ratio of increased hawk to prey usage being higher in urban areas suggesting more pronounced potential impacts on prey mortality and/or feeder usage in urban areas (Tryjanowski et al. 2024). An observational study in Edinburgh (UK) compared Eurasian sparrowhawk reproductive success and potential prey communities in the same area in 1986-89 and 2009-15 (Thornton et al. 2025). Changes in the prey community (more common wood pigeons, European goldfinches & house sparrows; fewer common starlings, European greenfinches & Eurasian chaffinches) were reflected in the hawk diet with common wood pigeon, feral pigeon and Eurasian magpie becoming more prominent and the dietary composition more diverse. This change in diet composition may have affected sparrowhawk reproduction as their clutch size (but not brood size) was higher in the recent period.

Interactions involving competition

Population changes amongst the key nominate beneficiary species: The selected competition data comprised 51 metrics (from 32 studies) of which 32 (26 studies) related to great tit and/or Eurasian blue tit as the nominate beneficiaries, and a further 2 (from 2 studies) related to crested and grey-headed chickadee. Both great tit and Eurasian blue tit have experienced large population increases in the UK since the late 1960s. Great tit numbers more than doubled up to about 2010 since when numbers have declined (by 13% between 2012-22). Eurasian blue tit numbers increased by approximately 50% up to around 2005 since when numbers have also fallen (by 8% between 2012-22; BTO Bird Facts). Elsewhere in this review (questions W1 and W2) we present evidence showing that SF can increase the abundance of both common tit species and it is likely that the UK population increases are at least in part driven by SF in residential settings. Provision of nest boxes and milder winters may also have contributed to population growth (BTO Bird Facts). Of the other beneficiary species in our sample, numbers of non-native rose-ringed parakeets (9 metrics, 2 studies) have increased enormously since the late 1990s (Table W5.1) but the role of SF in this increase is unknown and despite a marked range expansion this species still has a restricted distribution across the UK (Balmer et al 2013). Eurasian nuthatch (3 metrics, 3 studies) numbers have also increased substantially across the UK probably driven by milder winters and possibly dead wood availability (BTO Bird Facts). House sparrow (4 metrics, 3 studies) has experienced a large and ongoing population decline across England since the 1970s although numbers in the other UK countries have increased since the late 1990s (BTO Bird Facts). In England at least it is therefore unlikely that competitive interactions involving house sparrows have increased over time. We found no interaction studies involving several species whose abundance probably has increased at least in part due to widespread SF in residential settings (e.g. common wood pigeon and European goldfinch; Table W5.1) representing an important evidence gap. We also found 2 metrics (from 2 studies) relating to competition between wild birds and grey squirrels.

Potential competitive interactions involving nominate beneficiary species: Many studies have documented conclusively that interspecific competition affects foraging behaviour, fitness and breeding densities in birds especially amongst members of the **Paridae** family (reviewed by Newton 1998). For example, experimental reductions in socially dominant willow tit and crested tit densities in Swedish woodland during winter allowed subordinate coat tits and goldcrests to forage in the inner tree canopy where invertebrate densities were higher (Alatalo et al. 1985). When Eurasian blue tit nestlings were removed from nests in English woodland, the local great tit nestlings were significant heavier suggesting interspecific competition for invertebrate prey (Minot 1981); an identical finding was reporting from Hungary (Torok 1987). When great tits were excluded from winter roost sites in Belgium woodland, breeding densities subsequently fell and Eurasian blue tit breeding density increased suggesting competition for roost sites (Dhondt & Eyckerman 1980). Of the 32 interaction metrics for which Eurasian blue tit or great tit was the nominate beneficiary species, 20 of the impacts on the disadvantaged species were negative (from 19 studies), 10 neutral (7 studies) and 2 (from 1 study) were positive.

The commonest nominate disadvantaged species in our data selection was **willow tit** for which there were 11 competition metrics (from 7 studies), 8 of which related to nest site competition and 3 to competition for food. Willow tits are susceptible to nest eviction by Eurasian blue tits and great tits with the proportion of nesting attempts ended in this way varying markedly between studies in GB (0/50=0%, Lewis et al. 2009; 5/68=7%, Rustell 2015; 23/128=18%, Parry & Broughton 2018; 20/30=67%, Maxwell 2002). Two studies from continental Europe where blue/great tit densities were probably lower than in the UK, recorded no willow tit nest evictions by either great tit or Eurasian blue tit (Ludescher 1973, Orell & Ojanen 1983) although the former recorded 13% (8/62) evictions by marsh tits. Two correlative studies detected no relationship between willow tit abundance/site persistence and the local abundance of either great tits, Eurasian blue tits or Eurasian nuthatch (Siriwardena 2004, Lewis et al. 2007) although such studies may lack the power/resolution to detect such effects (Nicholl & Norris 2010). However, the nest eviction rates recorded in some GB studies (particularly Maxwell 2002 and Parry & Broughton 2018) may have been high enough to reduce overall productivity and thereby negatively affect population growth. Indeed, the Lanarkshire population studied by Maxwell (2002) went extinct in the years following his investigation. One study reported competition for foraging sites during winter involving great tit and crested tit (Alatalo et al. 1985) whilst another found willow tits use different winter food storage sites in the presence of dominant grey-headed chickadee (Alatalo & Carlson 1987).

Nine competition interaction metrics (from 7 studies) related to another nominate disadvantaged species **marsh tit**. Four of these were correlative studies of abundance change. One UK study analysed extensive monitoring data and found no relationships between marsh tit abundance and three nominate beneficiary species (Eurasian blue tit, great tit, Eurasian nuthatch; Siriwardena 2006) and one Swedish study reported a negative relationship between marsh and great tit numbers from a single long-term study site (Wittwer et al. 2015). Field studies of English marsh tits report low rates of nest failure including nest predation and nest eviction (Broughton et al. 2011). Many tit species join mixed species foraging flocks during autumn and winter the likely function of which is to share information about food sources and to reduce predation impacts. Studies of winter foraging behaviour report reduced access to food and higher vigilance amongst marsh tits (relative to Eurasian blue tits) in mixed-species flocks, and foraging niche separation involving greater marsh tit usage of the woodland understorey, a habitat whose extent and quality may be declining in the UK due to deer grazing and woodland canopy closure (Carpenter et al. 2007, Maziarz et al 2023). The suggestion was that marsh tits may have been forced to spend more time feeding in suboptimal understorey habitat as numbers of competitively dominant blue and great tits have risen. Notably, Broughton & Hinsley (2015) report a negative correlation between the survival of adult marsh tits and local combined blue and great tit breeding productivity, a relationship that might reflect intraspecific competition for food during autumn and winter. Taken together these studies suggest that competitive exclusion of marsh tits from the highest quality woodland feeding habitats during autumn and winter by more abundant, and socially dominant, blue and great tits provides a possible mechanism for the observed negative correlation between marsh tit survival and local great/Eurasian blue tit breeding productivity.

The other nominate disadvantaged species contributing multiple competition metrics to our selection was European **pied flycatcher** (6 metrics from 6 studies) and the sympatric **collared flycatcher** (2 metrics from 2 studies), all from mainland Europe. Four studies documented great tits killing flycatchers in disputes over nest sites that were usually initiated by flycatchers (Merila & Wiggins 1995, Ahola et al 2007, Samplonius & Both 2019, Potti et al. 2021). Usually, the numbers of flycatchers killed were considered too low to have a significant impact on local population size. Two further studies documented low rates of nest eviction success amongst flycatchers attempting to usurp tits (Slagsvold 1975, 1978). One study reported a negative temporal correlation between the breeding density of European pied flycatchers and that of both blue and great tits based on a 60-year time series of multiple cavity nesters which differed in migratory status (Wittwer et al. 2015).

Two studies considered competition between **rose-ringed parakeets** and native bird species. The first found no correlations between local abundance changes of UK parakeets and eight mainly hole-nesting passerines thus providing no evidence for nest site competition (Newson et al 2011). The second recorded reduced usage by great tits and Eurasian blue tits of feeders visited by parakeets (Peck at al 2014). Both metrics involving **Eurasian nuthatch** as the nominate beneficiary species reported non-significant correlations with disadvantaged species based on extensive monitoring data (one for marsh tit, one for willow tit). All four metrics (from 3 studies) involving **house sparrow** as the nominate beneficiary species, involved competition for nest sites with great tits, and in every case the sparrows usurped the tits and in one case increased their nest defence behaviour (Goldshtein et al 2018). As house sparrow numbers have declined strongly in England it is unlikely that competition pressure associated with this species has increased.

Two UK studies assessed the effects of **grey squirrel** usage of bird feeders on usage by wild birds. One study attached a taxidermy squirrel onto feeders, and this reduced total bird usage by 98% and species richness by 80% (Bonnington et al. 2014). Another collected video footage of actual squirrel feeder usage from 20 Reading (UK) gardens and found that squirrels accounted for 44% of total feeder usage, and when present at the feeder reduced bird usage by more than 99% (Hanmer et al. 2018). Feeder usage by four of the six species studied (Eurasian blue tit, great tit, coal tit, European robin) declined as grey squirrel usage rose, whilst Eurasian nuthatch usage was unaffected, and dunnock usage increased with squirrel usage (Hanmer et al. 2018). These two studies demonstrate significant interference competition for feeder usage between grey squirrels and some but not all wild bird species.

<u>Interactions involving commensalism or parasitism</u>
Five experimental studies (all from Finland) provided eight metrics relating to potential commensal or parasitic interactions between migratory and resident species. All studies consider heterospecific attraction whereby resident insectivorous species (tits, mainly great and willow tit) provide territory settlement cues for later arriving insectivorous migratory species (flycatchers, warblers or partially migrant Eurasian chaffinch). The local density of resident tits appears to be used by migratory species as an indicator of local habitat quality encouraging migratory species to settle close to already breeding resident tits. In 4 of the 5 studies (6/8 metrics) the interaction was considered beneficial to the later arriving migratory species which were able to settle in habitats of higher average quality (Monkkonen et al. 1990, Foresman et al. 1998 & 2002, Seppanen et al. 2005). One study (Foresman et al. 2007) documented lower breeding success (fewer and smaller chicks) amongst the great tits suggesting a potential parasitic interaction (migratory insectivores benefit to cost of the resident tits).

<u>Summary</u>

- The scientific literature on avian interspecific interactions is extensive, so we attempted to provide a focus on UK species that are likely either to have benefitted from SF in residential settings or to have experienced negative interactions with those beneficiaries. We identified lists of such species based on changes in feeder usage and population size, and evidence from this review that food is limiting fitness and/or abundance.
- The nominate beneficiary species considered most likely to have increased in abundance/distribution at least in part due to SF in residential settings are great tit, Eurasian blue tit, great spotted woodpecker, Eurasian magpie, western jackdaw, carrion crow, common wood pigeon, European goldfinch and wintering Eurasian blackcaps.
- Our literature search generated 67 relevant studies contributing 145 metrics of interspecific interactions between nominate beneficiary and other species. The data were dominated by interactions involving nest predation (mainly by corvids and woodpeckers as the nominate beneficiaries) and competition (mainly involving great tit, Eurasian blue tit and rose-ringed parakeet as the nominate beneficiaries).

- Several studies highlight the importance of corvids as predators of passerine nests in peri-domestic settings including higher nest failure rates close to supplementary feeders. Further work is needed to investigate the link between SF and corvid abundance/behaviour, and the implications for passerine nesting success.
- The review identifies great spotted woodpecker as a particularly important cause of nest failure for willow tit, a rapidly declining species that is vulnerable to woodpecker predation as it excavates nest sites in soft decaying wood.
- Competition between tit species for food, nest sites and roosting sites is well documented in the literature. The most concerning competitive interaction involving SF beneficiary species was the tendency for blue and great tits to evict willow tits from their nesting sites. In GB studies the rate of nest eviction of willow tits by blue/great tits varied between 0-67%, the higher measure recorded for a local willow tit population that subsequently went extinct.
- Many tit species join mixed species foraging flocks during autumn and winter to share information about food sources and to reduce predation risk. Subordinate marsh tits spent more time vigilant and less time feeding in mixed flocks than dominant Eurasian blue tits and made greater use of the woodland understorey when foraging. A negative temporal correlation between the survival of adult marsh tits and the combined reproductive output of great and Eurasian blue tits suggests these competitive interactions for food may have important fitness consequences for marsh tits.
- Although great tits sometime kill flycatchers during disputes for nesting sites, the magnitude of this mortality is probably too low to affect UK flycatcher populations. It is unlikely that the extent of competition for nesting sites between parakeets or nuthatches and other hole-nesting species is sufficient to cause population-level impacts amongst the latter.
- Grey squirrels appear not to be an important predator of bird nests but do compete with passerines for access to feeders.
- Eurasian sparrowhawks are attracted to hunt around bird feeders in peri-domestic landscapes and hawk diet composition may have changed in response to SF-related changes in peri-domestic bird communities.
- While the findings described above are concerning for several species experiencing negative interactions with SF beneficiaries (particularly willow tit and marsh tit) the evidence for population-level impacts is limited and/or variable across studies, and further research is urgently needed to confirm the magnitude and extent of such impacts. Priorities for further research include: (i) the extent of predation by corvids in peri-domestic settings on songbird nests and fledglings, (ii) the impact of nest predation by great spotted woodpeckers on the reproductive success of birds in peri-domestic and woodland habitats, (iii) the extent and population-level impacts of nest eviction by great tits and Eurasian blue tits on willow tits, (iv) the importance of interspecific competition between marsh tits and other tits outside of the breeding season.
- A clear evidence gap is the complete lack of studies into potential interactions between some of the more obvious SF beneficiaries (like common wood pigeon, Eurasian collared dove and European goldfinch) and other wild bird species.

Table W5.1. Criteria used to identify nominate 'beneficiary' species of SF in residential settings for inclusion in our literature search terms. Species are listed in descending order of feeder usage in UK gardens for all species having an average probability of usage greater than 0.2 (from Plummer et al 2019). Columns show changes in feeder usage and national population size, evidence from this review of impacts of supplementary food on fitness or abundance, and a derived categorical likelihood (likely, plausible, unlikely) that abundance changes are associated with SF in residential contexts (see methods for more details on the criteria used to determine these assignments). Feeder usage is categorised according to the proportion of gardens where each species used feeders in 2012 (>0.6 high, 0.2-0.6 medium, <0.2 low) with change in feeder usage reflecting statistically significant changes in the frequency of use during 1973-2012 (from Plummer et al 2019). Abundance change data are for all UK habitats and come from Heywood et al. (2024). Species categorised as likely or plausible beneficiaries of SF in residential settings were included in the literature search; ND indicates no data.

Species (in descending order of proportion of gardens where feeders used; from Plummer et al 2019)	Feeder usage (in 2012/change between 1973-2012)	Abundance changes (%) (1967-2022 /1997-2022)	Evidence from the review that SF affects reproductive output (RO), survival or adult abundance (AB), with directions of reported effects. Season and SF type indicated in brackets.	Assigned likelihood that SF has been a driver of abundance change in urban/suburban landscapes (bold font indicates species for which BTO Bird Facts[1] mentioned SF as a possible driver of population change).
European robin	High / Increase	+49* / +24*		Plausible
Common blackbird	High / Stable	-19* / +13*		Unlikely
Eurasian blue tit	High / Stable	+25* / -7*	+AB (winter seed)	**Likely**
Eurasian chaffinch	High / Increase	-22* / -34*		Unlikely
Great tit	High / Increase	+82* / +16*	+AB (winter seed)	**Likely**
Dunnock	High / Stable	-40* / +9		Unlikely
European greenfinch	High / Stable	-69* / -70*		Unlikely
Coal tit	High / Increase	+ 50 / -6		**Plausible**
Common wood pigeon	High/Increase	+152*/+29*		**Likely**
European goldfinch	High / Increase	+129* / +144 *		**Likely**
Eurasian collared dove	High/Increase	+211*/-24*		**Likely**
House sparrow	High / Decline	-71* / -15*	+RO (breeding, protein)	Unlikely
European starling	High / Decline	-90*/ -61*	+/- RO (breeding, protein)	Unlikely
Long-tailed tit	High / Increase	+86* / +8		Plausible
Eurasian Magpie	High / Increase	+102*/-5*	+RO, +AB (breeding, protein)	Plausible
Great spotted woodpecker	High / Increase	+388*/+104*	+RO (breeding, fat)	**Likely**
Eurasian sparrowhawk	Medium / Increase	+51 / -25*		Plausible

Species (in descending order of proportion of gardens where feeders used; from Plummer et al 2019)	Feeder usage (in 2012/change between 1973-2012)	Abundance changes (%) (1967-2022 /1997-2022)	Evidence from the review that SF affects reproductive output (RO), survival or adult abundance (AB), with directions of reported effects. Season and SF type indicated in brackets.	Assigned likelihood that SF has been a driver of abundance change in urban/suburban landscapes (bold font indicates species for which BTO Bird Facts[1] mentioned SF as a possible driver of population change).
Western jackdaw	Medium / Increase	+141* / +50*	+RO, +AB (breeding, protein)	Plausible
Eurasian siskin	Medium / Increase	>+200 / +12		**Plausible**
Song thrush	Medium / Decline	-48* / +29*		Unlikely
Eurasian wren	Medium / Increase	+107* / +31*		Unlikely
Carrion crow	Medium / Increase	+132* / +18*	+RO (breeding, protein)	**Plausible**
Eurasian nuthatch	Medium / Increase	+280* / +86*	+AB (summer-autumn, seed)	Plausible
Common pheasant	Medium/Increase	+83* / +25*		Unlikely
Brambling	Medium/Increase	ND[2]		Unlikely
White wagtail	Medium / Stable	ND / -22*		Unlikely
Eurasian bullfinch	Medium/Increase	-49* / -5		Unlikely
Eurasian blackcap (winter)	Medium / Increase	ND[3]	+AB (winter, fat)	**Likely**
Rook	Medium / Stable	ND / -23*		Unlikely
Eurasian jay	Medium/Increase	+11 / +23*		Unlikely[4]

Notes:

1. BTO (2025) BirdFacts: profiles of birds occurring in the United Kingdom. BTO, Thetford (www.bto.org/birdfacts, accessed on 22/07/2025).
2. Brambling is predominantly a wintering species for which there is no abundance monitoring.
3. Eurasian blackcap responses to SF relate mainly to the wintering population for which there is no abundance monitoring.
4. Eurasian jay is primarily a woodland species and therefore SF in peri-domestic landscapes is unlikely to affect a high proportion of the population.

Table W5.2a. Numbers of metrics and studies providing interactions data for different taxonomic groupings of nominate disadvantaged (rows) and nominate beneficiary (columns) species (listed alphabetically). The label 'mixed' refers to studies where findings were presented for multi-species groupings; the label 'artificial' refers to studies of artificial nests. Some studies contributed metrics to more than one taxonomic grouping hence the aggregate number of studies (78) exceeding the number of contributing studies (67; see Results).

	Metrics										Studies									
Taxonomic grouping for disadvantaged species	Corvid	Finch, sparrow, bunting	Nuthatch	Parakeet	Tit	Woodpecker	Grey Squirrel	Sparrowhawk	Corvid & grey squirrel	**Total**	Corvid	Finch, sparrow, bunting	Nuthatch	Parakeet	Tit	Woodpecker	Grey Squirrel	Sparrowhawk	Corvid & Grey Squirrel	**Total**
Columbid	0	0	0	1	0	0	0	1	2	**4**	0	0	0	1	0	0	1	1	0	**3**
Corvid	0	0	0	1	0	0	0	0	1	**2**	0	0	0	1	0	0	0	1	0	**2**
Finch, sparrow, bunting	6	0	0	0	2	2	4	0	2	**16**	2	0	0	0	1	2	0	2	1	**8**
Mixed	1	0	0	0	1	0	2	3	1	**8**	1	0	0	0	1	0	3	1	1	**7**
Nuthatch	1	0	0	1	0	0	0	0	0	**2**	1	0	0	1	0	0	0	0	0	**2**
Small insectivorous passerine	3	0	0	0	15	3	6	1	0	**28**	1	0	0	0	12	3	1	0	2	**19**
Tit	2	4	2	3	24	13	0	2	1	**51**	1	3	2	2	19	11	1	1	0	**40**
Woodpecker	0	0	0	2	0	3	0	1	0	**6**	0	0	0	1	0	3	1	0	0	**5**
Artificial	3	0	0	0	0	0	0	0	0	**3**	3	0	0	0	0	0	0	0	0	**3**
Turdidae/Starling	15	0	0	1	0	2	5	1	1	**25**	6	0	0	1	0	1	1	1	2	**12**
Total	**31**	**4**	**2**	**9**	**42**	**23**	**17**	**9**	**8**	**145**	**10**	**3**	**2**	**2**	**31**	**18**	**5**	**4**	**3**	**78**

Table W5.2b. Numbers of metrics and studies providing interactions data for different taxonomic groupings of nominate disadvantaged species (rows) and ecological guilds of the disadvantaged species (columns). The label 'mixed' refers to studies where findings were presented for combinations of species covering more than one ecological guild, and the label 'artificial' refers to studies of artificial nests. Some studies contributed metrics to more than one taxonomic grouping or ecological guild hence the aggregate number of studies (76) exceeding the number of contributing studies (67; see Results).

	Metrics							Studies						
Taxonomic grouping for disadvantaged species	Mixed	Hole-nesting resident	Hole-nesting migrant	Open-nesting migrant	Open-nesting resident	Artificial nests	**Total**	Mixed	Hole-nesting resident	Hole-nesting migrant	Open-nesting migrant	Open-nesting resident	Artificial nests	**Total**
Columbid	0	0	0	0	4	0	**4**	0	0	0	0	3	0	**3**
Corvid	0	1	0	0	1	0	**2**	0	1	0	0	1	0	**2**
Finch, sparrow, bunting	0	5	0	2	9	0	**16**	0	3	0	1	3	0	**7**
Mixed	8	0	0	0	0	0	**8**	7	0	0	0	0	0	**7**
Nuthatch	0	2	0	0	0	0	**2**	0	2	0	0	0	0	**2**
Small insectivorous passerine	0	0	13	10	5	0	**28**	0	0	11	7	2	0	**20**
Tit	0	51	0	0	0	0	**51**	0	30	0	0	0	0	**30**
Woodpecker	0	6	0	0	0	0	**6**	0	5	0	0	0	0	**5**
Artificial	0	0	0	0	0	3	**3**	0	0	0	0	0	3	**3**
Turdidae/Starling	0	7	0	0	18	0	**25**	0	5	0	0	9	0	**14**
Total	**8**	**72**	**13**	**12**	**37**	**3**	**145**	**7**	**36**	**11**	**7**	**12**	**3**	**76**

Table W5.2c. Numbers of metrics and studies providing interactions data for different taxonomic groupings of nominate disadvantaged species (rows) and human proximity habitat categories (peri-domestic = urban, suburban and rural domestic; gradient = gradient of sites encompassing peri-domestic through to wider countryside typically correlational studies based on national monitoring abundance data; wider countryside = rural woodland, farmland or mixed non-peri-domestic). Some gradient and wider countryside studies were conducted entirely on a mixture of habitats. Some studies contributed metrics to more than one taxonomic grouping hence the aggregate number of contributing studies summed across taxonomic groups exceeding the number of contributing studies (67; see Results).

	Metrics						Studies					
	Peri-domestic	Gradient	Wider countryside				Peri-domestic	Gradient	Wider countryside			
Taxonomic grouping for disadvantaged species	Peri-domestic	Multiple	Multiple	Woodland	Farmland	**Total**	Peri-domestic	Multiple	Multiple	Woodland	Farmland	**Total**
Columbid	2	2	0	0	0	4	1	2	0	0	0	3
Corvid	1	1	0	0	0	2	1	1	0	0	0	2
Finch, sparrow, bunting	2	7	0	3	4	16	2	2	0	2	0	6
Mixed	7	0	0	1	0	8	6	0	0	1	0	7
Nuthatch	0	2	0	0	0	2	0	2	0	0	0	2
Small insectivorous passerine	0	7	0	17	4	28	0	4	0	14	1	19
Tit	5	6	7	33	0	51	4	3	2	21	0	30
Woodpecker	0	3	0	3	0	6	0	2	0	3	0	5
Artificial	3	0	0	0	0	3	3	0	0	0	0	3
Turdidae/Starling	3	16	0	0	6	25	3	6	0	0	2	11
Total	**23**	**44**	**7**	**57**	**14**	**145**	**16**	**9**	**2**	**38**	**2**	**67**

Table W5.2d. Numbers of metrics and studies providing information on different interaction types (rows) subdivided by taxonomic groupings of nominate disadvantaged species (columns). See methods for explanations of interaction types. Some studies contributed metrics to more than one interaction type or taxonomic grouping hence the aggregate number of studies (89) exceeding the number of contributing studies (67; see Results).

	Metrics											Studies										
Interaction type	Columbid	Corvid	Finch, sparrow, bunting	Mixed	Nuthatch	Small insectivorous passerine	Tit	Woodpecker	Artificial	Turdidae/Starling	**Total**	Columbid	Corvid	Finch, sparrow, bunting	Mixed	Nuthatch	Small insectivorous passerine	Tit	Woodpecker	Artificial	Turdidae/Starling	**Total**
Commensalism/parasitism	**0**	**0**	**1**	**1**	**0**	**6**	**0**	**0**	**0**	**0**	**8**	**0**	**0**	**1**	**1**	**0**	**4**	**0**	**0**	**0**	**0**	**6**
Heterospecific attraction	0	0	1	1	0	6	0	0	0	0	**8**	0	0	1	1	0	4	0	0	0	0	**6**
Competition for:	**1**	**1**	**1**	**2**	**1**	**9**	**33**	**2**	**0**	**1**	**51**	**1**	**1**	**1**	**2**	**1**	**9**	**24**	**1**	**0**	**1**	**41**
Food	0	0	1	2	0	1	9	0	0	0	**13**	0	0	1	2	0	1	7	0	0	0	**11**
Nest	1	1	0	0	1	8	22	2	0	1	**36**	1	1	0	0	1	8	16	1	0	1	**29**
Roost	0	0	0	0	0	0	1	0	0	0	**1**	0	0	0	0	0	0	1	0	0	0	**1**
Unknown	0	0	0	0	0	0	1	0	0	0	**1**	0	0	0	0	0	0	1	0	0	0	**1**
Predation of:	**3**	**1**	**14**	**5**	**1**	**13**	**18**	**4**	**3**	**24**	**86**	**2**	**1**	**6**	**4**	**1**	**7**	**14**	**4**	**3**	**10**	**52**
Fully grown birds	2	1	2	1	0	0	1	0	0	1	**8**	1	1	2	1	0	0	1	0	0	1	**7**
Nests	1	0	12	4	1	13	17	4	3	23	**78**	1	0	4	3	1	7	13	4	3	9	**45**
Total	**4**	**2**	**16**	**8**	**2**	**28**	**51**	**6**	**3**	**25**	**145**	**3**	**2**	**7**	**7**	**2**	**19**	**30**	**5**	**3**	**11**	**89**

Table W5.2e. Numbers of metrics and studies providing information on different interaction types and sub-types (rows) subdivided by study design category. See methods for explanations of interaction types and study designs. A small number of studies contributed metrics to more than one interaction type, hence the aggregate number of contributing studies summed across interaction types exceeding the number of contributing studies (67).

	Metrics					Studies				
Interaction type	Observational	Descriptive	Experimental	Review	**Total**	Observational	Descriptive	Experimental	Review	**Total**
Commensalism/parasitism	**0**	**0**	**8**	**0**	**8**	**0**	**0**	**5**	**0**	**5**
Heterospecific attraction	0	0	8	0	**8**	0	0	5	0	**5**
Competition for:	**15**	**24**	**12**	**0**	**51**	**4**	**20**	**10**	**0**	**34**
Food	0	8	5	0	**13**	0	6	4	0	**10**
Nest	15	15	6	0	**36**	4	14	5	0	**23**
Roost	0	0	1	0	**1**	0	0	1	0	**1**
Unknown	0	1	0	0	**1**	0	1	0	0	**1**
Predation of:	**36**	**28**	**18**	**4**	**86**	**9**	**21**	**6**	**1**	**37**
Fully grown birds	4	3	1	0	**8**	2	1	1	0	**4**
Nests	32	25	17	4	**78**	7	20	5	1	**33**
Total	**51**	**52**	**38**	**4**	**145**	**11**	**35**	**20**	**1**	**67**

Table W5.3a. Numbers of negative, neutral, and positive interaction metrics for all combinations of nominate disadvantaged taxonomic group or species (rows) and nominate beneficiary species or group (columns). The direction of the intervention is expressed from the perspective of the nominate disadvantaged group.

	Taxonomic grouping for beneficiary species																													
	Corvid			Finch, sparrow, bunting			Nuthatch			Parakeet			Tit			Woodpecker			Grey Squirrel			Sparrowhawk			Corvid & grey squirrel					
Disadvantaged taxonomic group	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	**Total negative**	**Total neutral**	**Total positive**
Columbid	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	3	1	0
Corvid	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
Finch, sparrow, bunting	0	5	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	3	1	0	0	0	0	2	0	0	6	8	2
Mixed	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	3	0	0	1	0	0	5	2	1
Nuthatch	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Small insectivorous passerine	0	3	0	0	0	0	0	0	0	0	0	0	8	3	4	3	0	0	5	1	0	0	1	0	0	0	0	16	8	4
Tit	0	2	0	4	0	0	0	2	0	1	2	0	14	8	2	11	2	0	0	0	0	0	2	0	1	0	0	31	18	2
Woodpecker	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	6	0
Artificial	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Turdidae/Starling	5	9	1	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	4	1	0	1	0	0	1	0	0	11	13	1
Total	**8**	**21**	**2**	**4**	**0**	**0**	**0**	**2**	**0**	**1**	**8**	**0**	**22**	**12**	**8**	**15**	**8**	**0**	**13**	**4**	**0**	**5**	**4**	**0**	**8**	**0**	**0**	**76**	**59**	**10**

Table W5.3b. Numbers of negative, neutral, positive and unknown (unmeasured) interaction metrics for all combinations of nominate disadvantaged taxonomic group or species (rows) and nominate beneficiary groups or species (columns). The direction of the intervention is expressed from the perspective of the nominate beneficiary group or species.

	Taxonomic grouping for beneficiary species																																							
	Corvid				Finch, sparrow, bunting				Nuthatch				Parakeet				Tit				Woodpecker				Corvid & grey squirrel				Grey Squirrel				Sparrowhawk							
Taxonomic grouping for disadvantaged species	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	Negative	Neutral	Positive	Unknown	**Total negative**	**Total neutral**	**Total positive**	**Total unknown**
Columbid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	**0**	**0**	**2**	**2**
Corvid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**0**	**0**	**1**	**1**
Finch, sparrow, bunting	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	4	0	0	0	0	0	0	0	1	1	**0**	**2**	**7**	**7**
Mixed	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	2	1	0	0	0	1	**0**	**0**	**3**	**5**
Nuthatch	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	**2**
Small insectivorous passerine	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	5	8	0	0	3	0	0	0	6	0	0	0	0	1	0	0	0	0	**2**	**0**	**14**	**12**
Tit	0	0	0	2	0	0	3	1	0	0	0	2	0	0	1	2	3	3	9	9	0	0	9	4	0	0	0	0	0	0	0	2	0	0	1	0	**3**	**3**	**23**	**22**
Woodpecker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	1	0	0	0	0	**0**	**0**	**1**	**5**
Artificial	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**2**	**1**
Turdidae/Starling	0	4	4	7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	4	1	0	0	0	1	0	0	1	0	**0**	**6**	**9**	**10**
Total	**0**	**5**	**7**	**19**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**1**	**8**	**5**	**3**	**14**	**20**	**0**	**3**	**14**	**6**	**0**	**0**	**15**	**2**	**0**	**0**	**2**	**7**	**0**	**0**	**6**	**2**	**5**	**11**	**62**	**67**

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W5 Appendix

Table AW5.1. Question W5 search string.

Part-1 (modes of interference)	Part-2 (candidate disadvantaged species)	Part-3 (candidate beneficiary species)
("interspecific competition" OR "inter-specific competition" OR competit* OR predat* OR depredation OR herbivory OR evict* OR symbio* OR mutual* OR commensal* OR parasit*)	AND ("marsh tit" OR "parus palustris" OR "poecile palustris" OR "willow tit" OR "parus montanus" OR "poecile montanus" OR "lesser spotted woodpecker" OR "dryobates minor" OR "dendrocopos minor" OR "crested tit" OR "parus cristatus" OR "lophophanes cristatus" OR "pied flycatcher" OR "ficedula hypoleuca" OR "european starling" OR "sturnus vulagris" OR "house sparrow" OR "passer domesticus" OR "song thrush" OR "turdus philomelos" OR "wood warbler" OR "phylloscopus sibilatrix")	AND ("blue tit" OR "parus cyanistes" OR "great tit" OR "parus major" OR "great spotted woodpecker" OR "dendrocopos major" OR "nuthatch" OR "sitta europaea" OR "wood pigeon" OR woodpigeon OR "columba palumbus" OR "collared dove" OR "streptopelia decaocto" OR "eurasian magpie" OR "pica pica" OR "carrion crow" OR "corvus corone" OR "jackdaw" OR "corvus monedula" OR sparrowhawk OR "accipiter nisus" OR "grey squirrel" OR "Sciurus carolinensis" OR "ring-necked parakeet" OR "rose-ringed parakeet" OR "psittacula krameria" OR goldfinch OR "carduelis carduelis" OR "eurasian siskin" OR "carduelis spinus" OR "spinus spinus" OR "european robin" OR "erithacus rubecula" OR "long-tailed tit" OR "aegithalos caudatus" OR blackcap OR "sylvia atricapilla" OR "coal tit" OR "parus ater")

Figure AW5.1. Results from four search engines were screened based on title & abstract, yielding 178 studies. The numbers plotted are the number of relevant studies identified in each batch of 20 studies (or 'hit rate') out of the 400 most relevant studies selected by each of the four search engines. A hit rate declining to zero implies most relevant studies have been identified, but higher hit rates up to the 400 threshold implies some relevant studies were missed.

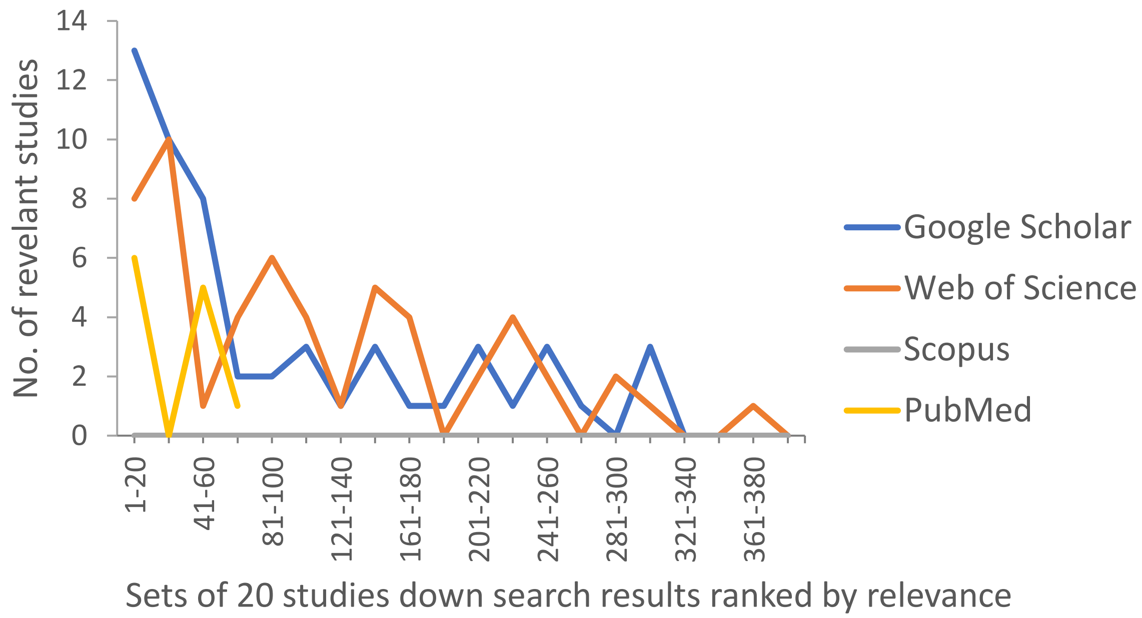

Table AW5.2. Geographic distribution of metrics and studies providing interactions data for different nominate disadvantaged species and taxonomic groups in Asia (both studies were from Israel), continental Europe (including Scandinavia), and the UK. Studies of artificial nests are listed separately. Some studies contributed metrics for more than one species, hence the sum of the contributing studies per species and taxonomic grouping exceeded the total number of contributing studies (67; see Results).

	Metrics				Studies			
Disadvantaged taxonomic group	Asia	Europe	UK	Total	Asia	Europe	UK	Total
Columbid	**0**	**0**	**4**	**4**	**0**	**0**	**3**	**3**
Stock Dove	0	0	1	1	0	0	1	1
Common Woodpigeon	0	0	1	1	0	0	1	1
Feral Pigeon	0	0	1	1	0	0	1	1
Eurasian Collared Dove	0	0	1	1	0	0	1	1
Corvid	**0**	**0**	**2**	**2**	**0**	**0**	**2**	**2**
Western Jackdaw	0	0	1	1	0	0	1	1
Eurasian Magpie	0	0	1	1	0	0	1	1
Finch, sparrow, bunting	**0**	**3**	**13**	**16**	**0**	**2**	**5**	**7**
Eurasian Chaffinch	0	3	3	6	0	2	2	4
European Goldfinch	0	0	1	1	0	0	1	1
European Greenfinch	0	0	1	1	0	0	1	1
House sparrow	0	0	5	5	0	0	3	3
Yellowhammer	0	0	3	3	0	0	2	2
Mixed	**0**	**3**	**5**	**8**	**0**	**3**	**4**	**7**
Mixed	0	3	5	8	0	3	4	7
Nuthatch	**0**	**0**	**2**	**2**	**0**	**0**	**2**	**2**
Eurasian Nuthatch	0	0	2	2	0	0	2	2
Small insectivorous passerine	**0**	**15**	**17**	**32**	**0**	**12**	**7**	**19**
Eurasian Blackcap	0	1	0	1	0	1	0	1
Collared Flycatcher	0	2	0	2	0	2	0	2
Dunnock	0	0	3	3	0	0	2	2
European Pied Flycatcher	0	10	1	11	0	8	1	9
Eurasian Skylark	0	0	1	1	0	0	1	1
Spotted flycatcher	0	0	3	3	0	0	2	2
Willow Warbler	0	2	0	2	0	1	0	1
Wood Warbler	0	0	2	2	0	0	2	2
Eurasian Wren	0	0	1	1	0	0	1	1
Common Whitethroat	0	0	2	2	0	0	1	1
Tit	**3**	**14**	**34**	**51**	**2**	**10**	**18**	**30**
Eurasian Blue Tit	0	4	7	11	0	4	5	9
Great Tit	3	2	3	8	2	2	3	7
Great Tit, Blue Tit	0	0	1	1	0	0	1	1
Marsh Tit	0	3	9	12	0	2	5	7
Willow Tit	0	5	14	19	0	4	7	11
Woodpecker	**0**	**0**	**6**	**6**	**0**	**0**	**5**	**5**
Great Spotted Woodpecker	0	0	2	2	0	0	2	2

	Metrics				Studies			
Disadvantaged taxonomic group	Asia	Europe	UK	Total	Asia	Europe	UK	Total
European Green Woodpecker	0	0	1	1	0	0	1	1
Lesser Spotted Woodpecker	0	0	3	3	0	0	3	3
Turdidae/Starling	0	0	25	25	0	0	11	11
Common Blackbird	0	0	8	8	0	0	7	7
Mistle thrush	0	0	1	1	0	0	1	1
European Robin	0	0	1	1	0	0	1	1
Song thrush	0	0	8	8	0	0	5	5
Common Starling	0	0	7	7	0	0	5	5
Artificial	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Artificial nests	0	1	2	3	0	1	2	3
Total	**3**	**36**	**106**	**145**	**2**	**25**	**40**	**67**

W6. What mitigation measures are available for any negative impacts of SF from W1-5, and how effective are they?

Rationale

The aim of this question is to summarise the available scientific evidence relating to the effectiveness of interventions that aim to mitigate the negative effects of SF in residential settings identified in questions W1-5. For this we used the same set of search engines as for W1-5. Where relevant we highlight links to, and implications for, existing national and international examples of policy advice on SF in residential settings developed by ornithological and conservation NGOs and wildlife health organisations, based on a combination of peer-reviewed science and expert judgement.

Methods

Literature search procedure

As with the other questions in this review, we first developed a search string based on key words and phrases from selected relevant studies combined with expert knowledge. Trials suggested it was impractical to devise a single search string that identified mitigations of problems linked directly to SF and those linked only indirectly via inter-specific interactions involving known beneficiaries of SF in residential settings (e.g. managing predation). We therefore conducted two separate searches.

Search A focused on problems linked directly to SF, while Search B focussed on nest box design to protect against nest predation, a problem highlighted under W5. Search A comprised three components selecting for (i) bird-related studies, (ii) specific potential mitigation categories (such as feeder hygiene, feeder placement, feeder guards etc), and (iii) a direct link to SF (Appendix W6: Table AW6.1). No attempt was made to locate studies relating to supplementary water provision as that was beyond the scope of the review. Search B also had three components specifying (i) bird-related studies, (ii) nest box studies and (iii) nest box design issues relating to predation risk mitigation (Appendix W6: Table AW6.1).

We ran the searches on Google Scholar, Web of Science, Scopus, and PubMed and used the software RAYYAN to screen the first 400 results from each search engine for relevance based on title and abstract. The 400-study threshold reflects a pragmatic trade-off between declining relevance and time taken to screen results. During screening we recorded the number of relevant studies in each batch of twenty studies to quantify the extent to which relevance declined with search engine rank. When this decay function declines to zero it is likely that the search has identified a high proportion of relevant studies; if it fails to reach zero by the 400-study threshold it is likely relevant studies were excluded by our threshold. For both searches the strong decay in the frequency of relevant studies after the first 100 or so studies suggests that we located most relevant works (Appendix W6: Figure AW6.1). After combining the relevant studies from the four search engines we checked for and removed duplicates and exported the remaining set of studies to a spreadsheet. We combined these results with studies identified as relevant to mitigation from searches W1-5 and a few additional mitigation-relevant studies identified during data extraction.

Study exclusions

Following amalgamation of selected studies across sources we inspected full text articles and, where studies were relevant, we extracted summary data for each study that satisfied the following criteria for each of our two searches:

Search A focussed on a suite of candidate mitigations for reported negative impacts of SF. We included any study that tested a potential mitigation action for a problem directly associated with SF as typically conducted in UK residential settings. These included studies considering mitigation measures for disease transmission risk at feeders, for competition for food at feeders and for reducing predation risk associated with feeders. We included studies irrespective of habitat or geographic location if they were relevant to SF in UK residential settings. We excluded studies that addressed mitigation of window strikes (e.g. decals, screens, cords, glazing), which are detailed in Carlson & Phillips (2025), and focused on evidence related to interactions between feeder location and window collision risk. We excluded any studies relating to supplementary water provision as these were beyond the scope of this review.

Search B was restricted to studies of nest box design intended to mitigate nest predation or nest site competition problems involving species that may have benefitted from the effects of widespread SF in the UK (like great spotted woodpecker, Eurasian blue tit or great tit). We excluded studies comparing bird fitness in different nest box designs if there was no mitigation link to nest predation or nest competition.

Data extraction – response metrics

For both searches there was a wide variety of response metrics including avian infection measures (e.g. pathogen load, infection prevalence), bird behaviours (e.g. feeder usage, nest box defence), bird condition (e.g. body mass, stress hormone levels), demographic rates (e.g. nest survival, adult survival) and abundance/abundance change. These are reported on a case-by-case basis, and no attempt is made to assess the directional balance or average responses across studies.

For each search we assigned each selected study to a SF mitigation category reflecting the aspect of SF that was manipulated. For Search A, eight mitigation categories were recognised: (A1) feeder hygiene in relation to pathogen transmission risk, (A2) feeder construction and design, (A3) feeder removal in relation to bird condition and disease risk, (A4) feeder density in relation to pathogen transmission risk, (A5) feeder placement in relation to predation risk of feeder users, (A6) feeder placement in relation to predation risk of nests, (A7) feeder placement in relation to window collision risk, (A8) grey squirrel activity in relation to bird feeder usage (Tables W6.1 & W6.2). For search B, seven mitigation sub-categories were recognised: construction material, cavity depth, construction quality, presence of hole guard, entry hole size, presence of a protective mesh cover, and a combination of these mitigation measures (Table W6.3). Unlike our other wildlife questions, some small but informative nest box design trials may have been published in minor journals not searched by large search engines. We therefore conducted a search for the terms 'nest box' and 'nestbox' using the Conservation Evidence website (https://www.conservationevidence.com/) but found no additional relevant studies.

Data extraction – context variables

For each extracted response metric from both searches, we also assigned a range of context variables. These allowed us to describe the composition of the extracted data. First, we assigned each response metric a continent (North America, Asia, Australasia, Europe). Second, we assigned each metric to one of four landscape context categories: (i) peri-domestic (urban, suburban, rural domestic), (ii) wider countryside away from human habitation (usually woodland or farmland), (iii) a mixture of the two including studies conducted across a peri-domestic to wider countryside gradient, and (iv) studies conducted on captive birds. Third, we assigned each metric to one of two study design categories: experimental which included at least one treatment with a suitable control, and observational in which responses to, or correlations with, defined potential mitigation measure were described. We summarised the findings of this literature search first by describing the composition of the selected studies for each search, and second, for each mitigation category in turn, we consider the extent to which interventions mitigated the problem being addressed.

Comparison with existing guidance on SF in residential settings

We compare our extracted evidence with current online bird feeding guidance from three UK and three North American organisations. Advice is summarised from organisational web pages but not from commentary in blogs or social media posts. The three related UK sources come from national conservation NGOs (ornithological and wildlife health expertise), while the three North American sources are a national wildlife health consortium from Canada, the Cornell Laboratory of Ornithology and the National Audubon Society both from the USA. Their websites were reviewed in June 2025 and are listed below:

- BTO: https://www.rspb.org.uk/birds-and-wildlife/feeding-birds-near-you
- Garden Wildlife Health (GWH; a partnership between BTO, Froglife, RSPB and ZSL): https://www.gardenwildlifehealth.org/wp-content/uploads/sites/12/2021/04/Feeding-Garden-Birds-Best-Practice-Guidance.pdf, and https://www.gardenwildlifehealth.org/garden-wildlife/
- RSPB: https://www.rspb.org.uk/birds-and-wildlife/feeding-birds-near-you#keeping-feeders-and-bird-baths-clean)
- Canadian Wildlife Heath Cooperative: //www.cwhc-rcsf.ca/publications.php#wildlife-health-notes
- Cornell Laboratory of Ornithology: https://feederwatch.org/learn/feeding-birds/?__hstc=75100365.9c49e44b73bd3bee6fa385653ecd7c96.1715472000430.1715472000431.1715472000432.1&__hssc=75100365.1.1715472000433&__hsfp=2036610538
- National Audubon Society https: //media.audubon.org/audubon_guide_to_bird_feeding.pdf

As this review question is focused on scientific evidence relating to potential mitigation for any negative consequences of SF, we do not consider the evidential basis for any existing advice for which our searches found no relevant scientific literature.

Results

Literature composition

Our data extraction for Search A identified 26 metrics from 20 studies, of which 6 metrics from 6 studies were measured in Europe (all in UK), with 19 metrics from North America (13 studies), and one from New Zealand (1 study) (Table W6.2a). This sample of metrics comprised 20 measured in peri-domestic habitats, 4 in wider countryside habitats (from woodland edge sites), and 2 from other situations (1 mixed peri-domestic/wider countryside, 1 captive; Table W6.2a). Of the 26 extracted metrics, 22 were from experimental studies with the remaining 4 being from observational studies (Table W6.2b). The most frequent mitigation category was feeder density (8 metrics from 3 studies), followed by feeder hygiene and feeder placement in relation to bird usage and predation risk (5 metrics from 5 studies and 4 metrics from 4 studies respectively).

Our data extraction for Search B identified 10 metrics from 10 studies. Five of these were conducted in Europe, 4 in Asia and 1 in North America (Table W6.3a). Seven studies were conducted in wider countryside woodland sites, 2 in peri-domestic settings and 1 across an urbanisation gradient (Table W6.3a). Seven studies followed experimental designs, while the remaining 3 were observational, and the most frequent nest box mitigation risk sub-categories were hole size (3 metrics) and hole guards (2 metrics).

Search A mitigation findings

(A1) Mitigating disease risk through feeder hygiene

Feeder hygiene is widely promoted as a disease mitigation measure both in the UK and beyond with weekly or bi-weekly cleaning recommended using hot soapy water followed by disinfection (e.g. weak bleach solution) followed by rinse with clean water and air dry before re-use (Appendix W6, Table AW6.2). General hygiene measures to keep SF dry, and avoid any buildup of faeces or contaminated food, are also advised.

Three experimental studies conducted in North America were identified from the peer-reviewed literature that directly considered the effects of feeder cleaning on pathogen persistence on feeders and infection risk:

- Surface contamination: Feliciano et al (2018) considered three methods of cleaning feeders (scrubbing with soap and water, bleach soak, and scrubbing with soap and water followed by a bleach soak) and measured effectiveness in reducing levels of *Salmonella* on feeders (immediately after cleaning) with and without the presence of food debris. The study concluded that while all cleaning methods were effective, in the presence of debris a combination of scrubbing with soap and water followed by bleach soak was most effective in reducing *Salmonella* contamination.
- Bacterial load: Boyd et al (2014) found the use of 10% bleach wipes reduced aerobic bacterial loads on feeders by 50%. Following fortnightly 10% bleach wipes (on all internal and external feeder surfaces) aerobic bacterial loads were reduced (relative to uncleaned control feeders) up until 6 weeks but subsequently returned to control levels by weeks 8 and 10. The load of anaerobic gram-negative (but not aerobic) bacteria was positively related to the intensity of feeder usage by birds, rather than cleaning efficacy.
- Parasite burden: Schaper et al (2021) used an experimental design to test the effectiveness of daily feeder cleaning (with a dilute bleach solution) to reduce infection prevalence and load with coccidian endoparasites in house finches over a five-week period. In male house finches at a rural site, the coccidia infection load decreased over time with daily feeder cleaning. However, no effect of feeder cleaning was found on parasite load in female finches, or in either sex at urban sites. There were no significant effects of feeder cleaning on parasite prevalence.

These studies suggest that feeder cleaning can reduce pathogen contamination and daily feeder cleaning may moderate infection intensity in some groups. However, impacts on pathogen transmission risk or bird infection prevalence and population health remain unknown for most pathogens and the evidence-base is therefore limited in its applicably to peri-domestic bird feeding in the UK. Importantly, there is no published evidence demonstrating the effectiveness of feeder cleaning in reducing transmission or prevalence of *Trichomonas gallinae* infection, the pathogen of current concern for birds in UK gardens. Theoretical concerns have been raised that bleach-tolerant bacteria may persist under suboptimal cleaning regimes (Rhouma et al 2020).

Rates of feeder cleaning amongst the public are largely unknown but may be relatively low. A questionnaire survey of residential bird feeders in New Zealand found that of 221 responses, 20% of those feeding garden birds never cleaned the containers or bird tables used, and a further 16% only cleaned them 2-3 times a year (Galbraith et al. 2014). Twenty percent cleaned once or twice a month, and 43% cleaned at least once a week. Eight percent of all respondents cleaned daily. Methods of cleaning also varied, with approximately 20% using soap or detergent to clean, but only 1% reporting using a disinfectant. In North America, 40% of a non-random sample of regular participants in garden bird feeding either never cleaned bird feeders or cleaned them only once a year (Horn & Johansen 2013). In a random questionnaire survey of residents of three English towns, 58% of 331 respondents agreed with the statement that they washed their bird feeders 'regularly', a term which was apparently undefined (Cox & Gaston 2016).

(A2) Mitigating disease risk through feeder construction and design
Current guidance on feeder design typically focuses on aspects of their construction related to ease and effectiveness of cleaning. For example, recommending they should be made of non-porous materials (like metal or plastic) and be of a design that allows them to be easily dismantled for regular cleaning and disinfection (Appendix W6, Table AW6.2).

A single study was identified which considered the effect of feeder construction material on pathogen persistence:

- Perez et al. (2025) inoculated garden bird feeders with domestic chicken faeces containing avian-derived *Salmonella* Typhimurium and compared persistence on different feeder materials (wood, plastic, anti-microbial coated plastic and anti-microbial coated wood). No significant differences were found in *Salmonella* prevalence or persistence times between feeder materials. However, prevalence and persistence were non-significantly higher on plastic feeders than wood feeders, with the longest persistence time of 5 days on a plastic feeder with anti-microbial coating.

<u>Summary (A1 and A2)</u>
Mitigating disease risk through feeder hygiene: Cleaning bird feeders and tables, particularly when combined with removal of food waste and faeces, has a high likelihood of reducing pathogen load and therefore decreasing the likelihood of bird exposure to pathogens and subsequent infection. However, the impact of hygiene precautions as a tool for disease prevention is likely to vary by pathogen, according to factors such as the route(s) of transmission, the relative importance of direct (i.e. contact between birds) and indirect transmission (e.g. consumption of contaminated food or contact with contaminated bird feeder surface), and the duration of viable pathogen persistence in the environment (see question W4 for further information). During disease outbreaks, hygiene measures alone (at the recommended frequency of practice likely to be practicable for the public to implement) are unlikely to adequately control pathogen transmission for many infectious diseases, including trichomonosis, if transmission is occurring on a short timescale between cleaning events. Such short-term transmission routes will include direct bird-bird contact and local contamination of food or feeder surfaces.

Given the prominence of feeder cleaning in the SF guidance and the paucity of associated empirical support for its efficacy as a disease mitigation measure, further research is needed particularly in a UK context with respect to trichomonosis. Probable low levels of public compliance further complicate the potential for feeder cleaning as a standalone mitigation measure. Research is required to investigate the potential for anti-microbial resistance to cleaning agents and the environmental impacts of disinfectant use.

Careful attention should be given to communicating public health guidance to support safe cleaning practice, since contact with bird feeders, food waste and faeces, may increase the risk of human exposure to zoonotic pathogens (See Other topics: Human health risks associated with SF). Such measures include the dampening of feeder surfaces prior to cleaning to reduce the chance of inhaling dust and the wearing of rubber gloves during cleaning conducted outdoors.

Mitigating disease risk through feeder construction and design: Disease transmission risk may be reduced by improvements in feeder design. Whilst we report one study on construction materials, further research is needed. We found no published evaluation of new feeder designs that aim to reduce inter-species mixing and access to potentially contaminated food and keep food dry. We found no studies that compared disease transmission risk among different feeder types, including flat surfaces, such as trays and bird tables, and hanging feeders.

<u>Implications for guidance</u>
Although the existing guidance to clean feeders on a weekly or bi-weekly basis is supported by limited empirical evidence, it remains appropriate as a precautionary measure for disease prevention supported by analogous practices in livestock and companion animal health. Guidance often focuses on bird feeder cleaning, with less attention given to the need for general hygiene precautions including removal of food waste and faeces.

Even in the absence of direct experimental evidence, current knowledge of routes of transmission of *T. gallinae* (i.e. repeat handling of discarded food by multiple individuals, see W4), and pathogens with faeco-oral transmission (e.g. *Salmonella* Typhimurium), strongly suggests bird feeders with horizontal surfaces (like bird tables and trays) that facilitate contact between food fragments and faeces, and often allow food to become wet, are likely to represent high risk bird food presentation methods even with recommended cleaning frequency. Since December 2024 the RSPB has advised against the use of feeders with flat horizontal surfaces and no longer offers them for sale.

(A3) Mitigating disease risk through feeder removal

A pause in SF though temporary feeder removal, and sometime supplementary water provision, is widely advocated by SF guidance sources as a means of controlling disease outbreaks once detected (Appendix W6, Table AW6.2). Temporary removal of SF and water may encourage birds to disperse and thereby reduce inter and intraspecific contact rates, density dependent transmission and risk of pathogen spillover.

Current UK advice for the control of finch trichomonosis suggests stopping feeding for 2-4 weeks and until no further sick birds are seen, extending up to 3-6 months if the problem persists (https://www.gardenwildlifehealth.org/portfolio/trichomonosis-in-garden-birds/). Canadian advice for trichomonosis control goes further and in the case of a summer/autumn outbreak recommends stopping feeding until the first frosts of winter (Canadian Wildlife Health Cooperative 2018). Feeder removal was recommended by the Department of Fish and Game to control a trichomonosis outbreak amongst columbids (band-tailed pigeons and mourning doves) in California (Jones & Reynolds 2008). In Newfoundland and Labrador (Canada), the Fisheries and Land Resources Department recommended feeder removal during summer following the emergence of finch trichomonosis (Newfoundland and Labrador Fisheries and Land Resources 2020). Temporary removal of SF is also advocated when garden bird disease is caused by zoonotic pathogens (e.g. *S.* Typhimurium, *Chlamydia psittaci*: https://www.gardenwildlifehealth.org/garden-wildlife/#birds), or if large-scale events of uncertain aetiology occur as a precautionary measure (USGS 2021).

We found no studies that considered the efficacy of feeder removal as a control measure during disease outbreaks, or that investigated the impact of temporary or seasonal feeder removal as a potential mitigation for disease prevention. However, we found one study (Wilcoxen et al. 2015) that examined how SF influences the health of wild birds by evaluating the effects of feeder introduction and then feeder removal on the health and condition of, and disease prevalence in, wild birds:

- The field study involved the experimental introduction of feeders into three forested areas in the USA for three successive years with three unfed forested areas serving as controls. Birds at the fed sites generally had improved health parameters (including increased antioxidant levels, reduced stress and increased innate immune defence) than birds at unfed sites, but also an increase in disease prevalence (mainly avian pox and conjunctivitis) assessed by clinical signs (Wilcoxen et al. 2015). After the three-year experimental period the feeders were removed, and ten months after removal health parameters and disease prevalence had returned to pre-feeding levels supporting the suggested link to SF. Although this study did not assess the net fitness impact of the feeding treatment, it demonstrates that feeder removal can reverse the increase in disease prevalence associated with the SF of wild birds. However, feeder removal also reversing the positive effects of SF on bird health and condition.

It is important to note that this study may lack direct applicability to a UK residential context where different pathogens are of greater concern.

Although there is little information available on the effects of feeder removal on disease prevalence and dynamics, two further studies provide additional insights into the likely ecological consequences of feeder removal. In a controlled experiment in urban gardens, Galbraith et al. (2015) found that bird community composition (measured at the garden scale) changed rapidly following the introduction of SF but largely reverted to pre-feeding states once feeders were removed. This suggests that feeder removal can swiftly reduce bird aggregation and inter-specific mixing, with potential implications for disease transmission, although this was not measured. Brittingham & Temple (1992) found that past use of feeders did not reduce chickadee survival when feeders were removed, suggesting no long-term nutritional dependency. Although these studies provide wider ecological support for the feasibility of temporary feeder removal as a potential mitigation measure, they provide no direct insight into the likely implications of feeder removal for disease dynamics amongst wild birds.

It should be noted that empirically evaluating the effects of feeder removal on disease outcomes in wild bird populations is challenging. Field-based experimental designs require replication and long-term monitoring, while disease emergence events are unpredictable and rarely synchronised with controlled interventions. An alternative and complementary approach is the application of agent-based modelling to disease dynamics. These approaches potentially allow exploration of disease dynamics under varying feeding regimes, contact rates and environmental conditions, incorporating species-specific behaviours and social networks (e.g. Bonnell et al. 2010, Nunn et al. 2014). Such models have proven valuable in wildlife epidemiology and may offer useful insights in the SF context. However, the impacts of specific mitigation interventions should be measured in the field or laboratory before being incorporated into predictive models.

<u>Summary</u>

Feeder removal may reduce pathogen exposure by lowering bird aggregation and inter-specific contact and is easily implemented, but evidence supporting its efficacy is limited. The available information suggests complex and potentially opposing effects of feeding on host condition and disease prevalence. Targeted research is needed to evaluate the effectiveness of the suspension of SF for key pathogens in the UK context such as *T. gallinae*, and to weigh any avian health benefits against potential costs to bird survival and public engagement. Another important evidence gap is the absence of studies comparing the implications for bird fitness and/or pathogen transmission from year-round versus seasonal provision of supplementary food.

<u>Implications for guidance</u>

Although the advice to temporarily remove feeders as a disease control measure is only weakly supported by empirical evidence, this precautionary measure should still be recommended as a means of reducing inter- and intra-specific mixing as well as bird-to-bird and bird-to-feeder contact rates and to minimise public health risks where relevant.

(A4) Mitigating disease transmission risk through feeder density

Four advice sources recommend spacing out and/or rotating feeders around gardens and separating different food types to reduce inter-species mixing and the risk of pathogen spillover, and to help reduce the build-up of food waste and faeces (Appendix W6, Table AW6.2). However, none of the guidance specifies recommended distances or feeder densities.

Two studies have experimentally examined the effects of feeder density on disease transmission in house finches, both focusing on *Mycoplasma gallisepticum* (*MG*):

- Moyers et al. (2018) exposed house finches to *MG* and allowed them to feed and interact in aviaries at either low (2 feeders) or high (4 feeders) feeder density. While overall transmission rates were generally low (7 out of 91 naïve birds became infected in the 27 days following inoculation), they were markedly higher under the high-density feeder treatment. *MG* antibody concentration was higher in the low-density treatment suggesting a higher rate of exposure to subclinical doses of the pathogen. Total time spent on feeders and average bout lengths did not differ between treatments and there were more displacements and shorter latency periods (time between successive feeding bouts) at lower feeder density.

- Aberle et al (2020) manipulated feeder density in experimental outdoor areas in Virginia, USA and measured the abundance, behaviour, and condition of house finches under high and low feeder density treatments (high feeder density was a line of three feeders spaced 3m apart, while low density was a single feeder). Under the higher density feeder treatment finch capture rates were higher (implying higher local abundance), while feeding bouts and the total time spent on feeders were longer. Finches first encountered on low density areas were more likely to move to neighbouring study areas than birds first encountered on high density treatments. Finches on the high-density treatment had lower body condition despite having apparently greater access to supplementary food, and *MG* blood antibody concentration did not differ between treatments. The authors concluded that higher feeder densities may pose a higher transmission risk for *MG* in house finches because previous work has suggested that higher finch abundance at feeders and more time spent on feeders are both risk factors for disease spread.

Together, these studies suggest that increased feeder density can elevate disease transmission risk in *MG* systems by attracting more birds and encouraging more time spent on feeders.

<u>Summary</u>
Two experimental studies support the hypothesis that higher feeder density increases *MG* transmission risk in house finches by attracting more birds to spend more time at feeders. However, the extent to which these findings apply to other pathogens associated with SF is unknown.

<u>Implications for guidance</u>
Although current advice to space out and rotate bird feeders appears to lack explicit empirical support, until further research is conducted it should be maintained as a precautionary measure that aligns with principles of disease outbreak management and contact reduction. Lower feeder density may reduce disease transmission risk for MG and house finches but the effects of this measure on other pathogens are unknown. A precautionary approach at UK sites which attract large numbers of finches, in particular European greenfinches and Eurasian chaffinches, which are known to be highly susceptible to trichomonosis, may be to moderate the volume of seed provision and/or the number of seed feeders in use, since congregation at high density for sustained periods might increase the risk of parasite transmission. The practicality of any advice to manipulate feeder density is currently limited by a lack of specific detail on spacing distances or feeder densities, and by limitations related to typical garden size.

(A5) Mitigating the risk of predation of feeder users through feeder placement
Three guidance sources provide information on positioning feeders close to vegetation to reduce predation risk of SF users, with a recommended distance specified in two of these, while one advises a break in SF if a predatory hawk is locally active (Appendix W6, Table AW6.2). Three studies have considered the effect of feeder placement in relation to the proximity of vegetation cover on feeder usage by birds (Cowie & Simons 1991, Giesbrecht & Ankney 1998, Horn et al 2003). All three studies placed identical feeders at increasing distances from vegetative cover into which feeder-using birds would flee in the event of disturbance or predator approach:

- Cowie & Simons (1991) show feeder usage in suburban Cardiff, UK, declined from approximately 32% of all observations at 0 m from cover to approximately 10% at 7.5m.

Responses differed between species with Eurasian blue tit and house sparrow preferring feeders close to cover and European greenfinches preferring feeders further away.

- Giesbrecht & Ankney (1998) assessed distance effects of feeder usage up to 3.7m from cover in Ontario, Canada. House sparrow and white-crowned sparrow selected feeders close to cover while house finches preferred feeders further from cover. Feeder use by black-capped chickadees and red-breasted nuthatches was unaffected by distance from cover probably because these species mitigated any perceived predation risk by carrying food to cover. Sparrows made greater use of feeders further from cover when those close to cover became depleted.
- Horn et al (2003) assessed effects of distance from cover (also up to 7.5m) on feeder usage in suburban Illinois, USA. Eight species (including black-capped chickadee, white-throated-sparrow, house sparrow and house finch) made greater use of feeders closer to cover while usage by two species (American crow and common starling) was unaffected by distance to cover.

Summary

All three studies found that overall bird usage was greatest when feeders were placed immediately adjacent to cover and declined with distance from cover. Together, these studies suggest that birds generally prefer feeding closer to cover probably due to reduced perceived predation risk. However, some species (e.g. European greenfinches) favour feeders further from cover possibly to improve visibility of approaching predators or to reduce interference competition. It should be noted that actual predation risk was not measured in any of these studies. Further research is needed to evaluate how feeder placement interacts with predation rates in typical UK garden settings and if this might differ between avian and mammalian predation threat. The practicality of siting feeders appropriately depends on garden size and vegetation layout.

Implications for guidance

To manage these multiple and sometimes species-specific feeder location preferences, current UK guidance suggests placing feeders approximately 2m from dense vegetation, far enough to reduce ambush risk from cats but close enough for birds to reach cover in the presence of an avian predator like Eurasian sparrowhawk (Appendix W6, Table W6.2). Although not directly underpinned by empirical evidence this precautionary advice reflects a pragmatic trade-off between mammalian and avian predation risk.

(A6) Mitigating the risk of predation of nests through feeder placement

Two guidance documents recommend keeping feeders away from nest boxes and nesting sites though no specific guidance is provided on suitable separation distances (Appendix W6, Table AW6.2). Three different studies have recorded higher nest predation rates in localities close to, or with high densities of, bird feeders providing peanuts or seed, the likely mechanism being the attraction of nest predators to those feeders. These studies involved both natural (Borgmann et al. 2013, Malpass et al. 2017) and artificial nests (Hanmer et al. 2017), and both semi-natural and peri-domestic landscapes:

- Borgmann et al. (2013) studied dusky flycatchers nesting in Californian montane meadows, USA. They reported higher densities of nest predators (corvids, squirrels, chipmunks) within 100 m of feeders and higher nest predation rates of open-nesting dusky flycatchers within 50 m of feeders.
- Malpass et al. (2017) studied seven suburban neighbourhoods in Ohio, USA, each approximately 3.5 ha in area. They found the local abundance of two nest predators (brown-headed cowbird and American crow) increased with local feeder density. Survival of American robin (but not northern cardinal) nests declined with increasing numbers of bird

feeders, but only where crows were most frequently detected. This suggests a species-specific and context-dependent impact of SF on nest predation risk.

- Hanmer et al. (2017) conducted an artificial nest experiment in suburban parkland/woodland in Reading, UK. Most (73%, n=102) artificial open nests were predated within 6 days of placement, mainly by Eurasian magpies (n=37) and European jays (n=28). Feeders fitted with cage guards (intended to exclude mammals and larger birds) attracted fewer potential nest predators including squirrels and Eurasian magpies, and nest predation was lower in localities having less feeder usage by predators. Nest predation rates were lowest close to unfilled feeders (51%) and were similar for filled feeders with (77%) and without (89%) guards. There was no difference in nest predation rate between nests located 5 m and 10 m from feeders.

Summary

Together, these studies provide evidence that SF during the breeding season can attract nest predators and elevate local nest predation rates, particularly for open-cup species nesting close to feeders. Effects appear to vary by species and landscape context, and there is little information on the effect of distance from feeder on predation risk other than finding similar overall risk at 5 m and 10 m from feeders. Cage guards reduced feeder usage by predatory species but did not significantly reduce nest predation rate. Further research is needed to establish safe placement distances and to assess how predation risk interacts with broader benefits of feeding.

Implications for guidance

Based on available evidence advice should recommend that feeders should be placed more than 10 m from suitable nesting cover for passerines having open-cup nests. The practicality of such advice will depend on garden size and vegetation cover and may not be feasible in smaller gardens. There may also be a contradiction between this advice and that to place feeders close to cover to minimise predation risk of birds at feeders (A5).

(A7) Mitigating collision risk at windows through feeder placement

Window collision risk is mentioned in one of the UK SF guidance sources and all three of the North American sources (Appendix W6, Table AW6.2). The North American advice recommends placing feeders more than 10 m or less than 1 m from windows to reduce the likelihood of bird collisions.

Our search identified two studies that considered window collision risk in relation to bird feeding. Both were experimental in nature and took place in North America but only one was conducted in a peri-domestic setting:

- Klem et al. (2004) was conducted in a wooded university campus in suburban Pennsylvania, USA. Collision risk increased with distance of the feeder from the window with 48% of all collisions (n=105), and 67% of all fatal collisions (n=52), at 10 m compared to 24%, and 0%, at 1 m from windows.
- Kummer & Bayne (2015) was conducted at 43 residential properties in suburban Canada and found that having a bird feeder at either 1 m or 5 m from a window increased bird collision rates by 120% (or by 84% when non-feeder using species were included) compared to windows without nearby feeders. This study was based on 61 collisions recorded in 284 31-day observation periods conducted on 55 windows at 43 houses, with 44 windows contributing multiple trials (range 2-4). Collision risk was slightly higher for feeders placed at 5 m from the window (compared to 1 m), but the difference was not significant.

Summary

Placing feeders in residential gardens increases the risk of bird-window collisions. Both studies found that collision risk was lower when feeders were close to windows (e.g. 1 m) probably because at short distances birds are less likely to build up sufficient speed when leaving the feeder to cause fatal impacts.

Implications for guidance

These findings in part from residential settings support the recommendation to place feeders either within 1m, or more than 10 m, from a window. The latter may be difficult to achieve in smaller gardens. This information should be included in guidance more widely. It is important to note that there may be a conflict between this window-related advice and that to place feeders within 2 m of vegetative cover (see A5 above). In the light of such conflicts, local decisions on feeder placement could be based on the relative risks (perhaps based on recent experience) of window collisions and predation by mammals or birds

(A8) Mitigating squirrel competition at feeders

Just one UK garden bird feeding guidance source provides advice on feeder designs to deter squirrels from using feeders. The advice does not distinguish between range-restricted native red squirrels and invasive North American grey squirrels. This contrasts with advice available from multiple North American sources which advises reducing squirrel access by mounting feeders on poles with baffles and barriers (Appendix W6, Table AW6.2). However, UK guidance on feeding red squirrels is available from other sources (e.g. https://www.northernredsquirrels.org.uk/squirrels/feeding-reds/).

Two UK studies have investigated how grey squirrel activity at SF stations affects bird feeder usage. Both studies provide clear evidence that grey squirrels can strongly deter bird feeding, either directly through physical displacement or indirectly through perceived predation risk:

- Bonnington et al. (2014) attached a taxidermy grey squirrel model to experimental feeders. They recorded an 80% reduction in bird species richness and a 98% reduction in total feeder visits by birds when the model squirrel was present relative to control feeders without the model.
- Hanmer et al. (2018) quantified feeder use in suburban gardens in Reading and found that grey squirrels accounted for 44% of all feeder usage time. Typically, there was an almost complete cessation of bird feeder usage while squirrels were present. Feeders with heavy squirrel usage were less likely to be used by Eurasian blue tit, great tit, coal tit and European robin, and more likely to be used by dunnocks. The addition of squirrel guards substantially reduced squirrel usage of seed and peanut feeders, but also reduced total bird usage, with mixed responses across species. For example, Eurasian blue tit, dunnock, and European robin showed reduced use in the presence of guards, while coat tit, Eurasian nuthatch and (marginally) great tit increased feeder use.

Summary

In the UK, grey squirrels can substantially reduce feeder usage by wild birds, both by occupying feeding time and by deterring or displacing birds. Use of squirrel guards can substantially reduce squirrel access to feeders, particularly seed feeders, but may also reduce total usage by birds, with variable responses across species. Using guards on feeders is practical but has a financial cost. Further research could support more targeted interventions that minimise negative impacts on priority bird species.

Implications for guidance

Advice should be extended to indicate the effectiveness of squirrel guards in deterring squirrel usage of feeders and to highlight that total feeder usage by birds, particularly by certain species, is likely to decline in the presence of guards.

Mitigation summary for finch trichomonosis

As finch trichomonosis is the most problematic feeder-related avian disease currently affecting garden birds in the UK we focus here on specific mitigation options for this problem. Options to prevent and control trichomonosis in wild birds are currently limited and largely of unknown efficacy.

Current advice for the control of trichomonosis amongst wild birds generally involves the temporary suspension of supplementary food and water provision (see examples under A3 above). Current GWH advice in the UK recommends suspending feeding for 2-4 weeks to encourage birds to disperse and only to reintroduce food and water when no further sick birds are being seen. If birds with clinical signs consistent with trichomonosis continue to be seen, then it is advised that feeding be stopped for 3-6 months (GWH 2022). Advice to control summer trichomonosis outbreaks in Canada recommends stopping feeding until the first frosts of winter (Canadian Wildlife Health Cooperative 2018).

Current advice for trichomonosis prevention amongst garden birds advocates regular cleaning and disinfection of feeders and water baths, only using feeders that keep food dry, limiting the number and/or capacity of feeders, only providing enough food to last 1-2 days at a time, rotating feeders around gardens to avoid the build-up of food waste, removal of any food accumulations inside or beneath feeders, and avoiding flat feeder surfaces where different species can mix and food spoilage can occur and provision of clean and fresh drinking water on a daily basis (GWH 2022, Canadian Wildlife Health Cooperative 2018). Although this best practice advice is based on current knowledge of how *T. gallinae* is transmitted between birds and how sick birds behave, we found no specific mitigation studies that tested the efficacy of this advice to prevent trichomonosis outbreaks, and only a few studies on the effects of feeder hygiene, feeder construction materials, feeder removal and feeder density on transmission risk for other pathogens (summarised in sections A1–A4 above). Conducting such mitigation studies focused on *T. gallinae* transmission at bird feeders should be a priority for future research. Specifically, we recommend research to:

- develop reliable means of intercepting any dropped or falling food from feeders and render that dropped food inaccessible to feeding birds
- prevent food within feeders getting damp via rainfall or condensation as *T. gallinae* survival times are increased in damp bird food (McBurney et al. 2017)
- compare *T. gallinae* survival times on different supplementary food types as previous work has shown these to vary substantially between food types (e.g. peas 24 hours, sorghum & buckwheat 120 hours; Kocan 1969)
- develop and field test new feeder designs that limit usage by different sized birds (to limit inter-species mixing).

Research opportunities for mitigating *T. gallinae* transmission risk via supplementary water include:

- alternative methods of water provision that avoid the sharing of water within larger communal basins. These might include gravity-fed drinkers that dispense water down a pipe to one bird at a time (e.g. ‘nipple drinkers’) or into small gravity-fed water trays (as used for caged birds) that may be less likely to collect any regurgitated water. Acceptance of these methods to wild birds is an obvious prerequisite for them have practical utility.

- additives that might reduce survival and persistence times of *T. gallinae* in water. These might include chlorinated water (as used in tap water for human consumption; Gerhold et al. 2013) or additives that reduce the pH of water and thereby reduce survival times of pathogens.
- *T. gallinae* survival times are reduced in oxygenated water (Purple et al. 2019), so any means of raising water oxygen levels (like mechanical aeration) might reduce *T. gallinae* survival times in supplementary water.

Any trials that aim to reduce survival times of *T. gallinae* outside of the avian host should initially be conducted under laboratory conditions to establish underlying relationships and interactions between parasite survival and environmental variables. Any additives would need to pass a risk assessment for unintended negative impacts on wild birds or other wildlife before being used in field tests.

Whilst these and other measures have the potential to mitigate trichomonosis outbreak risk amongst garden birds, our literature searches identified no field-based mitigation studies that have assessed the efficacy of such interventions in reducing *T. gallinae* transmission risk in supplementary food or water. The mitigation options for trichomonosis in garden birds are therefore currently restricted to largely unvalidated best practice advice.

Various nitroimidazoles including dimetridazole, ronidazole and carnidazole are used for the treatment of avian trichomonosis in captive birds (Amin et al. 2014). Concerns about growing resistance to nitroimidazoles has led to testing of natural plant compounds with some encouraging results in laboratory trials (Gómez-Muñoz et al. 2022, Khaki et al. 2024). However, treatments require repeated doses through time which is often impractical to deliver for wild birds or very labour intensive for nest-based administration. One study on an island population of wild pink pigeons involved repeated doses of carnidazole every 2-4 days in young squabs and this delivered a large increase in survival of treated birds (62% cf. to 27% in untreated birds; Swinnerton et al. 2005). However, subsequent administration of ronidazole or dimetridazole to free-flying juvenile and adult pigeons via supplementary water 1-4 times per year over nearly 5 years had no measurable impact on disease occurrence probably because effective treatment required birds to consume medicated water on a daily basis and this level of attendance at medicated water was not achieved (Swinnerton et al. 2005). Medication of infected wild birds carries risks of resistance development amongst *T. gallinae* and of potential harmful effects on non-target species (Amin et al. 2014). Advice aimed at controlling trichomonosis amongst garden birds therefore considers medication approaches to be impractical and unviable (e.g. GWH 2022).

<u>Search B mitigation findings</u>

(B) Mitigating nest predation and eviction risk using predator resistant nest box design

Extensive guidance on avian nest box design and placement is provided in de Feu (2003) and Cromack (2018). The BTO and RSPB websites only refer to metal plates around entrance holes as a predation mitigation measure (Appendix W6, Table AW6.2). There is also a recent review of nest box design modifications to reduce the likelihood of predation at nest boxes (Marcus et al 2024).

Here we cover seven nest box mitigation categories (Table W6.3a). These cover a wide range of nest box attributes and mitigation measures that have been tested for their utility in reducing nest predation by species such as great spotted woodpecker and European pine marten.

Nest box construction and resistance to predator attack

Nest boxes for secondary cavity nesting garden birds vary in their design features, construction materials and construction quality, and these attributes can influence the vulnerability of the box contents to predation. We found two studies on nest box construction:

- Mainwaring & Hartley (2008) tested a method to reduce great spotted woodpecker attacks on nest boxes. These birds peck holes in wood to access their main invertebrate prey but also use this ability to access and predate the chicks of secondary cavity nesting birds in natural and artificial nest sites, even when robust wooden materials are used. A wire mesh cover fitted to the nest box sides and top (Marcus et al 2024, Figure 2b) was shown to markedly reduce woodpecker predation on Eurasian blue tit nests in this UK study (14 of 58 predated before mesh vs. 1 of 48 predated after mesh fitted; Mainwaring & Hartley 2008).
- Skwarska et al. (2009) working in mixed deciduous forest in Poland found that the construction quality of wooden nest boxes affects the likelihood of predation, with high quality construction having no gaps between wooden components reducing woodpecker predation risk (12 out of 91 boxes with gaps were predated vs. 0 out of 103 boxes without gaps).

Competition for nest sites from Eurasian blue tits and great tits, likely beneficiaries of SF, have been implicated in the decline of a species of conservation concern, the willow tit (Maxwell 2002, Parry & Broughton 2018). Although willow tits do not frequently use supplementary food in gardens, they are often evicted from their nest sites by Eurasian blue tits or great tits (see W5 for details). Willow tits excavate their own nest sites from decaying tree stumps and one option for mitigating competition for nesting sites is to provide bespoke nest boxes that are attractive to willow tits and confer some protection from great spotted woodpecker attack (Maxwell 2002). Attached to tree trunks at a suitable height, they are constructed from bark-covered plastic drainage pipe of an appropriate diameter and length with capped ends and packed with fine wood shavings to replicate a deadwood stump. A suitably sized access hole allows willow tits entry to excavate a nest cavity (Maxwell 2002). These boxes are frequently occupied by willow tits and successfully fledge chicks (e.g. 4.8 chicks fledged per attempt from four nest boxes compared with 6.2 chicks fledged per attempt from 6 natural cavities across multiple sites and years, Maxwell 2002; see also Last & Burgess 2015). However, willow tit nest boxes only tend to be occupied when erected within existing territories and therefore need to be installed at the start of the breeding season when territories are first being established. Such detailed knowledge is onerous to collect over a short pre-breeding period and nest box deployment will therefore not always be a practical conservation measure. As far as we are aware there have been no formal experimental tests of the effects of nest box provision on either the number of willow tit breeding attempts (in relation to competition for nesting sites) or on nesting success (in relation to nest predation risk).

We found no experimental studies of metal hole plates (illustrated in Marcus et al. 2024, Figure 2a) but note there is anecdotal evidence of these plates excluding larger-bodied bird species and prolonging nest box life (Marcus et al 2024).

Accessibility of nest box contents to potential predators via the entrance area

Entrance hole size has a large impact on nest box occupancy, as reported by three studies:

- Yin et al (2023) studied the effects of nest box hole size on the nest defence behaviour of cinereous tits in China in response to models of predatory Eurasian red squirrels and common chipmunks. Tits preferred nest boxes having smaller holes and tailored the intensity of their defence response to those predators that could access the hole size of their nest box. This suggests that nest boxes constructed using minimum hole size for the target

occupants will reduce occupant investment in defence behaviour and vulnerability to nest predation.
- Charter et al. (2013) and Goldshtein et al. (2018) demonstrate the importance of nest box hole size on occupancy and breeding success in studies of great tits and house sparrows competing for nest sites in Israel. Larger holes reduced the breeding success of great tits because of eviction by sparrows (around 75% of boxes containing great tit nests were later used by house sparrows) although this effect was smaller for earlier nesting great tits. Investment in nest defence behaviour also increased in the presence of house sparrows. However, boxes with larger entrance holes were preferred by roosting great tits in winter.

Nest boxes can be fitted with a range of hole guard designs to reduce the vulnerability of box contents to predators, and extension tubes or baffles (physical barriers) to prevent predators reaching nest box contents (e.g. Marcus et al 2024, Figure 4d). The effectiveness of some of these measures have been studied:

- Yamaguchi et al (2005) trialled the use of wooden baffles inside and below nest box entrance holes to prevent Japanese martens reaching great tit nests in Japan (Marcus et al 2024, Figure 4d). Following one year of baseline monitoring of tit breeding success in over 100 nest boxes, predation fell from 22% to 6%, and nest success increased from 29% to 44% in the first year when all boxes were fitted with baffles. Although these effects are large, the lack of control boxes hinders interpretation as a confounding year effect cannot be ruled out.
- In contrast, Baily & Bonter (2017) used 24,114 citizen science nest records from the USA and Canada from the years 2014-16 to test the impact on nest survival of a range of species of different types of nest box protection interventions. Across all species, nest survival was 7% higher on boxes fitted with predator guards. Guards included Noel guards (wire mesh around entrance holes), hole extenders, and internal baffles (Marcus et al 2024, Figures 4b, 4c & 7 respectively). This positive effect was reported for seven of nine species considered, the remaining two species showing no effect. Birds nesting in boxes with entrance hole extenders and baffles on supporting poles, were most likely to breed successfully. In addition, birds nesting in boxes fitted with multiple predator guards were more successful than nests in boxes having a single guard.

A further method of making nest box contents less accessible to predators is to provide deeper box cavities (Marcus et al 2024, Figure 3). The effects of this have been evaluated by two studies:

- Fokkema et al. (2018) tested the impact of deeper nest boxes on Eurasian blue tits in the Netherlands by comparing nest success in standard, shallow and very shallow next boxes in a population where predation risk (by European pine martens) varied across their 12 study sites (all boxes were fitted with external metal plates around their hole entrances). Eurasian blue tits showed a preference for deeper boxes, but box depth did not affect the likelihood of predator attack. Deeper boxes contained deeper nests with more eggs and higher fledging success. Furthermore, these effects were most apparent in sites with higher predation risk. The authors concluded that Eurasian blue tits appear to tailor their reproductive effort to perceived vulnerability to predation.
- Consistent with these findings, Kalinski et al (2014) studied the effects of cavity depth and entrance tubes in a population of Eurasian blue tits predated by European pine martens in Poland. They found that nests in smaller boxes (reduced depth and width) were more likely to be predated, and that nests were taller in nest boxes equipped with entrance tubes (Marcus et al 2024 Figure 4a) regardless of nest box size. The authors concluded that the

fitness benefits of filling nest cavities (i.e. building larger nests) are traded off against ease of access by nest predators.

Summary

Various measures have been shown to protect nest box contents from predators and competitors including mesh cages, small entrance holes, internal baffles and deeper nest boxes (Table W6.3). We found no formal tests of the efficacy of metal plates surrounding nest box holes or of bespoke willow tit artificial nest boxes which are both important evidence gaps.

Implications for guidance

Guidance on RSPB and BTO websites relating to nest box design is restricted to one commonly used measure for which we could find no supporting evidence (metal plates). Detailed guidance and mitigation evaluation is available in bespoke publications (du Feu 2003, Cromack 2013, Marcus et al 2024). Where not already included, users of NGO websites could usefully be provided with links to more specialist web pages providing more detailed advice.

Overall Summary

- Empirical tests of potential mitigation measures for ecological problems associated with SF were generally limited in number, scope and relevance to UK residential settings.
- Feeder cleaning reduces pathogen load (3 studies) but anti-microbial feeder surfaces did not affect *Salmonella* prevalence or persistence (1 study), and studies relating to *T. gallinae* mitigation are lacking.
- The temporary suspension of SF and water provision is recommended as a control measure for trichomonosis outbreaks in wild birds by multiple statutory and non-governmental organisations, but we found no studies that attempted to evaluate the efficacy of this mitigation measure.
- One study considered how SF influences the health of wild birds by evaluating the effects of feeder introduction and removal on avian health status and disease prevalence in the USA. Experimental year-round feeding (over a 3-year period) was associated with enhanced bird condition and health status but also with increased disease prevalence. Subsequent removal of supplementary food was associated with a return of health status and disease prevalence to pre-study levels.
- Higher feeder density increased transmission risk associated with *Mycoplasma gallisepticum* (2 studies) but studies relating to *T. gallinae* are lacking.
- Placing feeders close to woody vegetation cover to reduce assumed vulnerability to predation increases total bird usage although some species prefer feeders further from cover (3 studies). Predation risk was not measured in these studies.
- Proximity to feeders increases nest predation rates for open-cup nesting species the effect being evident up to at least 10m from feeders (3 studies).
- Placing feeders close to windows increases bird-window collision risk although the risk falls when feeders are very close to (within 1 m of) windows (2 studies).
- The use of bird feeders by grey squirrels reduces bird usage (2 studies) and feeder squirrel guards reduce feeder usage by both squirrels and by most bird species (1 study).
- Survival of nests in artificial boxes is enhanced by external mesh, entrance hole guards and baffles, and by deeper box cavities (5 studies).
- Nest boxes designed specifically for nest hole excavating willow tits have been used successfully but we found no formal trials of their efficacy in mitigating nest site eviction or nest predation. Expert opinion indicates the likelihood of willow tit nest boxes being occupied is low unless they are erected within occupied territories before nest site excavation begins. Consequently, this probably limits their practical application to situations where territorial behaviour can be intensively monitored.

- Priorities for further research include measures to mitigate pathogen persistence and transmission risk particularly in a UK context with respect to *T. gallinae*. A further priority is to understand the risks and benefits of year-round versus seasonal SF and specifically the relative importance of the fitness and disease-risk impacts. Other priorities are quantifying the relationship between nest survival and distance to feeder and testing the efficacy of measures aiming to reduce nest predation risk associated with nest boxes.

Table W6.1. Topics of mitigation of SF impacts based on search results, previous review questions that they link to, the issues they address and current best practice mitigation advice. Topics A1 to A8 are from Search A, and topic B is from search B. Advice is assigned to three-level categories: General guidance (i.e. general principles mentioned but minimal specifics); Specific guidance (i.e. specifics included such as detail of frequency or distance); and No guidance (i.e. nothing). Advice categories are also qualified by their level of promotion. GWH refers to the Garden Wildlife Health project (partnership between BTO, RSPB, Froglife and ZSL). Details of the advice are provided in Table AW6.2.

	W6 mitigation category	Linked W1–W5 Question(s)	Issue addressed	Current UK guidance
A1	Feeder hygiene	W4 (Disease transmission)	Build-up of pathogens on feeder surfaces and contaminated food, waste and faeces in the vicinity of feeding stations	**Strongly promoted specific guidance** (GWH, NGOs) - clean feeders weekly
A2	Feeder construction and design	W4 (Disease transmission)	Build-up of pathogens on feeder surfaces, with flat surfaces (tables/ground feeders) of particular concern where high pigeon, greenfinch and chaffinch use	**General guidance** (GWH, NGO) table and tray feeders not advised
A3	Feeder removal	W4 (Disease transmission), W5 (Species interactions)	High contact rates and disease spread at feeders during outbreaks	**Strongly promoted precautionary guidance** (GWH, NGOs) pause feeding if disease observed
A4	Feeder density	W4 (Disease transmission), W5 (Species interactions)	Elevated transmission risk due to crowding at feeders	**No guidance** on optimal feeder spacing or density
A5	Feeder placement – avian predation	W5 (Species interactions)	Increased exposure to predators while birds are feeding	**Specific guidance** (GWH, NGO) place feeders ca 2 m from cover
A6	Feeder placement – nest predation	W5 (Species interactions)	Attraction of nest predators to areas near feeders	**No guidance** on nest predation risks related to feeders
A7	Feeder placement - window collisions	None	Increased risk of injury or mortality from window strikes	**General guidance** (GWH) it is advised not to position feeders close to windows or greenhouses due to the risk of window collisions
A8	Squirrel competition	W5 (Species interactions)	Reduced access to food for birds due to interference by squirrels	**General guidance** (NGO) on use of guards and squirrel exclusion feeders
B	Predator resistant nest boxes	W5 (species interactions)	Increased nest predation pressure from increased density of some SF beneficiaries	**General guidance** (NGOs) on metal plates around access holes

Table W6.2. Number of metrics and studies located for each mitigation category subdivided by (a) continent and landscape context, and (b) study design and landscape context. See methods for more details.

(a)

	No. metrics													No. studies												
	N. America				Europe				Australasia					N. America				Europe				Australasia				
Mitigation category	Captive	Mixed	Peri-domestic	Wider countryside	Captive	Mixed	Peri-domestic	Rural	Captive	Mixed	Peri-domestic	Wider countryside	**Total**	Captive	Mixed	Peridomestic	Rural	Captive	Mixed	Peri-domestic	Rural	Captive	Mixed	Peri-domestic	Wider countryside	**Total**
Feeder hygiene	0	1	3	0	0	0	0	0	0	0	1	0	**5**	0	1	3	0	0	0	0	0	0	0	1	0	**5**
Feeder construction & design	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Feeder removal	0	0	0	1	0	0	0	0	0	0	0	0	**1**	0	0	0	1	0	0	0	0	0	0	0	0	**1**
Feeder density	1	0	7	0	0	0	0	0	0	0	0	0	**8**	1	0	1	0	0	0	0	0	0	0	0	0	**2**
Feeder placement – predation of feeder users	0	0	2	0	0	0	1	1	0	0	0	0	**4**	0	0	2	0	0	0	1	1	0	0	0	0	**4**
Feeder placement - nest predation	0	0	0	1	0	0	1	0	0	0	0	0	**2**	0	0	0	1	0	0	1	0	0	0	0	0	**2**
Feeder placement - window collision	0	0	2	1	0	0	0	0	0	0	0	0	**3**	0	0	2	1	0	0	0	0	0	0	0	0	**3**
Squirrel competition	0	0	0	0	0	0	3	0	0	0	0	0	**3**	0	0	0	0	0	0	3	0	0	0	0	0	**3**
Total	**1**	**1**	**14**	**3**	**0**	**0**	**5**	**1**	**0**	**0**	**1**	**0**	**26**	**1**	**1**	**8**	**3**	**0**	**0**	**5**	**1**	**0**	**0**	**1**	**0**	**20**

(b)

		No. metrics									No. studies								
		Experimental				Observational					Experimental				Observational				
	Mitigation category	Captive	Mixed	Peri-domestic	Wider countryside	Captive	Mixed	Peri-domestic	Wider countryside	Total	Captive	Mixed	Peri-domestic	Wider countryside	Captive	Mixed	Peri-domestic	Wider countryside	Total
A1	Feeder hygiene	0	1	3	0	0	0	1	0	**5**	0	1	3	0	0	0	1	0	**5**
A2	Feder construction & design	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**
A3	Feeder removal	0	0	0	1	0	0	0	0	**1**	0	0	0	1	0	0	0	0	**1**
A4	Feeder density	1	0	7	0	0	0	0	0	**8**	0	0	2	1	0	0	0	0	**3**
A5	Feeder placement – predation of feeder users	0	0	2	0	0	0	1	1	**4**	0	0	2	0	0	0	1	1	**4**
A6	Feeder placement - nest predation	0	0	1	1	0	0	0	0	**2**	0	0	1	1	0	0	0	0	**2**
A7	Feeder placement - window collision	0	0	2	1	0	0	0	0	**3**	1	0	1	0	0	0	0	0	**2**
A8	Squirrel competition	0	0	2	0	0	0	1	0	**3**	0	0	2	0	0	0	1	0	**3**
	Total	**1**	**1**	**17**	**3**	**0**	**0**	**3**	**1**	**26**	**1**	**1**	**11**	**3**	**0**	**0**	**3**	**1**	**20**

Table W6.3. Number of metrics located for each nest box mitigation sub-category subdivided by (a) continent and landscape context, and (b) study design and landscape context. See methods for more details.

(a)

	N. America			Asia			Europ e			
Mitigation sub-category	Peri-domestic	Wider countryside	Mixed	Peri-domestic	Wider countryside	Mixed	Peri-domestic	Wider countryside	Mixed	**Total**
1 Box material	0	0	0	0	0	0	0	1	0	**1**
2 Cavity depth	0	0	0	0	0	0	0	1	0	**1**
3 Construction quality	0	0	0	0	0	0	0	1	0	**1**
4 Hole guard	0	0	1	0	1	0	0	0	0	**2**
5 Hole size	0	0	0	2	1	0	0	0	0	**3**
6 Mesh cover	0	0	0	0	0	0	0	1	0	**1**
7 Multiple	0	0	0	0	0	0	0	1	0	**1**
Total	**0**	**0**	**1**	**2**	**2**	**0**	**0**	**5**	**0**	**10**

(b)

	Experimental			Observational			
Mitigation sub-category	Peri-domestic	Wider countryside	Mixed	Peri-domestic	Wider countryside	Mixed	Total
1 Box material	0	0	0	0	1	0	**1**
2 Cavity depth	0	1	0	0	0	0	**1**
3 Construction quality	0	1	0	0	0	0	**1**
4 Hole guard	0	0	0	0	1	1	**2**
5 Hole size	2	1	0	0	0	0	**3**
6 Mesh cover	0	1	0	0	0	0	**1**
7 Multiple	0	1	0	0	0	0	**1**
Total	**2**	**5**	**0**	**0**	**2**	**1**	**10**

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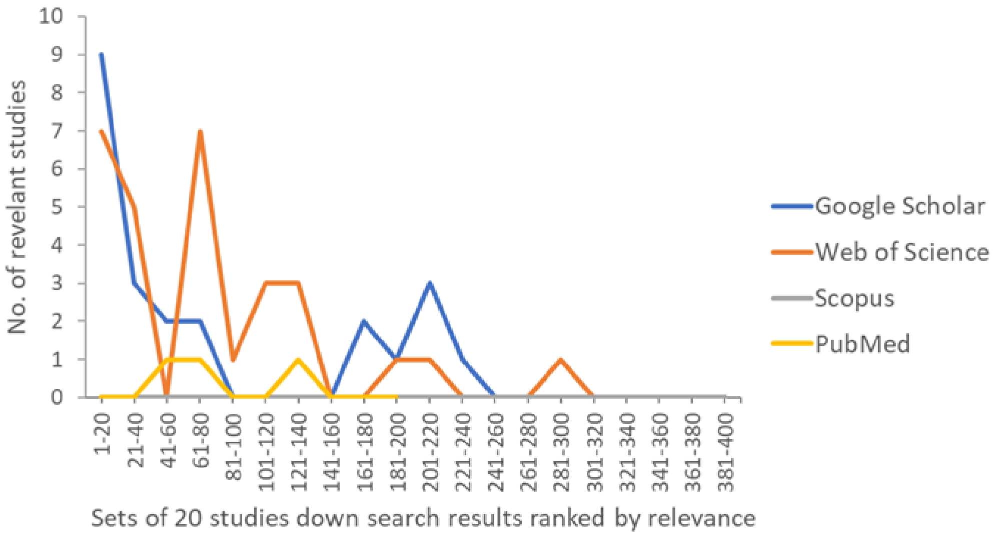
W6 Appendix

Table AW6.1. Question W6 search string.

Search	Part-1	Part-2	Part-3
A-general	(bird* OR avian)	AND (“feeder cleaning” OR “bird-feeder cleaning” OR “feeder hygiene” OR "feeder density" OR “feeder placement” OR “positioning of feeders” OR “feeder positioning” OR “squirrel guard" OR "squirrel cage" OR "squirrel proof" OR “squirrel cone” OR "window strikes" OR "bird-glass collisions" OR "bird-window collisions" OR "domestic cat" OR “felis catus” OR sparrowhawk OR “accipter nisus” OR aflatoxin OR “nest box” OR “nest boxes” OR predator* OR predation OR "predator management” OR “predation management”)	AND (feeder* OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "diet provision" OR "food subsidy" OR "feed subsidy")
B–nest boxes	(bird* OR avian)	AND (“nest box” OR “nest boxes”)	AND (design OR protection OR predation OR predator OR “predator-proofing” OR squirrel OR woodpecker)

Figure AW6.1. The numbers of relevant studies identified in each batch of 20 studies (or 'hit rate') out of the 400 most relevant studies selected by each of the four search engines. A hit rate declining to zero implies most relevant studies have been identified, but higher hit rates up to the 400 threshold implies some relevant studies were missed. Figure (a) shows the hit rate for search-A, while figure (b) for search-B. For both searches, the hit rate had reached zero by the 400-threshold suggesting that very few studies had been missed.

(a)



(b)

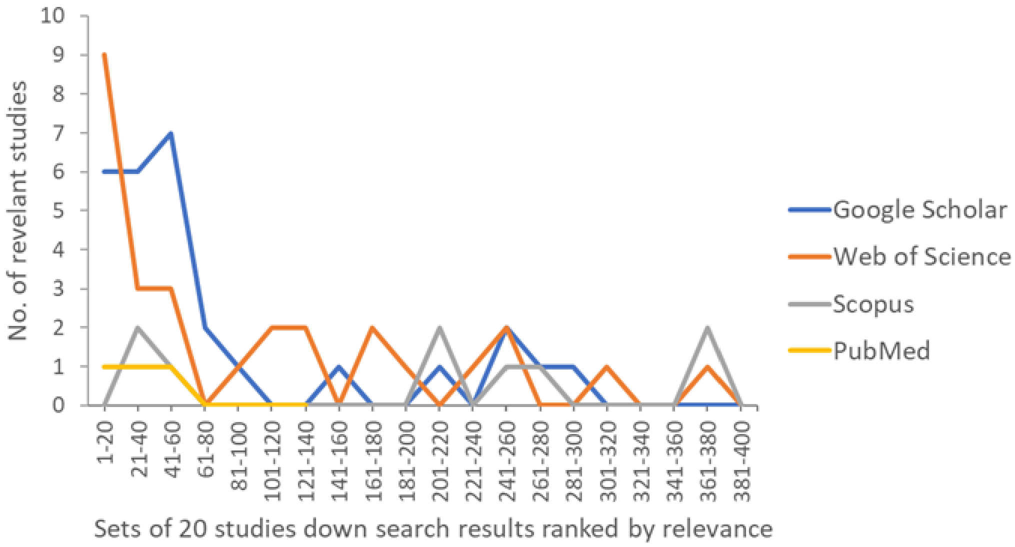


Table AW6.2. Relevant text from on-line guidance sources relevant to each mitigation topic (GWH refers to the Garden Wildlife Health project, a partnership between BTO, RSPB, Froglife and ZSL). Text accessed in June 2025.

(A1) Mitigating disease risk through feeder hygiene

Source	Relevant guidance
RSPB	Throw any leftover food from your bird feeder away into a bin. Fully dismantle your bird feeder. Use a non-toxic disinfectant like Ark-Klens or a mild (5%) bleach solution and our long-handled cleaning brush to scrub away any old food, waste and debris and clean the feeder. Rinse the individual parts of the feeder with fresh water once cleaned. Leave outside to dry and ensure they are completely dry before you reassemble.
BTO	Bird feeders, tables and bird baths should be regularly cleaned and disinfected (e.g. weekly) to avoid any build-up of food waste and bird droppings. Suitable disinfectants that can be used include a weak solution of domestic bleach (5% sodium hypochlorite) and other specially designed commercial products, diluted according to the instructions on the bottle. Before disinfecting feeders, dampen surfaces with water to reduce the chance of breathing in dry dust and wash off any dirt or debris as this will neutralise the disinfectant and reduce its effectiveness.
GWH	Bird feeders, tables and baths should be regularly cleaned and disinfected (e.g. weekly) to avoid build-up of food waste and bird droppings. Suitable disinfectants that can be used include a weak solution of domestic bleach (5% sodium hypochlorite) and other specially designed commercial products, diluted according to the instructions on the bottle. Before disinfecting feeders, dampen surfaces with water to reduce the chance of breathing in dry dust or aerosolised material and wash off any dirt or debris as this will neutralise the disinfectant and reduce its effectiveness. After disinfecting feeders, tables and baths, rinse them thoroughly with fresh water and allow them to air dry before re-filling with fresh, clean water. Where possible, bird feeding stations should also be sheltered from the weather (e.g. waterproof roofing) and tables should be designed with a slope to drain freely.
CWHC	Bird feeders should be cleaned and disinfected twice a month while in use. This involves using a scrub brush and hot soapy water to clean debris and bird faeces off of the feeders. Special attention should be given to the perches and openings where the birds have to place their heads inside to get access to the bird feed. After the feeders are washed and clean, they should be disinfected by immersion for two to three minutes in a solution of one part of liquid chlorine bleach and nine parts of warm water.
Audubon	The National Wildlife Health Centre recommends cleaning bird baths and feeders with a solution of nine parts water to one part bleach. (If there is visible debris, such as faeces, scrub it off before soaking in the bleach solution.) Dry out the feeder before hanging it back up. Project FeederWatch, a joint effort between Cornell Lab of Ornithology and Birds Canada, recommends cleaning seed feeders every two weeks or so. Double the frequency of cleaning if you suspect the presence of disease at all.
Cornell	Same advice as CWHC (via collaborative Project Feeder Watch).

(A2) Mitigating disease risk through feeder construction and design

Source	Relevant guidance
RSPB	RSPB has withdrawn sale of bird tables and tray feeders (https://shopping.rspb.org.uk/bird-feeders-boxes-tables/bird-feeders/garden-bird-tables)
BTO	None found
GWH	In gardens where pigeons, doves, European greenfinches or Eurasian chaffinches are known to visit, offering seed on table or ground feeders is not advised due to the increased potential for transmission of trichomonosis as these species are prone to this disease, which is transmitted via the saliva of infected birds, and may be present on dropped or regurgitated food. Feeders should be made of materials (e.g. metal, plastic) and be of a design that allows them to be easily dismantled and removed for regular cleaning and disinfection.
CWHC	None found
Audubon	SF presentation methods recommended were: ground, large hopper, large tube feeder, platform, small hopper, small tube feeder, suet cage.
Cornell	Mold and contaminated debris can attach to feeders, so to clean them, be sure to take them apart first and remove any visible debris (positive design feature implied).

(A3) Mitigating disease risk through feeder removal

Source	Relevant guidance
RSPB	If you see a sick bird on your feeders, stop feeding altogether, thoroughly clean your feeders and store away from the garden (e.g. in the garage or shed). Only resume feeding after 2-4 weeks but stop and repeat the process if you see any more sick birds.

BTO	If you see birds of any species that you suspect may be affected by disease in your garden, particularly if you see multiple sick or dead birds, we recommend that you stop feeding for at least two weeks (since you last saw an unwell bird) in order to encourage birds to disperse, thereby reducing the chance of birds infecting each other at your feeding stations. Only reintroduce feeding as long as you are no longer seeing birds with signs of disease and closely watch for any further signs. If you see further signs of disease, once again stop feeding. We also recommend leaving bird baths empty until no further sick or dead birds are seen.
GWH	If you have observed multiple sick or dead birds in your garden, it may be advisable to stop feeding for a period of at least 2-4 weeks. This encourages the birds in your garden to disperse, reducing the rate of disease transmission. During this period, birds using the feeders should be closely monitored and, if you see further signs of ill health, feeding should be held back for another 2-4 weeks. If the issue continues to recur, it is advisable to stop feeding for a longer period (e.g. 3-6 months).
CWHC	Once a disease outbreak is identified on a property, the bird feeders and artificial water sources should remain out of use until the end of the known transmission period for that disease. In the case of a summer or fall outbreak of trichomonosis, that would be after the first prolonged cold weather and frost of the winter. In the case of a winter or spring outbreak of salmonellosis or mycoplasmosis, that would be until the first warm weather and emergence of insects in the summer
Audubon	None found
Cornell	If you see a sick bird at your feeders, we recommend that you take down the feeders that the sick bird is using for a week or more to let the birds disperse and to assure that no disease is being spread at your feeders. If sick birds return once you put your feeders back up, avoid using feeders with large ports that birds put their heads into and wash your feeders at least weekly.

(A4) Mitigating disease transmission risk through feeder density

Source	Relevant guidance
RSPB	None found
BTO	If your garden size and design allow, have several sites where feeders can be positioned and rotate feeder locations between these regularly to reduce build-up of waste material in any one area. Offer different food types (e.g. seed and nuts, fruit, mealworms) at separate sites to reduce birds with different diets (e.g. seed-feeding, insectivorous) feeding together in close contact. Avoid placing feeders under garden features where birds perch or roost; this will prevent contamination with droppings.
GWH	Ideally, feeders should be placed at several different sites around the garden to minimise the build-up of food waste and bird droppings at any one site. Regularly rotating the locations of your feeders around the garden can further reduce this risk. Offering different types of foods at separate sites can also reduce close contact between species which would not feed together in the wild.
CWHC	To preclude large aggregations of birds at a single location which leads to high contact rates and increased potential for disease transmission, feeders should be placed at widely separated locations around a property.
Audubon	Cites National Wildlife Health Centre: “Spreading out food among a few feeders provides less opportunities for sick birds to touch and contaminate others.”
Cornell	None found

(A5) Mitigating the risk of predation of feeder users through feeder placement

Source	Relevant guidance
RSPB	Safe: not too close to bushes where predators could hide in wait, but close enough to cover so that birds can easily dart away. Birds like to have a view all around them while feeding.
BTO	None found
GWH	Whenever possible, feeders should be placed around two meters from dense vegetation. At this distance, cats are unlikely to be able to hide from view close to the feeder, yet birds can reach cover quickly if required.
CWHC	Place bird feeders < 3.5 metres from cover. Have an unobstructed view around bird feeders. Place fencing or barriers around low level bird feeders. Keep domestic cats indoors, on a leash, or in a kennel. If this is not possible, cats should wear an anti-predation collar. Use guarded feeders or install guards to discourage predators.
Audubon	None found
Cornell	The best solution is to take your feeders down for a few days. The hawk will get hungry and move on. Be sure to provide cover in your yard where feeder birds can hide from bird-eating hawks.

(A6) Mitigating the risk of predation of nests through feeder placement

Source	Relevant guidance
RSPB	None
BTO	Keep nest boxes away from bird feeders. High levels of activity of visiting birds could disturb nesting pairs.
GWH	Feeders should also not be placed near nest boxes or known nesting sites as this may draw potential predators into the area and increase the risk of nest predation.
CWHC	None found
Audubon	None found
Cornell	None found

(A7) Mitigating collision risk at windows through feeder placement

Source	Relevant guidance
RSPB	None found
BTO	None found
GWH	Finally, it is advised not to position feeders close to windows or greenhouses due to the risk of window collisions.
CWHC	Feeders should be placed either > 10 metres or < 1 metre away from windows, building walls, and vehicles and put decals on windows or attach streamers outside them to prevent bird collisions
Audubon	Reduce the risk of bird collisions by placing feeders less than three feet from a window or more than 30 feet away. Mobiles, opaque decorations, and fruit tree netting outside windows also helps to deflect birds from the glass.
Cornell	Some bird watchers have attached streamers or suction-cup feeders to their windows, crisscrossed branches within the window frames, or installed awnings or screens. Hawk “silhouettes” fastened to the window often help, not because they look like hawks, but because they break up the problematic reflections. Window strike mortalities also can be reduced by moving your feeders to within 3 feet of the window.

(A8) Mitigating squirrel competition at feeders

Source	Relevant guidance
RSPB	Look into investing in a squirrel buster feeder. The weight of a squirrel (or large bird) causes the feeder ports to shut, so they can’t access the food. You could also try plastic bottles, fixed so they revolve, slipped along the post, or one of the available squirrel deterrents or baffles from our shop.
BTO	None found
GWH	None found
CWHC	Squirrel baffles, or barriers placed between squirrels and feeders, are usually the best way to keep squirrels away from your seed. On pole-mounted feeders, baffles can be placed beneath the feeder to keep squirrels and other mammals from climbing the pole. Squirrels (and other mammals) may be deterred from consuming birdseed treated with capsaicin.
Audubon	Squirrels are best excluded by placing feeders on a pole in an open area. Pole-mounted feeders should be about five feet off the ground and protected by a cone-shaped baffle (at least 17 inches in diameter) or a similar obstacle below the feeder.
Cornell	Same advice as CWHC (via collaborative Project Feeder Watch).

(B) Mitigating nest predation and eviction risk using predator resistant nest box design

Source	Relevant guidance
RSPB	A metal plate fixed around the entrance hole may deter woodpeckers and squirrels
BTO	Consider a metal plate around the hole to deter squirrels. This preventive measure can be used to deter squirrels from gaining access. These plates are available commercially and can be purchased from any good garden centre or bird care company at very little cost.
GWH	Out of scope
CWHC	Out of scope
Audubon	None found
Cornell	These four common types of predator guards were compared in our national study. Types A (cone baffle), B (stovepipe baffle), and C (entrance hole extender) were equally effective, while D (Noel guard) was somewhat less effective.

Section 3: People questions

Introduction

The RSPB currently encourages members of the public to participate in year-round SF of birds and gives advice on the best types of food to provide during different seasons. In 2024 RSPB sales of bird food generated income of £9.9m. In 2009 it was estimated that 12.6 million UK households (48%) provided SF for birds, 7.4 million using bird feeders (Davies et al. 2009). Related research in 2024 found that 46.2% of the population “very often” or “often”, and another 20.2% “sometimes” provide food for wild animals such as birds (Natural England 2025). Whilst benefits of SF have been documented for provisioned species (see question W1) concerns are growing about potential negative ecological effects.

However, SF may provide a pathway for connecting people to nature that might lead to subsequent pro-conservation action (Behn et al. 2025; Carr and Hughes 2021; Hughes et al. submitted) and could also provide important well-being benefits for a wide range of people including those living in urban areas with limited access to nature (Barragan-Jason et al. 2023). Additionally, the bird food industry provides employment, tax revenues and is a route for some income for conservation organisations. Biodiversity conservation is the primary concern for the RSPB. Recognising certain conservation activities, such as SF, may act directly, indirectly, positively and negatively on biodiversity conservation, reviewing the evidence for the range of impacts is requisite to inform RSPB’s position on, and promotion of, activities.

SF is one of the few activities members of the public can undertake that enables them to relatively quickly and easily attract wildlife to their home. Feeding birds is one of the more accessible behaviours that people can conduct to engage themselves or family members with wild animals. While SF considered in this review does require equipment (e.g. feeder) and the purchase of food, feeders can be placed on balconies, window ledges or stuck to windows, as well as in a personal or shared garden and green spaces.

Feeding directly impacts conservation via the conservation status of some of bird species that consume the food (question W1) but also indirectly though impacts on people engaging in this activity. Indirect conservation impacts may occur as engagement in SF may connect people to nature and motivate other conservation behaviours among those that undertake it, known as behavioural spillover (Behn et al. 2025, Figure P1). Furthermore, people may also gain well-being benefits from SF and engaging with birds. However, feeding behaviour could also reduce participation in subsequent conservation activities, an effect known as moral licensing (Behn et al. 2025; Urban et al. 2021). By undertaking one pro-environmental behaviour, in this case SF, people may consider they have acted positively and therefore do not feel the need to undertake other pro-environmental behaviours or can even act negatively towards the environment.

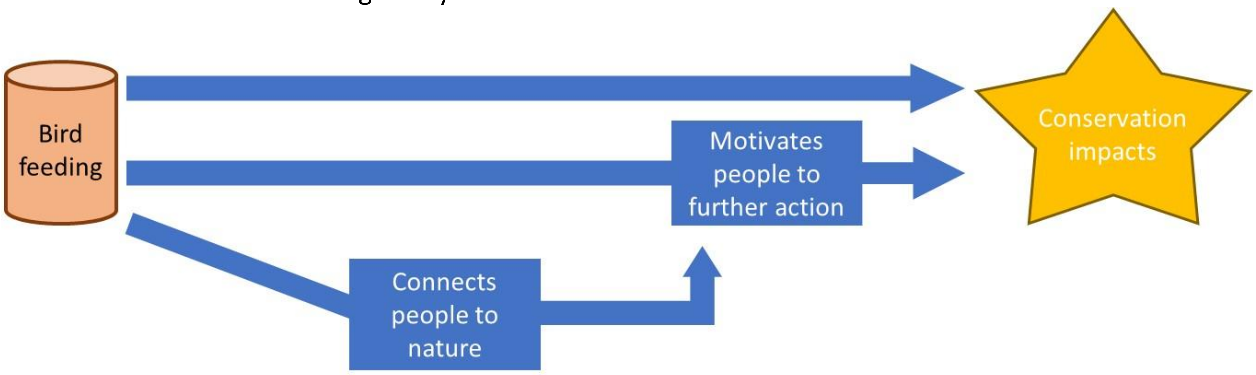


Figure. P1. SF may have both direct impacts on conservation related to the birds being fed and/or indirect impacts on conservation through motivating wider conservation behaviours.

Changes to SF recommendations may therefore have consequences for other conservation behaviours, for example if there is a link between SF and wider conservation behaviours, then reducing feeding activity may reduce occurrence of other behaviours. In the longer term, reducing feeding activity, which may be a gateway activity for people engaging with nature, may mean fewer people become connected to nature, which is known to correlate strongly with expressed pro-environmental behaviours (Barragan-Jason et al. 2023; Hughes et al. submitted; Mackay and Schmitt 2019). Furthermore, people may gain personal benefits from SF. Unless presented in an appropriate way, requesting people change a behaviour they gain personal benefits from may lead to negative perceptions of the RSPB/conservation community and risk negative consequences such as inaction, withdrawal from conservation or even negative actions towards conservation.

To inform the position of RSPB on SF we have conducted a review of scientific evidence on five questions:

1. What are the effects of involvement in SF in residential settings on people's well-being? *Aim: To understand potential impacts of any promoted changes in feeding behaviour on people's well-being*.
2. What is the relationship between involvement in SF in residential settings and people's connection to nature? *Aim: To understand potential impacts of any changes on people's connection to nature.*
3. What are the effects of involvement in SF in residential settings on people's likelihood of engaging in pro-environmental behaviour? *Aim: To understand potential impacts of any changes on people's pro-environmental behaviour, particularly whether SF leads to other behaviours or reduces the likelihood of other behaviours.*
4. Why do members of the public provide SF for birds in residential settings? *Aim: To understand motivations for SF that could inform a programme of behaviour change to alter feeding behaviour.*
5. What is the extent of public understanding of the risks and/or benefits of SF in residential settings? *Aim: To understand knowledge of wider impacts of SF and inform messaging used to change feeding behaviour.*

Methods

We anticipated a literature that was considerably more sparce than for the wildlife-focussed questions and adapted our inclusion criteria accordingly. We imposed no geographic limits on study inclusion but noted UK relevance when the results of individual studies were summarised. We also imposed no date limits on when studies took place. We included studies regardless of demographic or cultural contexts, but those that took place in public and domestic settings were of particular interest. Inclusion was open to all data collection approaches, highlighting in summaries when established measures were used. We included peer-reviewed studies and theses (Masters and Doctoral), along with book chapters and grey literature.

Studies were included based on title and abstract if there was a clear link to SF, defined as the intentional provision of food for wild birds (both in gardens and other settings such a public parks and nature reserves). Studies of the impact of unintentional food provision, such as birds feeding on waste food, were excluded. Studies were required to have a clear link to the people-focussed research questions, excluding those that only related to avian ecology. Studies that potentially related to multiple people-focussed research questions were marked as such and reviewed separately for each relevant question. Farmed birds (e.g. chickens) and long-term captive birds (e.g. pets, zoo animals) were excluded. In contrast to questions W1-6, we did not impose any taxonomic exclusions on the target bird beneficiaries of SF.
This subset of studies was then screened based on full text, retaining those that clearly focussed on links between provision of supplementary food for wild birds and the set of people-focussed research questions. At this stage all metrics relevant to each research question were extracted to a

spreadsheet for further consideration. Further details of this process are provided in Appendix A. Following Behn et al. (2025) and Galizzi & Whitmarsh (2019) study designs were classified as follows:

1. Qualitative (Qual) were studies involving interviews and open-ended surveys
2. Quantitative, cross-sectional (Quant, cross) were studies that collected data on a single occasion (single time-point surveys)
3. Quantitative, experimental (Quant, exp) were studies where an intervention was tested
4. Quantitative, longitudinal (Quant, long) were studies that followed a before-after design but with no intervention implemented
5. Mixed Methods (Mix) were studies that employed a mixture of quantitative and qualitative research methods.

Quantitative research may include some qualitative elements, for example open-ended questions, but generate data primarily for quantitative analysis. Similarly, qualitative research may include some quantitative data collection but apply mainly qualitative assessments of those data. Classification as ‘Mixed Methods’ required substantial components of the research to be both qualitative and quantitative.

P1. What are the effects of involvement in SF in residential settings on people's well-being?

Rationale

Described in the Oxford English Dictionary as "*the state of being healthy, happy, or prosperous; physical, psychological, or moral welfare"*, well-being is a broad term used as an umbrella for a wide variety of potential variables e.g. those contributing to physical and mental state, life satisfaction, sense of purpose and control, and may be measured at the individual, community or national level. The ONS (2022) conducted research into what people in Great Britain thought contributed to their own well-being. Mirroring results from previous research (see Evans 2011), dominant factors contributing to well-being were: Family members and their welfare; Physical or mental health; Personal financial situation; Friends or a community; Work or factors related to work; Good relationships or social interactions; Being happy; Doing things that have purpose; Being active or eating good food; Free time activities; Safety or security; Access to nature or outdoor spaces; Being free or able to do what I want.

The complex relationships between people's well-being and the nature present in their surroundings, or their experiences of nature can, and have been, studied in many ways. Research uses a variety of methodologies to investigate a variety of variables. While there are research gaps, green space, blue space, and levels of biodiversity (both flora and fauna) have been found to be positively related to aspects of both physical and mental health (Robinson et al. 2024; White et al. 2021), and it is generally accepted that there are beneficial effects of nature for people's well-being (Aerts et al. 2018). However, causal mechanisms for relationships between biodiversity and well-being variables remain unclear (Robinson et al. 2024).

When considering research specifically examining relationships between SF of birds and human well-being, literature should be viewed in the wider context of research examining relationships of bird abundance or species richness with human well-being. Research in this area has been conducted at the individual (Cameron et al. 2020), neighbourhood (Fuller et al. 2008), regional (Cox et al. 2017) and continental level (Methorst et al. 2021), showing a general positive relationship between these characteristics of avian communities and human well-being. However, as with the broader nature and human well-being research, relationships are correlative not causal.

Caveats to the positive research results between measures of avifauna abundance and richness with human well-being include the location - the measure of avian community may represent other features of nature, for example abundance and quality of greenspace and habitat, that may also align with social factors e.g. socio-economic status. Additionally, there may be different effects of biodiversity as perceived by people compared to actual biodiversity levels (Cox & Gaston 2016). Lack of defined causal pathways between nature experience and human well-being is an issue in comprehending these relationships.

Finally, when considering well-being effects, understanding the specific audience for whom these impacts may occur is also crucial. In the USA over a third of people who feed birds report physical or mental health challenges (Dayer et al. 2024). Data from the Natural England People and Nature survey (a national survey across England) showed that around 35% of people who responded positively to the statement "*I encourage wildlife in my [garden/space/garden or space] (e.g. feeding garden birds)*" report a health condition expected to last 12 months or more compared to around 30% of people overall (Natural England 2025). In addition, there is evidence that garden bird feeding increased during the Covid pandemic lockdown (Brock et al. 2021). SF may therefore provide a supportive, nature-based activity for people experiencing health challenges.

Methods

Literature search procedure
The literature search procedure is presented in Appendix A.

Study exclusions
Studies were excluded because of the lack of original data on SF or well-being variables.

Data extraction – response metrics
An inclusive approach was taken to any metrics considered to be influential on people's personal health or well-being.

Results

Literature composition
There is limited research relating SF to well-being (Table P1.1). The nine studies located that relate SF to human well-being were classified as two qualitative, three quantitative experimental, three quantitative cross-sectional and one mixed methods (Table P1.2). The two qualitative studies were based on interview data from unprompted mentions of wildlife from a broader study (Bell et al. 2018) and a specific investigation into bird-feeding relationships (Kirksey et al. 2018). The three experimental studies included a choice experiment (Brock et al. 2017), a bird feeding plus watching intervention (White et al. 2023) and a feeding intervention (Zieris et al. 2023). The three cross-sectional studies were a face-to-face survey of self-reported responses to bird feeding (Cox & Gaston 2016), an analysis of bird feeding in relation to neighbourhood deprivation status (Fuller et al. 2008) and an online survey of bird-feeding citizen scientists (Dayer et al. 2019). The mixed methods study combined qualitative interviews with a subsequent online, quantitative survey of a wider audience (Clark et al. 2019).

Well-being
Setting the scene of the potential impacts of bird feeding on people are the two qualitative studies. Qualitative studies based on interviews, while often small in sample size, can provide deep and rich information on topics, giving insights into the breadth of considerations for a topic rather than the extent of occurrence in a population. In the course of more general investigation into wildlife encounters and what they mean for people, Bell et al. (2018) found that bird feeding was considered a good way to bond with family (e.g. feeding ducks with children) and neighbours (e.g. interaction with neighbours over birds they have seen). The benefits of interactions over feeding birds identified by Bell et al. (2018) suggest ways in which SF can provide benefits to social well-being not shared by many other nature activities, as the mobile nature of birds means the event is different each time. Kirksey et al. (2018) focused on feeding cockatoos in Australia and revealed positive impacts of SF by supporting social relationships, both with the birds and other humans. However, the authors highlighted potential negative well-being impacts of feeding garden birds as feeding cockatoos, considered a pest by some, created conflict with neighbours that in severe cases led to the eviction of tenants.

Of the remaining seven studies, only one (White et al. 2023) used validated measures of aspects of well-being, while another examined neighbourhood-level correlations between SF, bird abundance and an index of social deprivation (Fuller et al. 2008). The other five studies used bespoke questionnaire survey statements to investigate factors linked to well-being such as a person's emotions, or social relations. While using bespoke survey statements can gain specific information from participants in a study, this approach can complicate comparisons with findings from studies that have used more widely accepted concepts of well-being unless some form of calibration has been conducted (e.g. Zieris et al 2023).

Of the six UK-based studies, which were all based on adults older than 18 years of age, Brock et al. (2017) and Clark et al. (2019) found personal enjoyment was the primary reason people provided for feeding birds. While activities conducted for enjoyment can increase well-being, how much the pleasure of bird feeding contributed to participants' overall well-being was not a focus of their research. Cox & Gaston (2016) found that the more regularly people fed birds, the more likely they were to 'strongly agree' or 'agree' with the statement "I feel relaxed when I watch birds in my garden". However, bespoke research statements like this are difficult to compare to other studies on well-being and to compare across a wider set of activities.

However, research using validated metrics of well-being also often carries inferential limits when applied to the question of the impact of SF. While White et al. (2023) used validated measures of anxiety and well-being to examine the effect of a garden bird watching event, the research compared two methods of watching birds. Motivated by previous research identifying psychological benefits of bird feeding, watching or listening to birds, White et al. (2023) examined whether the joy of simply observing birds or of counting birds was more impactful on well-being. They found significant positive effects of SF, with both groups showing decreased anxiety and increased well-being between pre and post bird watching. However, there was no control group ("no bird watching") in the same period to estimate magnitude of impact relative to a baseline.

Possibly the strongest research relating to this question comes from Zieris et al. (2023), which considered nursing home residents where a SF intervention was implemented. Surveys of residents were conducted across 65 nursing homes at three time points (pre-, post- and follow-up). A waitlist control sample provided data for comparison with pre-, post- and follow-up samples. Due to the vulnerable audience group (older adults aged 78 or more in care homes), not all individuals were surveyed repeatedly. The post-sample provided the largest sample, allowing cross-sectional analysis, which indicated an improvement in mobility (movement), social well-being (engagement with others about bird feeding) and cognitive resources (attention, working memory and executive function) related to engagement with the SF intervention. Pre-post data analysis showed an increase in cognitive resources, bird-related mobility and life satisfaction, with waitlist control data showing there were some, but smaller, increases in cognitive resources and social well-being in the control sample over the same period. Analysis of follow-up data showed that feeding over several months led to increases in cognitive resources, bird-related mobility and social well-being but not life satisfaction.

In contrast to the body of research focusing on the potential positive experiences of bird-feeding, Dayer et al. (2019) investigated observations of events at bird feeders in the USA that they hypothesised could cause negative well-being responses. Related to predation by cats and observations of disease, people reported feeling worried, sad and angry. However, as with the other studies examining positive emotional responses, the magnitude of the impact of these negative emotions on individual's well-being was not quantified. Some extrapolation of strength of impact can possibly be made from people's reported behavioural response: 1-2% of people would remove feeders in response to predation, nearly 10% reported they would remove feeders if they observed disease and it was hypothesised that people are more negatively impacted by the observation of disease. However, behavioural response is complex and not necessarily related to personal well-being impacts, but to other factors such as knowledge of SF impacts on bird populations and alternative options for removing such threats.

Finally, the Fuller et al. (2008) study was conducted at the neighbourhood level, and provides UK contextual information. The proportion of people in a neighbourhood feeding birds decreased with increasing social deprivation. Additionally, most measures of species richness and abundance increased with increasing prevalence of bird feeding (Fuller et al. 2008). The authors concluded that with fewer people feeding birds in areas of lower deprivation, there was a lower chance of seeing birds and gaining any well-being benefits.

Summary

- There is a small research base examining the relationship between SF and well-being making it difficult to draw general conclusions.
- While all research was conducted on adults, variation in location (and therefore cultures), measurements and aspects of well-being considered mean the evidence on SF and well-being relationships, plus implications for SF in the UK, are unclear.
- People report gains in personal pleasure and enjoyment from SF which suggests potential improvements in personal well-being.
- The qualitative research and experimental work in the care homes suggest that SF is a valued, simple, nature-based activity that can encourage people to interact and bond families or friends, potentially improving social well-being, but the magnitude of impact is unclear.
- SF is an accessible activity that takes place across different socio-economic groups and can increase people's opportunities for valuable interaction with biodiversity by increasing avifauna abundance in an area.
- Key knowledge gaps include the identity of the specific well-being benefits, conferred to which participant groups and magnitude of the impact relative to other activities that enhance well-being.

Table P1.1. Number of such results across the four search engines at successive stages of the review process for P1.

Search stage	Total Hits
Total search results	224,672
Number up to 400 threshold	680
Number with duplicates removed	532
Relevant based on title and abstract	24
Relevant based on full text	9

Table P1.2. Summary of evidence investigating the relationship between SF and human well-being. Dark green rows are UK based studies, light green rows are mainland European studies, white rows are rest of the world. Studies are classified as: Qualitative (Qual), Quantitative, cross-sectional (Quant, cross), Quantitative, experimental (Quant, exp), Quantitative, longitudinal (Quant, long), Mixed Methods (Mix) as per Behn et al. (2025). Some studies contribute multiple metrics (rows) to the table.

ID	year	Country	Habitat	Season	Feed type	Species	Study type	Duration	Data unit	Sample size	Audience	Metric	Effect
Bell et al	2018	UK	Urban	Unknown	Unknown	-	Qual	-	Individual	33	25-85 years old, 20 females, 13 males	Well-being: value of wildlife encounters for social well-being	Positive
Brock et al	2017	UK	Urban	July	Unknown	-	Quant, Exp	-	Individual	200	>18 years old, adults at garden centre	Well-being: enjoyment	Positive
Clark et al	2019	UK	Mixed	Winter	Unknown	Garden birds	Mix	<1yr	Individual	593 (30 interview,563 survey)	>16 years old, UK residents	Connection/Well-being: individual's response to feeding	Positive
Cox et al	2016	UK	Urban	Nov-July	Unknown	Garden birds	Quant, Cross	<1yr	Household	331	>18 years old	Connection/Well-being: Psychological benefits	Positive
Fuller et al	2008	UK	Urban	May-July	Unknown	-	Quant, Cross	-	Neighbourhood	35	Sheffield residents	Well-being: bird richness and abundance data in relation to data on bird feeding prevalence in a neighbourhood and Index of Multiple Deprivation	Positive
White et al	2023	UK	Unknown	Unknown	Unknown	Garden birds	Quant, Exp	30 mins	Individual	156	>18 years old, UK adults	Connection/Well-being: Joy rating	Positive
White et al	2023	UK	Unknown	Unknown	Unknown	Garden birds	Quant, Exp	30 mins	Individual	156	>18 years old, UK adults	Well-being: Anxiety measured by Spielberger state-trait anxiety inventory – short form	Positive
White et al	2023	UK	Unknown	Unknown	Unknown	Garden birds	Quant, Exp	30 mins	Individual	156	>18 years old, UK adults	Well-being: Positive affect and well-being scale - short form (Salsman et al 2013)	Positive
Zieris et al	2023	Germany	Unknown	Autumn or spring	Unknown	Unknown	Quant, Exp	<1yr	Nursing home	65/1684	78.5-83.9 years old	Well-being: Social	Positive
Zieris et al	2023	Germany	Unknown	Autumn or spring	Unknown	Unknown	Quant, Exp	<1yr	Nursing home	65/1684	78.5-83.9 years old	Well-being: Emotionally positive (3 items) and emotionally negative feelings (2 items)	Mixed

ID	year	Country	Habitat	Season	Feed type	Species	Study type	Duration	Data unit	Sample size	Audience	Metric	Effect
Dayer et al	2019	USA	Garden	Winter	Unknown	House finch	Quant, Cross		Individual	1176	>18 years old, citizen scientists for Project FeederWatch	Well-being: Emotional response to events at the bird feeder (seeing diseased bird, cat predation, hawk predation)	Mixed
Kirksey et al	2018	Australia	Urban	Unknown	Unknown	Cockatoos	Qual	-	Individual	10	Adults	Well-being: interspecific relationships	Positive
Kirksey et al	2018	Australia	Urban	Unknown	Unknown	Cockatoos	Qual	-	Individual	10	Adults	Well-being: interpersonal conflicts	Negative

P2. What is the relationship between involvement in SF in residential settings and people's connection to nature?

Rationale

"Connection to nature" is a broad, complex, psychological construct that describes a person's long-term relationship with nature and how much they feel part of a wider natural community (Carr & Hughes 2023; Zylstra et al. 2014). While the investigation of connection to nature in scientific research has increased exponentially in the past two decades (Richardson 2023), definitions and measurements are varied. Also referred to as "nature connection", "nature relatedness", "human-nature connection" and other variations, measurements can be on "short-term" (state) to "long-term" (trait) characteristics using validated or bespoke measures that examine various aspects of experience, self, knowledge or other aspects, and in relation to behaviour, health or well-being.
In wider research, connection to nature has been positively related to pro-environmental and pro-conservation behaviours, with people who have a stronger connection to nature more likely to undertake more frequent or more diverse behaviours (Mackay & Schmitt 2019; Whitburn et al. 2020). It is therefore important to build connection to nature amongst people in order to achieve the greater scale of action required to address biodiversity loss and climate change. Bird feeding may be important for developing or maintaining the connection to nature that delivers that action. Understanding how connection to nature and bird feeding are related is crucial for understanding the impacts of any change in feeding behaviour.

For this review we used the conceptual framework outlined by Zylstra et al. (2014) (Figure P2.1). In selecting studies for review, we have included research using validated connection measures and research investigating factors that could be considered components or indicators of connection.

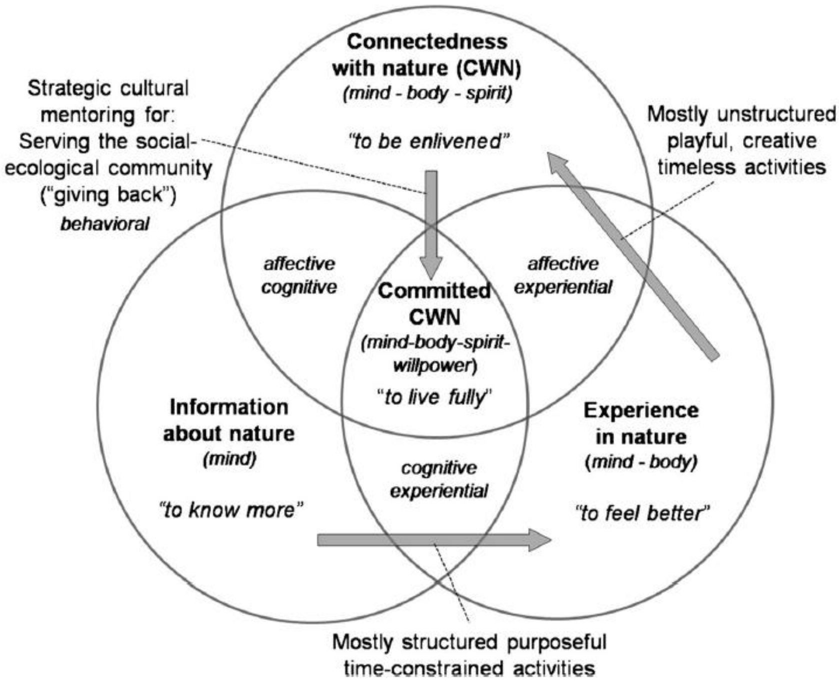


Figure P2.1 Conceptual framework of key components comprising connectedness with nature (CWN). The framework depicts CWN as comprising information about nature; experience in nature; connectedness with nature; and committed connectedness with nature. Information about nature is primarily based on cognitive concepts, intellect, and information as obtained through education or media to satisfy the mind's curiosity and increase knowledge. Experience in nature includes outdoor sports and recreation, facilitated eco-adventure and field trips, and is usually sought after to help the body and mind feel better or to support experiential learning. See Zylstra et al (2014) for further detail.

Methods

Literature search procedure

The literature search procedure is presented in Appendix A.

Study exclusions

Studies were excluded if they lacked original data on SF or variables that were, or could be, considered related to the broad construct of “connection to nature” (Carr & Hughes 2023; Zylstra et al. 2014).

Data extraction – response metrics

An inclusive approach was taken to any variables considered to be influential on people’s “connection to nature”. This included knowledge where it was measured as an indicator of participant’s engagement in feeding rather than a test of learning ability and knowledge of species identification or ecology.

Results

Literature composition

Eleven studies provided 17 metrics that were either direct measures of connection to nature (using validated measurement scales, n=4) or could be considered as contributing to, or indicators of, connection to nature (n=13) (Table P2.1). The latter included four ‘knowledge’ metrics, where participants’ ability to identify bird species was measured. While knowledge of bird species could be considered nature-based learning and not a good indicator of connection as it may reflect any positive or negative emotional relationship with birds, we have included it here as it was usually measured as an indicator of the interest in the activity rather than a knowledge test.
The 11 studies comprised: one mixed methods study combining qualitative interviews with subsequent online, quantitative survey to a wider audience (Clark et al. 2019), three quantitative experimental studies of bird feeding interventions delivered in schools and evaluated by pre-post surveys (Hammond 2021; Jensen et al. 2024; White et al. 2018), a bird feeding plus watching quantitative experimental study (White et al. 2023), one experiment providing feeders or other wildlife gardening equipment to people (van Heezik et al. 2020), two cross-sectional studies of data from a face-to-face survey of self-reported responses to bird feeding (Cox & Gaston 2015, 2016), cross-sectional research on care home residents (Zieris et al. 2023), a cross-sectional comparison of feeders and non-feeders at an urban wetland (Henson et al. 2023), and a cross-sectional survey of feeding in urban areas (Galbraith et al. 2014) (Table P2.2).

Connection to nature

For the 4 papers that measured connection to nature using validated scales (Hammond 2021; Henson et al. 2023; van Heezik et al. 2020; White et al. 2023), there were three experimental trials (Hammond 2021; van Heezik et al. 2020; White et al. 2023) that used pre-post assessments of bird feeding interventions. Of these, one USA study showed positive change in connection to nature over 1 month for adults but not children, one New Zealand study reported no change, while the UK study showed a positive relationships between nature connection and time spent bird watching (although there was no non-bird watching control group for comparison) and with people’s ‘joy’ at seeing a bird species. The Australian study was cross-sectional and reported no difference in connection to nature between feeders and non-feeders at a nature reserve. It caveats, however, that the research location meant the participants may have been a biased subset of the population who showed higher than average initial connectedness to nature.

Factors contributing to, and potentially indicative of, connection to nature

Other metrics measured experimentally through a pre-post feeding intervention were attitudes towards birds, and people’s ratings of joy from bird watching. Changes in attitudes and joy may be indicative of changes in the affective component of nature connection. One 6-week study in England (White et al. 2018) demonstrated an increased positive attitude towards birds, where people's emotional relationship with birds increased significantly during the intervention. A shorter 2-3 week intervention in Sweden (Jensen et al. 2024) did not detect a change in attitudes. Participant joy increased over the course of a 30 minute bird watch in the UK (White et al. 2023).

Five papers (Clark et al. 2019; Cox & Gaston 2015, 2016; Galbraith et al. 2014; Zieris et al. 2023) conducted cross-sectional, and therefore non-causal, observational research through surveys of bird feeding and non-bird feeding participants. All studies showed a positive relationship between people who fed birds and their emotional relationship with nature. In one UK study, personal pleasure, a positive emotional response, was the reason for feeding for 93% of people surveyed, with 57% mentioning species survival (compassion) and 40% making comments illustrating their sense of belonging to nature. People who fed birds were more likely to strongly agree or agree with statements about their nature connection and reported being more relaxed than people that did not feed birds, with regular feeders of birds reporting being more relaxed than irregular feeders. Time spent noticing birds (a route to developing connection to nature) was also positively related to how connected to nature a person felt and their knowledge.

In the four studies including a measurement of knowledge (the participant's ability to correctly identify species), there was a positive relationship between SF and participants' ability to identify birds (Cox & Gaston 2015; Jensen et al. 2024; van Heezik et al. 2020; White et al. 2018). Although this knowledge metric itself is not a component of connection to nature, learning can be a pathway to connection and the two are often correlated. However, knowledge was used in some of these studies to indicate engagement with, and therefore potential enjoyment of, the activity so we include it here. In the Swedish experimental research on school children (Jensen et al. 2024), while participants' knowledge improved, their attitude towards birds did not change. However, in a cross-sectional study of UK adults (Cox & Gaston 2015), knowledge of species identify was positively related to the connection to nature people feel when they feed birds.

<u>Summary</u>

- There is a small research base examining the relationship between SF feeding and connection to nature, making it difficult to draw conclusions.
- Variation in measures used, and non-validated scales being a poorer measure of connection, makes some results hard to relate to the "connection to nature" construct.
- Variation in audiences (children and adults), location (and therefore cultures) and measurements used mean the evidence on the relationship between SF and "connection to nature", specifically for UK feeders, are unclear.
- Similarly, the cross-sectional methods or short duration of interventions (with shorter-term studies having little evidence of persistent change), makes it difficult to draw overarching conclusions on effects on nature connection.
- Given these caveats, positive relationships are generally observed between SF of birds and nature connection. However, causality and effect size is difficult to establish. It is likely that the act of feeding birds will regularly reinforce the positive relationship between people and nature through stimulating a variety of positive responses in those that undertake it.

Table P2.1. Number of such results across the four search engines at successive stages of the review process for P2.

Search stage	Total Hits
Total search results	9,440
Number up to 400 threshold	340
Number with duplicates removed	312
Relevant based on title and abstract	33
Relevant based on full text	11

Table P2.2. Summary of evidence investigating the relationship between SF and connection to nature. Dark green rows are UK based studies, light green rows are mainland European studies, white rows are rest of the world. Studies are classified as: Qualitative (Qual), Quantitative, cross-sectional (Quant, cross), Quantitative, experimental (Quant, exp), Quantitative, longitudinal (Quant, long), Mixed Methods (Mix) as per Behn et al. (2025). NR/NR6 = nature related metrics, INS = inclusion of nature with self metric, CTN/CN-12/CNS = different connection to nature metrics.

ID	year	Country	Habitat	Season	Feed type	Species	Study type	Duration	Data unit	Sample	Audience	Metric	Effect
Clark et al	2019	UK	Mixed	Winter	Unknown	Garden birds	Mix	<1yr	Individual	593 (30 interviews, 563 survey)	>16 years old, UK residents	Connection/Well-being: individual's response to feeding	Positive
Cox et al	2016	UK	Urban	Nov-Jul	Unknown	Garden birds	Quant, cross	<1yr	Household	331	>18 years old	Connection to nature: Psychological benefits	Positive
Cox et al	2016	UK	Urban	Nov-Jul	Unknown	Garden birds	Quant, cross	<1yr	Household	331	>18 years old	Connection to nature: Nature orientation	Positive
Cox et al	2015	UK	Urban	Nov-Jul	Unknown	Garden birds	Quant, cross	<1yr	Household	331	>18 years old	Connection to nature: knowledge of birds	Positive
Cox et al	2015	UK	Urban	Nov-Jul	Unknown	Garden birds	Quant, cross	<1yr	Household	331	>18 years old	Connection to nature: experience	Positive
White et al	2018	UK	Urban	Apr-May	Unknown	Garden birds	Quant, exp	6 weeks	Individual	204 (8 schools, 8 classes)	7-10 years old	Connection to nature: Knowledge of birds	Positive
White et al	2018	UK	Urban	Apr-May	Unknown	Garden birds	Quant, exp	6 weeks	Individual	204 (8 schools, 8 classes)	7-10 years old	Connection to nature: Attitudes towards birds (10 items)	Positive
White et al	2023	UK	Unknown	Unknown	Unknown	Garden birds	Quant, exp	30 mins	Individual	156	>18 years old, UK adults.	Connection to nature: NR6 (Nisbet & Zelenski 2013), and INS (Schultz 2002)	Positive
White et al	2023	UK	Unknown	Unknown	Unknown	Garden birds	Quant, exp	30 mins	Individual	156	>18 years old, UK adults	Connection to nature: Joy rating	Positive
Jensen et al	2024	Sweden	Urban	Winter	Seed, tallow, peanuts	Unknown	Quant, exp	2-3 weeks	School	6 - 8 schools (285 pupils)	10-11 years old	Connection to nature: attitudes (8 items), outdoor experiences	No effect
Jensen et al	2024	Sweden	Urban	Winter	Seed, tallow, peanuts	Unknown	Quant, exp	2-3 weeks feeding	School	6 - 8 schools (285 pupils)	10-11 years old	Connection to nature: knowledge of birds	Positive
Zieris et al	2023	Germany	Unknown	Autumn/ Spring	Not disclosed	Unknown	Quant, cross*	4-11 months	Home & resident	65 homes, 1684 residents	78.5-83.9 years old	Connection to nature: 3-item scale based on the CNS	Positive

ID	year	Country	Habitat	Season	Feed type	Species	Study type	Duration	Data unit	Sample	Audience	Metric	Effect
Hammond et al	2021	USA	Urban	Autumn	Seed	Unknown	Quant, exp	1 month	Classroom	19, 4 schools	11-12 years old, and parents	Connection to nature: NR for parents, CTN for children	Mixed
Henson et al	2023	Australia	Urban/ Wetland	Jan-Feb	Multiple	Water birds	Quant, cross	5 weeks & 2 years	Individual	206	19-18 years old	Connection to nature: CN-12 (Hatty et al 2020)	No effect
Galbraith et al	2014	New Zealand	Urban	Nov-Dec	Unknown	Garden birds	Quant, cross	4 weeks	Household	801	>18 years old	Connection to nature: pleasure, compassion	Positive
Van Heezik et al	2020	New Zealand	Urban	Summer	sugar-water, seeds	Garden	Quant, exp	6 months	Individual	42 overall, 25 feeding birds	adults (>21 years old)	Connection to nature: NR (Nisbet et al 2009) & 2 items	No effect
Van Heezik et al	2020	New Zealand	Urban	Summer	sugar water and seeds	Garden	Quant, exp	6 months	Individual	42 overall, 25 feeding birds	adults (>21 years old)	Connection to nature: Knowledge of species	Positive

*. Zieris et al 2023 was categorised as "quant, exp" for question 1 on well-being however the "emotional affinity towards nature" was only reported from the cross-sectional data analysis

P3. What are the effects of involvement in SF in residential settings on people's likelihood of engaging in pro-environmental behaviour?

Rationale

Little is known about spillover effects of pro-environmental behaviours, essentially how conducting one pro-environmental behaviour may lead to an individual taking up other such behaviours. A recent review of environmental behaviours and spillovers by Behn et al. (2025) unites previous studies to propose a conceptual framework for how antecedents, behaviours and the outcomes are linked. The framework recognises that internal and external factors influence an individual's propensity to undertake an action, as does the type of initial action being considered. Following Dolan & Galizzi (2015), the framework outlines how the type of spillover behaviour subsequently observed can then be both positive or negative. For example, if the initial action is positive for the environment this might promote another environmentally positive action or, through moral licencing may mean the actor permits themselves to undertake an environmentally negative action (Urban et al. 2021). Alternatively, if the initial action is negative, this may lead to a pro-environmental 'purging' action or precipitate further negative actions. Spillovers can be behavioural, temporal or contextual (Behn et al. 2025; Nilsson et al. 2017). A behavioural spillover is where one behaviour leads to a different behaviour, a temporal spillover is where the original behaviour occurs at a later point in time, and a contextual spillover is the same behaviour in a different setting for example at home and at work.

SF of birds is a positive activity that could initiate behavioural spillovers and promote engagement in other pro-conservation behaviours, or permit environmentally negative actions (Behn et al. 2025; Dolan and Galizzi 2015). Spillovers may be behavioural, for example leading to other wildlife gardening behaviours, temporal, for example an initial feeding activity leads to repeated bird feeding, or contextual, for example feeding birds at home may lead to establishing feeding stations in community spaces or suitable work environments. As such, it is necessary to understand how altering the occurrence of SF at home may affect uptake of further behaviours and potentially impact other conservation goals.

Methods

Literature search procedure

The literature search procedure is presented in Appendix A.

Study exclusions

Studies were excluded because of a lack of original data on SF or variables that were, or could be, considered behaviours that would have a positive or negative impact on the environment.

Data extraction – response metrics

An inclusive approach was taken to any variables considered incorporate pro-environmental behaviours. This could include behaviours that may not have a direct impact on species and habitats but could be considered to indirectly impact them, for example campaigning action. Measures of intention to act were also included.

Results

Literature composition

There were only four papers in the literature review that related participation in the SF of birds to other pro-environmental behaviours (Table P3.1). Three papers reported a positive association between SF and such spillover behaviour, while one reported a negative association between garden bird feeding and a specific conservation behaviour.

Three papers were UK based: one was a mixed methods study of a bird feeding intervention experiment (White et al. 2018), the second was quantitative experimental research examining people's stated responses to different scenarios (Brock et al. 2017) and the third was a quantitative cross-sectional survey of behaviours (Goddard et al. 2013). A fourth USA study was qualitative research on bird feeders and willingness to contribute to citizen science (Martin and Greig 2019) (Table P3.2).

Pro-environmental behaviour

White et al. (2018) considered two behavioural outcomes for students. Firstly, participation in a bird feeding exercise for 4 weeks at school encouraged some children, who had never previously fed birds, to go bird watching outside of school (20% of students). Secondly, taking behavioural intention as an indicator of future behaviour, 90% of the children wished to continue feeding birds, more than 80% wished to carry on surveying birds and 86% wanted to continue learning about wildlife. Anecdotally, White et al. (2018) also reported evidence of spillover behaviour where some children asked parents to put bird feeders out at home. With regards to behavioural outcomes for teachers, there was a follow-up survey after one year. At follow-up, 50% (4/8) of teachers reported they were still feeding birds, and bird watching or surveying with classes. Two schools had gone on to take up the annual RSPB Schools Birdwatch survey, with another school planting wildflowers and making bee-friendly habitat.

Martin & Greig (2019) conducted a survey of people aged 18-50 years old who fed garden birds and who were currently not taking part in Project FeederWatch, a citizen science programme in the USA. By reaching out through different channels they surveyed 72 feeders. As part of a wider study on bird feeding motivations, they asked people whether they would be interested in participating in Project FeederWatch and 93% were willing. This demonstrated that bird feeding can motivate people to participate in citizen science (a pro-environmental behaviour) and suggests that closely related pro-environmental behaviours may be attractive to them. Motivations to participate in the citizen science project included recording bird monitoring data, contributing to scientific knowledge and potential personal benefits such as enjoyment of the activity and giving their existing birdwatching behaviour a wider purpose.

The study by Goddard et al. (2013) was a cross sectional survey conducted in Sheffield, UK, investigating metrics related to wildlife gardening behaviours. One metric was an Environmental Activity Index (EAI), which asked respondents whether they took part in none, one, or more than one of the following: 1. Household waste recycling; 2. Allotment gardening; 3. Practical conservation; 4. Wildlife surveys; 5. Other. A positive correlation was found between the frequency of bird feeding (binomial response variable: frequent vs. infrequent) and increasing EAI score (among a set of explanatory variables). The study did not formulate a causative hypothesis between the two metrics, and the correlation might reflect a relationship between SF and some other environmental behaviours.

Finally, Brock et al. (2017) investigated people's willingness to pay for Eurasian bittern conservation through their bird food purchase. People buying bird food at a garden centre participated in a choice experiment, one part of which was on the price of bird food in relation to factors such as the nutritional content for species. Respondents were also told that some of the price options included a contribution to bittern conservation through a wildlife charity. The results showed the additional cost of conservation action deterred people from purchasing the bird seed. This is an example of a pro-conservation behaviour pathway that may have negative effects. However, the specificity of the spillover action and pathway to action (payment) may be the issue rather than suggesting that SF in gardens does not motivate wider conservation action.

Summary

- The four studies do not constitute a strong evidence base. They are indicative of a depauperate evidence base rather than suggesting no link between SF and pro-environmental behaviours.
- The proliferation and widespread continuation of SF in the UK is, in itself, evidence of temporal behavioural spillover.
- Regarding leading to other environmental behaviours, there is some evidence that SF of birds can prompt people, particularly children, to take more pro-conservation action, for example, people that feed birds can be motivated to use their activity for wider scientific benefits.
- There was evidence from teachers in the White et al. (2018) study of SF leading engagement in other wildlife conservation action in the school grounds, however the sample size was small.
- Further investigation is required into the role that the accessible, inclusive activity of SF has in initiating other pro-conservation actions. SF is often carried out with children and could therefore initiate action throughout their life course.

Table P3.1. Number of such results across the four search engines at successive stages of the review process for P3.

Search stage	Total Hits
Total search results	8,963
Number up to 400 threshold	702
Number with duplicates removed	576
Relevant based on title and abstract	12
Relevant based on full text	4

ID	year	Country	Habitat	Feeding season	Feed type	Species	Study type	Duration	Data unit	Sample	Audience	Metric	Effect
White et al	2018	England	Suburban	April/ May 2016	Unknown	Mixed (21 species observed)	Mix	6 weeks (2 weeks monitoring only followed by 4 weeks feeding + monitoring)	School/ Class/ Individual	8/8/220	7-10 years old plus teachers	Behaviour: Number of nature activities engaged in in the last year and during project	Positive
White et al	2018	England	Suburban	April/ May 2016	Unknown	Mixed (21 species observed)	Mix	6 weeks (2 weeks monitoring only followed by 4 weeks feeding + monitoring)	School/ Class/ Individual	8/8/220	7-10 years old plus teachers	Behaviour: Future intentions of students	Positive
White et al	2018	England	Suburban	April/ May 2016	Unknown	Mixed (21 species observed)	Mix	6 weeks (2 weeks monitoring only followed by 4 weeks feeding + monitoring)	School/ Class/ Individual	8/8/220	7-10 years old plus teachers	Behaviour: Teaching behaviour follow-up after 1 year	Positive
Brock et al	2017	England	Urban	Unknown	Unknown	Multiple	Quant, exp	<1 month	Individual	200	>18 years old, Adults at garden centre	Behaviour: Bird feeding experience and hypothetical willingness to contribute to bittern conservation through cost of the bird food	Negative
Goddard et al	2013	England	Urban	Unknown	Unknown	Unknown	Quant, cross	Unknown	Household	533	18+ years old	Behaviour: relationship between bird feeding and bespoke Environmental Activity Index (5 item scale)	Positive
Martin et al	2019	USA	Rural and Urban	Unknown	Unknown	No	Qual	Unknown	Individual	72	18-50 years old	Behaviour: participation in environmental citizen science activities	Positive

Table P3.2. Summary of evidence investigating the relationship between SF and pro-conservation behaviours. Dark green rows show UK studies, white row rest of the world. For definition of study types see Table P3.1. Each row in the table represents a single metric with some studies providing multiple metrics.

P4. Why do members of the public provide SF for birds in residential settings?

Rationale

As highlighted by the COM-B (capability, opportunity and motivation) framework of behaviour change (Michie et al. 2011), understanding motivation is key to understanding behaviour and for designing interventions or programmes to enable behaviour change. The COM-B framework outlines how motivation works in conjunction with opportunity and capability to influence behaviour. Capability can be both psychological and physical, opportunity can be social and physical, while motivation can be both reflective, a conscious process of consideration, and automatic, an unconscious process as exhibited in habits and emotional responses. If any changes to SF behaviour are to be recommended for people who feed birds in UK gardens, understanding why people are motivated to undertake this behaviour is key to enabling this change. In contrast to questions P1-P3, the evidence review for this question is about eliciting motivations rather than assessing the effect as positive or negative. Motivations for feeding and motivations underlying any recorded changes to feeding behaviours were of interest.

Methods

Literature search procedure

The literature search procedure is presented in Appendix A.

Study exclusions

Studies were excluded because of lack of original data relating to motivation for SF of birds.

Data extraction – response metrics

An inclusive approach was taken to any variables considered to be motivations. There was some blurring of distinction between responses to, and motivations for, feeding. For example, people identifying personal pleasure as a response to feeding in some cases was then reinterpreted as a motivation for feeding. Whilst seemingly logical this is not necessarily the case. However, authors' interpretations of motivations were used here. Unlike previous 'People' questions, metrics were not ranked as positive, neutral or negative, as the impact of motivation was not being evaluated. Instead, motivation to feed is a crucial contextual variable to understand when considering any changes to behaviour.

Results

Literature composition

Twelve studies were selected as being relevant to this question (Table P4.1). These were conducted across a range of countries: UK (2), Finland (1 study, 2 articles), Australia (3), North America (1), South Africa (1) and New Zealand (2). The range of countries means there are diverse cultures and environments represented that may impact the relevance of these results to the UK situation. There was one mixed methods study (Clark et al. 2019) while all the others were cross-sectional surveys. Six studies examined feeding behaviour for specific species or species groups: red kite in the UK (Orros & Fellowes 2014), waterbirds in Australia (Henson et al. 2023), African woolly-necked storks in South Africa (Thabethe & Downs 2018), nectivores in New Zealand (Galbraith et al. 2014) and the New Zealand kãkã parrot (Mavrotheris et al. 2020) (Table 4.2). One study considered reasons for feeding at a popular park where some birds had become problematic (Ballantyne & Hughes 2006). While the supplementary food types (e.g. meat or sugar water) or locations (e.g. in protected areas) of these studies may not align with the main subject of this review (bird feeding in residential settings), they were included to provide insights into people's motivations for feeding wild birds. Research on motivations was primarily conducted through questionnaire surveys for quantitative analysis, that contained suggested reasons for motivations, often with an "other" option for providing alternative motivations. Supplying proposed answers without identifying how these options were selected makes it harder to establish how well the options genuinely reflect the motivation to feed. Indeed, participants may have adjusted their response to fit the available options. One exception to this is the research by Clark et al. (2019) where they conducted interviews on which they based their questionnaire. Furthermore, the work on red kites and kãkã parrots, while providing options for motivations to feed, included open-ended questions asking why people ceased feeding.

Regarding possible participant bias, study participants were mainly self-selected and recruited through media channels and organisational networks. For example, Clark et al. (2019) mentioned adverts were place in a range of conservation organisation publications and a high proportion of the respondents (47%) were members of conservation organisations. This is not representative of the UK population and may mean results only reflect the motivations of people who were more engaged with the topic of SF. However, until we know more about the UK population of people who feed birds, it is difficult to evaluate the levels of bias present.

Motivations

The main motivation for feeding birds expressed across the research reviewed, was personal pleasure. Indeed, the benefits that people gained for themselves from feeding birds were frequently cited as motivations, for example enjoyment at seeing birds, getting close to birds, bringing nature into the area and hearing birdsong (Aivelo et al. 2025; Clark et al. 2019; Erastova et al. 2021; Galbraith et al. 2014; Henson et al. 2023; Horn & Johansen 2013; Ishigame & Baxter 2007; Orros & Fellowes 2014; Thabethe & Downs 2018). Broader social benefits, for example entertainment and education for children were also referenced across the research (Ballantyne & Hughes 2006; Clark et al. 2019; Galbraith et al. 2014; Henson et al. 2023; Horn & Johansen 2013; Ishigame & Baxter 2007). It was also apparent that people found the well-being benefits and the opportunity to connect to nature as motivations for people to feed birds. Other motivations, mentioned by smaller numbers of respondents, included compensating for environmental damage caused by humans, and the opportunity to use up left-over food to reduce food waste (Clark et al. 2019; Galbraith et al. 2014; Henson et al. 2023; Thabethe & Downs 2018). The latter was a consideration for the feeding of African woolly-necked storks (Thabethe & Downs 2018) and suggests the people can use SF as a response to a species specific threat. However, the benefits of feeding for the birds were not the primary motivation for feeding cited in any of the research. Indeed Horn & Johansen (2013) found it the fourth most popular motivation in their study of feeding behaviour in USA and Canada.

Considering motivations to cease feeding, non-feeders in Australia expressed concerns for birds (not in the birds best interests, or the risk to them posed by pets), although lack of personal interest was also a factor (Ishigame & Baxter 2007). Similarly the negative consequences of SF on New Zealand kãkã parrot health was a factor in not feeding but damage to property was also mentioned (Mavrotheris et al. 2020). The most comprehensive work available on why people stop feeding was the Finnish study by Deshpande et al. (2025). This research surveyed people's changes in feeding behaviour from 2000-2020. Of the 1989 people that stopped or reduced feeding, the primary reasons were the attracting of rats, complaints from neighbours, impact of pets, disease and moving away from the area. The importance of these reasons varied by geographic location and level of urbanisation. More detailed analysis of this dataset by Aivelo et al. (2025) showed the most popular reason for decreasing feeding was the presence of unwanted bird species at the feeder. Concern regarding potential spread of disease to humans was the second most frequently selected reason, with concern regarding disease spread between birds the third.

In the two UK-based studies, pleasure was the primary motivation for feeding. Orros & Fellowes (2014) study of red kites found that 62% of people participated to see the birds up close, while 48% for the conservation of the species. People could select multiple answers so this indicates the breadth of motivation across the feeding population but not necessarily the strength. Building on previous research by Chapman (2015) that considered reasons that people feed wildlife, results from Clark et al. (2019) for SE England, showed that the majority of respondents strongly agreed with the item “Feeding birds gives me pleasure” which was more than any other motivation. Feeding birds to improve bird survival was the second most popular motivation but significantly more important to female than male respondents, and members versus non-members of conservation organisations. Other people-focussed benefits - satisfying a desire to nurture living things and finding it important for educating children about the natural environment - were the third and fourth strongest responses. Interestingly, Clark et al. (2019) investigated the triggers for feeding in the UK and, while the influence of family members was key, the importance of promotion by conservation organisations was the second most important trigger for more than 50% of respondents.

Summary

- The studies in this section came from around the world, primarily from higher-income countries of Europe, North America, Australia and New Zealand. Importantly, locational variation is likely to reflect variation in cultural and social contexts that may influence results. Therefore, implications from non-UK studies on motivations for SF in the UK are unclear.
- Most response options for motivations in surveys were proposed by the authors rather than informed by open-ended questions. Although this can provide evidence to compare the options provided, it may mean that respondents realigned their reported motivations to fit prescribed categories and other motivations may have been missed.
- Personal pleasure was the most commonly cited motivation for SF with other personal benefits frequently mentioned. Concern for birds ranked highly (often second) but was never considered the main motivation for SF.

Table P4.1. Number of such results across the four search engines at successive stages of the review process for P4.

Search stage	Total Hits
Total search results	205,633
Number up to 400 threshold	807
Number with duplicates removed	653
Relevant based on title and abstract	30
Relevant based on full text	12

Table P4.2. Results of review of evidence investigating motivations for SF. Dark green rows are UK based studies, light green are mainland European studies, white rows are rest of the world. For definition of study types see Table P3.1.

ID	year	Country	Species	Study type	Data unit	Sample	Audience	Metric	Results
Clark et al	2019	England	Garden birds	Mix	Individual	593	>16 years old, UK residents	Motivation: "Why do people feed?"	Personal pleasure, species survival, connection to nature. Other responses: nurturing, educating children, making amends [for human environmental damage], personal atonement [for environmental damage], companionship and not wasting food.
Clark et al	2019	England	Garden birds	Mix	Individual	593	>16 years old, UK residents	Motivation: Triggers to start feeding	Parents, having a garden, grandparents, conservation organizations.
Orros et al	2014	UK	Red kite	Quant, cross	Individual	129	Unknown	Motivation: "Why do (or did) you feed red kites?"	To see them up close, to conserve them. Other responses included: photography, to use left-over food.
Orros et al	2014	UK	Red kite	Quant, cross	Individual	129	Unknown	Motivation: "…why did you stop?" (n=19)	A change in circumstances (e.g. moving house). Other responses included: advice not to feed, concerns of over-reliance, other birds scared away
Deshpande et al	2024	Finland	Any	Quant, cross	Feed site	14127	Adults	Motivation: Increasing provisioning	9185 changed provisioning. Majority to attract more birds.
Deshpande et al	2024	Finland	Any	Quant, cross	Feed site	14127	Adults	Motivation: Stopping provisioning	1234 stopped provisioning. Main reasons were: rats, complaints from neighbours: Other reasons: mammalian predators, corvids, avian disease, domestic pets
Aivelo et al	2025	Finland	Any	Quant, cross	individuals	9473	Any	Motivation: two questions on changing and ceasing feeding	Responses from 4992 people grouped into three categories: 1) respondent's relation to another species 2) respondent's relation to other humans 3) relations between other species

ID	year	Country	Species	Study type	Data unit	Sample	Audience	Metric	Results
Ballantyne & Hughes	2006	Australia	Any	Quant, cross	Individual	141	Adults	Motivation: “Why do they feed birds?”	Regular bird feeders do so to attract birds to the area and because their children enjoy it
Henson et al	2023	Australia	Water birds	Quant, cross	Individual	206	18-19 years old	Motivation: Attitudes to feeding	To entertain children, to help birds, for enjoyment or recreation, to attract birds, to dispose of food scraps, and because other people feed them.
Ishigame & Baxter	2007	Australia	Any	Quant, cross	Household	372	Unknown	Motivation: For feeding in backyard (feeders)	Main reasons households started feeding were 1) "To attract wild birds", 2) "To provide wild birds with more food", 3) "to get closer to wild birds". Other reasons: “for kids,” “birds started feeding on pets’ leftovers”, “to help birds breed” and “to avoid magpie attacks.”
Ishigame & Baxter	2007	Australia	Any	Quant, cross	Household	372	Unknown	Motivation: For NOT feeding (non-feeders)	Main reasons for not feeding were "Not in the best interest of birds", "Lack of interest", "Have family pets", "Have native trees/plants" and "other"
Horn & Johansen	2013	USA, Canada	Any	Quant, cross	Individual	1291	15+ years old	Motivation: Benefits for feeder	Main reasons for feeding were: 1) Brings nature and beauty to the area, 2) Enjoy the sound of birds in the yard, 3) Hobby and/or fun 4) Want to help the birds, 5) Therapy and/or relaxation, 6) Learning bird behaviour and/or identifying species, 7) As part of the landscaping, 8) Maintain a list of bird species seen in yard, 9) As an educational experience for children, 10) Other reasons
Horn & Johansen	2013	USA, Canada	Any	Quant, cross	Individual	1291	15 years old	Motivation: benefits for birds	Feeding birds to help birds was the 4th most popular reason and varied by age group
Thabethe & Downs	2018	South Africa	African Woolly-necked Storks	Quant, cross	Unknown			Motivation: "Why do you feed African woolly-necked storks?"	Main reasons: Personal pleasure, Considered a privilege to be visited by storks, to facilitate stork survival, to compensate for habitat destruction, Non-feeders were concerned about bird welfare

ID	year	Country	Species	Study type	Data unit	Sample	Audience	Metric	Results
									and them becoming dependent on humans for food.
Erastova et al	2021	New Zealand	Nectivores	Quant, cross	Individual	566	>16 years old, adults	Motivation: “why do you feed birds?”	Four categories: 1) Benefits for people, 2) Benefits for birds, 3) Ecological benefits, 4) Other (no reason 1%)
Galbraith	2016	New Zealand	Garden birds	Quant, cross	Househol d	801	>18 years old	Motivation for feeding	Main reason: Personal pleasure. Other reasons: dispose of food, attract wildlife, assist birds through hard times, help birds. Smaller numbers of responses: ecosystem services they provide or ecological benefits, benefit/education of children, atone for environmental damage or ‘‘give something back’’, because they had done so as a child, for religious reasons.
Mavrotheri s et al	2020	New Zealand	Kãkã parrot	Quant, cross	Individual	2403	>18 years old, adult	Motivation: “Why did you stop feeding Kãkã?”	Main reason: learned about negative impacts on bird health and the damage to trees/properties that Kãkã cause.

P5. What is the extent of public understanding of the risks and/or benefits of SF in residential settings?

Rationale

It is accepted that purely supplying people with more information is not enough to change behaviour (Toomey et al. 2017). However, awareness of the risks and benefits to themselves and to birds may be an influential trigger for modifying people's feeding behaviour. Understanding whether people are cognisant of the risks, and how that influences their SF behaviour, may provide insight into the effectiveness of current messaging around species conservation to change action.

Methods

Literature search procedure

The literature search procedure is presented in Appendix A.

Study exclusions

Studies were excluded if they lacked original data on SF behaviour and considerations of risks and benefits of feeding.

Data extraction – response metrics

An inclusive approach was adopted. This question overlaps with question P4 as an awareness of risks and benefits was inferred from motivations for SF. In comparison to previous questions (P1-3), metrics were not ranked as positive or negative as this is a contextual variable to inform the process of eliciting any behaviour change required.

Results

Literature composition

Seven studies were considered relevant to this question (Table P5.1). One was qualitative research (Martin & Greig 2019), while the rest were cross-sectional surveys that were predominantly quantitative assessments of a range of reasons supplied by the authors, although an open-ended "other" option was often provided for more qualitative results (Table P5.2).

Awareness of risks and benefits of feeding birds in the garden

The most comprehensive study addressing this question was the research conducted by Galbraith et al. (2014). These authors conducted a randomised, cross-sectional survey of households, thus engaging feeders and non-feeders with questions on perceptions of benefits and risks around SF. People who fed birds were more likely to see benefits than non-feeders, and 64% of all respondents identified benefits. More respondents (51%) identified benefits for wildlife than benefits for people (35%), however the single most appreciated benefit was the enjoyment and pleasure provided for people (25%). The most widely identified benefit for wildlife was a reliable food source to mitigate periods of food scarcity (17%). Other benefits for wildlife were that feeding encourages avian diversity within a locality, that there are inherent benefits for birds in accessing food including benefits for survival, during breeding and for population growth. Conversely feeders were significantly less likely than non-feeders to identify disadvantages of SF. Overall, 45% of people identified disadvantages to wildlife, primarily predation and dependence on supplementary food, with disease risk only mentioned by 2%. Meanwhile 17% mentioned negative impacts for people, primarily increased fouling. While the research is applicable to this review question, it was conducted in New Zealand and therefore a different cultural and social context may exist around conservation and bird feeding than in the UK.

In the UK, research on garden bird feeding by Cox & Gaston (2016) included some statements that suggested potential welfare considerations for birds. They found that providers of bird food, particularly those providing food regularly, were more likely to disagree with the statement that there was sufficient food for birds in the environment. Additionally, data indicated around 58% of respondents wash their bird feeders 'regularly' indicating a broad perception of disease risk. Regular bird feeders were more likely to wash feeders than irregular feeders.

Research in Finland adds a little more insight into to how risks and benefits may change feeding behaviours (Aivelo et al. 2025; Deshpande et al. 2025). Of the 4992 people that supplied reasons for changing feeding behaviour in the last 20 years, the majority cited impacts on humans, for example attracting unwanted species, impact on pets or negative social relations, indicating that human disbenefit is the primary reason for change. Around 19% of respondents reduced feeding because of concerns about disease spread, while just under 2% reduced feeding because of impacts on bird community and because they considered feeding unnecessary for their local birds.

Dayer et al. (2019) investigated USA feeder's behavioural intentions towards five different threat scenarios variously seen as 'natural' (hawk) and anthropogenic (cat), disease, or a change in bird population. Regarding the most frequent responses: in response to a scenario of hawk depredation most people (54%) said they wouldn't do anything, while 84% said they would try to scare off a cat; an increase in bird population led to 54% saying they would keep their feeders fuller, while most people (65%) would not make changes if the population decreased; on seeing a diseased bird at their feeder most people (67%) said they would clean feeders more frequently while 30% wouldn't change anything. Most people thought their feeding provided birds with benefits of winter survival (64%) and nesting success (57%) while also bringing more birds (75%) and a greater variety of species (74%) to the area. However, only a small number thought their feeding increased disease risk (6%) and attracted cats (14%).

In tandem, the studies by (Aivelo et al. 2025; Dayer et al. 2019; Deshpande et al. 2025) suggest feeder's behaviour may be reactive to the observation of risks and threats rather than preventative.

Summary

- There are few studies assessing the scale of perceptions of risks and benefits of SF to birds and humans.
- Studies from non-UK locations may be influenced by cultural and social factors, for example history of promotion or discouragement of SF, that may make them less relevant to understanding the UK bird feeding population.
- From the limited evidence base, perception of benefits to birds from SF is much higher than awareness of risks to birds. This low perception may be due to lack of information and publicity about risk.
- Becoming cognisant of risks to birds was identified as a reason for reducing or stopping SF in some instances.
- The breadth of awareness among UK feeders of potential negative impacts of SF on birds is unknown however the research suggests feeders are less likely to perceive risks than non-feeders. Understanding perception of disease risk and potential behavioural responses to disease is important for effective messaging to encourage engagement with mitigation practice.

Table P5.1. Number of such results across the four search engines at successive stages of the review process for P5.

Search stage	Total Hits
Total search results	1,237,209
Number up to 400 threshold	796
Number with duplicates removed	741
Relevant based on title and abstract	8
Relevant based on full text	7

Table P5.2. Results of review of evidence investigating awareness of benefits and risks of SF. Dark green rows are UK based studies, light green are mainland European studies, white rows are rest of the world. For definition of study types see Table P3.1.

authors	Year	Country	Habitat	Species	Study type	Duration	Data unit	Sample	Audience	Metric	Results
Cox & Gaston	2016	England	Urban	Garden birds	Quant, cross	<1 year	Household	331	>18 years old	Welfare Concerns	Testing for welfare concerns, the study found that the perception that there is not enough natural food available for birds increased with the levels of bird feeding. Regular bird feeders likely to wash feeders to prevent disease.
Deshpande et al	2024	Finland	Rural and Urban	Any	Quant, cross	20 years	Feed site	14127	Adults	Motivation: Stopping provisioning	Top reasons for stopping provisioning were rats and neighbour concerns, then also mammalian predators, corvids, avian disease, presence of domestic pets,
Aivelo et al	2024	Finland	Rural and Urban	Any	Quant, cross	20 years	Individuals	9473	Any	Motivation: "Why have you changed your feeding patterns?" "…did any or several of the following factors influence decision to quit?"	4992 respondents gave reason for making changes (number respondents, inc=feeding increased, dec=feeding declined) as: - wanted more species (1408 inc) - did not want undesirable species (1920 dec) - Disease risk (941 dec) - Social relations (33 inc, 136 dec) - supporting biodiversity (143 inc) - impacts on pets, livestock, garden (75 dec) - effects on local bird community (69 dec)
Galbraith et al	2014	New Zealand	Urban	Garden birds	Quant, cross	4 weeks	Household	801	>18 years old	Perception of benefit and risk	Feeders see more benefits than non-feeders. Disadvantages to wildlife

authors	Year	Country	Habitat	Species	Study type	Duration	Data unit	Sample	Audience	Metric	Results
											(predation, dependency, disease) identified by 45%.
Horn & Johansen	2013	USA and Canada	Mixed	Unknown	Quant, cross	4 years	Individual	1291	>15 years old	Undesired impacts	Attracts undesirable species (squirrels and birds). 18% noted it attracted pests with 13% saying it attracted undesirable birds
Dayer et al	2019	USA	Unknown	Unknown	Quant, cross	4 weeks	Individual	832	>18 years old	Actions in response to e.g. disease or predation	Presented with the scenario of risk to birds through predation (hawk or cat) or disease, most respondents said they would take action in response (46% for hawk, 95% for cat, 70% for disease).
Dayer et al	2019	USA	Unknown	Unknown	Quant, cross	4 weeks	Individual	832	>18 years old	Perceived impact of feeding	Respondents largely perceived the impacts of their feeding on wild birds to be positive (increased abundance, overwinter survival, nesting success) Fewer respondents believed feeding had adverse effects (cats, disease).
Martin & Greig	2019	USA	Mixed	Unknown	Qual	5 weeks	Individual	72	18-50 years old	Pros and cons of feeding wild birds	Interviewees most often noted the belief that feeding helps birds (41%). Few comments about the drawbacks of wild bird feeding: dependency, pests, predators, undesirable species, disease.

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Section 4: Other topics

Human health risks associated with supplementary feeding of wild birds in residential settings

Garden bird species can carry a range of pathogens of potential human health concern. Human exposure can occur through contact with sick or dead birds, or via environmental contamination. SF in residential settings has the potential to increase risks of human exposure, due to the concentration of faeces and infectious secretions at feeding sites, and increased risks of exposure during filling or cleaning of feeders and bird baths. Here, we provide a brief description of pathogens of potential zoonotic concern carried by garden bird species and summarise available evidence for increased risk of human exposure due to SF activities.

(A) Bacterial pathogens

1. *Chlamydia psittaci*

Chlamydia psittaci is a bacterial pathogen which primarily infects avian species, but which can spill-over into humans causing the disease psittacosis. Symptoms in humans are typically mild, but can lead to severe pneumonia and respiratory failure, particularly in elderly or immunocompromised individuals (UK Health Security Agency 2024). The bacterium can persist in the environment for an extended period (days to weeks; Wannaratana et al. 2017), and infection can occur when breathing in dried-out droppings, dust from feathers, or aerosolised secretions from infected birds. A range of common garden bird species can carry *C. psittaci* including passerines (e.g. dunnock, great tit, Eurasian blue tit and European robin; Beckmann et al. 2014) and columbids (e.g. Eurasian collared doves; Beckmann et al. 2014; common wood pigeon, feral pigeon; Sharples & Baines 2009)

Cases of psittacosis in people in the UK are rare, with less than 10 per year typically confirmed each year in England (UK Health Security Agency, 2024). However, in Austria, Denmark, Germany, Sweden and The Netherlands, an unusual increase in psittacosis cases was reported in 2023-2024, including five human fatalities. Cases were associated with exposure to both domestic birds and wild birds (World Health Organization 2024; Izere et al. 2025). Studies on psittacosis cases in Sweden found that cleaning bird feeders was a risk factor for exposure (Rehn et al. 2013; Chereau et al. 2018), and the Public Health Agency of Sweden has recommended use of bird feeders whose design limits accumulation of faeces to mitigate the risk of infection via this route (Chereau et al. 2018).

2. *Salmonella* spp.

Garden bird species can act as carriers of a range of *Salmonella* species, and particular strains of *Salmonella enterica* serotype Typhimurium have caused mortality events in UK garden birds, commonly reported at bird feeding stations. While *Salmonella* spp. carried by birds can cause gastroenteritis in humans, only a small proportion (0.2%, 337 of 147,495 total cases identified from 2000-2010) of the human salmonellosis cases detected in England and Wales were found to be wild bird-associated isolates (Lawson et al. 2014). However, exposure can occur through handling sick or dead birds, or through indirect contact, including through contaminated bird feeders (Patel et al. 2023). Infection can also occur in domestic dogs and cats, which may also act as a route of transmission between wild birds and humans (Söderlund et al. 2019; Patel et al. 2023).

3. *Escherichia* spp.

Wild birds commonly carry the bacterial species *Escherichia coli* as part of their commensal gut flora, some strains of which are pathogenic to humans (Hughes et al. 2009*).* In addition, in 2003 the bacterial species *Escherichia albertii* was identified, which can cause disease in both humans and birds (Bengtsson et al. 2023). In humans, both *E. coli* and *E. albertii* infection cause symptoms of diarrhoea, fever, vomiting and abdominal pain. Transmission is via the faecal-oral route, therefore concentrations of faeces at SF sites presents a risk of exposure while filling or cleaning feeders. A study sequencing *E. albertii* cases from humans and birds in the UK found that most human cases were associated with travel or foodborne infection. However, a small number (4/83) were potentially from zoonotic exposure, highlighting the need for appropriate hygiene measures when filling or cleaning feeders (Bengtsson et al. 2023).

4. *Campylobacter* spp.

Wild birds can carry *Campylobacter* bacterial species, often as commensals that do not cause disease, but which can cause gastroenteritis in humans. Campylobacteriosis is one of the primary causes of gastrointestinal infections in the UK, with 70,352 reports in 2024 (UKHSA 2025). A study in Oxfordshire found 2.1-3.5% of cases annually were attributable to wild bird-associated isolates (Cody et al. 2015). However, association with garden bird feeding or feeder cleaning was not tested, and exposure to infected faeces may occur through a range of routes, such as via contamination of food products (e.g. raw or undercooked meat, especially poultry; unpasteurised milk and untreated water; [Campylobacter: guidance, data and analysis - GOV.UK]).

5. Multi-drug-resistant bacterial species

A recent study found high prevalences of *Salmonella* spp. (11.6%), *E. coli* (100%), *Campylobacter* spp. (18.9%) and *Enterococcus* spp. (78%) across 259 faecal samples from UK wild birds, including those caught at an SF site (Dunn & Clegg 2025). Multi-drug-resistant (MDR) strains were also detected in a high proportion of birds, with 75% of birds carrying at least one bacterial species that was MDR. House sparrows and common blackbirds were found to be particularly high-level carriers. Authors proposed that SF sites pose a transmission risk for MDR strains, from birds to humans and vice-versa. However, human exposure to these strains was not tested for, therefore the implications for human health are unclear.

(B) Viral pathogens

1. Avian influenza virus

Wild birds are hosts for avian influenza viruses, which in rare cases can spill-over into humans. Although garden bird species can be infected with avian influenza viruses, waterfowl and seabirds are the primary hosts, and very few cases have been detected in UK garden bird species (Atkinson et al. 2025). Furthermore, human cases of avian influenza reported in the UK to date have been associated with close contact with affected poultry, and not wild birds ([Human case of avian flu detected in England - GOV.UK]). The UK Health Security Agency has stated that the risk to the public from avian influenza in the UK is very low. Advice for the public to reduce the risk of catching avian influenza from wild birds is available (UKHSA, 2025).

2. Flaviviruses - Usutu and West Nile virus

Wild birds are reservoir hosts for the mosquito-borne pathogens Usutu virus and West Nile virus. Usutu virus was first detected in the UK in 2020 (Folly et al. 2020) and has been linked to declines of common blackbird populations, which are highly susceptible to the virus (Lawson et al. 2022; Agliana et al. 2025). While most reported human cases are asymptomatic or present with mild symptoms, on rare occasions this virus can cause neurological disease in humans: there have been no human infections of USUV reported to date in the UK (UKHSA, 2025).

The closely related West Nile virus poses a greater potential human health risk and viral RNA was recently detected in UK mosquitoes for the first time (Bruce et al. 2025). However, there is currently no evidence for continued circulation in mosquitoes and there have been no detections of locally acquired WNV in people or in birds in the UK ([First detection of West Nile virus in UK mosquitoes - GOV.UK]). While these viruses pose a zoonotic risk, transmission occurs primarily through the bite of an infected mosquito (UKHSA, 2025) and there is no evidence that SF increases risk.

Summary

Direct contact with wild birds, or indirect contact with their faeces or secretions, poses a potential human health risk. The primary concern from garden bird species are bacterial diseases including psittacosis, salmonellosis and campylobacteriosis. Providing supplementary food in residential settings could increase risk due to environmental contamination from aggregation of birds at feeding sites, and higher exposure risk while filling or cleaning feeders. While the risks are generally low, sensible hygiene precautions should be taken to reduce the risk of exposure while handling feeders. Wild birds may be infectious without showing obvious clinical signs, therefore precautions are advisable even where no sick or dead birds are seen. Advice from the Garden Wildlife Health project (a partnership between the British Trust for Ornithology, Froglife, the RSPB and the Zoological Society of London) to minimise human health risks associated with SF are presented below:

- Clean and disinfect feeders/ feeding sites regularly. Suitable disinfectants include a weak solution of domestic bleach (5% sodium hypochlorite) and other specially designed commercial products. Always rinse feeders thoroughly and air-dry them before re-use.
- Dampen surfaces with water before cleaning them to reduce the chance of breathing in dry dust or aerosolised secretions.
- Brushes and cleaning equipment for bird feeders, tables and baths should not be used for other purposes and should not be brought into the house but be kept and used outside and away from food preparation areas.
- Wear rubber gloves when cleaning feeders and thoroughly wash hands and forearms afterwards with soap and water, especially before eating or drinking.
- Avoid handling sick or dead birds directly. For instance, use disposable gloves or pick a carcass up through an inverted plastic bag.
- Wild birds should be prevented from accessing food preparation areas.

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Do wild birds become nutritionally dependent on SF?

Evidence relating to dependency in winter: A study in Wisconsin USA removed SF of black-capped chickadees after 25 successive winters of continuous feeding. Survival in the 26th winter did not differ from that in a nearby control area that also lacked feeders. During periods of SF the birds were estimated to consume nearly 80% natural foods (mainly invertebrates) during winter (Brittingham & Temple 1992). A study of great tits in northern Finland suggested a forest population was dependent on supplementary food from human settlements to survive the harsh winter conditions although this was inferred from observed aggregation around feeders during winter rather than experimental feeding (Orell 1989).

Evidence relating to dependency during breeding: In suburban Cardiff, supplementary fed Eurasian blue tits and great tits provisioned their young with 85% natural insect prey and there was no relationship between the amount of SF in chick diet and nestling survival (Cowie & Hinsley 1988). In suburban Hertfordshire, only 7% of feeding trips (great tits) and 0% (Eurasian blue tits) included supplementary food in a situation where peanuts were provided throughout the nesting period close to every nest box (Thompson 1987). Invertebrate dominated the diets of both species. In suburban Brisbane, Australian magpies fed their chicks entirely on natural invertebrate prey despite half the pairs having continuous access to supplementary food in the form of meat and cheese (O'Leary & Jones 2006).

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Section 5: Key Knowledge Gaps

This literature review has identified many important gaps in knowledge concerning the impacts of SF as conducted in residential settings on birds and people. There are also aspects of SF that have not been considered by this review such as the effects of nutritional quality and dietary composition on bird fitness and condition, and the wider environmental consequences of feeding such as the carbon footprint of the bird feeding industry. This section of the report aims to summarise some of the key knowledge gaps that need to be addressed to allow a more complete assessment of the benefits and disbenefits of SF. We arrange the key research needs using the structure provided by the questions addressed in the review plus additional topics (indicated using *) not addressed by the review.

1. Effects of SF on avian fitness

(a) Effects of SF on avian fitness in peri-domestic landscapes

One of the main limitations of the scientific evidence base identified during this review is the lack of experimental ecological studies conducted in peri-domestic landscapes. The probable explanation for this is the logistical difficulty of conducting experiments in suburban landscapes which would require large numbers of residents to adopt experimental protocols. Consequently, most studies of SF in peri-domestic landscapes have relied on observational/correlational approaches. Whilst such logistical challenges make it difficult to deliver replicated fed and unfed individuals or pairs within a formal experimental design, technology may facilitate the provision of contrasting levels of supplementary food consumption between individual birds or groups. For example, passive integrated transponder (PIT) tags have been used to measure variation in the usage of supplementary food by individual birds (Crates et al. 2021), and it should be possible to use such radio frequency identification technology to control access to feeders for individual birds. The amount of supplementary food taken by individual birds could be inferred either from the frequency of PIT tag triggers at feeders and/or using faecal metabarcoding to measure the presence/frequency of supplementary food in faecal samples (e.g. Shutt et al. 2021).

The most pressing gaps in ecological knowledge relate to the effects of supplementary seed and peanut provision especially outside of winter, and for taxonomic representation more typical of UK garden bird communities. Priority taxonomic groups in a UK context include finches, sparrows, tits, columbids and corvids. A key question is whether supplementary seed provision affects reproductive output and/or survival in granivorous species in peri-domestic landscapes. Studies are needed that identify the importance of seed limitation during different seasons, distinguishing for example, the impacts of seed limitation during the breeding season, from that during post-fledging, autumn and winter. Ideally these studies would be experimental in design and would include measures of dietary composition. However, observational studies measuring the proportion of the diet comprised of supplementary food for different species during different seasons would improve our understanding of the likely ecological importance of such food to birds.

(b) Effects of SF on songbird predation risk (for nests and free-flying birds)

Three studies recorded higher rates of passerine nest predation close to feeders, two in peri-domestic habitats (one involving artificial nests) and one in montane meadows (question W1). Further studies are needed to assess the generality of this effect, the distance from feeders over which nest survival is reduced and whether population-level nest survival rates are affected. None of the three studies considered the latter question and it could be that feeders lead to the aggregation of nest predation events around feeders but do not increase the overall rate of nest predation.

Further research is also needed to assess the effects of feeder placement on the predation risk experienced by free-flying birds using the feeders. Several studies have documented the effects of distance from vegetative cover on bird feeder usage, but none have measured the impacts on predation risk. The availability of low-cost motion-sensitive camcorders makes measuring predation events at feeders more feasible than it was previously.

(c) Effects of the nutritional composition of supplementary food on avian fitness and health*

Our review did not consider the importance of the nutritional composition and balance of supplementary foods for fitness in wild birds. For example, antioxidants like vitamin E and carotenoids are known to reduce oxidative stress in birds (Catoni et al. 2008) although dietary supplementation studies have produced variable findings (e.g. Blount et al. 2002, Plummer et al. 2013). On the other hand, high levels of linoleic acid (LA), an omega-6 polyunsaturated fatty acid (PUFA), is known to increase oxidative stress which can damage cell membranes particularly sperm cells. European greenfinches and hawfinches that regularly consumed sunflower seeds were found to have high levels of LA in their blood, and this was correlated with the frequency of sperm head abnormalities (Støstad et al. 2019). Initially a literature review would aim to summarise the evidence for the importance of dietary composition (including macronutrients like protein) and of key dietary components for avian fitness and health. Those components might include vitamins, minerals, essential amino acids, antioxidants and micronutrients (e.g. Ramsay & Houston 2003, Razeng & Watson 2015). The key initial research need is for a literature review documenting the nutritional requirements of birds during different ages and seasons. Further work could then map the nutritional requirements of birds against their content in natural and potential sources of supplementary food. The review could also consider the role and potential benefits of nutritional additives to supplementary bird foods. Such a review would benefit from input from avian nutritionists with experience of cage and aviary birds.

2. Effects of SF on avian abundance and population size

(a) Effects of SF on avian abundance in peri-domestic landscapes

Most previous studies of the effects of SF on avian abundance have either been conducted in wider countryside habitats (like woodland or farmland) or have employed an observational design in peri-domestic landscapes. However, the two approaches have generated broadly consistent conclusions thus increasing confidence that results from the wider countryside can be applied to peri-domestic settings. An obvious priority is to broaden the taxonomic range of the evidence base to include studies of granivorous species such finches, sparrows and columbids, and of species that might increase predation pressure (such as corvids).

(b) Effects of SF on avian community composition in peri-domestic landscapes

Further understanding is required of the impacts of SF on avian community structure in peri-domestic landscapes with the sampling units being sufficiently large to rule out local redistribution as a potentially confounding factor. Key questions include does SF lead to an increasing dominance of generalist species and do increases in predatory species like corvids increase overall nest predation risk in peri-domestic landscapes. Given the requirements for multiple, large, comparable study units with contrasting levels of SF, such studies will be challenging to establish in typical peri-domestic settings especially experimental studies.

3. Effects of SF aimed at wild birds on non-avian wildlife

Whilst previous studies have shown that the distributions of some mammals are associated with the local intensity of SF, further studies might usefully test whether SF aimed at birds in peri-domestic landscapes affects the abundance of mammals that are known to consume that food. Examples of such mammals in the UK are non-native grey squirrels and brown rats.

4. Effects of SF on pathogen transmission risk and disease in wild birds.

(a) Efficacy of potential mitigation measures that aim to reduce pathogen transmission risks at feeders and water baths

Given increased concerns about pathogen transmission at bird feeders and water baths (particularly in the UK *Trichomonas gallinae*) research is needed to develop and field test practical and affordable measures to reduce such risks. Potential mitigation measures might include different feeder/bath cleaning techniques and frequencies, different feeder/bath densities or placements (e.g. manipulating feeder density and spacing, baths located adjacent to vs further from feeders), different feeder/bath designs (e.g. to reduce contacts/interactions between individual birds and species), different feeding or watering regimes (e.g. seasonal provision), as well as designs to reduce access to any dropped food. A specific requirement is to assess the efficacy of current advice to temporarily suspend food and water provision as a control measure for disease outbreaks (e.g. a break of 2-4 weeks is recommended as a control measure for trichomonosis in the UK), and whether the recommended break period is effective.

Of particular value for mitigation development would be more studies that investigate factors affecting the viability of *T. gallinae* in food and water. Previous studies have shown survival in water of up to 16 hours (Purple & Gerhold 2015), 24 hours (Kocan 1969), 30 hours (Purple et al 2019) and promoted by organic matter and low dissolved oxygen. Survival on food varies between food types (e.g. peas 24 hours, sorghum & buckwheat 120 hours; Kocan 1969) and is promoted by moisture (up to 5 days, Thomas 2017) and presence of finely ground organic matter (McBurney et al 2017 but only tested up to 48 hours). Further studies could test *T. gallinae* persistence/survival under controlled laboratory conditions for additional food types and/or ambient environmental conditions following experimental inoculation (e.g. sunflower hearts vs seed mix vs nyjer, oxygenated vs de-oxygenated water).

(b) Comparison of infection and disease prevalence amongst wild birds at sites and habitats with and without SF

Our review identified many studies of disease outbreak investigation and pathogen surveillance at peri-domestic localities with SF. However, we found very few comparable studies of infection and disease prevalence at wider countryside localities either with or without SF. In a UK context, comparative observational data on infection and disease status could be collected by trapping and marking birds in peri-domestic habitats with SF, and for the same set of species in wider countryside habitats like woodland and farmland both with SF (like at gamebird feeders) and away from sources of supplementary food. Gamebird feeders in the UK have been estimated to account for 282,000 metric tonnes of wheat each year compared to 150,000 tonnes of seed in garden situations (Madden 2021, Harris 2021, Abraham et al 2024) and gamebird feeders are known to attract large numbers of columbids and songbirds including European greenfinches and Eurasian chaffinches where close proximity communal feeding will be facilitated (Sanchez-Garcia et al. 2015). Samples could be collected under appropriate licences (e.g. oral swab, faeces, cloacal swab, blood) to screen for targeted pathogens and to allow serosurveys. Effects of sub-clinical infection on host health and fitness could also be assessed, as well as the potential for between species transmission (e.g. from infection and contact rates).

A potential experimental approach would be to introduce SF in otherwise comparable habitats (for example woodland without nearby SF) to measure the condition, health and infection/disease prevalence of wild birds with and without access to supplementary food (e.g. following Wilcoxen et al. 2015).

Each of these approaches would benefit from resource for serial monitoring and recaptures of marked individual birds to allow estimation of survival and pathogen transmission rates to understand the net effects of SF on fitness.

(c) Understanding infection/disease ecology and dynamics especially for trichomonosis

Many of the fundamental dynamics of *T. gallinae* infection and host responses are unknown for finch trichomonosis and this limits our ability to develop mitigation measures and to model disease dynamics. Key metrics to measure include incubation and infectious periods, host immune responses, and survival rates along with detailed studies of pathogenesis, how virulence varies amongst *T. gallinae* strains and elucidating the relative importance of direct and indirect transmission routes in the field. Molecular studies using archives collected since the emergence of finch trichomonosis could be used to investigate host-pathogen dynamics such as potential selection for host immunity or changes in parasite virulence and how SF might influence virulence evolution.

(d) Effects of SF on avian responses to pathogen infection

Further studies could assess how contaminants in supplementary food (like mycotoxins or pesticides) influence host health, immunity and immune function, and how the nutritional value of supplementary food affects host health compared to a natural diet. The most powerful means of conducting such work would involve the dietary manipulation of captive birds.

(e) Understanding the role of trichomonosis in the population declines of Eurasian bullfinch and hawfinch in the UK

A similar demographic approach could be taken for Eurasian bullfinch as has been adopted using integrated population models for European greenfinch and Eurasian chaffinch (Hanmer et al 2022), although available data are likely to be sparser. Limited demographic and infection rate data exist for several UK hawfinch populations which could provide some insights into the demographic impacts of the disease.

(f) Associations between SF and disease-mediated bird population declines across Europe.

SF practices are suspected to vary strongly across mainland Europe with feeding in some countries limited to the winter period only (Jones 2018). Many European countries run bird population monitoring schemes that measure changes in population size through time (collated by the Pan-European Common Bird Monitoring Scheme, Home | PECBMS - PECBMS). If reliable data could be collected on the intensity and seasonal pattern of SF behaviour at a country scale, tests of association could be conducted between SF practices and bird population changes. Of particular interest is variation in the extent of trichomonosis-related declines affecting finch populations across Europe.

5. Inter-specific interactions involving species that have benefitted from SF

(a) The demographic impacts of nest eviction and nest predation on willow tits

The review has documented potentially serious negative impacts of nest eviction (by Eurasian blue tits and great tits) and nest predation (by great spotted woodpeckers) on willow tits. Further research is needed to measure the impacts of these nest losses on overall willow tit productivity and to identify any factors influencing the magnitudes of these impacts (e.g. the local density of blue/great tits, and great spotted woodpeckers). If important negative impacts are confirmed, then consideration should be given to field tests of mitigation options such as the provision of nest boxes that confer greater protection against woodpecker predation.

(b) The importance of competition between marsh tits and other tit species outside of the breeding season

Limited evidence suggests marsh tits may compete with other tit species for resources (especially natural food resources) outside of the breeding season. Further work is needed to assess the magnitude and generality of such competition perhaps across a gradient of blue/great tit abundance.

(c) The impact of predation by corvids on passerine nests and fledglings in peri-domestic landscapes

Several widespread corvid species have increased in abundance and feeder usage in peri-domestic landscapes in recent decades (Plummer et al. 2019 including Eurasian magpie, carrion crow and western jackdaw) and may be causing additional mortality amongst nests and fledglings of songbirds. Field studies are needed to assess the importance of corvid-related nest and fledgling predation relative to other sources of mortality in peri-domestic settings.

(d) Competitive interactions between seed-eating birds

UK populations of common wood pigeon and European goldfinch and, until approximately 2005, Eurasian collared dove have increased markedly in peri-domestic landscapes probably at least in part due to SF (Plummer et al. 2019). There have been no studies to test for competitive interactions between these and other seed-eating species whose abundance may have fallen. Competition could occur for nest sites, for natural food as well for supplementary food.

6. Impacts of SF on people

Our review highlighted a very limited evidence base relating to the effects of SF on human well-being and connection to nature. The available evidence was also difficult to synthesize or generalise as a variety of metrics were employed to draw inferences about human impacts not all of which had clear validatory support. The general need in this area is for more studies that focus explicitly on the impacts of SF on human well-being and connection to nature, that employ validated response metrics that can be compared across studies, and with strong counterfactuals or controls. Specific research questions include:

(a) what are the well-being impacts of engagement in SF, and how does the magnitude of those impacts differ between socio-economic groups and contexts, and compare to other potential well-being activities?

(b) what are the 'connection-to-nature' impacts of engagement in SF, how sensitive are those impacts to the duration of engagement with SF activity, and how do those impacts vary between socio-economic groups and contexts, and compare to other potential connection activities?

(c) what are the impacts of engagement in SF activity on attitudes towards environmental issues and the probability of future involvement in pro-environmental activities; how does the magnitude of any such relationships differ between socio-economic groups and contexts?

7. Wider environmental implications of SF*

This review lacked the capacity to consider the wider environmental aspects of SF such as the carbon footprint of the production and transport of food grown for birds, and the effects of SF on phosphorus cycles and the nutrient enrichment of ecosystems (Abraham et al. 2024). Some suggested research priorities viewed from a UK perspective are listed below:

(a) What is the composition, geographic origin and local (i.e. in the country of production) environmental impact of SF used in residential settings in the UK?

To assess any local environmental impact of production, information would be needed on typical growing methods for each of the common food types marketed for garden birds including any tillage requirements and usage of pesticides, fertilizer and water. The use of any land for growing bird food obviously carries an opportunity cost for alternative land uses such as food production for human consumption or the maintenance of natural habitats for biodiversity and ecosystem services. Any such assessment could consider the potential impact that any industry-wide sustainability ambitions might have.

(b) What is the carbon footprint of the supplementary food used in residential settings in the UK?

Information collected under (a) above, combined with a set of assumptions about packaging and transport, should allow an estimate to be made of the contribution of the UK SF industry to greenhouse gas emissions.

(c) What are the local impacts of SF on nutrient enrichment of ecosystems?

A recent study has modelled the total contribution of SF of birds (both in gardens and of gamebirds) to phosphorus cycling in the UK and has concluded that feeding contributes a similar magnitude of phosphorus as atmospheric deposition (Abraham et al. 2024). Phosphorous is transported into soils and water courses both directly via uneaten fallen food and indirectly via the excreta of animals that consume the food. Further field-based research is needed to measure the local nutrient enrichment of soils and water courses due to SF of birds in gardens, and of gamebirds in the wider countryside.

Any such assessment of the environmental impacts of the UK bird food industry could consider the potential reduction in impacts that might be achieved through any declared industry-wide sustainability ambitions.

8. Economic aspects of SF*

The value of the UK wild bird feeding industry is estimated to be £385m annually (UK Pet Food 2024). This activity clearly provides economic benefits in the form of employment, tax revenue and profits, both in the UK and overseas. Some of the income generated by bird food and feeders provides income for conservation organisations like the RSPB. These economic aspects of SF are important and need to be incorporated into any wider assessment of the benefits and disbenefits of SF of birds. Key questions from a UK perspective are listed below. We note that much of this information may be unavailable for review as it is likely to be considered commercially sensitive.

(a) what is the economic value of the UK bird food industry in terms of gross sales, profits, tax revenues and employment, both in the UK and overseas.

(b) what financial contribution does sales of bird food and associated accessories make to the UK conservation sector?

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Appendix A: Supplementary Feeding Evidence Review Protocol

Review Method Rational

This evidence review sits between a rapid evidence assessment and a systematic literature review. Systematic literature reviews usually involve multiple reviewers reviewing the same evidence and literature sources to account for bias and check inter-rater reliability when including or excluding sources. Systematic reviews also typically take 12-24 months to complete. This evidence review takes the format of a 'rapid evidence assessment', which follows the process of a systematic review streamlined for a shorter time scale (Tricco et al. 2017). Our review had the following objectives:

1. Synthesize current knowledge on the negative impacts of supplementary feeding (SF, Table 1) aimed primarily at garden birds in peri-domestic settings to the benefit of both wildlife, and people.
2. Where unwanted impacts are identified, review options for mitigation and its' supporting evidence.
3. Develop options for revising RSPBs policy and practice position on SF
4. Identify monitoring and evaluation actions necessitated by policy revision
5. Identify key knowledge gaps relating to provision of SF for garden birds

Building on a recent proposal led by Kate Plummer (BTO) and Becki Lawson (IoZ), we followed a 'One Health' perspective on SF considering the pros and cons for wildlife (mainly birds), and people (connection, wellbeing, motivation, behaviour) (Table 1). The scope was SF aimed primarily at birds conducted in private peri-domestic settings. The focus was the feeding of garden birds in the UK although relevant evidence from other habitats and regions were included where appropriate.

Methods

Search strategy

Where possible we followed the PRISMA 2020 reporting guidelines (Page et al. 2021). Initial steps included refining research questions, selecting information sources, and search strings based on Boolean operators (Figure A1). Based on iterative systematic searches scoping was done to ensure expected literature was being picked up by search strategies and terms. Following this iterative search string development process, the method for the systematic review process was fixed.

Search strings are shown in Table A2. After search strings were finalised, they were run in four search engines: Google Scholar, Web of Science, Scopus and PubMed (Table A3). Due to the large base of topical research identified in the literature for the wildlife questions, and generality of terms used in the social literature for people questions, the search results in Google Scholar were often in the tens of thousands while the number of results in other databases were typically in the hundreds or low thousands (Table A4 summary not yet done). Therefore, to make the review process tractable the number of relevant hits was recorded for every 10-20 results to establish the pattern in which levels of relevance declined across search output rank. This established the cut off points for number of hits to extract and screen for inclusion based on title and abstract alongside consideration of feasibility. For the wildlife questions the first 400 hits were exported from each database. For the people questions the first 200 hits were exported from each database (Figure A2).

Search result exports were imported to Rayyan systematic literature review software (Ouzzani et al. 2016). One reviewer for the ecological questions and one reviewer for the people questions screened for Stage 1 inclusion based on title and abstract separately for each search engine. When 60 consecutive results produced no new inclusions the subsequent results for each search engine were not reviewed. Labels for reasons for exclusion and other notes, such as whether results may be relevant for other questions, were applied in Rayyan. At this stage results for each search engines were combined and duplicates removed.

When this was complete data were exported to Microsoft Excel for Stage 2 screening on full text and extraction of data. Stage 2 screening was conducted by two-three reviewers for the ecological questions and two reviewers for the people questions. Based on full texts some studies were excluded at this stage, for example, out of scope, lack of relevance to SF, reviews, theses, opinion pieces.

Data Extraction

Metrics were the unit of data in our spreadsheet, with some studies contributing multiple metrics. The following generic contextual and design information was extracted across all questions. Context: country, habitat, feeding season, food type, bird species/group being fed. Design: research timing (season), research design, duration, data unit, sample size. For wildlife impact questions, results were assessed by two-three reviewers and coded as positive, no effect and negative on the basis of direction of change and its' statistical significance ($P<0.05$). For some questions data on effect size were extracted and summarised. Also, for some questions, quality flags were assigned where elements of design were considered to limit study inference (e.g. no controls, small sample size, inadequate or lack of statistical analysis) and used to exclude such metrics from summary tables.

For questions P1-P3, results for each metric were assessed by one reviewer as positive, mixed, neutral or negative. For quantitative results, if a metric increased and was statistically significant it was marked as positive, if a metric decreased and was statistically significant if was marked as negative, Non-significant effects were coded as no-effect. For qualitative results, if it was beneficial to birds or people it was positive, if it was a cost to birds or people it was negative. Where there were both positive and negative results for the same metric in the same study, it was marked as mixed. Quality concerns were recorded as comments and flags applied.

References

Ouzzani, M., Hammady, H., Fedorowicz, Z. & Elmagarmid, A. (2016) Rayyan — a web and mobile app for systematic reviews. SYSTEMATIC REVIEWS 5, 210, DOI: 10.1186/s13643-016-0384-4.

Page M.J, McKenzie J E, Bossuyt P M, Boutron I, Hoffmann T C, Mulrow C D et al. (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews BRITISH MEDICAL JOURNAL 372, n71 doi:10.1136/bmj.n71

Tricco, A.C., Langlois, E.V., Straus, S.E. (2017) Rapid reviews to strengthen health policy and systems: a practical guide. World Health Organization. https://iris.who.int/handle/10665/258698.

Table A1. Defining Key Concepts.

Concept	Definition and Context
Supplementary feeding (SF)	*The localised provision by humans of additional food (often accompanied by water) intended for consumption by wild birds*.
	In this context we are primarily concerned with bird feeding conducted by members of the general public usually within residential settings and shared/community spaces. The focus is therefore on UK garden birds. This type of SF accounts for a very high proportion of all SF in the UK and is the issue on which RSPB is most heavily engaged both as a source of public advice and as a commercial supplier of food and feeders.
Wildlife impacts	*The effects of SF on wild bird species and other wildlife.*
	Includes changes in breeding success, survival, behaviour, predation risk, competition, abundance/distribution, disease, and their interactions, along with associated impacts on non-avian wildlife.
People impacts and influences	*The effects of SF on people*.
	Inclusive of effects on wellbeing (physical, mental, social), connection to nature, promotion of pro-environmental values/behaviour. Also considering motivations for feeding and understanding of risks/benefits to birds.

Table A2. Search strings used for each question.

RQ		Term-1	Term-2	Term-3	Term-4
W 1	Direct impacts	(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "food addition" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")	AND ("breeding success" OR "reproductive success" OR productivity OR "nest success" OR "nesting success" OR "laying date" OR "clutch size" OR "brood size" OR survival OR mortality OR predation OR condition OR mass OR weight OR physiol* OR immun* OR trauma OR toxin)	
W 2	Abundance & distribution	(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR	AND (abundance OR density OR range OR distribution OR migration OR assemblage* OR "community structure" OR "community composition" OR richness OR diversity OR simplification OR evenness OR homogenisation)	

RQ		Term-1	Term-2	Term-3	Term-4
			"food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "food addition" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")		
W3	Non-avian nature	(bird* OR avian)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "experimental reduction of winter food" OR bird-	AND ("non-target animals" OR rat* OR "brown rat"* OR "rattus norvegicus" OR rodent* OR rodentia OR "small mammals" OR squirrel OR Sciuridae OR Sciurus OR fox OR "Vulpes vulpes" OR cat OR "felis domesticus" OR opossum OR possum OR deer OR mesopredator* OR mammal OR "bark dwelling" OR "bird prey" OR tick* OR beetle* OR aphid* OR plant* OR invertebrate* OR insect* OR arthropod*)	

RQ		Term-1	Term-2	Term-3	Term-4
			feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision")		
W4	Disease	(bird* OR finch* OR paridae OR tits OR sparrow* OR passerine OR avian OR pigeon* OR dove*)	AND ("anthropogenic food" OR "anthropogenic winter food" OR "artificial food" OR "artificial winter food" OR "food addition" OR "supplemental food" OR "supplemental winter food" OR "supplemental feeding" OR "supplemental winter feeding" OR "supplementary food" OR "supplementary winter food" OR "supplementary feeding" OR "supplementary winter feeding" OR "food supplementation" OR "feed supplementation" OR "supplementary diet" OR "supplementary winter diet" OR "food provision" OR "feed provision" OR "diet provision" OR "food subsidy" OR "feed subsidy" OR "diet subsidy" OR "subsidised food" OR "subsidised winter food" OR "subsidized food" OR "subsidized winter food" OR "subsidised feed" OR "subsidised winter feed" OR "subsidized feed" OR "subsidized winter feed" OR "subsidised feeding" OR "subsidised winter feeding" OR "subsidized feeding" OR "subsidized winter feeding" OR "subsidised diet" OR "subsidised winter diet" OR "subsidized diet" OR "subsidized winter diet" OR "experimental reduction of winter food" OR bird-feeder* OR "bird feeder" OR "bird feeders" OR "bird feeding" OR "supplementary water" OR "water supplementation" OR "water provision" OR feeder* OR "aggregation" OR "garden bird") AND (fomite* OR vector* OR parasite* OR health OR disease OR epidemic OR trichomonosis OR "trichomonas gallinae" OR "mycoplasmal conjunctivitis" OR "mycoplasma gallisepticum" OR "avian malaria" OR plasmodium OR "newcastle disease" OR paramyxovirus OR "beak and feather disease" OR circovirus OR "usutu virus" OR flavivirus OR "paridae pox"	(bird* OR finch* OR paridae OR tits OR sparrow* OR passerine OR avian OR pigeon* OR dove*) AND (fomite* OR vector* OR parasite* OR health OR disease OR epidemic OR trichomonosis OR "trichomonas gallinae" OR "mycoplasmal conjunctivitis" OR "mycoplasma gallisepticum" OR "avian malaria" OR plasmodium OR "newcastle disease" OR paramyxovirus OR "beak and feather disease" OR circovirus OR "usutu virus" OR flavivirus OR "paridae pox" OR "avipoxvirus" OR psittacosis OR ornithosis OR chlamydiosis OR "chlamydia psittaci" OR "escherichia albertii" OR "escherichia coli" OR papillomatosis OR papillomavirus OR knemidocoptes OR cnemidocoptes OR salmonellosis OR "salmonella typhimurium" OR "suttonella ornithocola" OR mycotoxin* OR aflatoxin OR ochratoxin)	

RQ		Term-1	Term-2	Term-3	Term-4
			OR "avipoxvirus" OR psittacosis OR ornithosis OR chlamydiosis OR "chlamydia psittaci" OR "escherichia albertii" OR "escherichia coli" OR papillomatosis OR papillomavirus OR knemidocoptes OR cnemidocoptes OR salmonellosis OR "salmonella typhimurium" OR "suttonella ornithocola" OR mycotoxin* OR aflatoxin OR ochratoxin)		
W5	Indirect impacts	(“interspecific competition” OR “inter-specific competition” OR competit* OR predat* OR depredation OR herbivory OR evict* OR symbio* OR mutual* OR commensal* OR parasit*)	AND (“marsh tit” OR “parus palustris” OR “poecile palustris” OR “willow tit” OR “parus montanus” OR “poecile montanus” OR "lesser spotted woodpecker" OR “dryobates minor” OR “dendrocopos minor” OR “crested tit” OR “parus cristatus” OR “lophophanes cristatus” OR “pied flycatcher” OR “ficedula hypoleuca” OR “european starling” OR “sturnus vulagris” OR “house sparrow” OR “passer domesticus” OR “song thrush” OR “turdus philomelos” OR “wood warbler” OR “phylloscopus sibilatrix”)	AND (“blue tit” OR “parus cyanistes” OR “great tit” OR “parus major” OR “great spotted woodpecker” OR “dendrocopos major” OR “nuthatch” OR “sitta europaea” OR “wood pigeon” OR woodpigeon OR “columba palumbus” OR “collared dove” OR “streptopelia decaocto” OR “eurasian magpie” OR “pica pica” OR “carrion crow” OR “corvus corone” OR “jackdaw” OR “corvus monedula” OR sparrowhawk OR “accipiter nisus” OR “grey squirrel” OR “Sciurus carolinensis” OR “ring-necked parakeet” OR “rose-ringed parakeet” OR “psittacula krameria” OR goldfinch OR “carduelis carduelis” OR “eurasian siskin” OR “carduelis spinus” OR “spinus spinus” OR “european robin” OR “erithacus rubecula” OR “long-tailed tit” OR “aegithalos caudatus” OR blackcap OR "Sylvia atricapilla" OR “coal tit” OR “parus ater”)	
W6	Mitigation	(bird* OR avian)			
P1	Wellbeing	(“bird*”)	AND (feed* OR food)	AND (wellbeing OR well-being OR "human health" OR “mental	AND (people OR public

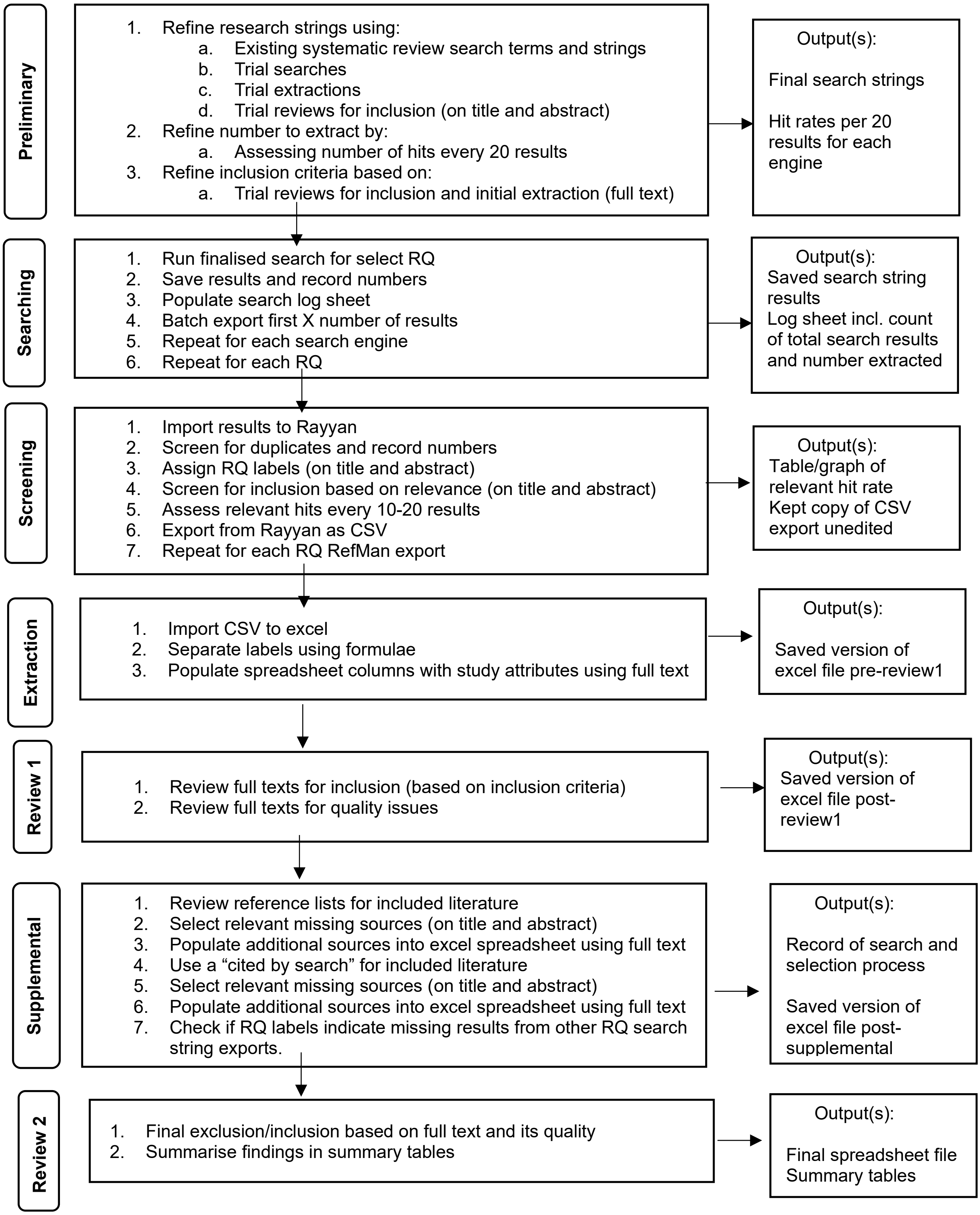
RQ		Term-1	Term-2	Term-3	Term-4
				health” OR “quality of life” OR life-satisfaction OR “life satisfaction” OR emotion* OR mood OR psycholog* OR psychosocial OR “positive affect” OR “negative affect” OR happiness OR stress OR anxiety OR depression)	OR “general public” OR citizen)
P2	Nature Connection	(“bird*”)	AND (feed* OR food)	(“Nature connection” OR “connection to nature” OR “nature connectedness” OR “connectedness to nature” OR “connection with nature” OR “connection to the natural world” OR “connectedness with nature” OR “connection with the natural world” OR “inclusion of nature in the self” OR “nature included in the self” OR “environmental identity” OR “identification with the environment” OR “identification with the natural world” OR “identification with the biosphere” OR “biospheric identity” OR “nature identity” OR “natural world identity” OR “environmental self-identity” OR “nature relatedness” OR “relationship with nature” OR “human-nature relationship” OR “relationship with the natural world” OR “emotional affinity toward nature” OR “emotional affinity for nature” OR “love and care for nature” OR “emotional attachment to nature”)	AND (people OR public OR “general public” OR citizen)
P3	Conservation	(“bird*”)	AND (feed* OR food)	AND ("pro-environmental attitudes" OR "pro-environmental education" OR "pro-environmental	AND (people OR public OR “general

RQ		Term-1	Term-2	Term-3	Term-4
				behaviour*" OR "pro-environmental action" OR "pro-environmental engage*" OR "environment* friendly behaviour*" OR "environment* friendly action*" OR "environment* friendly engage*" OR "environmental behaviour*" OR "environmental action" OR "environmental engage*" OR "pro-nature behaviour*" OR "pro-nature action" OR "pro-nature engage*" OR "nature behaviour" OR "nature action" OR "nature engagement" OR "nature positive behaviour*" OR "nature positive action" OR "nature positive engage*" OR "wildlife friendly behaviour*" OR "wildlife friendly action" OR "wildlife friendly engage*" OR conservation OR encourage* OR promote*)	public" OR citizen)
P4	Motivations	("bird*")	AND (feed* OR food)	AND (motivation* OR motivat* OR predict* OR intrinsic OR extrinsic OR drive* OR antecedent* OR mediat* OR promote* OR influenc* OR encourage*)	AND (people OR public OR "general public" OR citizen)
P5	Public Understanding	("bird*")	AND (feed* OR food)	AND (knowledge OR risk OR inform* OR perception OR harm OR benefit OR cost OR "public understanding" OR "citizen science" OR disease OR pest* OR pet* OR predation OR competition OR impact* OR implication* OR learn* OR educat*)	AND (people OR public OR "general public" OR citizen)

Table A3. The four search engines used across all wildlife and people questions.

Database	Rationale	Link
Google Scholar	Comprehensive literature search tool.	https://scholar.google.com/
Web of Science	Comprehensive search tool that may provide sources Google Scholar will not	https://www.webofknowledge.com/
Scopus	Elsevier's abstract and citation database of peer-reviewed literature.	https://www.scopus.com/
PubMed	Free resource for the search biomedical and life sciences literature.	https://pubmed.ncbi.nlm.nih.gov/

Figure A1. Flow diagram of the stages followed for each question of interest.



Appendix B.

Alphabetic list of common and scientific names of animal species mentioned in the text. For birds this was based on the British Ornithological Union U list, which also notes: AviList international English name. Non-bird names were those listed as current by Wikipedia.

https://www.worldbirdnames.org/new/ioc-lists/master-list-2/

Gill F, D Donsker & P Rasmussen (Eds). 2025. IOC World Bird List (v15.1).

Common name	Scientific Name
African woolly-necked stork	*Ciconia microscelis*
alpine accentor	*Prunella collaris*
American crow	*Corvus brachyrhynchos*
American goldfinch	*Spinus tristis*
American robin	*Turdus migratorius*
American yellow warbler	*Setophaga petechia*
Australian magpie	*Gymnorhina tibicen*
Australian reed warbler	*Acrocephalus australis*
band-tailed pigeon	*Patagioenas fasciata*
black redstart	*Phoenicurus ochruros*
black-billed magpie	*Pica hudsonia*
black-capped chickadee	*Poecile atricapillus*
black-throated blue warbler	*Setophaga caerulescens*
black-winged magpie	*Pica hudsonia*
brambling	*Fringilla montifringilla*
brown rat	*Rattus norvegicus*
brown-headed cowbird	*Molothrus ater*
Canada/Grey Jay	*Perisoreus canadensis*
Carolina chickadee	*Poecile carolinensis*
Carolina wren	*Thryothorus ludovicianus*
carrion crow	*Corvus corone*
chimney swift	*Chaetura pelagica*
cinereous tit	*Parus cinereus*
coal tit	*Periparus ater*
collared flycatcher	*Ficedula albicollis*
common blackbird	*Turdus merula*
common myna	*Acridotheres tristis*
common pheasant	*Phasianus colchicus*
common reed bunting	*Emberiza schoeniclus*
common reed warbler	*Acrocephalus scirpaceus*
common starling	*Sturnus vulgaris*
common whitethroat	*Curruca communis*
common wood pigeon	*Columba palumbus*
corn bunting	*Emberiza calandra*
corvid	*Corvus sp.*

Common name	Scientific Name
coyote	*Canis latrans*
crested tit	*Lophophanes cristatus*
dark-eyed junco	*Junco hyemalis*
domestic canary	*Serinus canaria forma domestica*
domestic cat	*Felis catus*
domestic chicken	*Gallus gallus domesticus*
downy woodpecker	*Dryobates pubescens*
dunnock	*Prunella modularis*
dusky flycatcher	*Empidonax oberholseri*
eastern bluebird	*Sialia sialis*
echo parakeet	*Psittacula eques*
Eurasian bittern	*Botaurus stellaris*
Eurasian blackcap	*Sylvia atricapilla*
Eurasian blue tit	*Cyanistes caeruleus*
Eurasian bullfinch	*Pyrrhula pyrrhula*
Eurasian chaffinch	*Fringilla coelebs*
Eurasian collared dove	*Streptopelia decaocto*
Eurasian jay	*Garrulus glandarius*
Eurasian magpie	*Pica pica*
Eurasian nuthatch	*Sitta europaea*
Eurasian siskin	*Spinus spinus*
Eurasian skylark	*Alauda arvensis*
Eurasian sparrowhawk	*Accipiter nisus*
Eurasian tree sparrow	*Passer montanus*
Eurasian wren	*Troglodytes troglodytes*
European goldfinch	*Carduelis carduelis*
European green woodpecker	*Picus viridis*
European greenfinch	*Chloris chloris*
European pied flycatcher	*Ficedula hypoleuca*
European pine marten	*Martes martes*
European robin	*Erithacus rubecula*
European turtle dove	*Streptopelia turtur*
feral pigeon	*Columba livia*
fisher	*Pekania pennantii*
Florida scrub jay	*Aphelocoma coerulescens*
goldrest	*Regulus regulus*
great spotted woodpecker	*Dendrocopos major*
great tit	*Parus major*
grey fox	*Urocyon cinereoargenteus*
grey gerygone	*Gerygone igata*
grey squirrel	*Sciurus carolinensis*

Common name	Scientific Name
grey-headed chickadee	*Poecile cinctus*
hawfinch	*Coccothraustes coccothraustes*
house finch	*Haemorhous mexicanus*
house sparrow	*Passer domesticus*
house wren	*Troglodytes aedon*
Inca dove	*Columbina inca*
indigo bunting	*Passerina cyanea*
Japanese marten	*Martes melampus*
lesser spotted woodpecker	*Dryobates minor*
long-tailed Tit	*Aegithalos caudatus*
marsh tit	*Poecile palustris*
mealworm	*Tenebrio molitor*
mistle thrush	*Turdus viscivorus*
mountain bluebird	*Sialia currucoides*
mountain chickadee	*Poecile gambeli*
mourning dove	*Zenaida macroura*
New Zealand fantail	*Rhipidura fuliginosa*
New Zealand kākā	*Nestor meridionalis*
northern cardinal	*Cardinalis cardinalis*
northern wheatear	*Oenanthe oenanthe*
pea aphid	*Acyrthosiphon pisum*
pink pigeon	*Nesoenas mayeri*
purple finch	*Haemorhous purpureus*
racoon	*Procyon lotor*
red fox	*Vulpes vulpes*
red kite	*Milvus milvus*
red squirrel	*Sciurus vulgaris*
red-breasted nuthatch	*Sitta canadensis*
red-faced warbler	*Cardellina rubrifrons*
redpoll	*Acanthis flammea*
red-winged blackbird	*Agelaius phoeniceus*
red-winged starling	*Onychognathus morio*
ring ouzel	*Turdus torquatus*
rook	*Corvus frugilegus*
rose-ringed parakeet	*Psittacula krameri*
rosy-faced lovebirds	*Agapornis roseicollis*
ruby-throated hummingbird	*Archilochus colubris*
silvereye	*Zosterops lateralis*
song sparrow	*Melospiza melodia*
song thrush	*Turdus philomelos*
spotted dove	*Spilopelia chinensis*
spotted flycatcher	*Muscicapa striata*
stitchbird	*Notiomystis cincta*

Common name	Scientific Name
stock dove	*Columba oenas*
striped skunk	*Mephitis mephitis*
swamp sparrow	*Melospiza georgiana*
tufted titmouse	*Baeolophus bicolor*
tui	*Prosthemadera novaeseelandiae*
varied tit	*Sittiparus varius*
Virginia opossum	*Didelphis virginiana*
western bluebird	*Sialia mexicana*
western jackdaw	*Coloeus monedula*
white wagtail	*Motacilla alba*
white-breasted nuthatch	*Sitta carolinensis*
white-crowned sparrow	*Zonotrichia leucophrys*
white-tailed deer	*Odocoileus virginianus*
white-throated-sparrow	*Zonotrichia albicollis*
white-winged dove	*Zenaida asiatica*
white-winged snowfinch	*Montifringilla nivalis*
willow tit	*Poecile montanus*
willow warbler	*Phylloscopus trochilus*
wood mouse	*Apodemus sylvaticus*
wood warbler	*Phylloscopus sibilatrix*
woodpecker	*Picidae sp.*
wrentit	*Chamaea fasciata*
yellowhammer	*Emberiza citrinella*
yellow-headed blackbird	*Xanthocephalus xanthocephalus*