Current Research in Environmental Sustainability 4 (2022) 100133

Contents lists available at ScienceDirect

Current Research in Environmental Sustainability

journal homepage: www.sciencedirect.com/journal/current-research-in-environmental-sustainability

Arthropod-related ecosystem services and disservices in smallholder farming in low and middle income countries

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ARTICLE INFO

Keywords:
Insects
Ecosystem disservices
Ecosystem services
Family farming
Smallholder farming
Transdisciplinarity

ABSTRACT

Smallholder farming (SHF) currently faces major challenges of sustainability to ensure food security while improving environmental conditions. Sound management of crop arthropods is central to SHF sustainability as these provide both services (e.g. pollination) and disservices (e.g. crop damages) with significant impacts on crop production. Understanding the synergies and trade-offs between arthropod services and disservices is key to achieve crop sustainability yet information about this important issue has never been compiled and analyzed for SHF. Here we review the recent literature with a specific focus on three key aspects of sustainable arthropod-management practices, namely 1) the systemic approach of the studies (crop vs. landscape scale), 2) the joint consideration of services and disservices provided by arthropods, and 3) farmers' involvement in the research. We found that most studies were performed at crop level (70.2%) without consideration of surrounding habitats. Moreover, services and disservices provided by arthropods were generally studied separately from each other (51.6% of articles) and were mainly focused on crop pests (34.6%). Farmers' knowledge was seldom considered and mainly concerned pests and pollinator-related services (20.5%). A majority of publications (73.8%) did not effectively involved farmers into the research process. Our review stresses the need to develop a more holistic view of arthropod management in SHF, including both the reduction of disservices and the enhancement of services. Furthermore, it would be necessary to promote transdisciplinary approaches to better articulate knowledge on arthropod ecological functions with farmers' needs.

1. Introduction

Worldwide, agriculture is facing a double challenge of increasing productivity and developing more sustainable ways of food production (FAO, 2003; FAO, 2014). Small-scale farming practiced on relatively small plots of land is the most dominant form of agriculture, constituting more than 70% of the global food production entities (Samberg et al., 2016; FAO, 2017). Family farmers with small landholdings represent about 80% of the world's farms and account for 85% of global population involved in agriculture (FAO, 2014; Lowder et al., 2016), mostly in low and middle-income countries (L&MIC), with strong strain on natural resources and pressing concern for food security (FAO, 2016); and addressing multiple goals and targets contributing to achieve the Sustainable Development Goals (SDGs (FAO, 2018)). Although widely used, a unique and unambiguous definition of smallholder farming (SHF) still remains to be established (FAO, 2017). It currently relies on several criteria, mostly related to land endowment (usually 2 to 5 ha threshold), labor productivity (i.e. familial) and income (FAO, 2017; Lowder et al., 2016). The definition of smallholding is however context-dependent and can vary according to socio-economic, technological and agroecological realities (FAO, 2017; FAO, 2010). SHF systems are highly diverse in terms of climatic, ecological and socioeconomic conditions as well as in their structure and functioning (Steward et al., 2014; Scialabba et al., 2014; Altieri, 2004). Still, these agroecosystems share certain properties like high levels of biodiversity and complex landscape composition (Altieri et al., 2012), key role of family-managed farms in supporting local livelihoods (FAO, 2014; Samberg et al., 2016; FAO, 2017), management methods tightly related to rich local knowledge system or shared cultural values in common social organization and strong adaptability to changes, sometimes in high risk environments (Altieri et al., 2012; Salcedo and De La, 2014). These agrosystems are also a leading representation of human-nature interactions and feedbacks, encompassing material and non-material benefits for humans as well as threats or unfavorable outputs (Altieri et al., 2012; Díaz et al., 2018;

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https://doi.org/10.1016/j.crsust.2022.100133
Received 30 July 2021; Received in revised form 15 February 2022; Accepted 18 February 2022
Available online 26 February 2022

Brush, 2008).

As for other ecosystems, long-standing interactions within SHF and their ecological functions provide direct and indirect fundamental benefits to humans, through supporting, cultural, provisioning and regulating ecosystem services (ES) (Millennium Ecosystem Assessment (Program), 2005). Because of the strong interconnected natural and agricultural features in SHF, unsustainable practices may undermine ES on which smallholders depend to meet urgent needs in contexts of great vulnerability and weak institutional support. Food production on SHF is strongly linked to biodiversity-derived services as increasing the levels of artificial inputs is not economically viable for resource-constrained households. Therefore, options to maintain or improve production are rather linked with improvement of the amount and integrity of ecosystem regulation and supporting services (International Fund for Agricultural Development (IFAD), 2013). Food production, especially in SHF, depends on a wide range of ecosystem functions including nutrient and water cycling, pollination, competitive interactions, and matter decomposition. These functions are fulfilled by several agrobiodiversity components, particularly arthropods. To date, research on arthropod-related ES has mainly focused on well-known functions and performed by charismatic or iconic groups such as butterflies, hymenoptera or beetles (Noriega et al., 2018), even though a large part of global crop production depends on pollination from bees and wild pollinators (Klein et al., 2007; Rader et al., 2016). Pollination also contributes to economic welfare and to rich and meaningful cultural and spiritual life for a large population (IPBES, 2016). Along with pollination, biological control is one of the most studied services as it implies high economic impacts for agriculture because parasitoids and predatory arthropods contribute to controlling pest insects in crops (Gurr et al., 2003; Rusch et al., 2017).

In contrast to ES, ecosystem disservices (EDS) are defined as ecological elements, functions and processes affecting negatively human well-being, directly (e.g. pollen allergens), by intermediate of negative impacts on ES (e.g. diseases from pathogens reducing pollination) or by reinforcing other EDS (e.g. wildfire occurrence mediated by invasive species) (Blanco et al., 2021). EDS scope on ecological phenomenon linked to negative outcomes affecting human well-being, which must be differenciated from the associated detriments or costs resulting from human actions on ecosystems (Shackleton et al., 2016). In agricultural systems, EDS affect functions and productivity, leading to important crop losses (Zhang et al., 2007). These disservices such as herbivory or competition for resources (e.g. water consumed by non-crop plants (Zhang et al., 2007)) have also been extensively studied, establishing a dominant viewpoint where insects are predominantly perceived as crops pest and harmful to anthropogenic environments (Wyckhuys et al., 2019; Dangles and Casas, 2019). Nevertheless, as stakeholders' actions may be largely driven by greater perception and willingness to reduce EDS (Shapiro and Báldi, 2014; Blanco et al., 2019), arthropod management for either mitigating EDS or enhancing ES can also be a powerful driver for transition towards sustainable agriculture in smallholder systems. In particular, promising results on agroecosystem management towards more sustainable agriculture have been reported when including ES-EDS synergies and trade-offs (Lundin et al., 2013; Gaba et al., 2014; Gagic et al., 2019).

To date published evidence on the relationships between arthropod-related ES and the sustainability of agricultural practices has been largely based in research from high-income countries (HICs) and temperate regions (Steward et al., 2014; Palomo-Campesino et al., 2018; Struelens and Silvie, 2020). Moreover, a combined analysis of services and disservices of arthropods in SHF systems has still to be performed for balancing positive and negative impacts of nature on human well-being (see (Blanco et al., 2021)) and for reframing entomological research to achieve the SDGs (Dangles and Casas, 2019). To address this issue, we performed a literature review capturing research trends in insect-related ES and EDS in SHF, detecting knowledge gaps and exploring to what extent these studies are conducted within a transdisciplinary framework (Stern, 2018). In particular, we were interested in research practices in SHF considering ES and EDS in a multidimensional view of agro-ecosystems (crops and natural habitats) and bringing together diverse knowledge systems, especially between academic and farmer communities.

2. Material and methods

2.1. Data base compilation

We conducted a systematic multilingual (English, Spanish and French) review of the scientific literature in peer-reviewed journal articles published between January 2015 and January 2021. We followed the systematic literature review (SLR) approach and the six steps protocol commonly used for scientific review (Higgins et al., 2019; Mengist et al., 2020). Detailed steps of the process are described in Appendix A. We first determined the research scope with the PICOC framework (Population, Intervention, Comparison, Outcomes and Context, see Table A.1, Appendix A). We identified concept groups for keywords from the terminology identified in PICOC and then ran a 'naïve search' for identifying search terms through an automated approach (Grames et al., 2019) using the litsearchr R package version 1.0.0 (Grames et al., 2020) (see Fig.A.1, Appendix A).

Then identified terms in the three languages were searched in different databases covering a broad range of academic contexts: Web of Science (general literature), Scopus (social sciences- oriented), BASE (multi-disciplinary), and Scielo (multi-disciplinary). The search string was a compilation of keywords of four main domains: *Arthropods*, *Agriculture*, *Ecosystem services and disservices*, and *Smallholder farming* (see the complete list of terms search in Table A.2, Appendix A). Keywords were searched in aggregated quests, progressively filtering articles, thereby giving us an idea of the shared publications of each subtheme in the overall literature on arthropods. Overall, we retrieved 454,703 records on arthropods, of which 40,720 were related to agriculture (8.96%). Among them 14,967 articles (3.29% of total records) were related to ES or EDS, of which 1564 (0.34%) concerned SHF. As diversified international databases and collection of published scientific research help cover citations more widely (Nuñez and Amano, 2021), especially for countries in L&MIC, we included bibliographic resources from other scientific search engines, scientific libraries and scholarly journals platforms as Dialnet, PKP Index (Public Knowledge Project) and AJOL (African Journals OnLine), using the four main keywords groups repeatedly in the search process. Finally, we conducted a complementary approach of citation tracking by backward snowballing (Wohlin, 2014) using articles' reference lists. We retrieved 57 additional references, leading to a total of 1621 articles.

All references were compiled into a unique bibliographic database organized and arrayed to eliminate duplicates and misreferenced entries using the revtools v. 0.4.1 (Westgate, 2019) and synthesisr v. 0.3.0 R packages (Westgate and Grames, 2020). Article titles and abstracts in the resulting database ($n = 991$) were subsequently screened to complete inclusion-exclusion procedure according to predefined criteria (see Table A.3, Appendix A). We excluded publications whose focus was not relevant to SHF systems (110 articles) or for which insect sampling was not done under real world conditions (e.g. experimental fields or laboratory experiments, 105 articles). This also implied excluding studies about intensive and high-input farming systems and those located in HICs (81 articles). Moreover, we excluded papers in which insects were not associated to any disservices or EDS (e.g. only inventory of diversity without indicating a function or role in the agroecosystem, 186 articles).

After this selection process, our database included 172 publications. These were selected for full screening and qualitative assessment, after which 122 publications were kept (see Fig. 1, Appendix A and Appendix C for complete list of references). The remaining 42 articles were excluded in the last full-text reading step when arthropods were not explicitly mentioned or ES and EDS were not clearly addressed. For the final data extraction step, we registered in separate subset datasets all

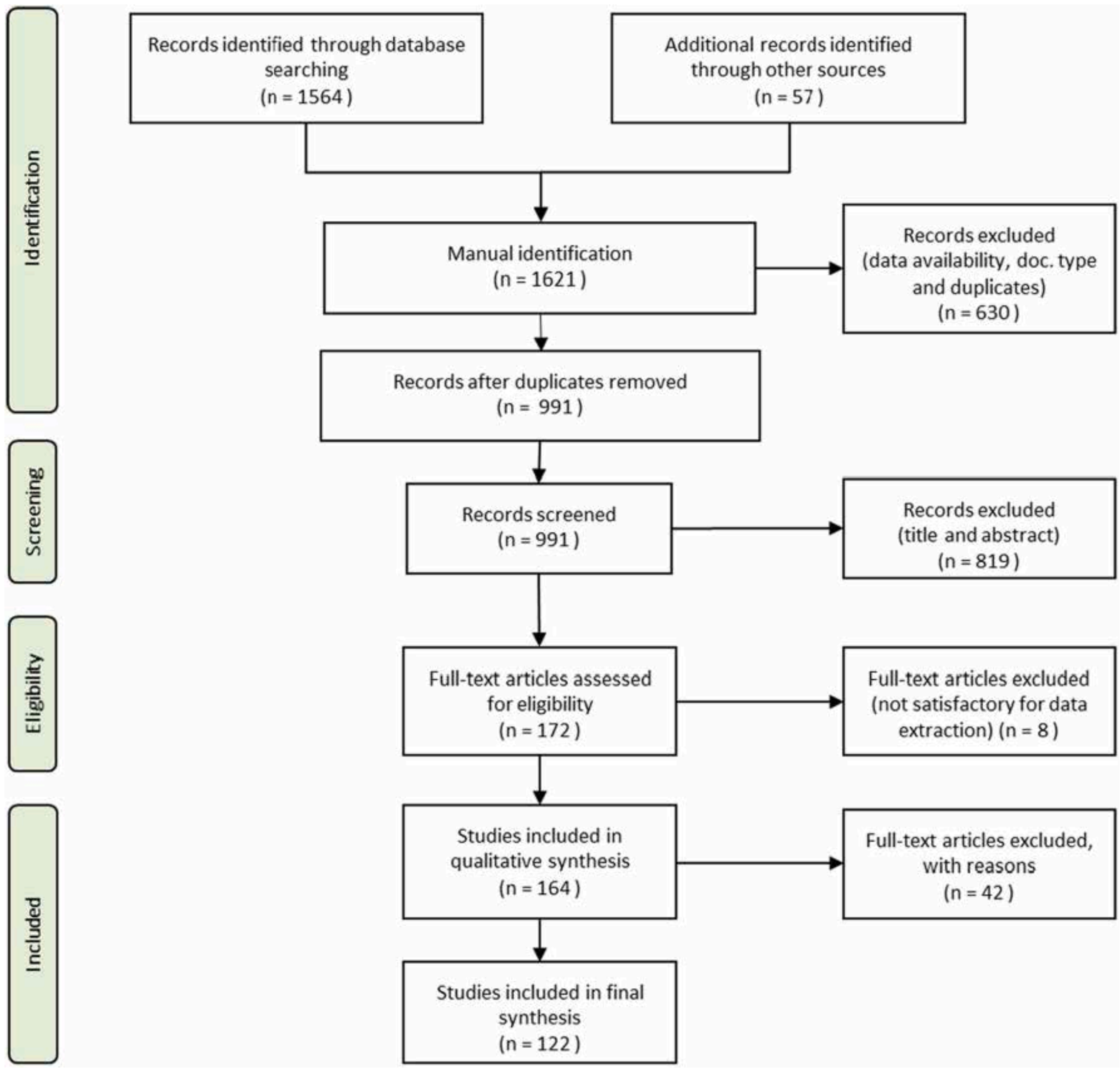

Fig. 1. Prisma diagram summarizing the methodological procedure of the SLR protocol from papers selection to the database formalization, towards eligibility criteria filtering and the application of methodological plan to summarize the review information.

information related to ecosystem services (see definitions in Table A.4.1, Appendix A), entomofauna and farmer knowledge and perceptions (see the *Data processing* section). Besides bibliographic default metadata, we registered data about country, income level (corresponding to the income groups from World Bank's Data excluding High-income economies) and study system (e.g. crop type) as well as scientific methodology variables (e.g. participation of farmers; see Table A.5, Appendix A).

2.2. Data processing

We defined four main thematic to analyze the articles listed in the final database and extracted information on arthropods, their services and disservices, farmers' knowledge and actions related to arthropod management; the transdisciplinarity approach of the research (see Table 1 and Table A.5). First, we examined the taxonomy of arthropod communities and at which spatial scale they were studied (i.e. crop-centered vs. crop in the surrounding landscape). This issue is important when assessing arthropod-related ES and EDS as understanding arthropod dynamics typically requires studies at the landscape scale (e.g. see (Crespo-Pérez et al., 2011)). For this, we reported which habitats were included in the study (i.e. agroforest, storage structures, non-crop habitat, crop field).

Second, we used the four Millennium Ecosystem Assessment's (Millennium Ecosystem Assessment (Program), 2005) broad categories of ES (provisioning, regulating, supporting, and cultural, see Table A.4.1, Appendix A) and registered all arthropod-related functions reported by each article. We followed Blanco et al. (2021)'s definition of final and intermediate EDS. We also registered whether ES or EDS were considered alone or by multiple functions. The interaction among ES and

Table 1
Criteria and variables extracted from the selected articles.

Criteria and variables	
Article general information	Article bibliographic information (year of publication, Title, Journal, DOI, keywords, authors name discipline and affiliation) and geographic information (location, income level, scale)
Study of arthropods in crop systems	Habitat, crop system (crop type, scale) and taxonomic information on arthropods studied (functional guild, taxonomic level and id.)
Ecosystem services & disservices	ES and EDS categories and functions associated with ES and EDS
Farmers knowledge and practices	Farmers' knowledge and perceptions (if studied), arthropod management strategies
Transdisciplinarity	Farmers' participation index and North/South collaborations

EDS were visualized through a network analysis using the R bipartite package (Dormann et al., 2008). In addition, we extracted diversity data of arthropod taxa related to ES or EDS (taxonomic level, name and functional guild).

Third, we gathered information on the type of farmers' knowledge (e.g. arthropods identification, functions, perceptions, associated knowledge) and associated management practices regarding arthropods in their farming systems. We also recorded all actions mentioned in the studies for subsequent classification of values based on arthropod management strategies (Zehnder et al., 2007; Gurr et al., 2004) (see Table A.4.2) and whether chemical pesticides were used.

Fourth, we analyzed to what extent the research works had been developed through a transdisciplinary approach. Transdisciplinarity addresses relations between science and society, making transformations from science building process and involving stakeholders since the first stages of research process to better target problems (Jahn et al., 2012). To assess whether research processes encompassed knowledge co-construction and sharing, we set a farmers' participation index (FPI) adapted from the typology proposed by Pretty (Pretty, 1995) and Brandt et al. (Brandt et al., 2013). The five levels of the FPI reflect the degree of involvement of farmers in research process, from an absence of farmers or no implicit participation (FPI = 0) to a shared and coordinated implication of farmers in research (FPI = 5; see Table A.4.3, Appendix 1 for details). In addition, we identified the person involved in arthropod identification (researchers or farmers). All statistical analyses and graphs were performed using R 4.0.4 (R Core Team, 2021).

3. Results

The 122 selected studies were conducted predominantly in Sub-Saharan Africa (50.4% of studies), Latin America & Caribbean (28.5%) and East Asia & Pacific (15.3%). Overall, 44% of the studies were conducted at a regional scale, 39.0% focused on local scale and 15.0% covered national or transnational scales. In total, 79.5% of the publications were English-language performed, followed by Spanish or bilingual version English/Spanish (13.9%) and French (6.5%). Research disciplines concerned mainly "*Agriculture and Agronomy*" (38.5% of publications), *Ecology-Biology* (20.5%) and *Entomology* (17.2%), with a low occurrence of studies belonging to social sciences, economics or multidisciplinary approaches (4.1% each) (see Fig. B.1, Appendix B).

The majority of publications focused either on crop fields (64.8%), agroforests (14.8%) or crop storages (10.7%), encompassing 68 different crops (mostly maize, coffee, beans, cassava, cacao, rice, potatoes and combined vegetable or fruits). In most cases (37.6%), those systems were polycultural (including intercropping and associated crops) with monoculture and mixed (monoculture-polyculture) systems representing 22.2% and 17.1% of the studies, respectively. Most works (70.2%) studied insect-plant relationship only at the plot-level (either the crop, the agroforest or the storage alone) and only 29.8% included the surrounding habitats (Fig. 2).

Articles studied either one (51.6%) or various (48.4%) arthropod-related ES and EDS. Because several services could be analyzed in a single study, the total number of studied ES and EDS was higher (228) than the total number of studies (122). Most studies focused on regulating ES (44.7% of studies) and EDS (37.14%). Only 6.86% of services referred to cultural services, and even fewer to provisioning and supporting services (7.43 and 4%, respectively). Overall, 16 main categories of ES and EDS were covered (Fig. 3). Arthropod functions and processes in SHF agrosystems were mostly related to pests, either their damage or their control (34.65% and 23.68%, respectively). For instance, articles reported arthropod-related damages concerning herbivory on plants (Novais et al., 2016) and consumption of stored grains (Midega et al., 2016), while potential of pest control by natural enemies was studied through parasitism and predation processes (e.g. larval parasitoids (Diatte et al., 2018)). Besides, pollination and hive-related products (honey, wax) represented 15.35% and 6.14% of the investigated

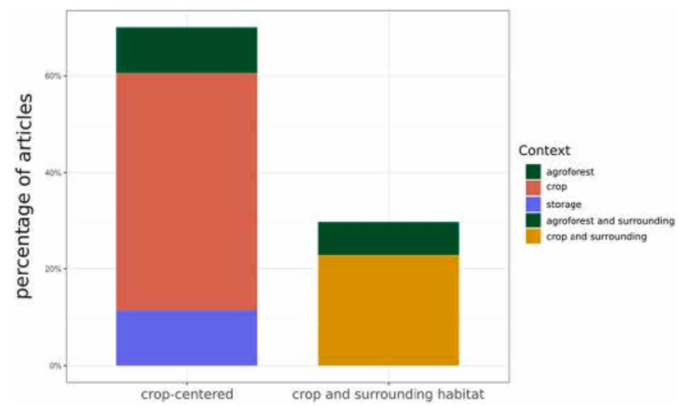

Fig. 2. – Percentage of reviewed articles according to the agroecosystem context in which arthropod-related ES and EDS were studied. Two levels were identified: (1) crop-centered (either the crop, the agroforest or the storage alone), and (2) crop and surrounding habitats.

functions, respectively (Table B.1, Appendix 2). These were studied to illustrate changes in knowledge and practices (e.g. honey consumption (Contreras Cortés et al., 2020)) and potential benefits from pollinators (e.g. contribution for crop pollination and household income (Rodríguez et al., 2020)). The remaining ES include education, medicinal, cultural or heritage services, and a lower proportion of services related to soil processes (matter recycling, soil fertility), bioindicator species, handcraft manufacturing or direct selling. These ES were considered through educational purposes (e.g. promoting interest and awareness (Marques et al., 2017)) and to examine the links between farmers' knowledge and decision-making (Beltrán-Tolosa et al., 2020). Jointly studied functions were mainly "crop pest and pest control" (33.6% of articles) and, to a lesser extent, "pollinator-related services and educational and cultural services" (20.5%). A low proportion of the reviewed literature (6.6%) assessed more than three functions together, often associated to cultural services or crossroads between cultural and regulating services (Fig. 3).

Three main categories accounted for the most studies on crop damage, pest control and pollination (Figs. B.4, B.5 and Tables B.2). The most studied taxa belonged to the hymenoptera (Fig. 4), either as natural enemies (e.g. parasitoid wasps), pollinators (e.g. domestic or wild bees) or pests (e.g. ants). Furthermore, many arthropod taxa were studied in intercropping systems (i.e. multiple crop fields, mixed or rotation cropping and agroforestry), stressing the key part of landscape heterogeneity in smallholder farming.

Only 4.9% of all articles assessed the management of both pollinators and natural enemies and/or pests (see Fig. B.2.1, Appendix B). Except for integrated pest management (mentioned in 10.6% of articles), options that represented combined forms of different arthropod management were rarely evaluated in the same study. Regarding management practices, farmers' strategies to improve an ES or counter an EDS mostly concerned chemical, organic and cultural practices for pest and habitat management (Fig. 5). Most of them were related to pest control and implied pesticide applications (chemical or botanical). Nevertheless, several management strategies sought to improve environmental quality of agroecosystems. Arthropod management included traditional practices mostly by habitat management (crop and non-crop). Other common strategies were related to storage facilities (e.g. hermetic bags) and pest control (e.g. use of ash dust).

Overall, 40.2% of articles addressed farmers' perceptions, actions and/or knowledge related to arthropods in SHF. Research covering farmers' knowledge or perceptions was mainly carried on cultural services (i.e. education, cultural heritage), especially for pollinator-related services (e.g. medicinal uses and production of honey and beeswax) (Fig. 6). In contrast, farmers' knowledge or perception was not prevalent in common agricultural services like pollination or pest-related

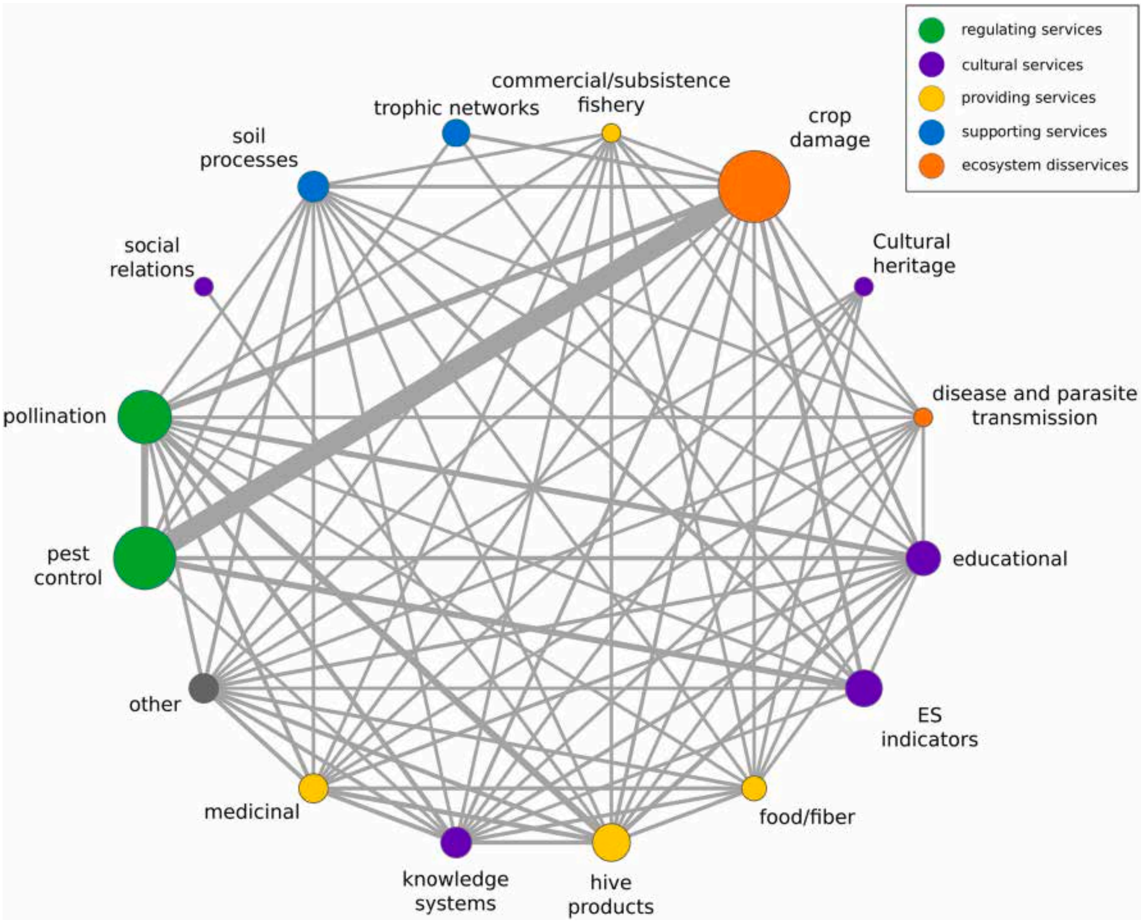

Fig. 3. Main categories of arthropod-related ecosystem services and disservices reported in the reviewed literature concerning smallholder farming systems. The size of the circles represents the number of studies on each ES or EDS and the lines represent the frequency ES or EDS studied jointly in the same article.

functions (damage and control). Very few studies addressed farmers' point of view on processes related to soil and to species as bioindicators.

Overall, farmers' opinion and knowledge was poorly considered (Fig. 7) as 73.8% of all articles had a participation index (FPI) scoring 0 or 1. In particular, farmers were poorly involved in the identification or survey processes: 78.2% of the 1264 taxa registered in the 122 articles were studied without local stakeholders (farmers, extensionists or students; Fig. B.3, Appendix B). Farmers' involvement was mainly passive through surveys or on-field sampling, and mostly aimed at collecting agronomic data, without consideration of their viewpoint in research questions or methods definitions. Furthermore, 17.2% of articles did not report any or not explicitly mention farmer's involvement within the research process (FPI = 0).

4. Discussion

In this review, we evaluated current literature on arthropod-related services and disservices in smallholder systems. Despite an increasing number of studies focusing on insect-related services in the last decades (Noriega et al., 2018; Dangles and Casas, 2019; Ameixa et al., 2018; Crespo-Pérez et al., 2020), we found that only 9.0% of the arthropod literature concerned agricultural systems. Even more challenging, only 0.34% of the search outputs referred to SHF, albeit 84% of the world's farms are small-holding, operating on about 12% of the world's land (Lowder et al., 2016). These results are in line with recent findings pointing that agricultural ES research is strongly biased towards large-scale intensive farming landscapes and temperate biomes in HICs (Steward et al., 2014; Palomo-Campesino et al., 2018). This review is subject to limitations inherent to the chosen scope and focus on recent literature (2015–2021). In addition, it is likely that some SHF studies from L&MIC may not be published in indexed peer-reviewed journals but rather in technical reports or local academic canals, keeping several potentially relevant documents out of our scope. Similarly, despite a multilingual search, we might have omitted several references, particularly from the Asian continent, which is a limitation commonly reported in the literature (Nuñez and Amano, 2021; Amano et al., 2016).

4.1. Ecosystem services and disservices

Agricultural ES and EDS related to arthropods mainly concerned regulating services. Most studied functions concerned pest, which reflects the longstanding negative view of arthropod roles in agroecosystems (Dangles and Casas, 2019). In most cases, arthropods were studied only as pests (Caniço et al., 2020a; Bigirimana et al., 2019) or pest antagonists (Diatte et al., 2018; Sisay et al., 2018; Caniço et al., 2020b) with no consideration of other ecological roles they could play. However, as smallholders' actions may be driven mainly by EDS reduction (i.e. limiting crop damage by pests), the negative impacts of these actions on ES supply should also be taken into account (Blanco et al., 2021). A few studies assessed floral visitors as potential enhancers of yield (Zou et al., 2017; Popak and Markwith, 2019) but almost none considered both pest control strategies and the maintenance of beneficial insects (but see (Motzke et al., 2015)). Moving in that direction, Integrated Pest Management (IPM) strategies could be adjusted for pollinator protection practices along with other beneficial arthropods for the agroecosystem (Biddinger and Rajotte, 2015). This relatively new paradigm of integrated pest and pollinator management (IPPM) merges both the welfare of all pollinators into the crop pest protection

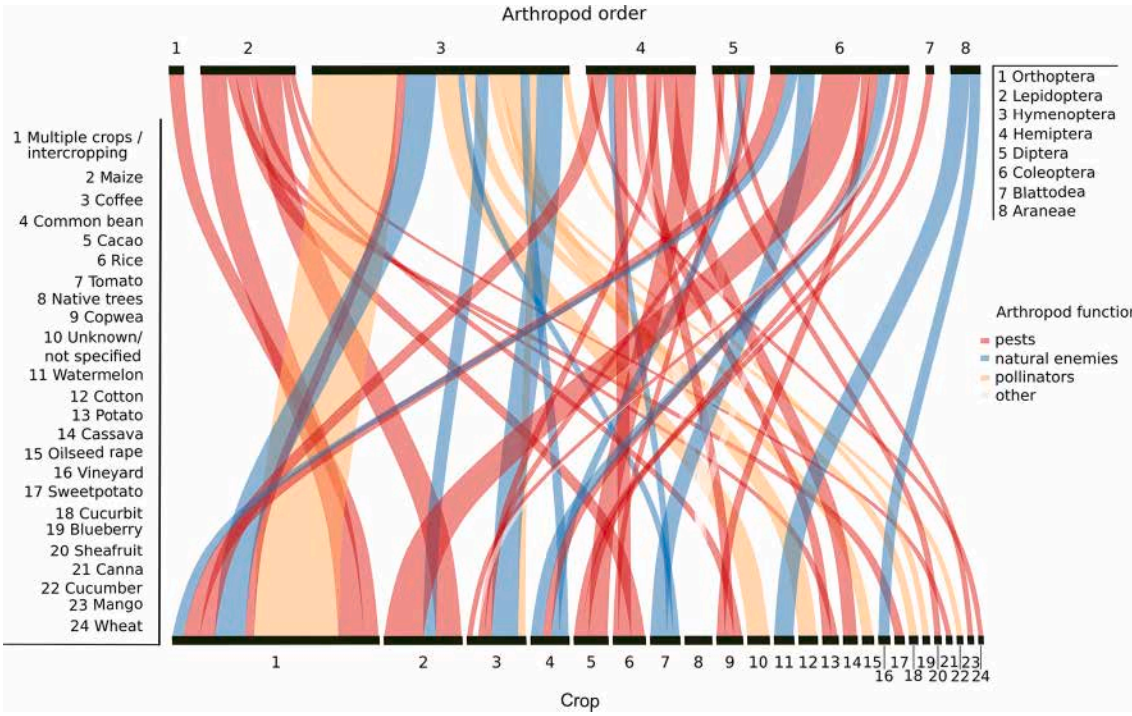

Fig. 4. Main arthropod orders in connection with their functions as pollinators (orange), natural enemies (blue) and pests (red) within the crop systems studied. Line width represents number of taxa reported by article for each function. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

programs and benefits of alternative pollinators into crop production (Biddinger and Rajotte, 2015; Lundin et al., 2021). IPPM can fit smallholder farming sustainable objectives as it intends to minimize trade-offs between ES and EDS, and to maximize co-benefits and synergies from insect management (Lundin et al., 2021). However, any application of these principles calls for extensive transdisciplinary research among scientists, farmers and stakeholders in order to develop collectively on-field trials and monitoring instruments, but also to co-design decision support tools and evaluation of IPPM adoption (Egan et al., 2020).

4.2. Habitats and crops: lacking a multilevel perspective

In the reviewed literature, arthropods were mainly studied separately along the food production process (i.e. either crop, surrounding habitats or post-harvest storage). However, agricultural ES and EDS require a wider consideration of the different crop stages, including management of harvested products (Mendoza et al., 2017; Sankara et al., 2017) as well as crop and non-crop habitats (Medeiros et al., 2019). This is especially important for ES and EDS related to arthropods whose life cycles often encompass both cultivated and natural habitats. The lack of a landscape level consideration may hamper farmers' actions and proper management strategies. Indeed, the majority of reviewed papers presented pest management through chemical pesticide applications in the different crop system components (i.e. crop field, surroundings, crop storage facilities) while more sustainable management of traditional SHF requires a multidimensional view of the system (e.g. to favor pest natural enemies though the maintenance of flower-hedges, semi-natural habitat, Fig. 2 (Kansiime et al., 2021; Blandi et al., 2016)). Farmers aware of the role of the entomofauna at the landscape level could lower pesticide use, even if their awareness is oriented towards phenomena they observe in their fields or storages (Djuideu et al., 2020). Indeed, various articles raised the importance of increasing the entomological literacy of farmers, for example through training programs on pollinators (e.g. multiple roles of bees), to achieve sustainable management actions in SHF (Elisante et al., 2019). Arthropods also support social practices and cultural values (i.e. cultural heritage) by enabling the identification and analysis of changes in intergenerational transmission of knowledge (e.g. about native stingless bees, see (Contreras Cortés et al., 2020)).

4.3. Farmers' knowledge, perception and practices

We found few studies focusing on how farmers' knowledge is linked to arthropod-related ES (e.g. (Sawe et al., 2020)). A similar trend was documented by Rawluk & Saunders (Rawluk and Saunders, 2019) who pointed at the scarcity of documentation of farmers' knowledge on beneficial insects' biology or ecology in agroecosystems. Farmer's knowledge or perception mainly concerned pest-related functions (i.e. damage or control) because of the strong interdependence of smallholder farming on pest threats and risks. This makes control techniques essential to increase productivity while dealing with harsh environmental conditions (FAO, 2016; Meza, 2014). The few articles directly engaging emic local knowledge systems on arthropod-related ES dealt primarily with bees' handling (e.g. (Contreras Cortés et al., 2020)). These practices cover a broad range of cultural, medicinal or educational services that contribute to empowering biocultural diversity and endogenous development (IPBES, 2016, Duffus et al., 2021). These relationships would be worth studying further and together with other services or disservices to assess potential tradeoffs and synergies in the agricultural system.

The objectives of most articles were either to identify and/or study the biology/ecology of arthropod species providing specific ES (e.g. how a bee taxon pollinates a given crop or plant). However, several articles reported farmers being unable to recognize or identify arthropods and/or their functions correctly (Sawe et al., 2020; Mkenda et al., 2020; Munyuli et al., 2017), leading to inappropriate arthropod management (Wyckhuys et al., 2019; Rawluk and Saunders, 2019). Furthermore, local beliefs in spontaneous generation can substitute concepts of insect reproduction and metamorphosis cycles (Bentley, 1989). These statements illustrate the mismatch between scientific and local knowledge

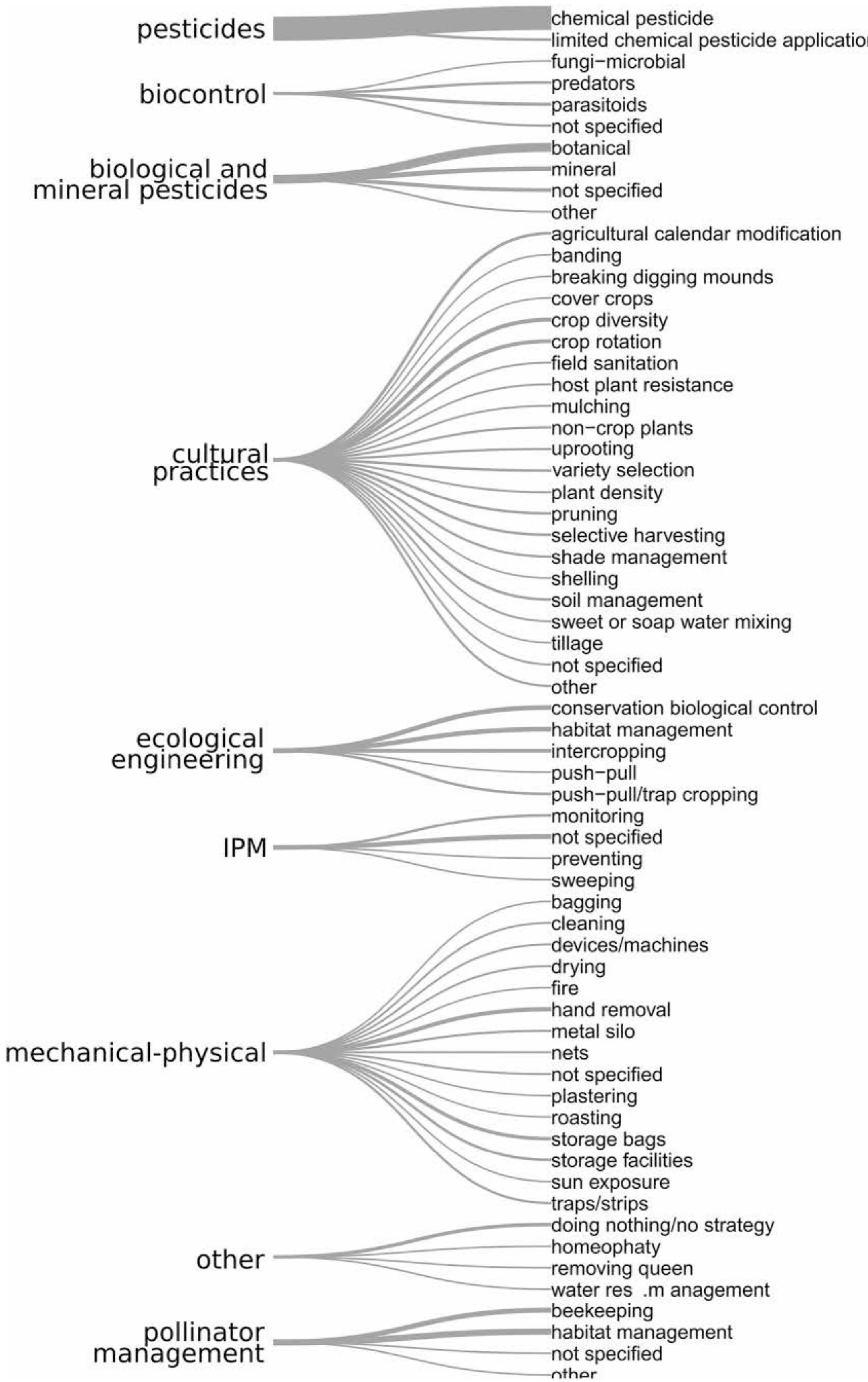

Fig. 5. Main arthropod management strategies reported in the literature concerning SHF. Line width represents frequency of an action being reported.

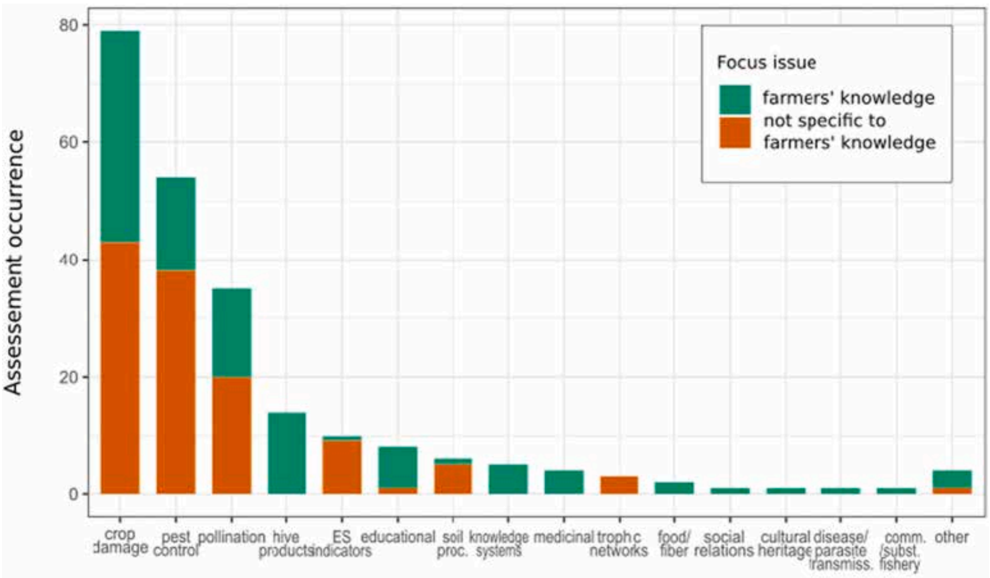

Fig. 6. Ecosystem services and disservices ranked from studies on farmers' knowledge and/or perception and/or actions. The ten categories of ES and EDS studied in SHF systems are of height according to number of articles assessing them. Proportion of articles having relevance with farmers' knowledge/perception/actions are green colored, while orange colour refers to articles addressing ES or EDS but not dealing with farmers' knowledge. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

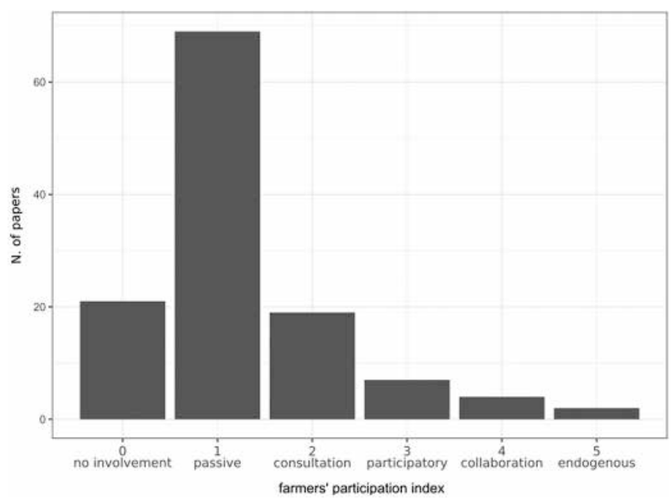

Fig. 7. Farmers' Participation Index (FPI) classifying involvement of farmers in research process through five levels: (0) no involvement or not mentioned; (1) passive participation limited to data collection; (2) consultation with material incentives but without sharing processes; (3) participatory/functional research with common objectives; (4) collaboration by farmers interactively participation in study design, data collection and outputs discussion; (5) endogenous initiatives from farmers and shared mobilization with scientists looking at long-term results.

that can be detrimental to cope with agronomic problems (e.g. new species outbreaks in changing environments). Most farmers have a remarkable experiential knowledge of several elements in their agricultural landscapes resulting from long-term human-agrobiodiversity interactions (Brush, 2008; Hill et al., 2020). However, certain aspects might be difficult or impossible to observe such as the morphological differences between immature stages of two different pest species or the predatory behavior of small parasitic wasps of crop herbivores. This may affect farmers' understanding of pest damage and biocontrol. For example, farmers can easily observe that insect pests may be preyed upon by vertebrates (e.g. birds) but not by other insects or microorganisms (Bentley, 1989). Likewise, farmers might over-react to certain pests that cause sub-economic damages or may perceive non-pest species as threatening (Bentley, 1989; Tarakini et al., 2020). Misidentification remains the main issue reported in the literature, either for species names or for their ecological functions (Elisante et al., 2019). On the other hand, even professional entomologists may have a limited knowledge on the taxonomy and ecology of many arthropods living in tropical SHS. It is therefore mandatory to reinforce transdisciplinary research by fostering the complementarity between local and scientific knowledge for arthropod management in SHF (e.g. (Liebig et al., 2016)). The recognition of local classifications could be an opportunity to build synergies between knowledge systems (Krause et al., 2010) and generate a common vision of arthropod communities.

In the reviewed literature, scientists made the vast majority of taxonomic identifications, asking farmers subsequently to recognize them and then evaluate/validate their knowledge. Very few studies proceeded to recognize local categories and how arthropods were locally classified or named (Contreras Cortés et al., 2020; Beltrán-Tolosa et al., 2020). This perspective widens the gaps between scientific and farmer knowledge, potentially affecting the effective implementation of more sustainable agriculture practices (Liebig et al., 2016; Parsa et al., 2014; Vidogbéna et al., 2016). Among the great diversity of insect species, farmers may name a set of organisms by a single term, even when they are not related species (Munyuli et al., 2017; Gurung, 2003). Ethno-entomological studies have shown that a lack of name designation does not always reflect a missing category, as when a combination of words or concepts encompasses adjacent categories (Bentley, 1989; Costa-Neto, 2000). Folk entomological classifications include cultural, social and ecological dimensions to differentiate life-forms based on morphologic, biological, behavior, utilitarian and psycho-emotional criteria (Hill et al., 2020; Krause et al., 2010). Thus, involving folk and farmers' knowledge systems that differ from the taxonomic systems may allow broadening the scope of research in the direction of knowledge co-construction through. This may be achieved through the development of collective referential categories between scientific and folk knowledge systems (Krause et al., 2010) or through a monitoring of knowledge changes (Brondízio et al., 2021) (e.g. loss of knowledge and biocultural diversity around beekeeping practices as in (Contreras Cortés et al., 2020)). Including emic knowledge and intrinsic value of entomofauna in SHF may also help to better understand their socio-ecological roles in the agroecosystem, as proposed for pollinators (Contreras Cortés et al., 2020; Marques et al., 2017) and natural enemies (Beltrán-Tolosa et al., 2020; Mkenda et al., 2020).

4.4. Transdisciplinary practices

While several authors recognized the importance of including farmers in agroecosystem ES and EDS studies, our review shows that questions related to local knowledge remained of limited interest for researchers. Poor participation of farmers and local people is a persistent problem in agricultural ES research (Rawluk and Saunders, 2019; Kanter et al., 2016) and may have long-term implications to link different types of experience around a common problem (e.g. pollination deficit (Christmann et al., 2021)). Applying transdisciplinary research concepts and methods may address this issue by favoring the initial co-design and co-creation of collaboration frameworks and research questions, the bidirectional information fluxes between scientists and farmers and the building of a solution-oriented knowledge (Liebig et al., 2016; Landis et al., 2016; Bartomeus and Dicks, 2019). In our review, only three studies out of 122 actively engaged farmers (FPI = 5, Fig. 7). These works documented the successful application of participatory approaches. For example by improving pest control networks Landis et al. (2016) (Landis et al., 2016) report on capacity building on IPM practices for wheat, providing a common learning process for farmers, crop advisors, and students. Also Smith et al. (2017) (Smith et al., 2017) proposed a coordinated pollinator management plan integrating both local and scientific knowledge while Christmann et al. (2017) (Christmann et al., 2017) investigated human values regarding friendly actions for pollinator protection by a participatory approach focusing on farmers decision making. Such initiatives may not only trigger large system change and achieve broader systemic impact on SHF but also catalyze sustainable agriculture transition process as it combines both knowledge (scientific advancement) and social processes among actors.

5. Conclusion

Our review revealed that arthropod management research in smallholder systems still mainly focuses on pest control at the field level. It is urgent to develop a more holistic approach of arthropod communities, both detrimental and beneficial to people, in cultivated and surrounding natural habitats. People and arthropods have lived in close interactions for centuries, yet research studies rarely include traditional knowledge to coproduce management options. Building innovative transdisciplinary collaborations are urgent to improve the development of sustainable solutions in arthropod management for smallholders. Traditional arthropod related knowledge and management (e.g. practices for conserving pollinators and/or natural enemies (Kansiime et al., 2021; Blandi et al., 2016)) can get forceful when combined with agroecological innovations and oriented towards applications-driven science and socioeconomic relevance (Altieri, 2004; Tarakini et al., 2020; Liebig et al., 2016; Dangles et al., 2010). It is more than ever timely to integrate on the same level both ecological and human dimensions of arthropod-related ES and EDS in smallholder farming.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work is part of the project “Agro-ecological management of crop insects: towards a sustainable collective goal for farmers” (AMIGO) conducted within the Crop Collaborative Research Program funded by the McKnight Foundation. TC is supported by a mixed scholarship grant from the McKnight Foundation and the French National Research Institute for Sustainable Development -IRD through the “*Allocations de recherche pour une thèse au Sud*”. We thank M. Gibernau for advices in data analyses.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crsust.2022.100133.

References

Altieri, M.A., 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. Front. Ecol. Environ. 2, 35–42. https://doi.org/10.1890/1540-9295(2004)002[0035:LEATFI]2.0.CO;2.
Altieri, M.A., Funes-Monzote, F.R., Petersen, P., 2012. Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. Agron. Sustain. Dev. 32, 1–13. https://doi.org/10.1007/s13593-011-0065-6.
Amano, T., González-Varo, J.P., Sutherland, W.J., 2016. Languages are still a major barrier to global science. PLoS Biol. 14, e2000933 https://doi.org/10.1371/journal.pbio.2000933.
Ameixa, O.M.C.C., Soares, A.O., Soares, A.M.V.M., Lillebø, A.I., 2018. Ecosystem services provided by the little things that run the world. In: Şen, B., Grillo, O. (Eds.), Selected Studies in Biodiversity. InTech.
Bartomeus, I., Dicks, L.V., 2019. The need for coordinated transdisciplinary research infrastructures for pollinator conservation and crop pollination resilience. Environ. Res. Lett. 14, 045017 https://doi.org/10.1088/1748-9326/ab0cb5.
Beltrán-Tolosa, L.M., Cruz-Garcia, G.S., Solis, R., Quintero, M., 2020. Mestizo Farmers' knowledge of Entomofauna is reflected in their management practices: a case study in the Andean-Amazon foothills of Peru. Front Sustain Food Syst 4, 539611. https://doi.org/10.3389/fsufs.2020.539611.
Bentley, J.W., 1989. What farmers don't know can't help them: the strengths and weaknesses of indigenous technical knowledge in Honduras. Agric. Hum. Values 6, 25–31. https://doi.org/10.1007/BF02217666.
Biddinger, D.J., Rajotte, E.G., 2015. Integrated pest and pollinator management — adding a new dimension to an accepted paradigm. Current Opinion in Insect Science 10, 204–209. https://doi.org/10.1016/j.cois.2015.05.012.
Bigirimana, J., Adams, C.G., Gatarayiha, C.M., et al., 2019. Occurrence of potato taste defect in coffee and its relations with management practices in Rwanda. Agric. Ecosyst. Environ. 269, 82–87. https://doi.org/10.1016/j.agee.2018.09.022.
Blanco, J., Dendoncker, N., Barnaud, C., Sirami, C., 2019. Ecosystem disservices matter: towards their systematic integration within ecosystem service research and policy. Ecosystem Services 36, 100913. https://doi.org/10.1016/j.ecoser.2019.100913.
Blanco, J., Bellón, B., Barthelemy, L., et al., 2021. A novel ecosystem (dis)service cascade model to navigate sustainability problems and its application in a changing agricultural landscape in Brazil. Sustain. Sci. https://doi.org/10.1007/s11625-021-01049-z.
Blandi, M.L., Cavalcante, M.S., Gargoloff, N.A., Sarandón, S.J., 2016. Prácticas, conocimientos y percepciones que dificultan la conservación de la agrobiodiversidad. El caso del Cinturón Hortícola Platense, Argentina. Cuad Des Rural 13 (97). https://doi.org/10.11144/Javeriana.cdr13-78.pcpd.
Brandt, P., Ernst, A., Gralla, F., et al., 2013. A review of transdisciplinary research in sustainability science. Ecol. Econ. 92, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008.
Brondízio, E.S., Aumeeruddy-Thomas, Y., Bates, P., et al., 2021. Locally based, regionally manifested, and globally relevant: indigenous and local knowledge, values, and practices for nature. Annu. Rev. Environ. Resour. 46, 481–509. https://doi.org/10.1146/annurev-environ-012220-012127.
Brush, S.B., 2008. Crop and Society in Centers of diversity. In: Farmers' Bounty. Yale University Press, pp. 70–97.
Caniço, A., Mexia, A., Santos, L., 2020a. Seasonal dynamics of the alien invasive insect Pest Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) in Manica Province. Central Mozambique. Insects 11, 512. https://doi.org/10.3390/insects11080512.
Caniço, A., Mexia, A., Santos, L., 2020b. First report of native parasitoids of fall armyworm Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) in Mozambique. Insects 11, 615. https://doi.org/10.3390/insects11090615.
Christmann, S., Aw-Hassan, A., Rajabov, T., et al., 2017. Farming with alternative pollinators increases yields and incomes of cucumber and sour cherry. Agron. Sustain. Dev. 37 https://doi.org/10.1007/s13593-017-0433-y.
Christmann, S., Aw-Hassan, A., Güler, Y., et al., 2021. Two enabling factors for farmer-driven pollinator protection in low- and middle-income countries. Int. J. Agric. Sustain. 1–14 https://doi.org/10.1080/14735903.2021.1916254.
Contreras Cortés, L.E.U., Vázquez García, A., Aldasoro Maya, E.M., Mérida Rivas, J., 2020. Conocimiento de las abejas nativas sin aguijón y cambio generacional entre los mayas lacandones de Nahá, Chiapas. ECM 56, 205–225. https://doi.org/10.19130/iifl.ecm.2020.56.2.0008.
Costa-Neto, E., 2000. The significance of the category “insect” for folk biological classification systems. JEA 4, 70–75. https://doi.org/10.5038/2162-4593.4.1.4.
Crespo-Pérez, V., Rebaudo, F., Silvain, J.-F., Dangles, O., 2011. Modeling invasive species spread in complex landscapes: the case of potato moth in Ecuador. Landsc. Ecol. 26, 1447–1461. https://doi.org/10.1007/s10980-011-9649-4.
Crespo-Pérez, V., Kazakou, E., Roubik, D.W., Cárdenas, R.E., 2020. The importance of insects on land and in water: a tropical view. Current Opinion in Insect Science 40, 31–38. https://doi.org/10.1016/j.cois.2020.05.016.
Dangles, O., Casas, J., 2019. Ecosystem services provided by insects for achieving sustainable development goals. Ecosystem Services 35, 109–115. https://doi.org/10.1016/j.ecoser.2018.12.002.

Dangles, O., Carpio, F.C., Villares, M., et al., 2010. Community-based participatory research helps farmers and scientists to manage invasive pests in the Ecuadorian Andes. AMBIO 39, 325–335. https://doi.org/10.1007/s13280-010-0041-4.
Diatte, M., Brévault, T., Sall-Sy, D., Diarra, K., 2018. Parasitoid control of the tomato fruitworm, *Helicoverpa armigera* , in smallholder farmer fields in Senegal. International Journal of Pest Management 64, 140–147. https://doi.org/10.1080/09670874.2017.1346328.
Díaz, S., Pascual, U., Stenseke, M., et al., 2018. Assessing nature's contributions to people. Science 359, 270–272. https://doi.org/10.1126/science.aap8826.
Djuideu, T.C.L., Bisseleua, D.H.B., Kekeunou, S., et al., 2020. Plant community composition and functional characteristics define invasion and infestation of termites in cocoa agroforestry systems. Agrofor. Syst. 94, 185–201. https://doi.org/10.1007/s10457-019-00380-w.
Dormann, C., Gruber, B., Fruend, J., 2008. Introducing the bipartite package: Analysing ecological networks. R News vol 8 (2), 8–11.
Duffus, N.E., Christie, C.R., Morimoto, J., 2021. Insect cultural services: how insects have changed our lives and how can we do better for them. Insects 12, 377. https://doi.org/10.3390/insects12050377.
Egan, P.A., Dicks, L.V., Hokkanen, H.M.T., Stenberg, J.A., 2020. Delivering integrated Pest and pollinator management (IPPM). Trends Plant Sci. 25, 577–589. https://doi.org/10.1016/j.tplants.2020.01.006.
Elisante, F., Ndakidemi, P.A., Arnold, S.E.J., et al., 2019. Enhancing knowledge among smallholders on pollinators and supporting field margins for sustainable food security. J. Rural. Stud. 70, 75–86. https://doi.org/10.1016/j.jrurstud.2019.07.004.
FAO, 2003. World Agriculture: Towards 2015/2030: An FAO Perspective.Pdf.
FAO, 2010. Policies and Institutions to Support Smallholder Agriculture.
FAO, 2014. Innovation in Family Farming. Rome.
FAO, 2016. Climate Change, Agriculture and Food Security. FAO, Rome.
FAO, 2017. Defining small-scale food producers to monitor target 2.3. of the 2030 agenda for sustainable development. In: 51 FAO STATISTICAL DIVISION Working Paper Series ESS/17–12 51.
FAO, 2018. Transforming Food and Agriculture to Achieve the SDGs: 20 interconnected actions to guide decision-makers.
Gaba, S., Bretagnolle, F., Rigaud, T., Philippot, L., 2014. Managing biotic interactions for ecological intensification of agroecosystems. Front. Ecol. Evol. 2 https://doi.org/10.3389/fevo.2014.00029.
Gagic, V., Marcora, A., Howie, L., 2019. Additive and interactive effects of pollination and biological pest control on crop yield. J. Appl. Ecol. 56, 2528–2535. https://doi.org/10.1111/1365-2664.13482.
Grames, E.M., Stillman, A.N., Tingley, M.W., Elphick, C.S., 2019. An automated approach to identifying search terms for systematic reviews using keyword co-occurrence networks. Methods Ecol. Evol. 10, 1645–1654. https://doi.org/10.1111/2041-210X.13268.
Grames, E., Stillman, A., Tingley, M., Elphick, C., 2020. _litsearchr: automated search term selection and search strategy for systematic Reviews_. R package version 1.0.0.
Gurr, G.M., Wratten, S.D., Luna, J.M., 2003. Multi-function agricultural biodiversity: pest management and other benefits. Basic and Applied Ecology 4, 107–116. https://doi.org/10.1078/1439-1791-00122.
Gurr, G.M., Scarratt, S., Wratten, S.D., et al., 2004. Ecological Engineering, Habitat Manipulation and Pest Management. Ecological Engineering for Pest Management: Advances in Habitat Manipulation for arthropods, pp. 1–12.
Gurung, A.B., 2003. Insects – a mistake in God's creation? Tharu farmers' perception and knowledge of insects: a case study of Gobardiha Village development committee, dang-Deukhuri, Nepal. Agriculture and Human Values 20, 337–370. https://doi.org/10.1023/B:AHUM.0000005149.30242.7f.
Higgins, J.P., Thomas, J., Chandler, J., et al., 2019. Cochrane Handbook for Systematic Reviews of Interventions. John Wiley & Sons.
Hill, R., Adem, Ç., Alangui, W.V., et al., 2020. Working with indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. Curr. Opin. Environ. Sustain. 43, 8–20. https://doi.org/10.1016/j.cosust.2019.12.006.
International Fund for Agricultural Development (IFAD), 2013. Small Holders, Food Security and the Environment. IFAD, Rome, Italy.
IPBES, 2016. The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany.
Jahn, T., Bergmann, M., Keil, F., 2012. Transdisciplinarity: between mainstreaming and marginalization. Ecol. Econ. 79, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017.
Kansiime, M.K., Girling, R.D., Mugambi, I., et al., 2021. Rural livelihood diversity and its influence on the ecological intensification potential of smallholder farms in Kenya. Food Energy Secur 10. https://doi.org/10.1002/fes3.254.
Kanter, D.R., Schwoob, M.-H., Baethgen, W.E., et al., 2016. Translating the sustainable development goals into action: a participatory backcasting approach for developing national agricultural transformation pathways. Global Food Security 10, 71–79. https://doi.org/10.1016/j.gfs.2016.08.002.
Klein, A.-M., Vaissière, B.E., Cane, J.H., et al., 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B 274, 303–313. https://doi.org/10.1098/rspb.2006.3721.
Krause, R.J., Vaccaro, I., Aswani, S., 2010. Challenges in building insect Ethnobiological classifications in Roviana, Solomon Islands. J. Ethnobiol. 30, 308–320. https://doi.org/10.2993/0278-0771-30.2.308.
Landis, D.A., Saidov, N., Jaliov, A., et al., 2016. Demonstration of an integrated Pest management program for wheat in Tajikistan. J Integr Pest Manag 7, 11. https://doi.org/10.1093/jipm/pmw010.
Liebig, T., Jassogne, L., Rahn, E., et al., 2016. Towards a collaborative research: a case study on linking science to Farmers' perceptions and knowledge on Arabica coffee pests and diseases and its management. PLoS One 11, e0159392. https://doi.org/10.1371/journal.pone.0159392.
Lowder, S.K., Skoet, J., Raney, T., 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041.
Lundin, O., Smith, H.G., Rundlöf, M., Bommarco, R., 2013. When ecosystem services interact: crop pollination benefits depend on the level of pest control. Proc. R. Soc. B 280, 20122243. https://doi.org/10.1098/rspb.2012.2243.
Lundin, O., Rundlöf, M., Jonsson, M., et al., 2021. Integrated pest and pollinator management – expanding the concept. Front. Ecol. Environ. 19, 283–291. https://doi.org/10.1002/fee.2325.
Marques, M.F., Hautequestt, A.P., Oliveira, U.B., et al., 2017. Local knowledge on native bees and their role as pollinators in agricultural communities. J. Insect Conserv. 21, 345–356. https://doi.org/10.1007/s10841-017-9981-3.
Medeiros, H.R., Grandinete, Y.C., Manning, P., et al., 2019. Forest cover enhances natural enemy diversity and biological control services in Brazilian sun coffee plantations. Agron. Sustain. Dev. 39, 50. https://doi.org/10.1007/s13593-019-0600-4.
Mendoza, J.R., Sabillón, L., Martinez, W., et al., 2017. Traditional maize post-harvest management practices amongst smallholder farmers in Guatemala. J. Stored Prod. Res. 71, 14–21. https://doi.org/10.1016/j.jspr.2016.12.007.
Mengist, W., Soromessa, T., Legese, G., 2020. Method for conducting systematic literature review and meta-analysis for environmental science research. MethodsX 7, 100777. https://doi.org/10.1016/j.mex.2019.100777.
Meza, L., 2014. La agricultura familiar y el cambio climático. In: La agricultura familiar en América Latina y el caribe: Recomendaciones de política, pp. 79–100.
Midega, C.A.O., Murage, A.W., Pittchar, J.O., Khan, Z.R., 2016. Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. Crop Prot. 90, 142–149. https://doi.org/10.1016/j.cropro.2016.08.033.
Millennium Ecosystem Assessment (Program), 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
Mkenda, P.A., Ndakidemi, P.A., Stevenson, P.C., et al., 2020. Knowledge gaps among smallholder farmers hinder adoption of conservation biological control. Biocontrol Sci. Tech. 30, 256–277. https://doi.org/10.1080/09583157.2019.1707169.
Motzke, I., Tscharntke, T., Wanger, T.C., Klein, A.-M., 2015. Pollination mitigates cucumber yield gaps more than pesticide and fertilizer use in tropical smallholder gardens. J. Appl. Ecol. 52, 261–269. https://doi.org/10.1111/1365-2664.12357.
Munyuli, T., Cihire, K., Rubabura, D., et al., 2017. Farmers' perceptions, believes, knowledge and management practices of potato pests in south-Kivu Province, eastern of Democratic Republic of Congo. Open Agriculture 2, 362–385. https://doi.org/10.1515/opag-2017-0040.
Noriega, J.A., Hortal, J., Azcárate, F.M., et al., 2018. Research trends in ecosystem services provided by insects. Basic and Applied Ecology 26, 8–23. https://doi.org/10.1016/j.baae.2017.09.006.
Novais, S.M.A., Macedo-Reis, L.E., DaRocha, W.D., Neves, F.S., 2016. Effects of habitat management on different feeding guilds of herbivorous insects in cacao agroforestry systems. Rev. Biol. Trop. 64, 16.
Nuñez, M.A., Amano, T., 2021. Monolingual searches can limit and bias results in global literature reviews. Nat Ecol Evol 5, 264. https://doi.org/10.1038/s41559-020-01369-w.
Palomo-Campesino, S., González, J., García-Llorente, M., 2018. Exploring the connections between Agroecological practices and ecosystem services: a systematic literature review. Sustainability 10, 4339. https://doi.org/10.3390/su10124339.
Parsa, S., Morse, S., Bonifacio, A., et al., 2014. Obstacles to integrated pest management adoption in developing countries. Proc. Natl. Acad. Sci. U. S. A. 111, 3889–3894. https://doi.org/10.1073/pnas.1312693111.
Popak, A.E., Markwith, S.H., 2019. Economic valuation of bee pollination Services for Passion Fruit (Malpighiales: Passifloraceae) cultivation on smallholding farms in São Paulo, Brazil, using the avoided cost method. J. Econ. Entomol. 112, 2049–2054. https://doi.org/10.1093/jee/toz169.
Pretty, J.N., 1995. Participatory learning for sustainable agriculture. World Dev. 23, 1247–1263. https://doi.org/10.1016/0305-750X(95)00046-F.
R Core Team, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Rader, R., Bartomeus, I., Garibaldi, L.A., et al., 2016. Non-bee insects are important contributors to global crop pollination. Proc. Natl. Acad. Sci. U. S. A. 113, 146–151. https://doi.org/10.1073/pnas.1517092112.
Rawluk, A., Saunders, M.E., 2019. Facing the gap: exploring research on local knowledge of insect-provided services in agroecosystems. Int. J. Agric. Sustain. 17, 108–117. https://doi.org/10.1080/14735903.2019.1567244.
Rodríguez, B.G., Rodríguez, G., Machado, M., 2020. Caracterización de la meliponicultura en dos ecosistemas de la provincia de Cienfuegos. Revista Científica Agroecosistemas 82, 4.
Rusch, A., Delbac, L., Thiery, D., 2017. Grape moth density in Bordeaux vineyards depends on local habitat management despite effects of landscape heterogeneity on their biological control. J. Appl. Ecol. 54, 1794–1803.
Salcedo, S., De La, O., Guzmán, L., 2014. El concepto de agricultura familiar en América Latina y el Caribe. Agricultura familiar en América Latina y el Caribe: recomendaciones de política 17–34.
Samberg, L.H., Gerber, J.S., Ramankutty, N., et al., 2016. Subnational distribution of average farm size and smallholder contributions to global food production. Environ. Res. Lett. 11, 124010 https://doi.org/10.1088/1748-9326/11/12/124010.

Sankara, F., Sanou, A.G., Antoine, W., et al., 2017. Pratique paysanne post récolte du maïs dans la région des Hauts-Bassins du Burkina Faso. Journal of Animal & Plant Sciences 15.

Sawe, T., Nielsen, A., Eldegard, K., 2020. Crop pollination in small-scale agriculture in Tanzania: household dependence. Awareness and Conservation. Sustainability 12, 2228. https://doi.org/10.3390/su12062228.

Scialabba, N.E.-H., Pacini, C., Moller, S., 2014. Smallholder Ecologies. FAO, p. 55.

Shackleton, C.M., Ruwanza, S., Sinasson Sanni, G.K., et al., 2016. Unpacking Pandora's box: understanding and Categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19, 587–600. https://doi.org/10.1007/s10021-015-9952-z.

Shapiro, J., Báldi, A., 2014. Accurate accounting: how to balance ecosystem services and disservices. Ecosystem Services 7, 201–202. https://doi.org/10.1016/j.ecoser.2014.01.002.

Sisay, B., Simiyu, J., Malusi, P., et al., 2018. First report of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), natural enemies from Africa. J. Appl. Entomol. 142, 800–804. https://doi.org/10.1111/jen.12534.

Smith, B.M., Chakrabarti, P., Chatterjee, A., et al., 2017. Collating and validating indigenous and local knowledge to apply multiple knowledge systems to an environmental challenge: a case-study of pollinators in India. Biol. Conserv. 211, 20–28. https://doi.org/10.1016/j.biocon.2017.04.032.

Stern, M.J., 2018. Social Science Theory for Environmental Sustainability: A Practical Guide. Oxford University Press.

Steward, P.R., Shackelford, G., Carvalheiro, L.G., et al., 2014. Pollination and biological control research: are we neglecting two billion smallholders. Agric & Food Secur 3, 5. https://doi.org/10.1186/2048-7010-3-5.

Struelens, Q., Silvie, P., 2020. Orienting insecticide research in the tropics to meet the sustainable development goals. Current Opinion in Insect Science 40, 24–30. https://doi.org/10.1016/j.cois.2020.05.015.

Tarakini, G., Chemura, A., Musundire, R., 2020. Farmers' knowledge and attitudes toward pollination and bees in a maize-producing region of Zimbabwe: implications for pollinator conservation. Tropical Conservation Science 13. https://doi.org/10.1177/1940082920918534, 194008292091853.

Vidogbéna, F., Adégbidi, A., Tossou, R., et al., 2016. Exploring factors that shape small-scale farmers' opinions on the adoption of eco-friendly nets for vegetable production. Environ. Dev. Sustain. 18, 1749–1770. https://doi.org/10.1007/s10668-015-9717-z.

Westgate, M., 2019. _revtools: tools to support evidence Synthesis_. R package version 0 (4), 1.

Westgate, M., Grames, E., 2020. Synthesisr: import, assemble, and deduplicate bibliographic datasets. R Package Version 0.3.0.

Wohlin, C., 2014. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14. ACM Press, London, England, United Kingdom, pp. 1–10.

Wyckhuys, K.A.G., Heong, K.L., Sanchez-Bayo, F., et al., 2019. Ecological illiteracy can deepen farmers' pesticide dependency. Environ. Res. Lett. 14 https://doi.org/10.1088/1748-9326/ab34c9.

Zehnder, G., Gurr, G.M., Kühne, S., et al., 2007. Arthropod Pest Management in Organic Crops. Annu. Rev. Entomol. 52, 57–80. https://doi.org/10.1146/annurev.ento.52.110405.091337.

Zhang, W., Ricketts, T.H., Kremen, C., et al., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ. 64, 253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024.

Zou, Y., Xiao, H., Bianchi, F.J.J.A., et al., 2017. Wild pollinators enhance oilseed rape yield in small-holder farming systems in China. BMC Ecol. 17, 6. https://doi.org/10.1186/s12898-017-0116-1.