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Not All Birds of the Same Feather: A Systematic Review of Ecosystem Services and Disservices in Horticulture

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ABSTRACT

Wild birds can provide essential benefits and cause significant harm in food production systems, commonly framed as ecosystem services and disservices, respectively. We conducted a systematic review of the literature on avian ecosystem services and disservices in horticultural systems, analysing 251 studies published between 1912 and 2023. Species richness and abundance were the most commonly used metrics. A total of 128 studies investigated ecosystem services, 109 addressed disservices, and only 22 considered both. Pest control (137 occurrences) and crop damage (120) were the dominant subjects within ecosystem services and disservices, respectively. However, crop damage was frequently reported without assessment, suggesting a confirmation bias towards birds as pests. The methods used to assess services and disservices were diverse, including species identification, damage and yield surveys, landscape analysis, experiments, published data, social surveys, laboratory techniques, and economic or ecological modelling. Despite this methodological diversity, most studies used only one or two approaches. Studies incorporating human-wildlife conflict were rare, despite their relevance for both conservation and horticultural management. This review reveals a bias towards studying avian contributions that are more easily measurable, such as pest control and crop damage, while more complex or less visible effects, such as pollination, disease control, or herbivore release, remain underexplored. As a result, birds' roles in horticultural systems are often understood in fragmented terms, potentially leading to ineffective or unjustified management decisions. A more holistic, species-focused, and integrative approach is needed to fully understand the trade-offs between ecosystem services and disservices. Such understanding is critical not only for enhancing the sustainability and productivity of food systems, but also for conserving wild birds in increasingly intensified agricultural landscapes.

1 | Introduction

Agriculture dominates the Earth's landscape, with more than one third of the world's terrestrial surface dedicated to agricultural production. There is a global need for increased food production while simultaneously ensuring the sustainability of the surrounding environment and the biodiversity it supports (Tilman et al. 2001). Nonetheless, although food production allowed the expansion of human populations and an increase in quality of life, the effects of agricultural intensification rival climate change as global drivers of environmental change and biodiversity loss (Maxwell et al. 2016; Tilman et al. 2001).

Agriculture is essential to human life, relying heavily on ecosystem services provided by natural ecosystems even if those are often underappreciated (Matson et al. 1979; Power 2010). With the well-documented impact of agricultural intensification on biodiversity, scientific discourse has focused on components of the natural environment that can provide indirect benefits to food production systems. Termed 'ecosystem service' (Daily 1997), these services relate to natural ecosystem functions that are, or can be, useful to humans.

Ecosystem services can be divided into four classes: provisioning, cultural, regulating, and supporting services (Daily 1997). Supporting services are the ones that allow the production of all other services. They make possible provisioning services, which relate to products that can be obtained from ecosystems. Regulating services are the benefits that are obtained from regulation within ecosystem processes. Cultural services are non-material benefits that can be obtained from ecosystems.

Nature's significant benefits to humans through ecosystem services have been recognised for more than 40 years (Costanza et al. 1998, 2014; MEA 2003; Ehrlich and Ehrlick 1981). Biodiversity contributes a variety of supporting services to agricultural systems, such as pest control and pollination (Power 2010; Matson et al. 1979; Daily 1997). Food production systems can thus be managed to provide natural supporting ecosystem services to the advantage of these systems (Swinton et al. 2007). However, the loss of biodiversity triggered by agricultural intensification leads researchers to believe that trade-offs between food production and ecosystem services may be unavoidable (Power 2010). Consequently, effective management, allied with the practice of maintaining biodiversity within food systems, is paramount to preserve these natural ecosystem services (Power 2010; Lyver et al. 2010).

Although it is now widely accepted that conserving natural ecosystem functions is essential for the maintenance of basic components of human quality of life, non-human species interact with human systems in ways that may result in negative outcomes for humans (Zhang et al. 2007). These costs have been aptly named 'ecosystem disservice' (Lyytimäki and Sipilä 2009). The discourse on ecosystem disservices is gaining traction (Kronenberg 2014), but their true costs are still poorly understood (Shackleton et al. 2016; Wu et al. 2021).

1.1 | Birds as Providers of Ecosystem Services and Disservices

Biodiversity can influence food production both positively and negatively, but birds have attracted particular interest due to their behavioural diversity and broad range of feeding guilds. These traits allow them to provide multiple ecosystem services—and at times, disservices (Şekercioğlu et al. 2016; Whelan et al. 2015; Triplett et al. 2012).

In recent decades, researchers have called for a better understanding of how agricultural practices affect native species (Green et al. 2005). Agricultural intensification is now widely recognised as a major threat to bird species, particularly in developing regions (Green et al. 2005). Current conservation cannot rely solely on protected areas with minimum human presence. While some species have shown population declines due to land use, others have adapted to or become tolerant of crops (Goijman et al. 2015). Bird occupancy in these landscapes is closely linked to the availability of food resources, highlighting the importance of agricultural systems in supporting at-risk species (Goijman et al. 2015). The role of agricultural systems in providing food for threatened species is a more recent and essential topic of research for modern conservation (Luck et al. 2015). Therefore, birds in agriculture should be viewed from both standpoints: how agricultural systems can support the permanence of native bird populations, and in turn which services and disservices those species can provide and how they can be encouraged (services) and mitigated (disservices).

To date, the literature on costs and benefits of wild animals to agriculture has evolved independently, with few authors attempting to bridge the gaps between those subjects (Triplett et al. 2012). These gaps hinder the understanding of costs and benefits within a spectrum and their potential trade-offs (Triplett et al. 2012). In this review, we synthesise the current literature on the ecosystem services and disservices provided by birds in horticultural systems, with a focus on the biological groups studied, knowledge gaps, and methodological trends.

2 | Methods

We conducted a systematic review following the guidelines proposed by Pullin and Stewart (2006). The search was conducted in the Dimensions CMTM platform (Hook et al. 2018). The keywords reflected the possible interactions between the three foci of the search: birds' services, birds' disservices, and type of horticultural system (e.g., vineyard, orchard, crop, plantation). Those interactions were examined in a round of preliminary searches; then adjusted to avoid undesirable results or maximise the scope of the search. Ultimately, the review was conducted using the following keywords from the first available publication until April 2023: (*bird* OR avia* OR avifauna* or ornithol**) *AND* (*service* OR disservice* OR pest* OR control* or pollinat* OR engineer* OR damage* or scaveng* OR release**) *AND* (*agr* OR hort* OR orchard* OR vineyard* OR crop* OR plantation* OR coffee OR finca**).

The search produced an initial result of 2223 documents. We included similar keywords to services, disservices, and horticultural systems to allow for a more comprehensive search, especially of older documents that would not necessarily refer to now widely used terms. For example, nuts and fruit crops studies usually include 'orchar' in the title or abstract, while 'coffe' needed to be included as a keyword to avoid missing relevant papers. In a similar logic, the keyword for agriculture was inserted in the review to avoid losing information on plant crops. However, this review focuses exclusively on plant food production systems for direct human consumption; therefore, excluding pastoral studies.

Documents were screened using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) diagram (Page et al. 2021) (Figure S1); the process resulted in 251 documents. Data were extracted into the following categories: publication date, geographic location, crop systems, data collection methods, bird taxa, and community diversity metrics.

3 | Results and Discussion

Of the 251 publications, 243 were journal articles, four were book chapters, three were pre-prints, and one was a university

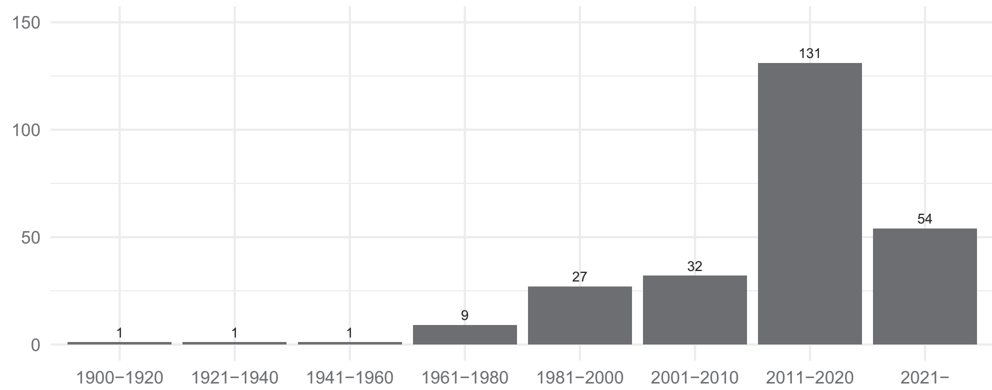

FIGURE 1 | Temporal distribution of documents. Distribution of document publications from the first available document (1912) to 2023. Each decade is represented in the y-axis, with three decades (1911–1940) presenting empty values.

report (Table S1). The earliest study dates to 1912, but the majority were published in the last 15 years (Figure 1).

3.1 | Horticultural and Biological Focus

Fruits and grains were the most studied horticultural crops found in the review (Table 1). These are essential staples of all human societies and recognised for their importance to human health (Awika 2011; Yahia et al. 2017). Vineyards and cacao plantations were particularly well represented—likely due to the economic relevance of wine and chocolate (Yahia et al. 2017). Greens, seeds, and beans were moderately represented (45 and 44 studies), with coffee (24) being the most represented crop in the seeds and beans category (Table S1). Nuts, oils, and root crops were less common (13, 9, and 3 studies, respectively). Apples (18 studies) and vineyard grapes (17) were the most cited fruit crops. Roughly one-third of publications (69) did not specify crop types, either covering multiple crops or focusing solely on bird species and their ecosystem roles. Case studies focusing on fruit orchards were concentrated in North America and Europe, with fewer case studies on the coastal regions of Africa, South America, Oceania, and Southeast Asia (Figures S2 and S3). Publications focusing on grains were mostly distributed across Africa and Europe, with a few on North America, South America, and Southern Asia. Case studies on seed crops were mainly distributed across the tropical and subtropical regions, including the Caribbean, Central America, and Sub-Saharan Africa. Leafy crop studies were clustered in North America and Southeast Asia.

Most publications (133) surveyed the horticultural systems without focusing on species or taxonomic groups, rather having a look at the general community of birds present on the system. An additional 53 publications did not include any taxonomic data, assessing services and disservices without species identification. The remaining 65 publications focus on bird species, taxonomic groups, or feeding guilds. A comprehensive list of all species and guilds studied is available in the Table S2. While 22 publications within the review looked at species of conservation concern, only six publications expressed the importance of investigating the permanence of native or endemic species in horticultural systems (Brambilla et al. 2017; Gámez-Virués et al. 2007; Jones, Sieving, and Jacobson 2005; Maas et al. 2018; Kross et al. 2012; da Silva et al. 2022). Studies looking into the integration of conservation of endemic species, such as the Moltoni's warbler *Sylvia subalpine* (Brambilla et al. 2017) and the Azores woodpigeon *Columba palumbus azorica* (Lamelas-López and Marco 2004), into food production systems, remain rare. Most documents, in fact, failed to discern between introduced or exotic and species native to the regions of study. With the projected advance of agriculture into natural habitats (Power 2010), this represents a missed opportunity to explore how horticultural systems might support the conservation of native avifauna. Community diversity metrics were reported in 79 publications, most commonly species richness (60 studies) and abundance (48), with many studies including both (Table 2). Functional diversity and feeding guilds were rarely reported (9 and 4 studies, respectively). Only one study employed a weighted

TABLE 1 | Types of systems and managements described in the studies retrieved from the search. The first two columns refer to the types of systems studied, with the last two columns referring to the management described by the researchers in each study. Total sum of systems will not reflect the number of documents (251) given that many studies assessed different systems.

System	T	Management	T
		Not specified	122
		Conventional	51
Fruits	81	Agroforestry	20
Multiple/not specified	69	Organic	15
Grains/cereals	60	Conventional vs. organic	12
Greens	45	Traditional	11
Seeds/beans	44	Small	7
Nuts	13	Experimental	5
Other	13	Sun vs. shade	5
Oils	9	Low-intensity	3
Roots	3	Cooperatives	2
		Indigenous practice	2
		Large vs. small	1
		Mixed management	1

TABLE 2 | Types of community metrics used to measure diversity of bird communities specified in 79 out of the 251 documents included in the review. Several metrics could be applied in the same study. The second section of the table describes the distinction between documents that presented or not a discussion on human-wildlife conflicts.

Community metrics	T
Species richness	60
Abundance	48
Weighed bird abundance	1
Feeding guilds	9
Functional diversity	4

Discussion on human-wildlife conflicts	T
N	206
Y	45

measure of avian abundance (Martínez-Núñez et al. 2020a). Despite frequent discussions of human-wildlife conflict, fewer than 20% of studies (45) explicitly addressed these issues. Approximately 39% of the publications (99) identified factors influencing bird communities (Table S3). Of these, 74 focused exclusively on positive factors, 17 discussed both positive and negative influences, and eight focused solely on negative factors. The most cited positive factors were landscape heterogeneity and proximity to natural habitats. The most common negative influences were pesticides, bird deterrents, and habitat loss. These findings echo previous literature emphasising the importance of natural habitat, shade and tree covers for the persistence of bird communities in human-managed lands (Loreau et al. 2003; Barbaro et al. 2021; Maas et al. 2015; Winqvist et al. 2012). However, there were considerably fewer documents investigating the negative factors affecting bird communities, although pesticides and other human-managed activities can be highly damaging to birds (Geiger et al. 2010; Power 2010). This indicates a research bias towards studying factors that promote or maintain bird populations, rather than those that hinder birds' survival in horticultural systems.

Furthermore, many studies failed to report management practices in detail (Table 1). This hinders understanding how different practices can affect the provision of ecosystem services and disservices by birds. Managing horticultural systems to maintain high levels of biodiversity, while avoiding reducing crop yield, is one of the greatest conservation challenges of current times (Yahia et al. 2017). Because high levels of biodiversity can translate into ecosystem services that contribute to crop productivity, it would be desirable to pay better attention to the effects of management practices within these systems to birds and their services and disservices.

3.2 | Investigating and Reporting on Ecosystem Services and Disservices

Out of 251 publications, 128 investigated ecosystem services, 109 investigated ecosystem disservices, and 22 delved into both services and disservices. Six ecosystem services and seven disservices were featured, with pest control (service) and crop damage (disservice) being the focus of most publications (Tables 3 and 4). Fertilising, disease control, pollination, and weed control were the other ecosystem services studied (Table 3), while herbivore release, disease spread, pollinator predation, seed predation, repellent action, and killing of livestock are included in the list of disservices (Table 4).

TABLE 3 | Compilation of ecosystem services studied in the 150 documents retrieved by the search, with different evidence (e.g., positive, negative, more data needed) as indicated by the researchers of each study. 128 documents presented a focus on only ecosystem services, while 22 had a focus on both ecosystem services and disservices. In some instances, researchers investigated more than one service per study. The difference before reported and expected (column of evidence) refer to researchers presuming a certain ecosystem service but not specifically measuring or assessing it (expected but not assessed) and to interviewees reporting a certain service without the researchers assessing it (reported but not assessed).

Ecosystem services	Evidence	*N*	Total
Pest control	Y	100	137
	More data needed	15	
	N	7	
	Weak	6	
	Reported but not assessed	4	
	Expected but not assessed	2	
	Neutralised by crop damage	1	
	Outweighs crop damage	1	
	Variable	1	
Fertilising	Y	4	5
	Reported but not studied	1	
Disease control	Y	3	4
	N	1	
Pollination	Y	2	4
	More data needed	1	
	Expected but not assessed	1	
Weed control	Y	1	3
	More data needed	1	
	Expected but not assessed	1	
Aesthetics	Y	1	1

Pest control was the most frequently studied service (137 instances; Figure 2 and Table 4), likely reflecting the substantial

TABLE 4 | Compilation of ecosystem disservices studied in the 131 documents retrieved by the search, with different evidence (e.g., positive, negative, more data needed) as indicated by the researchers of each study. 109 documents presented a focus on only ecosystem disservices, while 22 had a focus on both ecosystem services and disservices. In some instances, researchers looked into more than one disservice per study. The difference between reported and expected (column of evidence) refer to researchers presuming a certain ecosystem disservice but not specifically measuring or assessing it (expected but not assessed) and to interviewees reporting a certain disservice without the researchers assessing it (reported but not assessed).

Ecosystem disservices	Evidence	*N*	Total
Crop damage	Y	58	120
	Reported but not assessed	24	
	N	12	
	More data needed	10	
	Weak/not significant	7	
	Expected but not assessed	4	
	Variable	3	
	Neutralised by pest control	2	
Herbivore release	Y	4	7
	N	2	
	More data needed	1	
Disease spread	More data needed	3	5
	N	2	
Pollinator predation	*N*	1	2
	Y	1	
Seed predation	Y	1	2
	More data needed	1	
Repellent action	More data needed	1	1
Killing of livestock	*N*	1	1

economic impacts of invertebrate pests (Ferguson et al. 2019). But the provision of pest control is often dependent on particular species and their feeding habits; insectivorous birds, for example, will be better agents of biological control of arthropod pests than granivorous species (Şekercioğlu 2006), while birds of prey can act as efficient agents of control of other birds in horticultural settings (Kross et al. 2012). Given the context-specificity between different agrosystems and geographical regions, there are still knowledge gaps on the overall effects of birds as biological pest control agents (Díaz-Siefer et al. 2022).

Other ecosystem services are likewise valuable; a third of food crops are estimated to rely on faunal pollinators, a service also valued at billions of dollars annually (Klein et al. 2007). However, pollination was only evidenced in two documents (Requier et al. 2023; Ndang'Ang'A et al. 2013). This might be explained by the higher importance of insects, which were not the focus of this review, as pollinators to crops. Nonetheless, pest control and pollination have been indicated as easier services to quantify given the direct costs of replacing such natural agents (Power 2010). Evidence for the provision of fertilising services was confirmed in four documents (Navedo et al. 2015; Baling et al. 2016; Gorosábel et al. 2019; Plotnikov and Sinyavskiy 2020). Disease control was another ecosystem service included in the review, with three documents presenting evidence for the provision of this service (Gorosábel et al. 2020, 2022; O'Bryan et al. 2018). Weed control also had a minor representation, with a single study in the review, although the spread of weeds and their damage to crops is already a recognised issue (Peters et al. 2014). Finally, the ecosystem service of aesthetics was studied in one document (Geladi et al. 2022). This unique occurrence might be explained by the difficulty of translating a subjective notion into economic values.

Crop damage was the most reported ecosystem disservice, with 120 occurrences (Figure 2 and Table 4). The main issue in this area of research is that birds are often assumed to cause damage to crops, even though the perceived losses can be significantly higher than the actual damage (Şekercioğlu et al. 2016). This became evident when comparing the assumptions of researchers for crop damage with pest control. Crop damage was seven times more likely to be reported but not assessed (Tables 3 and 4). Expectations of damage—both by researchers and growers—frequently outpaced assessments. This discrepancy suggests a bias towards negative assumptions about birds perceived as pests. The provision of crop damage is also highly dependent on the context specifics of birds involved and the systems in question. Some bird species such as the red-billed quelea (*Quelea quelea*) and village weaver (*Ploceus cucullatus*) are consistently reported as troublesome pests, especially due to their natural history trait of feeding within big groups (Ward 1965; Adegoke 1983). However, even in those cases, damage might be overestimated, with documents reporting damage but not actually assessing it (Manyama et al. 2014; Musiwa and Mhlanga 2020). Worthy of note was the change in the methods employed to study crop damage. Until the 1980s, data was gathered by studying birds shot within the horticultural systems, then moving to the collection of faeces from live animals to study their diet content. This switch was probably inspired by the increasing importance of animal welfare in society and academic circles (Singer 2009).

Although six other disservices are accounted for in the review, only herbivore release (i.e., predation of mesopredators leading to the growth of herbivore populations and thus potential crop damage) and seed and pollinator predation featured documents presenting evidence for the provision of such disservices, with disease spread, repellent action, and killing of livestock being disproven or needing more data (Table 4). Birds of prey and scavengers were often assumed to be pathogenic spreaders, although this concept has been disputed (O'Bryan et al. 2018). Foodborne pathogens were also studied in other wild birds, although the researchers indicated the

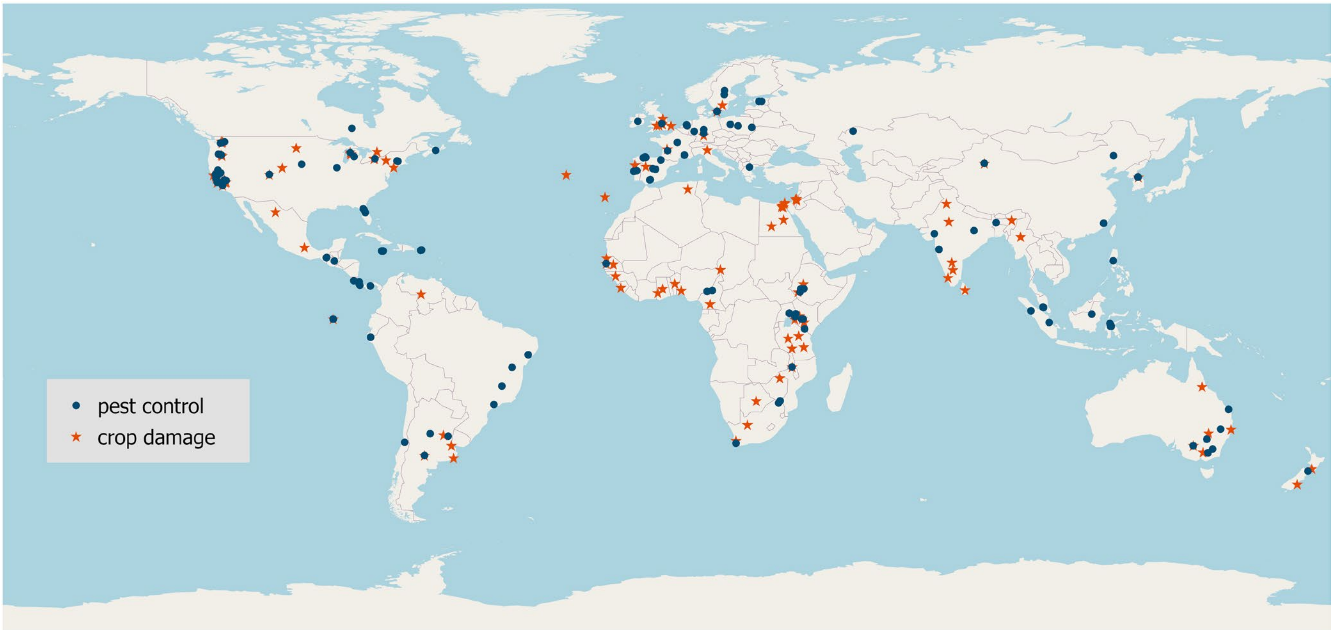

FIGURE 2 | Global distribution of pest control and crop damage studies. World map indicating the location for the studies focusing on pest control (143 occurrences, dark blue dots) and crop damage (124 occurrences, orange stars). Occurrences were higher than the number of evidence in Tables 3 and 4 because some case studies surveyed multiple systems in different locations. Locations were retrieved from GIS coordinates provided or approximated by the researchers. Map constructed on ArcPro (ESRI 2023).

need for more data before conclusive evidence can be drawn (Smith et al. 2022). Herbivore release is an example of the evidence of complex food webs within agricultural and horticultural systems, with birds indirectly affecting crops by feeding on the predators of herbivores and thus increasing the population of potential pests (Denmead et al. 2017; Garfinkel et al. 2020). Repellent action and killing of livestock were considered for specific groups, with waterfowl assumed to repel cattle from agricultural lands due to their faeces (Fox et al. 2017) and birds of prey assumed to cause mortality to livestock (O'Bryan et al. 2018). The repellent effect of waterfowl was inconclusive, while researchers on the second case study disproved the disservice for birds of prey. However, the low number of studies on these subjects hinders a definitive conclusion as to whether such disservices are being provided.

There was a marked discrepancy in how services and disservices were studied. While two-thirds of pest control studies found positive evidence, only half of crop damage studies confirmed actual harm. Moreover, studies often cited growers' concerns about crop damage without measuring it. This pattern inflates the literature on disservices without robust data and may distort policy or management responses. Fundamentally, more studies on the other services and disservices included in the list would be needed to warrant conclusions on birds being de facto provisioners of such benefits and damages. There was also a low number of studies investigating services and disservices in the same system. By not approaching ecosystem services and disservices as a continuum, researchers might underestimate or ignore holistic dynamics, such as pest control being neutralised by crop damage (Gonthier et al. 2019), or vice versa (Weyell et al. 2015). A dual approach could reveal complex dynamics—where positive and negative outcomes interact in unexpected ways—which are currently underexplored.

3.3 | Methods Used to Investigate Ecosystem Services and Disservices

A key aim of this review was to examine how methodological approaches to studying ecosystem services and disservices provided by birds in food production systems have evolved over time. From the earliest records in the 1900s to contemporary studies, the development of new technologies—such as GIS in the 1960s (Maguire 1991) – has shaped how researchers approach this field.

From the 251 publications, we identified 77 methods spread over 615 occurrences. These methods could be classified into 9 groups, with an additional miscellaneous category accounting for 16 occurrences (Table 5). The categories are as follows:

1. Estimation of species richness and/or abundance, via bird and arthropod counts, trapping, or observations (159 occurrences)
2. Exclosures, for birds, mammals, arthropods, and others (90 occurrences)
3. Damage and yield surveys (86 occurrences)
4. Spatial landscape analysis, through GIS data or digital photography (61 occurrences)
5. Use of published data, in the form of literature reviews, metanalyses, databases and agricultural reports (61 occurrences)

TABLE 5 | Compilation of different methods employed for the study of ecosystem services and disservices retrieved from the 251 documents assembled from the review. Methods were separated into distinct themes: estimation/identification of species involved in the systems; exclosures for different biological groups; surveys to assess crop yield and damage; spatial analysis of the landscape; use of published data; experiments of sentinel prey removal and provision of environmental enhancements; interviews and surveys; laboratory analysis involving DNA and isotope samples and microscope analysis; modelling of previous data and economic estimation; and a final category of miscellaneous methods. The second column distinguishes different methods within each theme. The third column further specifies the methods in each category, with others referring to biological groups other than birds.

Theme	Category	Specifics	*N*	T
Estimation/ identification	Counts	Point counts	31	159
		Transect counts	19	
		Not specified	10	
	Counts (others)	Arthropods	38	
		Lizards	1	
		Mammals	1	
	Trapping	Mist-nets surveys	6	
	Trapping (others)	Arthropods	8	
		Rodents	3	
		Other mammals	1	
	Direct observations	General	13	
		Foraging	23	
		With cameras	3	
	Misc.	Call recordings	1	
		Faecal dropping counts	1	
Exclosures	Birds	Birds	62	90
	Mammals	Bats	14	
		Others	2	
	Arthropods	Ants	4	
		Bees	2	
	Others	Others	4	
		Lizards	1	
		Weed	1	
Damage and yield surveys	Damage surveys	Crops	66	86
		Leaves	13	
	Yield surveys	Yield	7	
Spatial landscape analysis	GIS	Gis	60	61
	Digital photography	Digital photography	1	
Use of published data	Reviews	Literature reviews	37	61
		Metanalysis	5	
	Available data	From previous studies	9	
		Databases	6	
		Agricultural reports	4	
Experiments	Sentinel prey removal	Artificial prey	21	52
		Natural prey	16	
	Provision and monitoring of	Nest boxes	8	
		Perches	5	
		Shelters	1	
	Species reintroduction	Raptors	1	

(Continues)

Theme	Category	Specifics	*N*	T
Human surveys	Interviews	Not specified	26	46
		Semi-structured	11	
		Structured	3	
		Group discussions	4	
	Observations	Ethnographic observations	2	
Laboratory analysis	Microscope analysis	Stomach content from regurgitation	3	33
		Stomach content from culled birds	2	
		Faeces collected from mistnets	4	
		Faeces collected from nests	3	
		Faeces collected from nest boxes	2	
		Faeces collected from droppings	2	
		Faeces collected from roosting sites	1	
	DNA analysis	Faeces collected from mistnets	2	
		Faeces and stomach content collected from mistnets	9	
		Faeces collected from nest boxes	1	
		Faeces from droppings	1	
		Arthropods collected from pit falls	1	
	Isotope analysis	Blood samples	1	
		Faeces collected from droppings	1	
Estimation and modelling	Economic estimations	Crops	7	11
	Estimation (others)	Food consumption	1	
		Pollination rates	1	
	Modelling	Crop losses	1	
		From previous data	1	
Miscellaneous	Misc.	Tree traits measuring	2	16
		Bird scarring	2	
		Seed removal experiment	2	
		Breeding and nesting monitoring	1	
		Feeding trials in captivity	1	
		Fertilising experimentations	1	
		Fruit measurements	1	
		Leaf chemistry characterisation	1	
		Nest searches	1	
		Pollination visitation rates	1	
		Prey recognition trials	1	
		Presence/absence surveys	1	
		Faecal contact rates	1	

6. Experimental studies, including sentinel prey experiments and habitat manipulations (52 occurrences)
7. Human surveys, such as interviews and ethnographic observations (46 occurrences)
8. Laboratory analysis, including microscopy, DNA and isotope techniques (33 occurrences)
9. Estimation and modelling of crop growth, crop losses, food consumption, and pollination rates (11 occurrences).

3.4 | Estimation/Identification

The most common approach involved species identification and estimation of community metrics via bird counts, mist-netting, or direct observations. Point and transect counts were the most widely used, due to their low cost, accessibility, and support from citizen science (e.g., birdwatching networks). Arthropod counts were similarly conducted on leaves and branches. Mist-netting, while effective, is resource-intensive and requires trained personnel, likely explaining its relatively limited use.

Direct observations allow researchers to identify potential beneficial or damaging species in situ, but this method was used in only a fifth of the studies in this group.

3.5 | Exclosures

Exclosures represent an efficient way of investigating the effects of the absence of a certain taxonomic group in a particular system, and they were the second most common group of methods in the review (Table 5). Methods focused on birds and bats, indicating the importance of non-avian flying animals to agroforestry systems (Maas et al. 2013; Gras et al. 2016; Maas et al. 2019; Ferreira et al. 2023). Arthropods were less studied, with bees and ants being the most common groups, although this might simply reflect the inherent bias of the review by focusing on avian species. Exclosures were often combined with estimation and identification methods.

3.6 | Damage and Yield Surveys

Surveys of the plants themselves configured the third most common group of the review (Table 5). Yield estimation, where the final yield of the crops was estimated to account for potential loss (Horgan et al. 2017; Garfinkel et al. 2020), was employed less frequently than direct damage surveys. This group was often connected to exclosures and estimation and identification. Damage made to crops often is undistinguishable at the level of family or genus; thus, methods that can combine these surveys with identification of the causes of crop damage would increase the robustness of the studies.

3.7 | Spatial Landscape Analysis

Spatial analyses—almost always GIS-based—were used to assess biotic and abiotic landscape features. Analysing photographs of the landscape through digital software (Filloy et al. 2023) will probably become more common in future years with the advance of GIS technologies. The use of geographical data allowed researchers to investigate factors affecting bird communities, reaching results that promote landscape heterogeneity as an important consideration for the permanence of birds in the systems (Martínez-Núñez et al. 2020b). This type of analysis was more strongly connected to estimation and identification, exclosures, and damage and yield surveys.

3.8 | Use of Published Data

By mid-1940s, researchers were already making use of published data to conduct reviews on the subject (Southern 1945). Most reviews had a specific focus on a species or biological group (Owen 1990; Allan et al. 1995; Mols and Visser 2002), a service (Kirk et al. 1996; García et al. 2021; Requier et al. 2023) or disservice (Gebhardt et al. 2011; Hermira and Michalski 2022; Sausse et al. 2021), a horticultural system (Catling and Islam 1999; Chain-Guadarrama et al. 2019; Sausse and Lévy 2021), or a region (Schroth et al. 2000; Bomford and Sinclair 2002; de Mey et al. 2012). In fact, the occurrence of a wide range of perspectives was limited to three documents (Johnson et al. 2011; Triplett et al. 2012; Peisley et al. 2015), indicating the importance of this current review in systematising the available knowledge. Several reviews need to be systematically undertaken and published before the full benefits of the reviews to global knowledge can be realised (Pullin and Stewart 2006). Meta-analysis, a more robust form of review, was applied in only five publications, all within the past 15 years (van Bael et al. 2008; Philpott et al. 2009; Weyell et al. 2015; Díaz-Siefer et al. 2022; Monteagudo et al. 2023). The global scope of the research leads to a wide range of results and how they are reported, which is a common issue to the proper development of meta-analysis (Gurevitch et al. 2018). This group of methods also included the use of available databases, reports from governmental agencies and previous data from the same or related authors (Table 5). This category also encompassed governmental reports and previously collected data but was rarely combined with other methods, as many of these documents were standalone reviews (Manikowski 1984; Elliott 1988; Dhindsa and Saini 1994; Allan et al. 1995; Kirk et al. 1996; Catling and Islam 1999).

3.9 | Experiments

This category included field experiments beyond exclosures, including sentinel prey removal experiments, provision and monitoring of nest boxes, perches and shelters, and the reintroduction and monitoring of species (Table 5). Natural prey experiments often involved the use of mealworms or common pests to the agricultural or horticultural system (Jordani et al. 2015; Garfinkel and Johnson 2015), while artificial experiments were made using plasticine models of caterpillars (Howe et al. 2015; Barbaro et al. 2017). A couple of documents reported using both types of sentinel prey, potentially increasing the accuracy of the investigation of pest control (Peisley et al. 2016; Denmead et al. 2017). This group was more strongly connected to estimation and identification, indicating the attempts of researchers to not only assess if arthropod pests are being consumed in the systems (provision of pest control), but to also identify the potential agents of this biological control.

3.10 | Human Surveys

Given that horticulture is directly related to human health and wellbeing, it was not surprising to find studies assessing the human component of ecosystem services and disservices through interviews—i.e. investigating the opinions and assumptions of the people that manage the lands the birds occupy and feed in. However, social and conservation sciences traditionally are treated separately (Sandbrook et al. 2019). Some researchers utilised both qualitative and quantitative methods in their research (Schäckermann et al. 2014; Smith et al. 2021; Alemayehu and Tekalign 2022), an approach called'triangulatio'. This approach has been suggested as a way to reduce bias from a single method in the social sciences (Jupp 2001), and this rationale works here to create a more robust investigation of the provision of ecosystem services and disservices. In general, however, human surveys did not hold strong connections to other groups of methods.

3.11 | Laboratory Analysis

Microscopic and other laboratory analyses compose the first group of methods in temporal order, with the analysis of stomach content of birds killed by farmers (Hammond 1912). Examination of faeces was the most common laboratory method used, being more acceptable than killing wild birds in current times. Although microscope analysis of samples is still more common, DNA analysis has expanded in the past decade (Karp et al. 2013; Garfinkel et al. 2020) and is bound to increase in occurrence with the advancements of genetic technologies. Techniques such as barcoding (Sow et al. 2020) and next generation sequencing (Crisol-Martínez et al. 2016) allow for better accuracy than microscope identification, and they will likely uncover new discoveries in the near future. These methods were strongly connected with estimation and identification, since trapping and surveying the communities gave researchers access to faeces, and occasionally linked to damage and yield surveys.

3.12 | Estimation and Modelling

This small but growing category used economic or computational models to estimate crop losses, consumption, or pollination rates (Table 5). The first document within this group dates from the late 1990s (Basili and Temple 1999), but few researchers have adopted this approach. This might be due to ecologists still straying away from economics, be it for philosophical reasons (the inherent value of nature that cannot, or should not, be valued in human terms) or for what is seen as two insurmountably different theoretical fields (Hughey et al. 2003; Kaval and Baskaran 2013; Johnson and Hackett 2016). Nonetheless, incorporating economic models in food production systems has become increasingly necessary (Ferguson et al. 2019). Economic incentives are believed to be one of the most feasible methods for wildlife conservation in human-managed lands within a capitalist culture (Kareiva et al. 2012; Kross et al. 2018). Given the inclusion of only 11 documents in this group of methods, it is not surprising that it did not hold strong connections with any other group. Understanding the net return of benefits and damages to horticulture is paramount to establish efficient management practices. Quantifying damages will include not only the direct losses of production but also the costs of controlling techniques and potential increased processing of crops (Triplett et al. 2012). Benefits will also not be completely straightforward, since ecosystem services might fluctuate in their net return due to market prices (Luck 2013). However, although economic considerations are important in our current economic system, few documents in this review attempted to bridge this gap.

3.13 | Miscellaneous

This catch-all group included less common or emergent methods. Bird-scaring trials (Murton and Jones 1973; Lindell et al. 2018), fertilisation experiments (Plotnikov and Sinyavskiy 2020), and prey recognition trials (Jones, Sieving, Avery, and Meagher 2005) exemplify underused but potentially valuable tools. Seed removal experiments (Tschumi et al. 2018a, 2018b) also hold promise, given their similarity to established prey-removal protocols.

3.14 | Combining Methods

The methods featured in the review have been thus far discussed separately, but in the studies, authors would often combine multiple groups. Most publications featured the use of only one or two groups (102 and 74, respectively), with 53 publications featuring three groups, 16 featuring four groups and only four publications having a combination of five different groups. We decided to examine the relationships between each group to inspect the most common pairing of methods. The most common pairings were between methods of estimation and identification with spatial landscape analysis (47 occurrences), exclosures (46), and damage and yield surveys (45); exclosures with damage and yield surveys (32) and spatial landscape analysis (29); estimation and identification with experiments (28) and damage and yield surveys with spatial landscape analysis (27). Less common pairings included laboratory analysis with estimation and identification (18 occurrences), and experiments with spatial landscape analysis (14) and exclosures (10).

The least occurring pairings were of human surveys with estimation and modelling, and laboratory analysis with experiments and estimation and modelling, with one occurrence each. Use of published data did not have any strong connections to the other groups, being featured in uncommon pairings with laboratory analysis, experiments, and exclosures. Human surveys also did not feature strong connections, being the group of methods that was most featured by itself (Table S1).

Only four documents presented a variety of five groups of methods in their research (Peisley et al. 2016; Kross et al. 2020; Martínez-Sastre et al. 2020; Taylor et al. 2022), all from the past decade. This indicates a potential current change towards integrating several different methods for the same study, allowing for a better understanding of the complexities of birds as providers of services and disservices in horticultural systems.

3.15 | Human-Wildlife Conflicts

Given the importance of horticulture to human societies, it is perhaps surprising that less than a fifth of the documents (45 out of 251; Table 3) discussed potential or acknowledged human-wildlife conflicts arising from the interactions of wild animals in these human-managed lands. In the broader context of such conflicts, attention typically centres on mammals, particularly large species such as elephants, rhinoceros and tigers, whose impacts can be severe, especially in developing nations (Linkie et al. 2007). When avian species are considered, it is often birds of prey for their perceived threat to livestock and wildlife game, and the negative connotations associated with scavengers (Şekercioğlu 2006; Pohja-Mykrä et al. 2012; O'Bryan et al. 2018). Birds of prey represent some of the most threatened bird groups, with species suffering from lead poisoning and hunting pressure (Hallmann 1985; Heggøy and Øien 2014).

However, other bird groups are also frequently targeted. Historical and contemporary accounts reveal that farmers and growers have shot wild birds perceived as pests, regardless of the actual extent of their impact (Hammond 1912; Murton and Jones 1973). As stated previously, farmers and growers often overestimate the negative effects of native avifauna in their lands, which can lead to an increase in human-wildlife conflicts (Dickman 2010; Gorosábel et al. 2019). Population declines of scavengers can also feed into the loss of potential ecosystem services, leading to the spread of diseases and higher costs in human healthcare (Michel et al. 2020). Managing cost–benefit trade-offs of bird activity in agricultural systems can involve promoting desirable functional traits, targeted control of pest species, managing community composition, increasing ecosystem diversity, and reducing agricultural intensification (Triplett et al. 2012). These practices need to be further studied and compared, so that informed recommendations can be suggested.

While it is true some bird species worldwide can cause significant damage to food production systems, the long history of confirmation bias towards ecosystem disservices by birds (Bonhomme 2021) needs to be discussed; those beliefs need to be challenged. While the scientific community has largely moved away from endorsing the killing of wild birds, this practice remains common in many regions. A comprehensive and evidence-based understanding of birds' ecological roles in horticultural systems is critical to dismantle harmful narratives and support conservation-informed management. Without this shift, unsustainable and indiscriminate practices will persist, threatening both biodiversity and the ecological stability of food production systems.

4 | Conclusions

1. There seems to be a bias towards studying services and disservices that are arguably easier to measure (i.e., pest control, crop damage) than other, harder-toto-detect (i.e., disease spread, pollination, ecological releases of predators or herbivores). This hinders a holistic view of birds' roles in these systems, in turn deterring potential opportunities to change growers' assumptions and attitudes towards wild birds.

2. Crop damage was found to be up to seven times more likely to be reported than pest control; yet in many cases, damage was not empirically assessed. Birds' long-standing reputation as pests often leads to the unjustified targeting of species. Greater effort is needed to distinguish between harmful and beneficial species through empirical, species-specific evaluations.

3. The lack of focus on specific species or taxonomic groups hinders understanding the presence of native and/or endangered species in food production systems. A species-focused approach could thus allow the design of strategies to aid the permanence of such species in those systems.

4. Ecosystem services and disservices tend to be studied separately, hindering their comprehension in a biological continuum. Integrating these dimensions would support a more ecologically realistic understanding of avian roles and reveal unexpected synergies or trade-offs.

5. The study of ecosystem services and disservices has employed a myriad of methods throughout time, with most researchers opting for identifying and estimating bird species in the food systems. Other methods include exclosures, damage and yield surveys, spatial landscape analysis, literature reviews, sentinel prey removal experiments, human surveys, laboratory analysis, and estimation and modelling of crop growth and losses. Most studies used only one or two groups of methods; however, recent papers indicate a potential shifting trend towards multi-methodological approaches.

6. Effective management of bird activity in food production systems may involve promoting desirable functional traits, implementing species-specific control measures, enhancing community diversity, and reducing agricultural intensification. However, these practices require further empirical comparison to determine their efficacy and broader impacts.

7. Less than a fifth of the documents discussed potential or acknowledged human-wildlife conflicts. Because of the inherent bias of farmers and growers to assume birds as pests, the diminished number of studies focusing on this aspect of the discourse presents a clear issue for the conservation of native birds in food production systems. Without this approach, several bird groups are kept unjustifiably targeted, or not properly managed to reduce or control their impact in horticultural systems. Changing this current scenario will not only assist in promoting better conservation practices for the permanence of wild birds in an ever-changing world of agricultural intensification and expansion of human-managed lands but also provide opportunities for the betterment of human societies through the reduction of the damages and the increase of potential benefits.

Author Contributions

Giuliana Caldeira Pires Ferrari: conceptualization, data curation, formal analysis, investigation, methodology, project administration, writing – original draft, writing – review and editing. **Karen Mason:** data curation, funding acquisition, investigation, methodology, project administration, supervision, writing – review and editing. **Alastair Robertson:** formal analysis, investigation, methodology, supervision, validation, visualization, writing – review and editing. **Isabel Castro:** funding acquisition, investigation, methodology, supervision, validation, visualization, writing – review and editing.

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Data Availability Statement

The data that supports the findings of this study are available in the Supporting Information—S1 of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Flow diagram summarising the review strategy of studies inclusion and exclusion based on PRISMA guidelines. Adapted from (Page et al. 2021). **Figure S2:** Global map indicating the occurrences of studies focusing on the horticultural systems with more than 10 occurrences each: fruits (71 occurrences), grains (58 occurrences), seeds and beans (35 occurrences), and greens (22). Locations were retrieved from GIS coordinates provided or approximated by the researchers. Map constructed on ArcPro (ESRI 2023). **Figure S3:** Global map indicating the location for the studies focusing on services and disservices other than pest control and crop damage. Ecosystem disservices include herbivore release (seven occurrences), disease spread (five occurrences), pollinator predation (two occurrences), seed predation (two occurrences) and killing of livestock (one occurrence). An additional disservice, repellent action, was only studied in a document that did not specify the location, therefore it is not included in this map. Ecosystem services include fertilising (five occurrences), disease control (four occurrences), pollination (four occurrences), weed control (three occurrences) and aesthetics (one occurrence). Locations were retrieved from GIS coordinates provided or approximated by the researchers. Map constructed on ArcPro (ESRI 2023). **Table S2:** Compilation of the 77 documents (out of 251) that report on focused species and/or species of conservation concern (endemic, endangered (EN), native, uncommon, reintroduced, and vulnerable (VU)). Population status for each species were retrieved from IUCN Red List (IUCN 2024). Birds studied include specific species targeted by the researchers or a general look into the community occupying the systems (birds present in the system). **Table S3:** Compilation of 99 documents out of 251 that indicated abiotic and biotic factors affecting positively and negatively bird communities in the systems surveyed. **Table S1:** Complete description of the 251 documents included in the systematic review. Include the title, year and publication type of each document, with further information on specific details analysed by the review: filiation of the first authors, countries and regions of the case studies, types of horticultural systems, main research questions, methods of data collection, ecosystem services and disservices studied, bird species and community metrics measured, factors affecting bird communities positively and negatively, discussions on human-wildlife conflicts, and further notes if necessary. **Table S1:** has been submitted separately given its length and dimension as a large Excel table, to be made available publicly if thus accepted by the journal to provide the complete table of search results for this systematic review.