INFORMATION AS AN ECOLOGICAL DRIVER: AVAILABILITY AND ACCESSIBILITY OF POLLINATOR MANAGEMENT KNOWLEDGE FOR SPECIALTY CROP SYSTEMS IN THE U.S. MIDWEST

G. DiGiacomo[1], O. Megahed[2], M. Schuh[3], M. Wimmer[4]

[1]*Department of Applied Economics, University of Minnesota, 146H Ruttan Hall, 1994 Buford Ave., St. Paul, MN 55108, USA.*
[2]*College of Science & Engineering, University of Minnesota, 105 Lind Hall, 207 Church St. SE., Minneapolis, MN 55455, USA.*
[3]*Food Systems & Vegetable Production, University of Minnesota Extension, 4100 220th St. W., Suite 100, Farmington, MN 55024, USA.*
[4]*Food Systems & Fruit Production, University of Minnesota Extension, 140 Elton Hills Dr. NW., #201, Rochester, MN 55901, USA.*

Journal of Pollination Ecology, 42(14), 2026, pp 163-179

DOI: 10.26786/1920-7603(2026)910

Received 19 November 2025, accepted 29 June 2026

*Corresponding author: gigid@umn.edu

Abstract—Fruit and vegetable growers broadly recognize the ecological and economic importance of pollinators; however, they often lack credible, regionally specific, and discoverable guidance to support on-farm decision-making. To better understand these limitations, we explored two central questions for growers in the U.S. Midwest: (1) To what extent do pollinator-related resources exist for specialty crops? and (2) How accessible are these resources to the farming community and other end users?

A digital scoping review of 1,023 pollinator-related resources, including scientific peer-reviewed articles, non-profit organization literature, and institutional websites was conducted in 2024-2025. This analysis revealed substantial information gaps in crop coverage, regional representation, and best management practices. Next, we applied a weighted rubric grounded in common data principles to evaluate each resource's reachability, metadata quality, search-engine visibility, indexing, and shareability. The results showed considerable variability across resource type and criteria: scientific articles demonstrated strong metadata structure and discoverability but restricted access due to paywalls, whereas non-profit, educational, and government resources were openly accessible but suffered from poor metadata and low digital visibility.

Together, these findings underscore a persistent paradox in pollination information systems and their ecological implications: the most rigorously structured resources are often the least reachable, while the most reachable and accessible are insufficient or difficult to locate. Our study highlights the need for more geographically relevant, crop-specific pollinator guidance, as well as improvements in metadata standards and long-term hosting infrastructure to ensure information is findable, accessible, and usable for growers and technical advisors.

Keywords—Accessibility, shareability, pollinator, agricultural information, outreach, knowledge dissemination

INTRODUCTION

Pollination ecology traditionally examines the interactions between flowering plants and the animals that transfer pollen among them, thereby enabling plant reproduction (Faegri & van der Pijl 1979). More recently, the field has expanded to include an ecosystem service perspective, recognizing pollination as a critical process supporting both biodiversity and agricultural production (Klein et al. 2007; Garibaldi et al. 2013). This understanding is particularly important for specialty crops such as fruits, vegetables, nuts, herbs and floriculture (Specialty Crops Competitiveness Act 2004) which generally rely on insect pollinators for fruit set, yield, and quality (Klein et al. 2007; Garibaldi et al. 2013).

Specialty crop growers have been found to recognize the ecological and economic importance of both managed and wild pollinators for crop production and agroecosystem resilience (Hanes et al. 2013; Gaines-Day & Gratton 2017; Hevia et al. 2020; Park et al. 2018; DiGiacomo et al. 2026 *under review*). However, this awareness has not consistently translated into widespread adoption of pollinator-supporting best management practices.

Behavioural research suggests that the adoption of pollinator best management practices remain limited when growers lack the knowledge, resources, or perceived capacity to implement new practices (Rose et al. 2018; Lutter et al. 2021). Readily available, reliable, and contextually relevant information reduces uncertainty, lowers perceived risk, and facilitates decision-making (Schmidt et al. 2010; Llewellyn 2007). Information access and understanding is therefore essential for sustaining and improving pollination services and their ecological benefits in specialty crop systems. In other words, the format, structure, and regional specificity of information shape whether growers act on new knowledge.

In Belgium, Eeraerts et al. (2020) found that sweet cherry growers valued pollinators but lacked institutional outreach linking awareness to practical management. Similarly, Park et al. (2018) reported that apple growers in New York and Pennsylvania undervalued native pollinators, largely due to a shortage of credible, regionally tailored educational materials. Enthoven and Van den Broeck (2021) thus called for tighter alignment between agricultural research outputs and growers' local needs, emphasizing that regional specificity determines whether information becomes actionable. In the U.S. Midwest, Bloom et al. (2021) found that cucurbit growers supported pollinator conservation but rarely translated that support into on-farm action—attributing the gap partly to economic pressures and partly to the absence of user-friendly, context-specific resources. Larson & Duram (2000) noted similar challenges among researchers and practitioners in the North Central U.S., emphasizing the persistence of communication barriers that impede knowledge transfer. Even when shared, crop–pollinator data are often buried in supplementary materials or published in inconsistent formats, limiting reusability and integration (Trekels et al. 2023).

Collectively, this body of work suggests that the issue is not necessarily a shortage of regionally relevant pollinator information, but systemic shortcomings in discoverability and accessibility. Kopiawattage et al. (2018) found that agricultural producers obtain information from multiple sources including the Internet and electronic media, indicating that digital sources are a major pathway for locating agricultural information. Studies of agricultural knowledge systems indicate that search engines such as Google often serve as the primary gateway through which producers locate management information, extension materials, and industry resources online (Lubell et al. 2014). Extension materials are produced by outreach program educators affiliated with land-grant universities in the United States (Seevers et al. 2007; Franz et al. 2010). The Cooperative Extension System, established by the Smith–Lever Act of 1914, formalized partnerships between federal, state, and county governments to disseminate agricultural research and innovations to producers (Rasmussen 1989).

Producers tend to search for information using practical or problem-oriented language related to crops, pests, or management decisions, rather than the technical terminology commonly used in scientific literature (Llewellyn 2007). Growers frequently rely on extension publications, crop consultants, peer networks, and industry organizations for information about pollination management rather than academic literature and databases (Prokopy et al. 2008; Lubell et al. 2014). Yet, research suggests that many of these resources may be siloed in institutional repositories, or presented in formats ill-suited to agricultural decision-making. These barriers extend to "grey literature" such as extension bulletins, agency reports, and non-profit publications—materials that are often freely available but inconsistently indexed, weakly tagged, or hosted on unstable platforms (Mahood et al. 2014; Godin et al. 2015; Cooper et al. 2019). As Paez (2017) argues, grey literature contributes significantly to evidence-based practice in applied sciences, but only if it is discoverable and locally relevant.

This study addressed two central research questions for U.S. Midwest growers: (1) How prevalent are geographically-relevant and specialty crop-focused pollinator information resources? and (2) How accessible are these existing pollinator resources to growers and other end users? We explored these questions by systematically evaluating the availability of regionally appropriate pollinator resources for specialty crops in the U.S. Midwest (Iowa, Illinois, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin). After applying a scoping review of pollinator-related resources spanning 125 years of peer-reviewed literature, extension materials, and institutional websites, we next assessed the reachability, usability, metadata quality, and digital visibility of the resources using a modified rubric grounded in FAIR Data Principles. The acronym FAIR, which stands for *Findable, Accessible, Interoperable,* and *Reusable,* was originally developed by Wilkinson et al. (2016) for data management but it has been increasingly applied to ecological and agricultural information systems.

By identifying both systemic patterns and specific weaknesses in digital resource infrastructure, this work provides an evidence base for improving regional pollinator information. In doing so, it bridges pollination ecology with data management principles, helping transform new and existing pollinator research and outreach into meaningful, on-farm action.

MATERIALS AND METHODS

SCOPING REVIEW

A systematic inventory or scoping review of pollinator-related educational and technical resources was conducted by a team of three reviewers during January 2024 - July 2025 using manual and large-language model automated search practices. The scan targeted digital resources, produced between 1900 and 2025, from scientific journals, land-grant institutions, state extension programmes, and non-governmental organizations operating in the U.S. Midwest.

A "recipe book" of search terms for the scoping review was developed collaboratively by a multidisciplinary team with expertise in entomology, horticulture, beekeeping, agricultural economics, ecology and extension outreach. The list of search terms was refined in consultation with a research librarian at the University of Minnesota and a final codebook was developed to identify 11 geographic, 15 crop, 9 management-based terms as well as other terms such as "barrier(s)," "challenge(s)," "benefit(s)," "adopt," "cost(s)," "efficiency," "timing," "neighbour(s)," and "plan(s)" (Table 1). The primary codebook terms were then crossed with 14 pollinator-specific words, including: "pollinator(s)," "wild bee(s)," "native bees," "solitary bee(s)," "honey bee(s), "bumble bee(s)," "managed pollinator(s)," "native pollinator(s)," and "wild pollinator(s)."

The search for resources containing codebook words was conducted using the databases Google (for extension, government, and non-profit resources) and Google Scholar (for peer-reviewed publications). A large language model developed by OpenAI™ (San Francisco, CA, U.S.) was used only as a supplementary tool to help identify potential additional resources after the initial manual searches of Google and Google Scholar were completed. All materials identified by OpenAI™ were independently verified and screened by a human reviewer before inclusion in results. Results were organized in a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA, U.S.) and sorted by codebook term, database, resource title, source location, publication date, and author(s). Manual cleaning of the resource list was performed by one researcher to remove duplicates and to verify working website links.

RUBRIC DESIGN

A weighted rubric was developed to assess both the availability, reachability, findability and usability of resources identified in the scoping review, as well as the findability of pollinator information for specialty crop growers in the U.S. Midwest. Several existing frameworks for evaluating digital resource availability and accessibility were considered, but they were not suitable for the objectives of this study. The FAIR principles introduced by Wilkinson et al. (2016) provide guidelines for improving the findability, accessibility, interoperability, and reusability of digital resources, but they were designed as a scoring rubric that could be used to evaluate data sets rather than manuscripts and other literature.

Table 1: Codebook search terms applied to scoping review.

Geographic Term	Crop Term	Management Term	Pollinator Terms	Other
Midwest	Specialty crop(s)	Acre(s)	Bee(s)	Adopt
Great Lakes	Fruit(s)	Buffer(s)	Beehive(s)	Barrier(s)
Great Plains	Apple(s)	Conventional	Beekeeper(s)	Benefit(s)
Illinois	Berry/Berries	Farm(s)	Bumble bee(s)	Budget
Indiana	Blueberry/Blueberries	Farmer(s)	Butterfly/Butterflies	Certified
Iowa	Cherry/Cherries	Field(s)	Colony/Colonies	Challenge
Michigan	Cranberry/Cranberries	Fungicide(s)	Ecosystem	Cost(s)
Minnesota	Cucumber(s)	Grower(s)	Hive	Efficacy
North Central	Dandelion	Herbicide(s)	Honey bee(s)	Expense
North Dakota	Elderberry/Elderberries	Insecticide(s)	Native bee(s)	Funding
Northern Great Plains	Honeyberry/Honeyberries	Integrated Pest Management/IPM	Pollinator friendly	Guide
Ohio	Melon(s)	Management	Solitary bee(s)	Money
South Dakota	Raspberry/Raspberries	Neighbor(s)	Wild bee(s)	Practice
Urban	Strawberry/Strawberries	Organic		Time
Wisconsin	Flower(s)	Pesticide(s)		Timing
	Vegetable(s)	Picking		
	Corn	Plan(s)		
	Garlic	Strip(s)		
	Pumpkin(s)			
	Seed(s)	Sustainable		
	Weed(s)			

Subsequent FAIR assessment approaches, including the FAIR Metrics framework and the RDA FAIR Data Maturity Model, primarily evaluate the FAIRness of structured research data and repositories from a machine-actionability perspective (Wilkinson et al. 2018; RDA FAIR Data Maturity Model Working Group 2020). Automated tools such as FAIRsFAIR metrics and the F-UJI FAIR assessment tool similarly focus on datasets and repository landing pages using machine-detectable metadata and identifier infrastructure (Devaraju & Huber 2021; FAIRsFAIR 2022). Recent domain-specific frameworks, such as the agricultural biodiversity FAIR data assessment rubrics developed by Drucker et al. (2024), focus on evaluating the FAIRness of structured biodiversity datasets and the metadata practices used to publish them.

While valuable for assessing dataset stewardship and interoperability, these existing frameworks do not evaluate how outreach publications and web-based resources are discovered and accessed by users through typical information-seeking pathways such as web search engines. In practice, growers and advisors typically locate information through general web-based searches rather than repository infrastructures or metadata (Hill 2009; Kopiyawattage et al. 2018). As a result, factors such as search engine visibility, paywall-free access to full text, usability of web content, and the ability to cite or share resources can strongly influence whether information is realistically discoverable and usable.

The rubric in this study builds on established FAIR principles representing findable, accessible, interoperable and reusable as well as sub-principles describing elements such as persistent identifiers, rich metadata, registration in searchable resources, standardized access protocols, and clear licensing and provenance (Conrad & Leonard 2015; Wilkinson et al. 2016; McKelvey & Hunt 2019; Schilhan et al. 2021; Zhu 2023; Ferri 2024). These FAIR-derived concepts were combined into a weighted scoring system with practical measures of information discovery, such as search engine visibility and shareability, to evaluate how pollinator resources can realistically be located, accessed, and reused by growers, advisors, and researchers in the U.S. Midwest. We define each of the rubric elements in the sections that follow.

REACHABILITY AND USABILITY

Reachability is defined as the ability to read and download the full text without payment, subscription, or institutional sign-in, which is consistent with the FAIR principle that data and metadata should be retrievable using standardized communication protocols and remain accessible even when access conditions change (FAIR principles A1–A2) (Wilkinson et al. 2016). Usability means that the content worked with assistive technologies and followed basic good practice so it can be used in real settings, not only scrutinized for formal compliance (Ferri 2024). For example, a website could include alt-text for every image, but if that text merely reads "image" or "graphic," it offers no meaningful information to a low-vision user. Keyboard navigation may be enabled, yet if the tab order jumps unpredictably across the page, the experience remains inaccessible despite being labelled "compliant." Therefore, usability elements in this study are defined as "includes alternative text for images, keyboard access, descriptive link text, colour contrast, and captions or transcripts for audio or video" (Ferri 2024; Wilkinson et al. 2016).

A score of three (highest score) was assigned when the full text was open access or freely reachable without a paywall, and all but one of the usability elements were present. A score of two was assigned when the full text was open, and at least three of the elements were present for usability. A score of one was assigned when a paywall or institutional login blocked the full text, when the main file was a scanned image without readable text, or when two or fewer usability elements were present overall.

The reachability and usability metric received the highest weighting in our study (40%) because it ultimately determines whether these elements lead to actual use and, therefore, is considered most impactful. If the full text cannot be reached or is incompatible with assistive technologies, improvements in metadata, search rank, indexing, or sharing have little practical effect. This weighting aligns with the FAIR principle that information must be accessible to be useful, and reflects the idea that accessibility is shaped by design and format rather than by narrow compliance checks (Wilkinson et al. 2016; Ferri 2024).

METADATA

Metadata was defined as structured descriptive information that enables resources to be identified, discovered, and interpreted by users and information systems (Wilkinson et al. 2016; Riley 2017). Metadata quality in this rubric primarily reflects the Findable principle which states that data should be described using rich, structured metadata and linked to persistent identifiers (FAIR principles F1–F3) (Wilkinson et al. 2016). Key metadata fields included title, abstract or summary, author names and affiliations, keywords, publication or posting date, publisher, and an identifier such as a Digital Object Identifier (a permanent code that always links to the resource) or a stable Uniform Resource Locator (a web address designed not to break over time). Well-structured and accurate metadata improves visibility even when the content itself does not change, a point supported by applied studies and reviews of practice (Zhu 2023; Ferrari et al. 2024). This criterion reflects the central role of metadata within the FAIR framework, which emphasizes rich, structured metadata and persistent identifiers to enable resources to be identified, indexed, and retrieved (Findable principles F1–F4; Wilkinson et al. 2016).

A metadata score of three was assigned when all core metadata fields were present, accurate, and consistently formatted, including a DOI or stable URL. A score of two was assigned when most fields were present with only minor omissions or errors, for example, missing affiliations or keywords. A score of one was assigned when major fields were missing or incorrect, for example, no abstract, a vague or malformed title, or no persistent identifier.

Metadata was weighted at 20 percent in the overall rubric because it supports both human interpretation and search engine indexing. However, well-structured metadata alone does not guarantee that a resource will be easily discovered in practice. Discoverability also depends on factors such as whether the resource is freely reachable and usable by readers. As a result, a resource may have well-structured metadata yet remain difficult to locate or access in real search environments (McKelvey & Hunt 2019; Zhu 2023).

SEARCH ENGINE VISIBILITY

Search engine visibility was used to measure how well a resource can be found by users in routine searches. While the FAIR framework states that resources should be registered or indexed in searchable systems (FAIR principle F4) (Wilkinson et al. 2016), it does not evaluate how easily those resources can be located through typical user search pathways such as web search engines. Searches were first run in Google. The first query used keywords derived from the title and, when available, author-supplied keywords. If the site appeared within the first 30 results it received a score of three. If it did not appear, the exact title was searched again on Google Scholar; placement within the first 30 results earned a score of two. If the resource still did not appear within the first 30 results, the resource was assigned a score of one. This procedure reflects how users discover materials with search engines where rankings are shaped by algorithms and competition, rather than by metadata alone (McKelvey & Hunt 2019; Schilhan et al. 2021; Ferrari et al. 2024).

The weight for search engine visibility was set at 20 percent, equal to metadata, because search placement serves as the entry point for many users seeking resources. Even with complete metadata, materials that do not appear in search results are unlikely to be discovered, making visibility an important factor in information use. However, unlike metadata, which is entirely under the control of authors and publishers, visibility depends on external factors such as algorithms and keyword competition (McKelvey & Hunt 2019; Schilhan et al. 2021; Ferrari et al. 2024).

Although social media platforms increasingly serve as channels for sharing information, the outreach resources evaluated in this study consisted primarily of institutional webpages, extension publications, and online reports that are hosted on the web. These materials are typically located through web search engines, while social media platforms more often act as secondary distribution channels linking back to those resources (Kopiyawattage et al. 2018). Assigning equal weight to visibility and metadata acknowledges this balance; metadata reflects the quality of information authors can provide, while visibility represents the constraints of how users discover resources. Both are treated as equally important to discovery, while remaining secondary to reachability and usability, which ultimately determine whether a resource can be accessed at all.

Search results can vary depending on location, personalization, and other contextual factors. To reduce these effects, searches were conducted using standardized queries in private browsing conditions such as IP location, although some variation may still occur.

INDEXING

Indexing represented resources that were listed in recognized scholarly databases or discovery services described for the scoping review. Presence in major indexes makes the resource easier to find and reach for typical users of library tools (Conrad & Leonard 2015; Wilkinson et al. 2016; Schilhan et al. 2021). While the FAIR framework states that data and metadata should be registered in searchable resources, it does not evaluate whether web-hosted outreach materials are actually indexed in the discovery systems commonly used. The indexing criterion operationalizes this principle by assessing whether resources appear in these environments.

A score of three was given when the item appeared in at least one major index listed above. A score of two was given when it appeared only in niche indices or only in an institutional database. A score of one was given when it was not indexed in any known database.

The weight for indexing was set at 10 percent because it adds trusted entry points and signals curation, but it does not play as great of a role as accessibility, metadata, and search placement in first contact and immediate use (Conrad & Leonard 2015).

SHAREABILITY

Shareability was defined as the ease with which a resource could be cited, exported, linked, and reused. Evaluation checked for a DOI or other identifier, a visible citation tool, export formats to other sites, such as email, X, or Facebook, and a stable permalink. These features increase reach and reuse and align with FAIR goals for reuse and accessibility which emphasize persistent identifiers, clear attribution, and mechanisms that allow resources to be cited and redistributed. Features such as DOI identifiers, citation tools, export formats, and stable links facilitate the reuse and dissemination of information resources (Fair principles R1–R1.3) (Wilkinson et al. 2016). While the FAIR framework provides guiding principles for improving the findability, accessibility, interoperability, and reusability of digital resources, it was not designed as a scoring rubric for evaluating individual outreach materials distributed across the web. The shareability rubric, therefore, operationalizes aspects of the Reusable FAIR principle by evaluating practical mechanisms that enable users to cite, distribute, and reuse these resources.

A score of 3 was given when share options were visible and worked as expected, for example, a citation button, export options, or a direct PDF. A score of 2 was given when sharing was possible but limited or hard to find, for example, only a copyable URL. A score of 1 was given when sharing was difficult, for example, links were unstable.

The shareability weight was set at 10 percent because it primarily affects what happens after a resource is found. Clear identifiers, citation tools, export formats, and stable links make it easier for others to cite and redistribute the item, which helps with long-term visibility and reuse, but these features do not determine first contact in search results (Wilkinson et al. 2016; Schilhan et al. 2021). This places shareability on par with indexing as supportive rather than foundational.

Evaluation process

Using the rubric, each resource identified during the scoping review was first scored for individual metrics and then weighted to achieve an overall score. Scores ranged from one to three for each metric and were ranked by a single reviewer to maintain scoring consistency. The overall weighted score was found using the formula: 0.40A + 0.20M + 0.20V + 0.10I + 0.10S, where A is reachability and usability, M is metadata, V is search visibility, I is indexing, and S is shareability.

The scoring process consisted of a two-step procedure used by a single reviewer. First, to evaluate reachability and usability, the reviewer applied a keyword query in Google. The keyword was derived from the title and any author keywords, followed by an exact-title query if the keywords did not pull up the resource. Second, indexing was checked in recognized scholarly indexes, including Google Scholar. Shareability and metadata were scored per the rubric's definitions. Searches were run in private browsing with caches cleared to reduce personalization effects. Results were summarized with a score by source type and keywords. Keywords were compared across source types to identify inconsistencies in the availability of certain information across source types.

Scores from the rubric were aggregated using Python 3.13.5 (Python Software Foundation 2024) and the pandas 2.3.1 library (The pandas development team 2025; McKinney 2010). The script grouped resources by article type and calculated the mean, median, minimum, maximum, range and standard deviation for each score: reachability and usability, metadata, search engine visibility, shareability, indexing, and overall. The output was exported to a CSV file for interpretation and comparison across resource types. This process was used to make the analysis reproducible.

Results

Scoping review

A total of 1,023 resources were identified through the scoping review, with the majority (96%) originating from scientific and peer-reviewed journals dating 2000 to 2025. The distribution of sources was as follows: for-profit businesses (*N* = 5), not-for-profit organizations (*N* = 44), government institutions (*N* = 68), educational institutions and extension (*N* = 193), and scientific/peer-reviewed journals (*N* = 713). Scoping review findings by individual key word are presented in Table 2.

Specialty crops appeared in 51% of all pollinator-related resources identified (*N* = 521), while fruit-specific terms appeared in 38% (*N* = 489) of resources referencing fruits (Table 2). Fruit terms included *fruit(s)*, *apple(s)*, *berry/berries*, *blueberry/blueberries*, *cherry/cherries*, *cranberry/ cranberries*, *elderberry/elderberries*, *honeyberry/ honeyberries*, *melon(s)*, and *raspberry/raspberries*.

Table 2. Scoping review findings by keyword. Findings are organized by resource descriptors: crop, geographic location, pollinator type, and management practice. Keyword frequency (the number of resources in which the key term appeared) and percent (the keyword frequency as a percent of all resources identified) are listed in each column. N = 2,707 keywords; 1,023 resources.

Key Word	Frequency (# pollinator-related resources)	Percent (% total resources)
Crop		
Specialty crop(s)	521	51
Fruit(s)	149	15
Apple(s)	88	9
Berry/Berries	17	2
Blueberry/Blueberries	59	6
Cherry/Cherries	4	<1
Cranberry/Cranberries	14	1
Elderberry/Elderberries	4	<1
Honeyberry/Honeyberries	2	<1
Melon(s)	25	2
Raspberry/Raspberries	27	3
Vegetable(s)	34	3
Cucumber(s)	27	3
Garlic	22	3
Pumpkin	27	3
Geographic location		
Great Lakes	10	1
Midwest	36	4
Northern Great Plains	0	0
Iowa	3	<1
Illinois	0	0
Indiana	0	0
Michigan	4	<1
Minnesota	36	4
North Dakota	0	0
South Dakota	0	0
Wisconsin	6	1
Pollinator type		
Managed pollinator(s)	240	23
Native pollinator(s)	341	33
Wild pollinator(s)	0	0
Bumble bee(s)	1	<1
Honey bee(s)	251	25
Native bee(s)	0	0
Solitary bee(s)	64	6
Wild bee(s)	510	50
Management practice		
Integrated pest management/IPM	45	4
Fungicide	51	5
Herbicide	1	0
Pesticide	88	9

Pollinator–vegetable term combinations comprised just 11% of all resources ($N = 110$) (Table 2). Vegetable terms included *vegetable(s), garlic, pumpkin(s),* and *cucumber(s)*. Taken together, these patterns indicate that research addressing pollinator interactions within specialty crop systems remains highly uneven—and in some cases notably underdeveloped.

Geographic gaps were similarly apparent. The term “Midwest” appeared in only 36 of the 1,023 resources identified (4%), and individual Midwest states were referenced in just 59 resources (6%) (Table 2). More than half of these references were related to Minnesota, while other states in the region appeared rarely or not at all. This uneven distribution suggests that several Midwestern states have received comparatively limited attention in pollinator–crop research and associated outreach efforts.

Practice-based gaps also emerged when terms such as *pesticide*, *herbicide*, and *IPM* were paired with crop or pollinator terms. These terms appeared in only 185 resources (18%), with most occurrences involving pollinator–pesticide combinations and less than 2% representing pollinator-pest management-fruit crop combinations (Table 2). The relative scarcity of these management pairings indicates limited integration of pest management and pollinator-focused research, as well as insufficient attention to how pesticides and herbicides affect specific pollinator groups—such as wild bees and honey bees—within specialty crop systems.

Pollinator-focused search terms received the greatest coverage overall. References to managed pollinators—particularly honey bee—were common, appearing in 491 resources (48%). Native pollinators, wild bees and solitary bees were included in 915 resources (89%) (Table 2). Bumble bees, however, were markedly underrepresented, comprising fewer than 1% of pollinator-specific references. Results suggest that wild pollinators receive attention within scientific literature and outreach materials that is more than equivalent to managed pollinators. Taken together, these patterns highlight three broad areas of underrepresentation: specialty crops, certain U.S. Midwest states and management practices. Research themes that have generally been well-documented include the importance of wild and managed bee habitat (with the exception of bumble bees), pesticide use and pollinator exposure and IPM.

Rubric

After applying the rubric metrics described in the Methods section, the scientific articles had an overall mean of 2.41 (strong), with an average publication year of 2018 and a median of 2020. Resources produced by educational institutions were rated with a mean of 2.25 (moderate), with an average publication year of 2016 and a median of 2023. Government sources had a mean of 2.24 (moderate), with an average publication year of 2013 and a median of 2018. Resources produced by non-profits had a mean of 2.20 (moderate), with an average publication year of 2017 and a median of 2017. All rubric metrics are listed in Table 3, which uses an orange, yellow, green colour scheme to indicate rubric strengths and weaknesses across article types, with green (2.33 +) indicating strong performance, yellow (1.66–2.33) showing moderate performance, and orange (≤1.66) marking areas needing improvement.

Rubric results revealed only modest variation in overall scores across source types. A visual summary of rubric performance across resource types is presented in Fig. 1, complementing the values reported in Table 3. Scientific articles achieved the highest mean score (2.41), while non-profit sources had the lowest (2.20), a difference of just 0.21. However, this narrow spread masked more substantial variation across individual criteria. Scientific articles scored lowest on accessibility (mean 2.21), largely due to paywalls, whereas non-profits (2.98), educational institutions (2.91), and government sources (2.75) were considerably more accessible. Despite this limitation, scientific articles ranked highest overall because they consistently performed well in metadata quality, search visibility, shareability, and indexing.

Discussion

Scoping review findings indicate that a substantial body of generalized knowledge about pollinators has emerged digitally since the early 2000s, particularly for broad categories such as pollinator biology and conservation practices. This

Table 3. Mean and standard deviation scores across article types. Values reported as mean (standard deviation).

Dimension	Scientific Articles *N* = 712	Educational Institution *N* = 193	Government *N* = 68	Non-Profit *N* = 44
Overall	2.41 (0.42)	2.25 (0.23)	2.24 (0.29)	2.20 (0.23)
Accessibility	2.21 (0.98)	2.91 (0.38)	2.75 (0.63)	2.98 (0.15)
Metadata	2.52 (0.56)	1.20 (0.46)	1.56 (0.65)	1.18 (0.50)
Search Engine Visibility	2.27 (0.45)	2.02 (0.31)	2.01 (0.50)	1.98 (0.34)
Shareability	2.69 (0.59)	2.24 (0.92)	1.74 (0.86)	1.66 (0.94)
Indexing	2.98 (0.14)	2.22 (0.45)	2.56 (0.53)	2.25 (0.44)
Recommendations	Strong in metadata, indexing, and shareability, weaker in accessibility	Strong in accessibility, weak metadata	Moderate indexing, low shareability	High accessibility, weak metadata/shareability

Color coding: Scores ≤ 1.66 = Red (low performance), 1.67 – 2.33 = Yellow (moderate performance), ≥ 2.34 = Green (high performance).

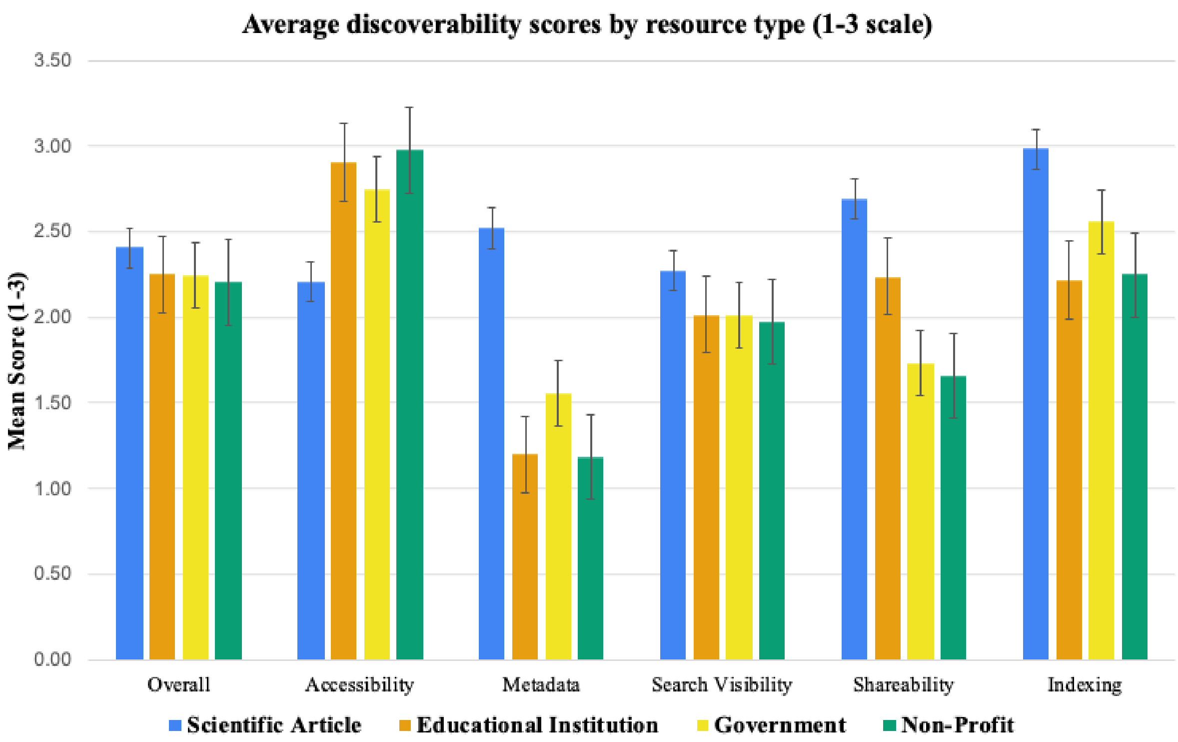

Figure 1. Mean discoverability scores by resource type (1–3 scale with standard error bars). Discoverability is defined as accessibility, metadata, search engine visibility, shareability and indexing. Resources include information generated for scientific articles, educational institutions, governments, for profit businesses and non-profit organizations. For-profit businesses were included in the search and the total sample size (*N* = 1,023), however, due to the small number of for-profit resources identified (*N* = 5), they were not included in the graph.

pattern likely reflects the rapid expansion of pollinator research following widespread concern about pollinator declines and colony losses in the early twenty-first century, which stimulated both scientific publications and publicly available outreach materials (vanEngelsdorp and Meixner 2010; Goulson et al. 2015).

However, when pollinator-related terms are paired with U.S. crop, management, and geographic terms necessary for implementing pollinator best management practices, the availability of relevant digital information declines markedly. While broad guidance is abundant, actionable knowledge tailored to specific farming systems, climates, and cropping calendars remains comparatively sparse. In practice, growers and advisors must navigate fragmented information landscapes in which generalized information is readily available, but detailed, context-specific recommendations linking pollinators, crops, and management practices to a specific geographic locale are more difficult to locate. This gap is particularly consequential in diversified fruit and vegetable systems that rely on interactions with pollinators.

This disconnect between the abundance of general knowledge and the scarcity of context-specific pollinator guidance reflects broader dynamics in how agricultural information is produced and disseminated. Universities, government agencies, and non-profit organizations generate much of the available outreach material, yet these resources are often structured in ways that do not align with how growers search for and use information. As a result, knowledge that exists within scientific or institutional systems may remain difficult to locate through the digital pathways commonly used by farmers and advisors.

Results reveal a clear trade-off between accessibility and discoverability. Scientific publications excel in technical rigor and are well indexed but remain frequently restricted due to paywalls, while outreach materials produced by non-profits, extension, and government institutions are generally open but often difficult to locate through typical search processes. As a result, users searching for information encounter two distinct barriers: resources that are well indexed and visible but restricted by paywalls, and resources that are freely available but difficult to locate due to poor indexing. This disconnect between accessibility and discoverability can limit the practical usefulness of pollinator guidance and ecological outcomes for end users.

Our findings align with prior work on access, metadata, and search platform dynamics. The limited reachability and usability of scientific articles reflect prevailing publishing models, where paywalls restrict reach (Larivière et al. 2015). Although open access expands availability, it does not by itself ensure discoverability. Previous studies have shown that discoverability improves only when publications include complete metadata and are deposited in repositories or search systems (Piwowar et al. 2018; Raju et al. 2019; Zhu 2023), a pattern confirmed by this study. Paywalled scientific articles maintained relatively high composite scores because their metadata and indexing practices were robust. In contrast, materials produced by non-profits, government agencies, and educational institutions were generally open, reachable, and usable, but discoverability was constrained by inconsistent metadata, unstable links, or weak hosting infrastructure (Cooper et al. 2019). Missing keywords and dates, unstable links, and image-only or untagged PDFs, were common deficits that limited discoverability and reuse.

By quantifying these trade-offs across source types, this study advances earlier work on open access and digital discoverability. Prior studies have demonstrated that open access can increase reach, but effective discoverability requires complementary practices such as persistent identifiers, standardized indexing, and consistent metadata (Piwowar et al. 2018; Raju et al. 2019; Zhu 2023). Others have highlighted how SEO and metadata quality improve the visibility of extension and outreach materials (Moore et al. 2015; Schilhan et al. 2021). From the perspective of the FAIR principles (Wilkinson et al. 2016), these results highlight an imbalance between different principles of information accessibility. Scientific publications tend to satisfy findability criteria through structured metadata, indexing, and persistent identifiers, yet accessibility is often constrained by paywalls. In contrast, outreach resources are generally accessible but frequently lack the metadata and indexing needed to support consistent discovery through search systems.

Study findings also carry implications for how agricultural knowledge systems are organized and supported. Improving pollinator outcomes may depend not only on generating new research, but also on strengthening the digital infrastructures through which existing knowledge is curated and shared. Investments in standardized metadata, persistent identifiers, and stable hosting platforms could substantially improve the visibility and usability of publicly funded outreach materials. Greater coordination among universities, government agencies, and non-profit organizations may also help ensure that pollinator guidance is more consistently indexed and linked across platforms. By aligning knowledge production with stronger practices of digital organization and discovery, agricultural institutions could enhance the ability of growers and advisors to locate and apply pollinator best management practices in real-world farming contexts.

Implications

The digital landscape for pollinator information in the U.S. Midwest can be understood as both fragmented and promising: while important gaps remain, relatively modest improvements in knowledge organization and dissemination could meaningfully support sustainable crop–pollinator systems. The availability of a large volume of generalized pollinator resources, for example, highlights a clear opportunity to improve the accessibility and usability of existing knowledge. Strengthening metadata practices, improving search visibility, and more explicitly linking general pollinator information to crop- and region-specific management guidance could substantially enhance the practical value of these materials.

By contrast, public-facing resources from non-profits, educational institutions, and agencies generally are open to the public at no cost but are poorly described. Many of these resources lack dates, keywords, or stable links, and some are available only as scanned PDFs that cannot be searched or indexed. Even when the information is strong, these limitations reduce discoverability and reuse by slowing down retrieval and limit use in the field (Cooper et al. 2019; Zhu 2023; Ferri 2024). This helps explain why growers may support pollinator conservation in principle but fail to apply it consistently (Park et al. 2018; Bloom et al. 2021). Recommendations include providing clear titles, including keywords and summaries, adding author and affiliation information, and ensuring stable links to raise digital visibility and use.

Moreover, publishers of scientific journals and public institutions should move toward more open access or at least more cost-effective options, with digital copies posted in places that remain online and can be indexed (Larivière et al. 2015; Piwowar et al. 2018; Zhu 2023). By applying open access and affordability criteria, journal content that already excels in terms of structure and metadata is not wasted behind closed doors.

The consequence of inaccessible and non-discoverable information is that ecological knowledge frequently does not translate into ecological outcomes. If scientifically rigorous information remains locked behind paywalls while publicly available, cost-neutral materials remain difficult to discover, the effective dissemination of pollination ecology knowledge may be constrained. Improving both accessibility and metadata quality across pollinator-related resources could therefore play an important role in strengthening knowledge transfer between research, extension, and agricultural practice, ultimately supporting more resilient pollination services in managed landscapes. If a grower cannot locate a resource during bloom or pest-control decision windows, the opportunity to act in ways that benefit pollinators may be lost. In this sense, information itself functions as an ecological driver, influencing whether pollinator-friendly practices are adopted in agroecosystems. Efforts to conserve habitat or diversify landscapes are undercut if the guidance supporting those practices is locked behind poor metadata, missing identifiers, or unstable hosting.

For agencies and funders of research, making resources discoverable should be treated as a core project deliverable; otherwise, the results risk remaining buried and inaccessible to the stakeholders they are intended to serve. When possible, projects should publish open-access copies, with complete metadata fields including title, date, authors, keywords, and a short summary or abstract. Resources should also include a stable link or identifier and be presented in a format that can be indexed. These relatively straightforward practices address weaknesses commonly seen in non-profit and government materials and increase the likelihood that pollinator resources are found and applied in the field (Moore et al. 2015; Piwowar et al. 2018; Cooper et al. 2019).

The same logic applies to academic publishing. Scientific articles consistently scored highest on metadata, indexing, and shareability because journals rely on standardized workflows with identifiers and repositories. Yet those same articles ranked lowest in accessibility because of paywalls and login barriers. This creates a paradox; the most structurally visible resources are the least reachable to those who could apply them. Journals and universities could reduce this gap by supporting persistent identifiers and by maintaining formats that can be reused by extension agents and educators. If the rigor and metadata strength of scholarly publications were paired with broader accessibility, ecological science would circulate more effectively into management decisions.

Conclusion

This study demonstrates that while pollinator information exists for specialty crop agriculture in the U.S. Midwest, there remain critical weaknesses in regional applicability, accessibility, metadata quality, and digital visibility limit the information's practical value for growers. Scientific articles remain the most discoverable due to standardized metadata and indexing but are often locked behind paywalls, while publicly available materials from non-profits, educational institutions, and government agencies are more reachable and usable, yet poorly described and inconsistently hosted. These trade-offs mean that ecological knowledge does not reliably reach the U.S. Midwest farmers who may be interested in adopting ecological pollinator-friendly practices. These findings underscore the importance of evaluating not only whether pollinator information exists, but also how it is structured and made discoverable to growers and advisors.

Addressing accessibility barriers requires pairing reachability with robust metadata, persistent identifiers, and stable hosting, while ensuring resources are regionally specific and tailored to crop systems found there. Treating information itself as an ecological driver underscores the need for discoverability to be embedded in agricultural research, extension, and policy, so that pollinator conservation strategies can translate into consistent on-farm practice.

Limitations

The scoping review keyword set was broad, but it may not reflect the exact phrases growers or educators would use in real searches. The expertise of the research team helped mitigate this issue, but it cannot be eliminated entirely. The focus was also on the U.S. Midwest, which means results may not capture important crops and management practices that are prominent in other regions.

Moreover, the scoping review relied primarily on digitized and searchable literature sources, which likely explain the limited number of resources identified from the period 1900–1999 (N = 40). Relevant materials that have not been digitized or indexed in searchable databases would have been missed. For most of the twentieth century, for example, extension systems disseminated agricultural information primarily through printed bulletins, circulars, and newsletters. Beginning in the mid-1990s, many extension programs began digitizing publications and distributing them through university websites, and by the mid-2000s most had transitioned toward predominantly digital dissemination of agricultural information (Franz et al. 2010; Lubell et al. 2014).

Additionally, this study did not attempt to account for lack of digital literacy among growers who seek decision-making information. The growing volume of digital information can make navigating online knowledge increasingly challenging for users, particularly those with limited information literacy (Nambisan et al. 2017; Orrensalo and Nikou 2024).

The rubric was scored by a single reviewer, so there is some subjectivity in how the criteria were applied. Moreover, despite clearing the digital cache with each search, results may still vary due to factors such as IP-based location and other contextual signals. Finally, standards for accessibility, metadata, and indexing evolve over time meaning that classifications of "weak" and "strong" metadata and accessibility should be interpreted as time-specific rather than fixed benchmarks

Future Research

Future research should focus on developing and testing tools that address the most basic weaknesses identified in this study. One option is a publishing checklist that institutions and agencies could use when posting new documents. The checklist could standardize elements such as titles, dates, keywords, and stable links, while encouraging formats that support indexing and reuse. Applying this checklist in real-world publishing settings would help determine whether common issues documented in this study - weak metadata, unstable links, and poor indexing - can be effectively addressed in practice.

Further work should also examine whether the same tradeoffs appear in other agricultural regions and crop systems. Expanding the scope would reveal if the challenges observed in the U.S. Midwest are region-specific or part of a wider structural issue in how pollinator knowledge is shared. A comparative approach would also help identify models or institutions that already succeed in balancing accessibility with strong metadata and indexing.

Lastly, future research should assess digital literacy among U.S. Midwest farmers to better understand how they search for and access information online. Such knowledge would help guide efforts to improve the discoverability of agricultural resources.

ACKNOWLEDGEMENTS

This study was funded with support from the University of Minnesota College of Food, Agriculture, and Natural Resource Sciences under grant number 1806-11033-FAPOL-137705.

AUTHOR CONTRIBUTION

G. DiGiacomo: Concept and design, data analysis, writing, editing, funding and approval for publication. O. Megahed: Concept and design, data analysis, writing, and editing. M. Schuh: Concept and design, data collection, writing. M. Wimmer: Concept and design, data collection, writing.

DISCLOSURE STATEMENT

The authors have no conflicts of interest, relational, financial or otherwise, that might be perceived as influencing the authors' objectivity.

GENERATIVE AI DISCLOSURE STATEMENT

Open AI (August 2025) was used to cross-reference citations with the reference section and to check for grammar proficiency.

DATA AVAILABILITY STATEMENT

Data and supporting materials are available at https://hdl.handle.net/11299/276638.

REFERENCES

Bloom EH, Bauer DM, Kaminski A, Kaplan I, Szendrei Z (2021) Socioecological factors and farmer perceptions impacting pesticide use and pollinator conservation on cucurbit farms. Frontiers in Sustainable Food Systems 5:1-15. https://doi.org/10.3389/fsufs.2021.672981.

Conrad L., Leonard E (2015) Improving the discoverability of scholarly content: academic library priorities and perspectives. [online] https://uk.sagepub.com/sites/default/files/discoverability2015.pdf (accessed 11 November 2025).

Cooper K, Marsolek W, Riegelman A, Farrell S & Kelly J (2019) Grey literature: use, creation, and citation habits of faculty researchers across disciplines. Journal of Librarianship and Scholarly Communication, 7(1):1-26. https://doi.org/10.7710/2162-3309.2314.

Devaraju A, Huber R (2021) An automated solution for measuring the progress toward FAIR research data, Patterns 2(11):100370. https://doi.org/10.1016/j.patter.2021.100370.

DiGiacomo G, Iles M, Lee K, Hutchison B, Yue C. Specialty crop growers' motivation to support pollinators constrained by informational, institutional and financial barriers in the Upper Midwest. (under review). Journal of Integrated Pest Management (forthcoming).

Drucker DP, Salim JA, Poelen J, Soares FM, Gonzalez-Vaquero RA, Devoto M, Ollerton J, Kasina M, Carvalheiro LG, Bergamo PJ, Alves DA, Varassin I, Tinoco FC, Rünzel M, Robinson D, Corona-Duque J, Idárraga M, Agudelo-Zapata MC, Marentes Herrera E, Taliga C, Parr CS, Cox-Foster D, Hill E, Motta Maués M, Agostini K, Rech AR, Saraiva, A. (2024) WorldFAIR (D10.3) Agricultural biodiversity FAIR data assessment rubrics (Version 1.) Zenodo. https://doi.org/10.5281/zenodo.10719265

Dwyer C, Clough Y, Bartholomée O, Smith HG (2023) What evidence exists on the use of pollinator tools in agricultural landscapes: a systematic map protocol. Ecological Solutions and Evidence, 4(3):1-9. https://doi.org/10.1002/2688-8319.12275.

Eeraerts M, Borremans L, Smagghe G, Meeus I (2020) A growers' perspective on crop pollination and measures to manage the pollination service of wild pollinators in sweet cherry cultivation. Insects, 11(6):1-8. https://doi.org/10.3390/insects11060372.

Enthoven L, Van den Broeck G (2021) Local food systems: reviewing two decades of research. Agricultural Systems, 193(103226):1-14. https://doi.org/10.1016/j.agsy.2021.103226.

Faegri K, van der Pijl L (1979) The Principles of Pollination Ecology. 3rd ed. Pergamon Press, Oxford.

FAIR Data Maturity Model Working Group (2020) FAIR Data Maturity Model. Specification and Guidelines (1.0). Zenodo. https://doi.org/10.15497/rda00050.

FAIRsFAIR (2022) FAIRsFAIR Data Object Assessment Metrics. (online) https://www.fairsfair.eu/ [accessed 26 June 2026].

Ferri D (2024) Advancing an embodied understanding of accessibility for persons with disabilities. Journal of Human Rights Practice, 17(2):1-18. https://doi.org/10.1093/jhuman/huae049.

Ferrari E, Striewski F, Tiefenbacher F, Bereuter P, Oesch D, Di Donato P (2024) Search engine for open geospatial consortium web services improving discoverability through natural language processing-based processing and ranking. ISPRS International Journal of Geo-Information, 13(4):128. https://doi.org/10.3390/ijgi13040128.

Franz NK, Garst BA, Gagnon RJ (2010) The cooperative extension service and public value: building learning networks for social change. New Directions for Youth Development, 2010 (126):7–16. https://doi.org/10.1002/yd.357.

Gaines-Day HR, Gratton C (2017) Understanding barriers to participation in cost-share programmes for pollinator conservation by Wisconsin (USA) cranberry growers. Insects 8(79):2-13. https://doi.org.10.3390/insects8030079.

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, Carvalheiro LG, Harder LD, Afik O, Bartomeus I, Benjamin F, Boreux V, Cariveau D, Chacoff NP, Dudenhöffer JH, Freitas BM, Ghazoul J, Greenleaf S, Hipólito J, Holzschuh A, Howlett B, Isaacs R, Javorek SK, Kennedy CM, Krewenka KM, Krishnan S, Mandelik Y, Mayfield MM, Motzke I, Munyuli T, Nault BA, Otieno M, Petersen J, Pisanty G, Potts SG, Rader R, Ricketts TH, Rundlöf M, Seymour CL, Schüepp C, Szentgyörgyi H, Taki H, Tscharntke T, Vergara CH, Viana BF, Wanger TC, Westphal C, Williams N, Klein AM (2013) Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science, 339:1608–1611. https://doi.org/10.1126/science.1230200.

Godin K, Stapleton J, Kirkpatrick SI, Hanning RM, Leatherdale ST (2015) Applying systematic review search methods to the grey literature: a case study examining guidelines for school-based breakfast programmes in Canada. Systematic Reviews, 4(138):1-10. https://doi.org/10.1186/s13643-015-0125-0.

Goulson D, Nicholls E, Botías C, Rotheray EL (2015) Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science, 347(6229):1255957. https://doi.org/10.1126/science.1255957

Hanes SP, Column KK, Hoshide AK, Asare E (2013) Grower perceptions of native pollinators and pollination strategies in the lowbush blueberry industry. Renewable Agricultural Food Systems, 30:124-131. https://doi.org/10.1017/S1742170513000331.

Hevia V, García-Llorente M, Martínez-Sastre R, Palomo S, García D, Miñarro M, Pérez-Marcos M, Sanchez JA, González JA (2020) Do farmers care about pollinators? A cross-site comparison of farmers' perceptions, knowledge, and management practices for pollinator-dependent crops. International Journal of Agricultural Sustainability, 19:1–15. https://doi.org.10.1080/14735903.2020.1807892.

Hill M. (2009) Using farmer's information seeking behaviour to inform the design of extension. Extension Farming Systems Journal, 5(2):121–125. (online) https://www.apen.org.au/static/uploads/files/efs-journal-vol-5-no-2-14-hill-wfudfgosljyx.pdf [accessed 29 June 2026].

Klein AM, Vaissière B, Cane J, Steffan-Dewenter I, Cunningham SA, Creman C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B, 27:303–313. https://doi.org/10.1098/rspb.2006.3721.

Kopiyawattage KPP, Warner LA, Roberts TG (2018) Information needs and information-seeking behaviors of urban food producers: implications for urban extension programs. Journal of Agricultural Education, 59(3):229–242. https://doi.org/10.5032/jae.2018.03229.

Larivière V, Haustein S, Mongeon P (2015) The oligopoly of academic publishers in the digital era. PLOS ONE, 10(6): e0127502. https://doi.org/10.1371/journal.pone.0127502.

Larson KL, Duram LA (2000) Information dissemination in alternative agriculture research: an analysis of researchers in the North Central Region. American Journal of Alternative Agriculture, 15(4),171–180. https://doi.org/10.1017/s0889189300008742.

Llewellyn RS (2007) Information quality and effectiveness for more rapid adoption decisions by Farmers. Field Crops Research, 104(1–3):148–156. https://doi.org/10.1016/j.fcr.2007.03.022.

Lubell M, Niles M, Hoffman M (2014) Extension 3.0: managing agricultural knowledge systems in the network age. Society & Natural Resources, 27(10):1089–1103. https://doi.org/10.1080/08941920.2014.933496.

Lutter SH, Jeanneret P, Schneider S, Jütte R, Albrecht M (2021) Farmers' perspectives on the adoption of pollinator-supporting practices in agricultural landscapes. Journal of Applied Ecology, 58:2010–2021. https://doi.org/10.1111/1365-2664.13906.

Mahood Q, Van Eerd D, Irvin E (2014) Searching for grey literature for systematic reviews: challenges and benefits. Research Synthesis Methods, 5(3):221–234. https://doi.org/10.1002/jrsm.1106.

McKelvey F, Hunt R (2019) Discoverability: toward a definition of content discovery through platforms. Social Media + Society, 5(1):1-15. https://doi.org/10.1177/2056305118819188.

McKinney W (2010) Data structures for statistical computing in Python. In S. van der Walt & J. Millman (Eds.), *Proceedings of the 9th Python in Science Conference* (pp. 56–61). https://doi.org/10.25080/Majora-92bf1922-00a.

Moore R, Shackleton E, Bellows L (2015) Using search engine optimization techniques to enhance the visibility of web-based extension fact sheets. Journal of Extension, 53(2):1-11. https://doi.org/10.34068/joe.53.02.17.

Nambisan S, Lyytinen K, Majchrzak A, Song M (2017) Digital innovation management: reinventing innovation management research in a digital world. MIS Quarterly, 41(1):223–238. https://doi.org/10.25300/MISQ/2017/41:1.03.

OpenAI. 2025. ChatGPT (version 5). San Francisco, CA, U.S.A. https://chatgpt.com.

Orrensalo TCB, Nikou S (2024) Entrepreneurs' information-seeking behaviors in the digital age–a systematic literature review. Journal of Small Business Management, 62(2):892-937. https://doi.org/10.1080/00472778.2022.2100896.

Paez A (2017) Grey literature: an important resource in systematic reviews. Journal of Evidence-Based Medicine, 10(3):1-8. https://doi.org/10.1111/jebm.12266.

Park MG, Joshi NK, Rajotte EG, Biddinger DJ, Losey JE, Danforth BN (2018) Apple grower pollination practices and perceptions of alternative pollinators in New York and Pennsylvania. Renewable Agriculture and Food Systems, 35(1):1–14. https://doi.org/10.1017/s1742170518000145.

Piwowar H, Priem J, Larivière V, Alperin JP, Matthias L, Norlander B, Farley A, West J & Haustein S (2018) The State of Oa: A Large-Scale Analysis of the Prevalence and Impact of Open Access Articles. *Peer Journal*, 6:1-23. https://doi.org/10.7717/peerj.4375.

Prokopy LS, Floress K, Klotthor-Weinkauf D, Baumgart-Getz A (2008) Determinants of agricultural best management practice adoption: evidence from the literature. Journal of Soil and Water Conservation, 63(5):300–311. https://doi.org/10.2489/jswc.63.5.300.

Python Software Foundation (2024) Python (Version 3.13.5) [Computer software]. https://www.python.org/.

Raju J, Mfengu A, Kahn M, Raju R (2019) Transition to open: a metrics analysis of discoverability and accessibility of Lis scholarship. South African Journal of Science, 115(7/8):1-8. https://doi.org/10.17159/sajs.2019/5867.

Rasmussen WD (1989) Taking the university to the people: seventy-five years of Cooperative Extension. Iowa State University Press, Ames, Iowa (online) https://books.google.com/books?id=AijwWCIaqMkC&printsec=copyright#v=onepage&q&f=false [accessed 29 June 2026].

Riley J (2017) Understanding metadata: what is metadata, and what is it for? a primer. National Information Standards Organization (NISO). (online) https://niso.org/publications/understanding-metadata-2017 [accessed 29 June 2026].

Rose D, Keating C, Morris C (2018) Understand how to influence farmers' decision-making behaviour. AHDB. (online) https://ahdb.org.uk/knowledge-library/understand-how-to-influence-farmers-decision-making-behaviour [accessed 11 November 2025].

Schilhan L, Kaier C, Lackner K (2021) Increasing visibility and discoverability of scholarly publications with academic search engine optimization. Insights the UKSG Journal, 34:1-16. https://doi.org/10.1629/uksg.534.

Schmidt KA, Dall SR, Van Gils JA (2010) The ecology of information: an overview on the ecological significance of making informed decisions. Oikos, 119(2):304-316. https://doi.org/10.1111/j.1600-0706.2009.17573.x.

Seevers B, Graham D, Gamon J, Conklin N (2007) Education through Cooperative Extension. 2nd ed. Thomson Delmar Learning, Clifton Park, New York.

Specialty Crops Competitiveness Act (2004) Specialty Crops Competitiveness Act of 2004, Pub. L. 108–465, 118 Stat. 3882 (United States Congress, Washington, DC). (online) https://uscode.house.gov/view.xhtml?req=specialty+crop+block+grants&f=treesort&fq=true&num=0&hl=true&edition=prelim&granuleId=USC-prelim-title7-section1621 [accessed 13 March 2026].

The pandas development team (2025) pandas-dev/pandas: Pandas (Version 2.3.1) [Computer software]. Zenodo. https://doi.org/10.5281/zenodo.3509134.

Trekels M, Pignatari Drucker D, Salim JA, Ollerton J, Poelen J, Miranda Soares F, Rünzel M, Kasina M, Groom Q, Devoto M (2023) WorldFAIR project (D10.1) agriculture-related pollinator data standards use cases report. Zenodo. (online) https://zenodo.org/records/8356529 [accessed 18 November 2025]

vanEngelsdorp D, Meixner MD (2010) A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. Journal of Invertebrate Pathology, 103(S1):S80–S95. https://doi.org/10.1016/j.jip.2009.06.011.

Wilkinson MD, Dumontier M, Aalbersberg IJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten JW, da Silva

Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, ‘t Hoen PAC, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martonne ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, Van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenberg P, Wolstencroft K, Zhao J, Mons B (2016) The Fair guiding principles for scientific data management and stewardship. Scientific Data, 3(1):1-9. https://doi.org/10.1038/sdata.2016.18.

Wilkinson MD, Sansonne S-A, Schultes E, Doorn P, da Silva Santos LOB, Dumontier M (2018) A design framework and exemplar metrics for FAIRness. Scientific Data, 5:180118. https://doi.org/10.1038/sdata.2018.118.

Zhu J (2023) Unlocking potential: Harnessing the power of metadata for discoverability and accessibility. Information Services and Use, 43(3–4):249–256. https://doi.org/10.3233/isu-230202.

 ISSN 1920-7603