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REVIEW ARTICLE

Semi-natural habitats support biological control, pollination and soil conservation in Europe. A review

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Abstract Semi-natural habitats are integral to most agricultural areas and have the potential to support ecosystem services, especially biological control and pollination by supplying resources for the invertebrates providing these services and for soil conservation by preventing erosion and run-off. Some habitats are supported through agri-environment scheme funding in the European Union, but their value for ecosystem service delivery has been questioned. An improved understanding of previous research approaches and outcomes will contribute to the development of more sustainable farming systems, improve experimental designs and highlight knowledge gaps especially for funders and researchers. Here we compiled a systematic map to allow for the first time a review of the quantity of evidence collected in Europe that semi-natural habitats support biological control, pollination and soil conservation. A literature search selected 2252 publications, and, following review, 270 met the inclusion criteria and were entered into the database. Most publications were of pest control (143 publications) with less on pollination (78 publications) or soil-related aspects (31). For pest control and pollination, most publications reported a positive effect of semi-natural habitats. There were weaknesses in the evidence base though because of bias in study location and the crops, whilst metrics (e.g. yield) valued by end users were seldom measured. Hedgerows, woodland and grassland were the most heavily investigated semi-natural habitats, and the wider landscape composition was often considered. Study designs varied considerably yet only 24% included controls or involved manipulation of semi-natural habitats. Service providers were commonly measured and used as a surrogate for ecosystem service delivery. Key messages for policymakers and funders are that they should encourage research that includes more metrics required by end users, be prepared to fund longer-term studies (61% were of only 1-year duration) and investigate the role of soils within semi-natural habitats in delivering ecosystem services.

Keywords Agroecology · Ecosystem services · Agricultural policy · Pollinators · Sustainable agriculture · Integrated pest management · Experimental design · Agricultural research

Contents

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1 Introduction

Throughout the European Union, member states are implementing agri-environment schemes through the Common Agricultural Policy that protect or create semi-natural habitats, here defined as "any habitat within or outside of the crop containing a community of non-crop plant species". Agri-environment schemes typically have multiple objectives that include nature conservation and resource protection (e.g. water quality), yet despite their considerable cost, their benefits have been questioned. This has been highlighted most with respect to conservation, because the target species have not always shown the expected response (Kleijn et al. 2006). However, semi-natural habitats have the potential to support ecosystem services and, since the Millennium Ecosystem Assessment (MA2005), there has been increasing interest in investigating and quantifying these services in agricultural systems (e.g. Vihervaara et al. 2010; van Zanten et al. 2014). In addition, EU member states are obliged to adopt Integrated Pest Management principles as of 2014 under the Sustainable Use Directive (2009/128/EC) and semi-natural habitats can contribute towards this through enhancement of biological control. The other important ecosystem services provided or supported by semi-natural habitats are pollination and soil conservation (Wratten et al. 2012). Semi-natural habitats provide habitats and resources for the agents delivering biological control and pollination. These resources include shelter for aestivation or overwintering, breeding sites, food resources and an appropriate environment protected from agricultural operations (Landis et al. 2000; Holland et al. 2016). Semi-natural habitats themselves can sequester carbon within both vegetation and soil (Walter et al. 2003), whilst the vegetation's physical structure can also hinder soil loss through erosion (Lowrance et al. 2002).

The role that semi-natural habitats play in providing ecosystem services has been widely investigated using a range of empirical approaches across the European Union. The types of investigation vary from evaluations of individual habitats (Holland et al. 2016) to landscape scale studies (e.g. Thies and Tscharntke 1999). How such studies were conducted varied considerably. For pollination, a relatively straightforward ecosystem service to measure, 62 unique metrics were used in 121 publications (Liss et al. 2013). Such variation makes comparisons difficult between publications and can lead to discrepancies in the interpretation of findings and recommendations (Liss et al. 2013). A similar review of the approaches used to investigate other ecosystem services is not readily available. Yet, ensuring consistent methodologies are used could ensure that there is no bias in emphasis for policy and may make it possible to assess trade-offs between ecosystem services (Fig. 1).

Knowing which approaches have been used previously and their sensitivity to measuring ecosystem services has a number of advantages: (1) it can help ensure standardised ones are used in future research, (2) reviewing the success of previous publications across Europe can help identify which semi-natural habitats and cropping systems have already been investigated allowing users to identify research from countries with similar ecological infrastructure and cropping, (3) it can help to highlight knowledge gaps and identify topics for in-depth meta-analysis and (4) such reviews can help determine the most appropriate metrics, scale and experimental design on which to base further investigations and can help researchers and funding bodies to better target their research strategy.

If semi-natural habitats are to be managed optimally to improve ecosystem services provision on farmland across Europe thereby helping justify the public money invested in it through the Common Agricultural Policy, then it is important to understand the current state of knowledge. The main objective in this study was to summarise the quantity of evidence that has been collected in Europe on semi-natural habitats with respect to the key ecosystem services that semi-natural habitats support, namely biological control, pollination and soil conservation. The secondary objectives were to synthesise this knowledge for use by other researchers, funders and end-users, and to provide a map on this topic that is searchable. Specifically, we asked the following:

1. To what extent have these ecosystem services (biocontrol, pollination, soil conservation) in relation to semi-natural habitats been investigated across Europe's agricultural production areas?

Fig. 1 Grass strip between fields with pan traps for collecting pollinators and example of a flower-rich margin

2. Which semi-natural habitat types have been investigated and for which ecosystem services?
3. What methodologies were used and how did this influence the outcomes?
4. What were the outcomes for ecosystem services delivery?

The outcomes can (1) provide researchers and funding bodies with summary information that will support them in targeting research, (2) enable policymakers to consider the strength of evidence currently available to underpin decision-making, (3) help them identify priorities for research scoping (4) identify consistent benefits that can be utilised in the development of more sustainable farming systems.

2 Method

A systematic map approach was chosen as the appropriate method for this review as it allowed the identification and categorisation of available evidence to form a searchable database (Grant and Booth 2009). Systematic maps are methodical overviews of the quantity and quality of evidence in relation to a broad (open) question of policy or management relevance. They help to understand the breadth and depth of the evidence available. The process and rigour of the mapping exercise is the same as for systematic review except that they make no attempt to answer a specific question but instead collate all the evidence available on a topic of interest (James et al. 2016). However, the systematic map still allows areas to be identified where there is sufficient evidence for meta-analysis. In addition, it allows the identification of gaps for future research. Systematic maps include all the publications that meet a set of a priori inclusion rules set by the authors thereby effectively summarising the relevant literature. Guidance on the compilation of systematic maps has been published (James et al. 2016) and is available online (http://www.environmentalevidence.org/Instructionsforauthors_maps.html [27/04/2016].

The types of semi-natural habitat that occur and are supported by agri-environment schemes across Europe vary considerably (Keenleyside et al. 2011), although there are some broad categories. Of the 63 types of entry-level options classified from the EU-27 Rural Development Plans, 15 broader categories were identified some of which are semi-natural habitats (grassland, cover in permanent crops, buffer strips, management for wildlife and land taken out of production), but the list does not encompass all semi-natural habitats commonly occurring on farmland (e.g. woodland, hedgerows) and there are some semi-natural habitats designed specifically for ecosystem services such as pollination (flower-rich areas) and biological control (beetle banks). In addition, semi-natural habitats may also occur within fields such as the cover under perennial crops or established to prevent soil erosion. The final list selected for investigation therefore included some additional semi-natural habitat types (see search terms below).

A literature search was conducted that was comprehensive and precise enough to find as much of the relevant literature as is realistically possible whilst avoiding the capture of too much irrelevant literature. Only peer-reviewed, published papers describing empirical, original research was included (reviews, meta-analyses and landscape modelling were excluded), and searches were carried out using the online database: Web of Knowledge (v.5.10) for the period 1950–2015 (November). A scoping process that included review by the partners of the QuESSA project was used to refine and select the final search terms (Holland et al. 2014). Searches were only conducted in the English language, and a wildcard (*) was used to select multiple word endings or plurals. The final search term was ((woodland OR "field margin" OR "grass margin" OR hedge* OR "unimproved grass*" OR "field boundary" OR "cover crop" OR fallow OR "semi-natural grass*" OR landscape*) AND ("ecosystem service*" OR pollinat* OR "pest control" OR biocontrol OR "biological control" OR "seed predation" OR "soil erosion" OR "soil organic matter") AND (agricultur* OR farm*)). The search was restricted to research conducted in Europe by adding 31 European countries to the address option (see Appendix). All results from the search results were reviewed at title and abstract level to ensure they met a set of inclusion criteria as follows:

1. European: the study must have been entirely carried out in a European country.
2. Agricultural interest: it must not only have a conservation concern, but must also be relevant to farming systems.
3. Semi-natural habitat OR Landscape complexity: the effects of semi-natural habitats OR landscape complexity must be investigated in the study.
4. Invertebrates OR Other service provider: the organisms providing an ecosystem service must be invertebrates OR an ecosystem service must be influenced by semi-natural habitats or landscape complexities (e.g. use of semi-natural habitats to prevent soil erosion).
5. Empirical study: the article must report the results of a primary empirical study. Correlative and manipulative studies are included, but literature reviews and statistical models are not.
6. Natural populations: papers investigating the effect of introduced pest enemies were not included, but enhancement of existing populations was acceptable.

Following initial scoping exercises to test search terms and responses, two reviewers divided the workload to determine whether the papers met inclusion criteria. A search was conducted in October 2014. Quality was controlled through reciprocal sub-sampling between assessors. If one or more of these criteria were not met, the paper was not included in the final systematic map. Articles that passed the inclusion criteria were then read in full, and entered into the database by extraction of the relevant data (Table 1). The search was then repeated in November 2015 adding in the term for landscape, and the whole process was repeated, adding any additional literature, which provided a further check on the original search.

3 Results

The search terms returned 2252 publications, and these were reviewed for suitability for inclusion; of these, 270 met the inclusion criteria and were entered into the systematic map database. The number of publications investigating the selected ecosystem services covered by the systematic map rose steadily over the last 10 years reaching approximately 30 per year by 2014 (Fig. 2).

3.1 The extent to which the ecosystem services (biocontrol, pollination, soil conservation) in relation to semi-natural habitats have been investigated across Europe

The majority of publications looked at regulating ecosystem services (250), whilst 28 investigated supporting services, 12 measured provisioning and three measured cultural services. The most commonly investigated regulating ecosystem services were pest control (55%) and pollination (30%), with the other ecosystems services having 20 (7%) or less publications (Fig. 3). Thirty-one publications investigated soil-related ecosystem services such as soil resilience and carbon sequestration. Of supporting services, 26 investigated nutrient cycling or levels of soil organic matter and one publication each on seed dispersal and soil formation. Twenty-three publications investigated two or more ecosystem services, these most often being pest control and pollination.

3.1.1 Geographic variation of publications

Publications originated from 23 countries, but there was geographic bias because most were conducted in 9 countries that had >10 publications. The highest number of publications originated from Germany (64), followed by France, Spain, Sweden and the UK (21–26) (Fig. 4). Only nine publications reported on studies conducted in more than one country. Pest control was the most widely researched ecosystem services, investigated in all but three countries. Pollination was most heavily investigated in Germany, Sweden and UK with each 10 or more publications. Few publications on other ecosystem services were included in the database.

3.2 The types of semi-natural habitats that have been investigated and impact for a range of crops

A total of 245 publications specifically investigated a type of semi-natural habitat of which half (137 publications) investigated more than one habitat type. Thirty-one percent of these publications included hedgerows/field margins, 23% woodland or shrubland and 28% grassland (Fig. 5). Investigations of fallows were reported in 8% of publications whilst the other habitats were addressed by only 12 (2%) or fewer publications. In these publications, the locations where service providers or ecosystem services were most commonly measured were hedgerows or field margins (44%), woodland/shrubland (19%) and grassland (25%) (Fig. 6). Only areas within fields, orchards, olive groves or vineyards were sampled in 106 publications.

Of the 230 publications that looked at ecosystem services within crops, the most studied were wheat (25%) and oilseed rape (15%), followed by barley (9%) and other cereals such as triticale, rye, spelt and oats (9%) (Fig. 7). Perennial, vegetable and root crops were relatively poorly investigated.

Table 1 Fields used to code publications in the database

ID	Identification code (in bold) assigned by WoK during search or descriptive text was used
First author	Surname, initial of first author
Title	Full article title
Year	Four-digit year of publication
Reference	Full reference of article (Harvard)
Ref. type	**Journal**
	What type of source did the entry come from
Text read	**Full text**
	How much of the text was read by review author when entering
Linked studies	ID codes of all other entries in review that are linked by the same first author and/or the same study
Coded	**YES** Has the article been coded into review
Intervention	What is the independent variable
English	**Y/N** Is the language of the article English
Countries	Which country/countries was the study conducted in
Length of study in years	How long, in full years, did the study take place for
Study type	**Manipulative/correlative**
	Was the study manipulative or correlative
Control	**Y/N** Was there a control
Randomised	**Y/N** Was randomisation incorporated into the study design
Spatial replicate	**Y/N** Was there a spatial replicate
Temporal replicate	**Y/N** Was there a temporal replicate
Study Scale	**Farm/multi-farm**
	Was the study restricted to one farm or did it incorporate multiple farms
Time of year of measurements	Which season(s) was the study conducted in
Farm system	**Arable/orchard/livestock**
	What type of farming system was being used
Sampling Location	In what specific location(s) within the farm was the study conducted
Reason heterogeneity results	Reasons that led to any heterogeneity in results
Semi-natural habitat types	What types of semi-natural habitats were involved in the study
ES provided by invertebrates?	**Y/N**
	Is the ES being provided done so via invertebrates, or from other source (e.g. semi-natural habitats improving soil quality in adjacent fields)
Providers	*Only applicable when ES is provided by invertebrates*
	Pest natural enemies/pollinators/nutrient cycling
	What type of ES were the arthropods providing
Sampling method for predation	*Only applicable when ES is provided by invertebrates*
	What method was used to sample the providers
Provider Sampling Location	*Only applicable when ES is provided by invertebrates*
	Crop/semi-natural habitats
	Which location were the providers sampled from
Sampling for provider resources	*Only applicable when ES is provided by invertebrates*
	What sampling (if any) for provider resources was conducted
ES Type	**Regulating/provisioning/cultural/supporting**
	What type of ES is being provided
ES measured: Provisioning	*Only applicable when ES type = Provisioning*
	Food/water/energy/pharmaceuticals/minerals
	What type of provision is being examined

Table 1 (continued)

ID	Identification code (in bold) assigned by WoK during search or descriptive text was used
ES measured: Regulating	*Only applicable when ES type = Regulating*
	Pollination/pest control/carbon sequestration/soil resilience/water purification/waste decomposition
	What type of regulation is being examined
ES measured: Cultural	*Only applicable when ES type = Cultural*
	Cultural inspiration/recreational experience/scientific discovery
	What type of cultural ES is being examined
ES measured: Supporting	*Only applicable when ES type = Supporting*
	Nutrient cycling/seed dispersal/soil formation/primary production
	What type of supporting ES is being examined
ES methodology	What was measured in order to quantify ES provided
Effect on yield	**Positive/negative/no effect/not measured**
	What effect of the intervention on the yield
% change in yield	The % increase or decrease in yield that was found
Type of semi-natural habitats effecting yield	The type semi-natural habitats with the greatest impact on yield
Effect on Pest Control	**Positive/negative/no effect/not measured**
	What effect did the intervention have on the level of pest control
% change in pests	The % increase or decrease upon the level of pest control
Type of semi-natural habitats effecting pest control	The type of semi-natural habitats with the greatest effect on pest control
Effect on Pollination	**Positive/negative/no effect/not measured**
	What effect did the intervention have pollination
% change in pollination	The % increase or decrease upon the level of pollination
Type of semi-natural habitats effecting pollination	The type of semi-natural habitats with the greatest effect on pollination
Effect on seed predation	**Positive/negative/no effect/not measured**
	What effect did the intervention have on the level of seed predation
% change in seed predation	The % increase or decrease upon the level of seed predation
Type of semi-natural habitats effecting seed predation	The type of semi-natural habitats with the greatest effect on seed predation
Effect on soil Erosion	**Positive/negative/no effect/not measured**
	What effect did the intervention have on the level of pest control
% change in soil erosion	The % increase or decrease upon the level of soil erosion
Type of semi-natural habitats effecting soil erosion	The type of semi-natural habitats with the greatest effect on soil erosion
Effect on SOM	**Positive/negative/no effect/not measured**
	What effect did the intervention have on the level of SOM
Type of semi-natural habitats effecting SOM	The type of semi-natural habitats with the greatest effect on SOM
Extracting data	**Easy/moderate/difficult**
	What level of difficulty was experienced in extracting data from the publication
Organism investigated	Which organism(s) where the subject of the study
Notes	Any additional relevant notes about the entry

3.3 Other factors effecting ecosystem service delivery

A high proportion of publications (43%) investigated whether the composition of the surrounding landscape affected the selected ecosystem services. These publications were used for example the proportion of arable land, uncropped land or specific habitats to provide an indication of the landscape complexity. Some other factors that may also affect these ecosystem services were also investigated. These included 41 publications in which farming systems such as conventional and organic or those with different levels of inputs were examined. There were 30 publications in which the type of ground management, fertiliser inputs, grazing intensity or seed mix was investigated and 18 publications of cover crops. Only two publications examined grazing management.

3.4 Study setup, sampling methodology, sampled locations and farming systems

The experimental design used in each study was extracted. Excluding 12 publications in which long-term data (>8 years) was analysed, 64% were single-year studies, 18% of 2-year duration and 13% of 3–8-year duration. The most common design was one using a non-randomised, correlative approach without a control (34%), whilst a further 20% used the same design but with a randomised approach. To show effects on the selected ecosystem services, the correlative studies usually employed some quality or quantity of semi-natural habitats rather than formal randomised designs with experimental manipulations of semi-natural habitat type or area. Overall, only 24% of all publications included any type of control treatment. The majority of publications included spatial or temporal replication (Fig. 8). In manipulative studies that tested interventions through experimental manipulations to create treatments, more studies did not use controls (59 publications) than those that did (44); however, randomisation was more commonly employed when there was a control. The most robust experimental approach using manipulation, randomisation and controls was only used in 11% of publications. It was not possible to identify whether the type of experimental design determined the final recommendations because, where an effect was reported, most were positive regardless of the approach or ecosystem service (pest control 83%, pollination 79%).

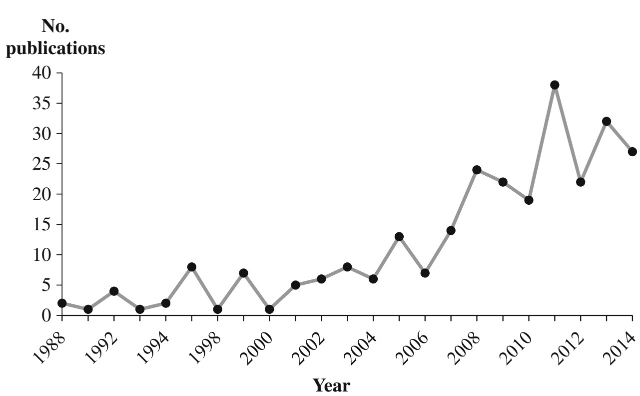


Fig. 2 The number of publications in the systematic map per annum ($n = 270$)

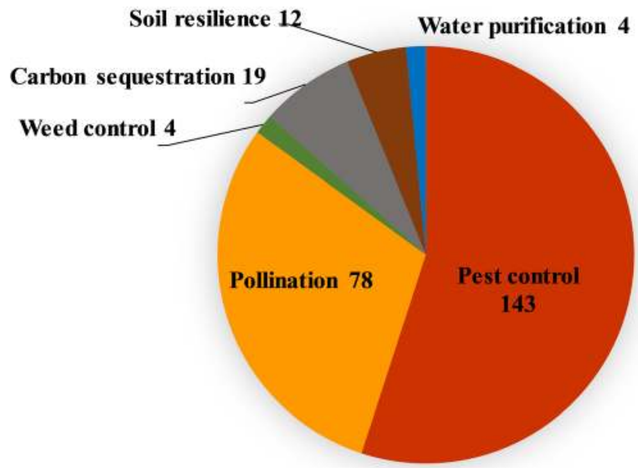


Fig. 3 The number of publications for each regulating ecosystem service ($n = 260$)

Overall, 73% of publications reported on studies conducted on more than one farm (site), whilst the remainder were of a single study site. Most publications originated from studies conducted on arable farms (81%), 12% were in orchards and 6% were on livestock farms; these were the most frequently investigated systems regardless of whether pest control or pollination was investigated (Fig. 9).

3.5 Studies of pest control

Of the 143 publications that investigated the ecosystem service "pest control", none included measurements of yield. Of these, 138 publications measured the pests, or levels of predators and parasitism. Of these, a remarkably low percentage, 22%, reported on actual pest levels, and only 9% of these also measured pest predators or parasitism rates (6%) or both of these (2%) (Fig. 10). The majority of the publications on pest control measured predators (70%) and fewer parasitism (25%).

3.6 Studies of pollination

There were 78 publications that investigated pollinators or pollination, and most were conducted in arable crops (Fig. 9). Of these, 87% measured the number of pollinators; however, only 24% measured any metric of pollination such as fruit or seed set. The predominant method for assessing pollinators was through transect counts (57%), pan traps (14%) (Fig. 11), flower visiting observations (14%) or netting (10%).

3.7 Approaches for investigating service providers

The most commonly used methods for assessing invertebrates were visual counts of some form either along transect or on the vegetation (34%) and pitfall traps (19%) which collected

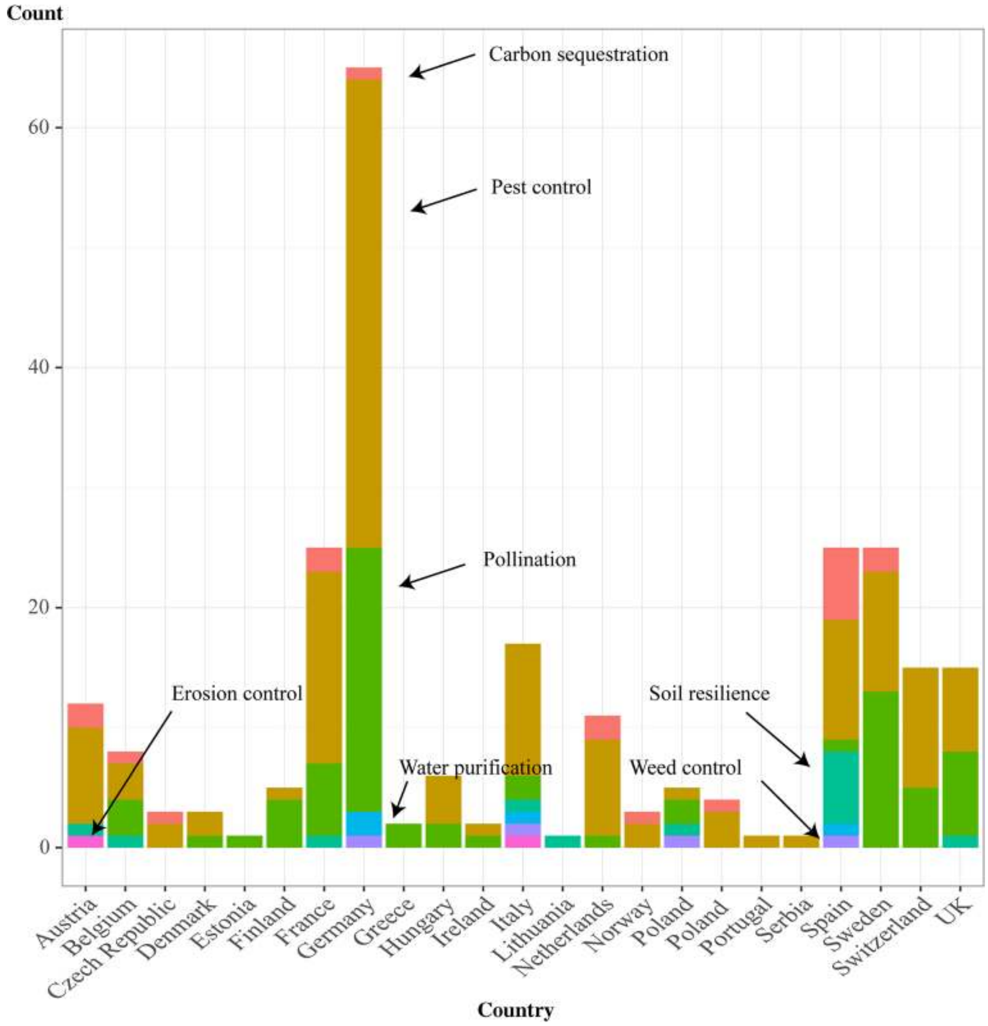


Fig. 4 The number of publications originating from European countries and the type of ecosystem service investigated

epigeal invertebrates (Fig. 11). The transect counts and pan traps were most often used for assessments of pollinators, whilst pitfall traps, suction sampling, sweep nets, window traps and sticky traps were used for collecting predators. Considering all sampling methods, it was more common for either the crop or the semi-natural habitats to be sampled than for both, with the exception of sweep netting (Fig. 11). The crop was also more frequently sampled than the semi-natural

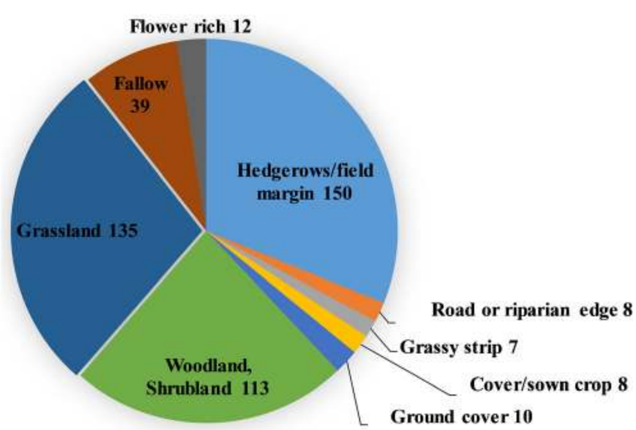


Fig. 5 The number of publications for each type of semi-natural habitat

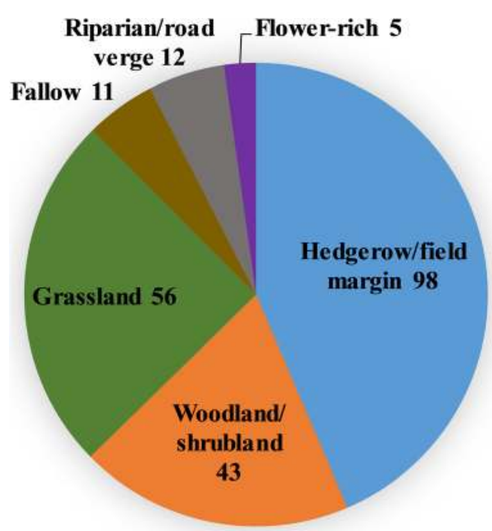


Fig. 6 The number of publications for the semi-natural habitats that were sampled ($n = 225$)

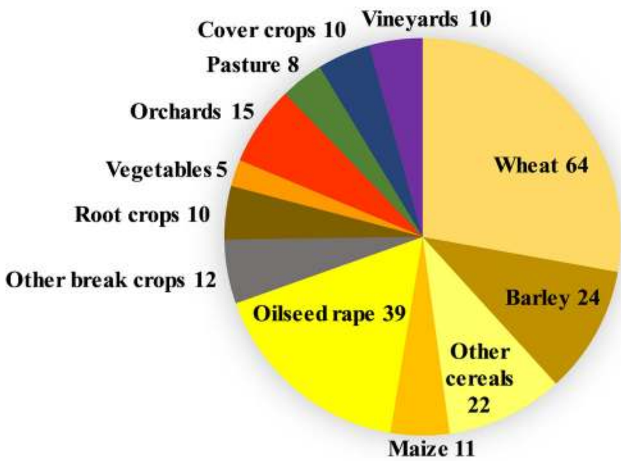


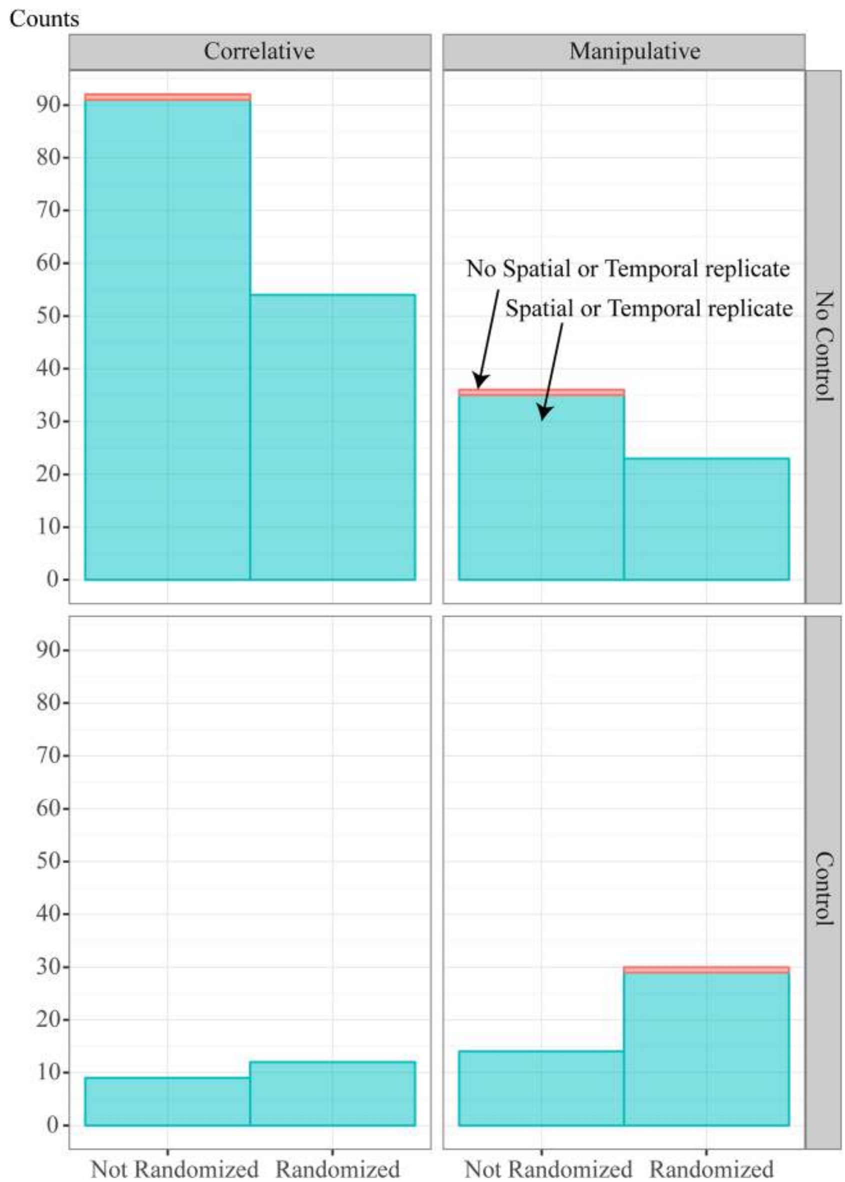
Fig. 7 The number of publications for each crop type

habitats for the majority of methods, except where the soil was sampled or when transect counts and water traps were used.

The most extensively studied ecosystem service providers were invertebrates (217) of which 66% were of pest natural enemies and 36% of pollinators, although only 1% of papers covered both groups and there were only two studies of organisms responsible for nutrient recycling. The botanical resources for pest natural enemies and pollinators were less well investigated. Vegetation surveys were conducted in 13% (35 publications) and 5% (13 publications) conducted assessments of flower abundance or other measures of floral resources.

Of the invertebrates, Hymenoptera were studied in the most publications (123) because this order includes both bees (pollinators) and parasitic wasps (pest regulators) (Fig. 12). Coleoptera (beetles) were investigated in 37 publications.

Fig. 8 Type of experimental design used to study semi-natural habitats: whether correlative (use of existing landscape elements) or manipulative (habitats created or manipulated), randomised or not, and with or without control treatments



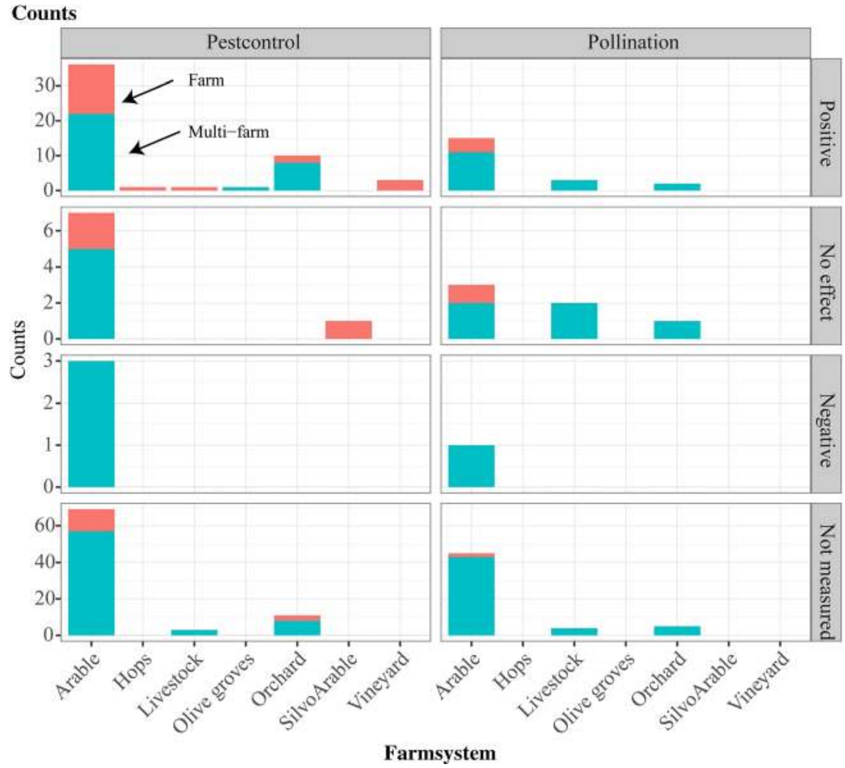


Fig. 9 The effect of semi-natural habitats on pest control and pollination separated by the scale of the study and the cropping system

Thirty-two studies were more general in their approach and only assessed functional groups such as predators and aphidophagous predators or total invertebrates.

3.8 Outcomes for ecosystem service delivery

Of the 24% publications that reported an effect of pest control, 81% of these concluded that there was a positive effect, although of these publications usually the abundance of predators or parasitism (67%) was used as a proxy for pest control and pest levels were only measured in 10%. A negative effect was found in only three publications, and all of these measured the abundance of predators or parasitism to obtain the recommendation (Fig. 9). Most positive effects were reported for arable crops but also for other systems. Only two publications reported on yield with one positive finding and the other both negative and positive effects of semi-natural habitats on weed levels.

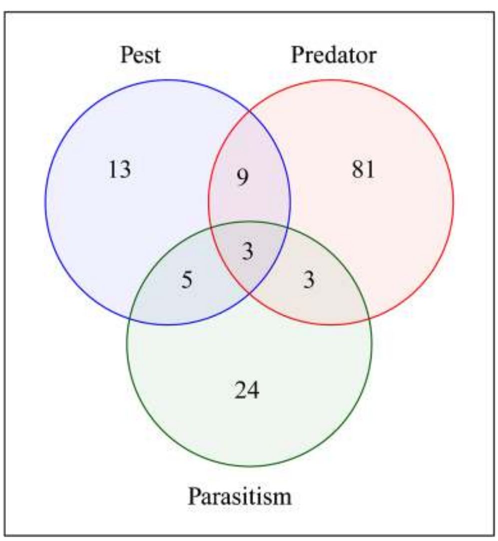


Fig. 10 Number of publications separated by the service providers that were measured

Whether a positive or negative recommendation was provided was unrelated to the scale of the study. Fifty-eight publications provided a recommendation as to the best semi-natural habitats for enhancing pest control which included some landscape-scale studies. Of these publications, 52% recommended field boundary habitats such as hedgerows, hedgebase or field margins; 17% recommended cover crops, leys or fallows to enhance pest control; woodland or forest was recommended in 12% and grassy habitats were recommended in 9%. Some publications recommended more than one habitat type.

Twenty-eight publications reported on whether there was any effect of the interventions on pollination or pollinators, and of these, 79% reported a positive effect of the landscape, one found a negative response and 5% no effect (Fig. 9). In all but one study, however, pollination itself was not measured but abundance of pollinators and floral resources instead. Those studies found an increase in pollinators or floral resources after interventions and assumed it to be positively

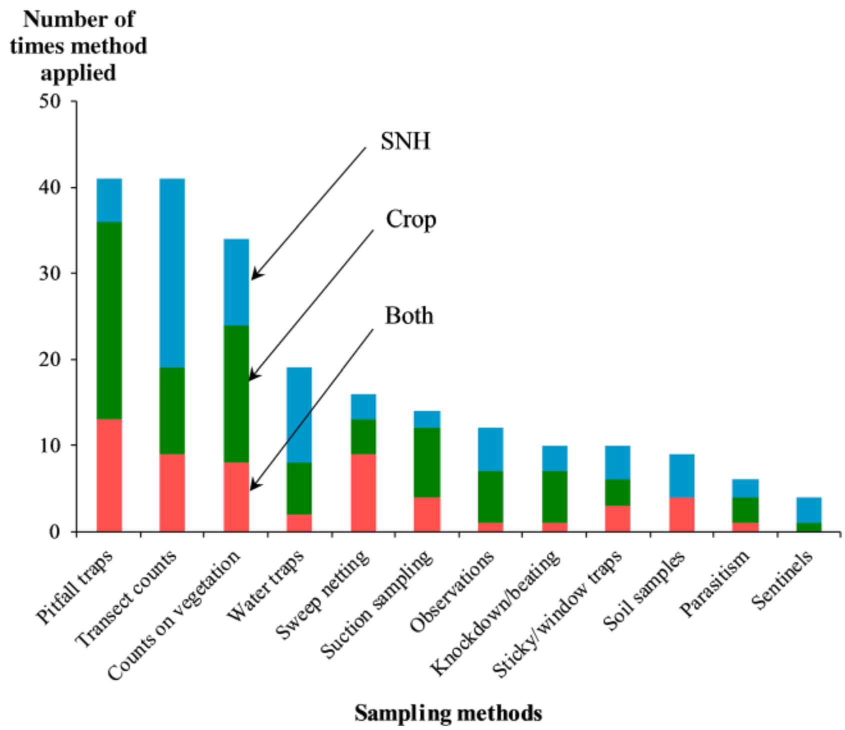


Fig. 11 Number of times in which different invertebrate sampling methods were used in the crop, semi-natural habitat (SNH) or both locations

related to pollination. Three times as many of the multi-farm-scale publications reported a positive effect compared to single-farm studies. Of those 28 publications reporting an effect of interventions, six recommended field boundary habitats such as hedgerows, hedge base or field margins and seven mentioned that floral abundance was important irrespective of the specific semi-natural habitats. An increase in the area of semi-natural habitats per se was advised in five publications. The negative effect reported occurred in wild cherry trees where increasing vegetation complexity around the trees decreased bee species richness and crop flower visitation rates.

Of the 10 publications investigating soil erosion, eight reported a positive effect of semi-natural habitats and one no effect. In 17 publications, a positive effect on soil organic matter was found whilst two reported no effect. In the 15 publications that provided a recommendation on ways to increase soil organic matter, seven recommended using grass leys, two using

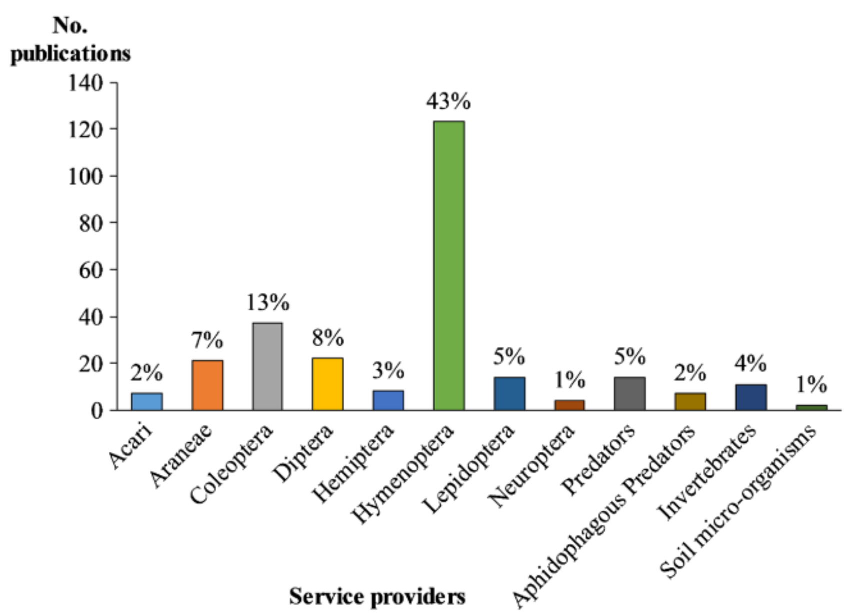


Fig. 12 The number and percentage of publications for each type of service provider

fallows and four using cover crops. Woodland and hedgerows were also found to have high soil organic matter.

4 Conclusions

The systematic map revealed that the majority of the publications found a positive effect of semi-natural habitats on pollination and pest control or their proxies, although there were some weaknesses to the evidence base. The study design and sampling methodology varied largely across studies, which were conducted in a limited number of countries and crops. Yield was not measured in any of the pest control studies nor were metrics such as reduced pesticide use that are valued by end users. Likewise for pollination, only 24% of publications measured a metric of pollination such as pollen deposition or measures that end users are interested in such as seed quality, fruit set or quality (Bommarco et al. 2012). To some extent, these omissions are because the studies were not designed to measure ecosystem services. Yet, they can provide a useful indication of what further information may be gained in future studies.

4.1 Extending the geographic extent of ecosystem services research across Europe

The systematic map revealed that biocontrol, pollination and soil conservation have been relatively poorly investigated in most European countries with only five having more than 20 publications suitable for inclusion. There may be many different reasons for this geographic bias, apart from the size of the countries' research community, funding opportunities or publication in national languages. The great majority of publications were from Germany followed by Spain, France, Sweden and Switzerland, whilst Eastern Europe and the far south of Europe were poorly represented. This may be a reflection on the types of landscapes that occur in Western Europe where there has been a history of smaller farms and fields, surrounded by distinct boundary types or woodland, as opposed to Eastern Europe where large state farms predominated during the twentieth century. Thus, the geographical bias in the evidence base prevents researchers from generalising effectively across pedo-climatic zones. If further studies were conducted to allow generalisation across pedo-climatic zones, this would give insight into the role of semi-natural habitats on pest control and pollination across Europe. For some services, it may be prudent to focus on those that are particularly relevant to the pedo-climatic zone, for example, some zones may be more susceptible to soil erosion.

4.2 Ways of improving ecosystem service delivery

The most heavily investigated semi-natural habitats were hedgerows or other field boundary habitats, woodland and grassland as these represent the main areas of non-crop land on farmland. For these semi-natural habitats, the abundance of service providers was typically measured. This provided some indication of the resource potential of the habitats, yet if the semi-natural habitat is studied in interaction with the crop and its surrounding landscape, a better understanding of ecosystem services provisioning may be gained. This is because there will be local and landscape influences on ecosystem services provision due to, for example, differences in the mobility of the various service providers (Tscharntke et al. 2005). For less mobile providers, it is the interchange between the semi-natural habitats and the adjacent crop that may determine the level of ecosystem services provision (Bianchi et al. 2006). For more mobile service providers such as bumblebees and hoverflies, it is important to consider the surrounding landscapes that may provide additional service providers to those of local semi-natural habitats.

Different experimental approaches are needed to evaluate local and landscape effects. At the local level, it is valuable to determine the zone of influence of semi-natural habitats yet such studies are difficult and costly to conduct, relying on extensive sampling networks and service providers that exhibit a degree of gradation from the habitat edge into the crop or across the landscape (for examples, see Holland et al. 1999; Holland et al. 2005). That explains why these studies are less frequently conducted, and instead, spatially explicit individual-based models are employed, although these still require realistic data on the service provider's mobility (Bianchi and van der Werf 2003). Tracking the movement of individuals is sometimes feasible either by marking physically (Holland et al. 2004; Winder et al. 2005), using chemical markers such a Rubidium (Tillman et al. 2007) or for larger insects using a tracking device (Tahir and Brooker 2011). All of these require considerably more resources. Directional trapping using window, sticky or pitfall traps can also be employed for some species (Winder et al. 2001; Muirhead-Thomson 1991) to show movement in or out of habitats. Sampling for ecosystem services providers was conducted in crops adjacent to semi-natural habitats and/or the semi-natural habitat. When appraising the value of semi-natural habitats adjacent to different crops, the crop management should also be taken into account because there is some evidence that this can also influence service providers within adjacent semi-natural habitats (Rand et al. 2006).

For landscape-scale studies, the influence of landscape composition has been widely investigated and the literature on this periodically reviewed for biocontrol (e.g. Bianchi et al. 2006; Tscharntke et al. 2007, 2012; Chaplin-Kramer et al. 2011) and pollination and pollinators (Viana et al. 2012). Meta-analyses were also conducted to examine the effects of landscape and local features on the comparative abundance of pollinators and natural enemies (Shackelford et al. 2013; Rusch et al. 2014) and on levels of pest control (Rusch et al. 2016). Evidence from these studies can be contradictory, but is not surprising given the complexity of the ecosystems and number of interacting factors that eventually determine the level of ecosystem service that is provided. In addition, these studies typically make use of existing landscapes with contrasting levels of landscape composition that may have unforeseen and unaccountable influences on the service provision. For example, the metric of the proportion of non-crop habitats (or cropped area) is commonly used and related to the level of ecosystem service provision. Yet, the composition of the non-crop areas may differ considerably and some types may be more influential than others. More compelling evidence could be gained from manipulations of existing farms or landscapes with ecosystem services evaluations pre and post habitat enhancement. Such designs were only used in 11% of publications. However, we were unable to identify if specific designs led to stronger recommendations because positive effects were predominantly reported. Meta-analyses, more detailed landscape mapping (García-Feced et al. 2015) and use of spatial models (Ekroos et al. 2014) may help in identifying if there are optimal designs for utilising the ecosystem services supported by semi-natural habitats.

4.3 Filling the gaps

4.3.1 Crops

This investigation revealed that arable crops, predominantly cereals and oilseed rape, were the most heavily investigated whilst those for which pests and pollination are more important (orchards and vegetable crops) were less frequently studied. This may be because horticultural crops occupy less land and are economically less important in the countries conducting most of the research. In addition, the development of integrated pest management is more problematic for high-value crops with stringent cosmetic quality targets. On the other hand, such a finding may indicate that research is not being driven by end user requirements.

4.3.2 Interactions between ecosystem services

More than one ecosystem service was rarely investigated in the same publication. It may be that other ecosystem services were investigated but published elsewhere; however, these findings suggest that there could be potential to investigate trade-offs between services and to include disservices. If semi-natural habitats are to be optimally utilised, it is essential that trade-offs are understood as they may be beneficial or disadvantageous (Rodriguez et al. 2006).

4.3.3 Yield

The majority of publications examined supporting ecosystem services, notably pest control and/or pollination, which is to be expected as most semi-natural habitats occur outside of the crop and these services rely on mobile agents that will benefit from semi-natural habitat enhancement. Yield was only examined in 13 publications despite its importance. This may be because yield is affected by many other inputs including levels of agrochemical inputs, crop variety, water availability, soil type and environmental conditions that may have a much larger impact than that of the service. Moreover, such factors may vary considerably between plots or fields that were chosen to provide a particular habitat and not to standardise management inputs for example, therefore making it difficult to ascertain any difference in yield attributable to a supporting service alone. Nevertheless, many of these other variables can be accounted for using an appropriate design. However, the majority of studies were of 1-year duration even though many factors that influence the level of service provision are likely to vary considerably between years, such as the weather, levels of invertebrate service providers, disease and pest pressure. More long-term experiments are therefore needed.

Impacts on pests or yield are the most compelling evidence for farmers and are needed if wider adoption of semi-natural habitats for pest control is to be advocated. Of the publications that investigated insect pest control, the emphasis was on measurement of service providers and only 22% measured pest levels. Yield was not measured for pest control studies, yet 57 publications made recommendations on the value of semi-natural habitats for pest control. Most predation publications focussed on insect pests and only five publications were included in the map that investigated seed predation in relation to semi-natural habitats, despite the agronomic importance of weeds. The proportion of sales accounted for by insecticides was less than 5% in most EU countries whereas sales of herbicides were usually over 50% and reached 80% in some countries (Eurostat 2016). These findings and the EU policies on Sustainable Use of Pesticides indicate that further research is needed, incorporating that measurements of impact on either yield or suitable surrogates are needed if farmers are to move towards IPM utilising conservation biocontrol.

4.3.4 Pollination

Pollination was investigated in 78 publications of which only six measured pollen transfer or pollinator foraging activity on flowers, with a further 14 measuring seed or fruit set. Most measured pollinators as a surrogate for pollination. There is consequently a knowledge gap for measurement of pollination and its effect on yield with respect to the value of semi-natural habitats. With respect to the study of pollination itself, there is also a need for the development and use of standardised methods as recommended by Liss et al. (2013).

The majority of publications of pest control and pollination focussed on measurements of the service providers whereas few also measured factors that determine their abundance, such as the type and quality of the vegetation in the semi-natural habitats. As a consequence, identification of plant species or traits that are particularly beneficial are seldom made (Lavorel et al. 2011), nor are recommendations on how to create or improve semi-natural habitats.

4.3.5 Seldom investigated ecosystem services

Few other ecosystem services have been investigated in relation to semi-natural habitats, but these included levels of soil organic matter or carbon storage that reflect carbon sequestration, soil erosion that impacts on water quality, nutrient levels as a measure of nutrient cycling and the aesthetic value of semi-natural habitats. There was evidence that semi-natural habitats stored carbon and helped prevent soil erosion. The role of soil organisms in pest control, carbon sequestration, nutrient cycling and erosion was seldom investigated. All of these areas require further investigation.

4.4 Recommendations for improving ecosystem services delivery

Agriculture has been long reliant on artificial agrochemical inputs, and farmers may be reluctant to adopt alternative pest control strategies whilst such inputs remain relatively cheap and reliable. As a consequence, there has not been much pressure to develop alternative techniques and it is only recently with changes in legislation and the advent of more widespread insecticide resistance that alternatives are being investigated. Yet, the most compelling evidence on the benefits of semi-natural habitats will come from measures on yield, pesticide use, level of pollination and/or seed quality.

Despite this, it was apparent from this review that many of the publications focussed on one aspect of ecosystem services, such as abundance of service providers rather than the ecosystem services delivery. This was in part because the studies had a different focus, such as nature conservation, rather than ecosystem services delivery. However, even where an ecosystem service was the focus, there was often a tendency to focus on the service providers and typically those that are easiest to sample and identify are most prolific or are typically used as indicators rather than focussing on end user requirements. By measuring the ecosystem service itself (yield, pest control, pesticide use, or level of pollination, seed quality), more persuasive evidence may be gained. In addition, there is a need to harmonise data collection with standard methodologies so that studies can be compared and integrated. This will include selecting metrics that are biologically meaningful and developing indices that can advise us when, for example, sufficient service providers are present. The development of rapid assessment methods would also help reduce the sampling effort per unit resource.

If more resources become available or if sampling becomes more efficient, we recommend to focus on the following:

1. Measuring the ecosystem services, including year-to-year variability, rather than only service providers to generate recommendations for end users
2. Investigations that include more than one ecosystem services including disservices so that trade-offs can be identified
3. Extending the geographical scope of studies to Eastern Europe because at present the majority are from Western Europe
4. The impact of semi-natural habitats in preventing the movement of soil and water. This was identified as a knowledge gap. In addition, the potential of semi-natural habitats to sequester carbon was rarely measured, although there was evidence that soil organic matter and thereby carbon storage is higher than in the surrounding fields (Walter et al. 2003).
5. Study the effectiveness of semi-natural habitats in relation to the (trait) composition of crops and non-crop habitats in the landscape (e.g. Lavorel et al. 2011)
6. Developing proxies that are easier to measure yet still give insight if semi-natural habitats are advantageous (see discussion earlier) and need to be stimulated through policy

4.5 Recommendations/notes for policymakers

Knowledge exchange for policymaking should be a two-way process; policymakers need reliable advice that is evidence based, and the policymakers should work with researchers and practitioners to develop research priorities.

This work suggests that policymakers could call for the following:

1. Estimation of how effective semi-natural habitats are at providing ecosystem services such as food production, pest control, pollination and soil preservation. For farmers, some estimate of the reliability and risk associated with more reliance on ecosystem services would also be needed if they are to be encouraged to adopt more sustainable farming practices reliant on ecosystem services (Duru et al. 2015). The predominance of short-term studies of 1–3-year duration does little to help meet this requirement. Research funders need to recognise that ecosystems change slowly and that longer-term support is needed.
2. Some semi-natural habitats in EU member states are supported through agri-environment scheme funding, and therefore, economic evaluations of the costs and benefits of semi-natural habitats to ecosystem services would help in the justification for this spend. Other habitats that are not supported yet may be important need to be identified and measures put in place to encourage their retention and improvement where necessary.

Caveat: the authors acknowledge that although the search terms used were devised to identify all relevant publications, they were not comprehensive and therefore may not cover the entire record. Moreover, only those papers that met the inclusion criteria, which was subjective to some extent, were included in the systematic map and other publications exist that also investigated aspects of these ecosystem services.

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List of European countries included in the search terms and number of publications found per country

Albania	0
Andorra	0
Austria	13
Belarus	0
Belgium	9
Croatia	0
Cyprus	0
Czech Republic	3
Denmark	3
Estonia	1
Finland	6
France	26
Germany	64
Greece	2
Ireland	4
Hungary	6
Italy	18
Latvia	0
Lithuania	1
Moldova	0
Netherlands	12
Norway	3
Poland	4
Portugal	2
Romania	0
Serbia	1
Spain	24
Switzerland	14
Sweden	24
UK	21
Ukraine	0

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