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PROJECT FINAL REPORT

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4.1 Final publishable summary report

Nature can provide a multitude of hidden benefits to humans such as control of crop pests by their natural enemies, crop pollination and prevention of soil erosion that keeps rivers clean. These are known as ecological services (ecosystem services) and are worth billions of euros every year in each European country. Semi-natural habitats (SNH) on farmland support these services by providing resources for service providers such as natural enemies and pollinators. Through their vegetation composition and structure they also directly support other ecosystem services (ES), shaping our perceptions of landscapes and sequestering carbon.

The QuESSA project aimed to quantify the contribution of SNH such as hedgerows, grass strips and woodland to key ES for sustainable agriculture. The project focused on pest control and pollination, but also included services such as erosion mitigation, carbon sequestration and aesthetic value. Research focussed around 16 case studies that included wheat, oilseed rape, sunflowers, pumpkins, pears, olives and vines across eight countries.

The vegetation composition and structure for key SNH was measured in the case studies and a functional plant traits database collated. Although plant species composition in European SNH was different, the abundance of beneficial insects (flying predators and pollinators) could be predicted based on the functional traits of plant species and the vegetation as a whole. Actual ES provision was measured for pollination, biological control and five other ES in the case studies. Data from the case studies were used in novel kernel analyses that weighed contributions of different semi-natural habitats across a landscape, and predicted the level of biological control in a focal field on the basis of contributions from different semi-natural habitats in the surrounding landscape.

A pollination deficit was found in 2 out of 6 case studies (sunflowers in Italy 8%; oilseed rape in Switzerland 6%) but the overall deficit was 3%. Pollinator visitation varied widely but was unrelated to the deficit. A positive association between crop performance and the presence of woody linear features in the area surrounding a focal field was found for pears in the Netherlands, however, the opposite effect was found with sunflowers in Italy. Sentinel systems comprised of surrogate prey or pests were used to measure levels of biological control in the case studies. Overall SNH were positively related with levels of biological control, but relationships were weak. Different SNH types were important in different case studies therefore it was not possible to make Europe wide recommendations. Levels of biological control also varied hugely between and within case studies indicating that there is potential to make improvements. Likewise, other ES differed markedly between and within case studies and the attained ES level depends on context specific landscape characteristics (e.g. proportion of semi-natural habitats) and management (e.g. application of green manure increasing carbon sequestration). Soil carbon was 35-50% higher in SNH but when total carbon was calculated according to the area occupied by each habitat in the landscape sectors, >80% was stored in the fields. When exploring trade-offs and synergies of alternative landscape designs, trade-offs were observed between aesthetic and conservation value, whereas synergies were observed between aesthetic value and carbon sequestration (in terms of soil organic matter), the prevention of soil erosion and aesthetic value, and biocontrol and carbon sequestration. For pollination and pest control scoring systems were developed for semi-natural habitats and used to generate Europe wide predictions of service levels generated using existing land categorisation data.

Guidelines were produced for the agricultural community and scoring systems incorporated into a web-based tool used to calculate the value of Ecological Focus Areas.

Summary description of project context and objectives

FARMING IMPACTS ON THE ENVIRONMENT

Current conventional farming systems are heavily reliant on agrochemical inputs that cause pollution of the natural resources and may cause a health risk to users and consumers. At the same time they are implicated in declining biodiversity causing disruption of ecosystem services provided by biodiversity. Soil carbon levels are also under pressure from rotations with cash crops, in which soil organic matter turnover is enhanced by intensive tillage and the ensuing carbon loss is not replenished by crop residues. The resulting low soil organic matter content may affect the capacity of the soil to absorb water, which aggravates runoff of water and soil in hilly areas, and causes excess problems at lower altitudes. The homogenization of landscapes also affects landscape visual and culture-historical quality, and has negative impacts on cultural heritage and tourist benefits.

INTENSIFICATION FOR INCREASED FOOD PRODUCTION

There is an expectation that 70% more food will need to be produced by 2050 that will require further intensification of agricultural land use. These developments call for bio-technical and social breakthroughs to improve the sustainability of farming systems without reducing their productive capacities. There is a need therefore to make more efficient use of the possible ecosystem services in order to increase crop production in a sustainable way. In this regard, more knowledge on and awareness of the role of semi-natural habitats may contribute to finding the way out of the current lock-in of many conventional farming systems. Such knowledge and awareness will help policy makers to further refine policy instruments already available in the CAP Pillar II, or future CAP, and will support farmers and other local stakeholders to adopt technologies based on eco-functional rather than external-input oriented intensification.

ECOSYSTEM SERVICES

The Millennium Ecosystem Assessment distinguished four types of ecosystem services: provisioning, regulating, habitat and cultural services. Provisioning services are the goods and products obtained from ecosystems such as food, water, timber or medicines. Regulating services are the benefits obtained from an ecosystem's control of natural processes, for instance pollination or pest control by natural enemies. Cultural services are the non-material benefits obtained from ecosystems such as recreation in forests. Finally, habitat services are supporting the provision of other services by providing habitat. Although we aim to use the concept of ecosystem services in a scientific way, it remains a subjective, socially determined notion because an ecosystem service is defined as a benefit *appreciated* by humans. Operationalizing eco-functional intensification which maximizes ecosystem services thus requires a distinction of goals and the means to achieve them. There is therefore a great need to 1) identify which habitat types are able to provide important ecosystem services for cropping systems, and 2) determine which cropping systems and regions would most benefit from which services.

SEMI-NATURAL HABITATS FOR ECOSYSTEM SERVICE PROVISION

Semi-natural habitats contribute to ecosystem services in all four categories distinguished by the above mentioned Millennium Assessment. The vegetation in semi-natural habitats is the basis for provision of many valuable ecosystem services. On the one hand, the vegetation in a determinate area is determined by its environmental conditions and management, and this is determined in turn by the ecosystem response traits of the plant species composing the vegetation. On the other hand, the present vegetation provides ecosystem services through the quality and composition of the effect traits. The vegetation can provide both direct and indirect services to the agro-ecosystems. Direct services are a) soil biological quality and organic matter accumulation, b) nitrogen fixation, c) erosion control, and d) buffer functions against nutrient leaching, wind, agrochemical drift. These can be measured on-site. Furthermore, the vegetation offers food, shelter, overwintering/oviposition sites to beneficial organisms, and has an impact on presence and efficacy of all ecosystem services provided by these organisms such as pollination and pest control. Those functions can be provided at distances of up to several km from the habitat as a result of movements of beneficials in the agricultural landscape. However, movement of organisms depend first of all on the movement capacity of the organisms and second on the connectivity of suitable habitat or presence of barriers within the landscape. Therefore, both farm and landscape management affect ecosystem service provision. Semi-natural habitats providing these services through their vegetation are found in non-cropped areas - hedgerows, grass strips and woodland - and in cropped areas – cover crops, spontaneous vegetation during fallow, living mulches (temporary semi-natural habitats). Across Europe there are relatively few types of semi-natural habitats on uncropped land in agricultural regions and these are comprised of hedgerows, perennial herbaceous vegetation between fields often associated with linear features, woodland, unimproved grassland and agri-environment scheme habitats. In addition to the spontaneous vegetation occupying the fields throughout the year, a number of habitats created within fields may improve functional biodiversity: cover crops, fallows and understoreys. While studies have appeared that describe *ecological functions* of semi-natural habitats (i.e. identification/quantification of beneficial plants/insects/fungi), very few studies addressed their beneficial impacts, or *ecosystem services*. In view of this lack of knowledge it is not surprising that quantification of the relative value of the ecosystem services provided by different semi-natural habitats is rare, let alone that positive, negative or neutral interactions between services have received attention.

SCALE ISSUES IN RELATION TO ECOSYSTEM SERVICES

Ecosystem services from semi-natural habitats originate at different spatial scales. Some services are local, such as production of wood in woodlots whilst others have a strong spatial component and require knowledge of processes operating at several square kilometres, e.g. pollination. In addition to the need to understand biological processes at different scales, sustainable reliance on ecosystem services from semi-natural habitats requires taking into account stakeholders operating at different scales. Retailers, consumers and recreation seekers perceive ecosystem services at larger scales, because they are interested in larger volumes produced or because the service is associated with the landscape or regional scale, e.g. cultural heritage. Farmers affect ecosystem performance through field and farm level management. In current conventional farming systems there is little active management of permanent semi-natural habitats to protect, exploit and sustain their ecosystem services. In contrast, innovative and organic farms are heavily dependent on ecosystem services but these growers, like conventional farmers, would benefit from information to maximise the impact of semi-natural habitat: which type of habitat of which amount of area and in which configuration will enable a desired service. The adaptation of farm and landscape management may cause a cost for farmers, but this cost should be balanced against the benefits provided by increased ecosystem service provision in terms of decreased pesticide use and increased yields though more effective pollination. If indications can be formulated for the local case study areas, it would be important to design criteria that indicate if these measures can be effective also in other European regions. However, semi-natural habitats which provide ecosystem services in one agro-climatic zone, may not do so in other agro-climatic zones. Therefore, enhancing ecosystem services is not a technology waiting to be adopted but requires more knowledge, proof of concept and local adaptation of potential solutions. Science has a role to play by developing simple, robust techniques to measure and predict ecosystem services across a range of scales, climatic zones and farming systems, by demonstrating synergies and trade-offs among ecosystem services, and by identifying areas in Europe where investment in semi-natural habitat enhancement would result in greatest benefits. Developing such knowledge and techniques together with local stakeholders provides a sound basis for enhancing credibility and saliency of results, future acceptance of policy measures and impact on the ground.

GENERAL OBJECTIVES AND STRUCTURE OF QUESSA

This project aimed to Quantify Ecosystem services of Sustainable Agriculture focussing on the role of semi-natural habitat in a wide diversity of European cropping and farming systems. In order to fulfil this task the project has formulated the following general objectives:

1) In a sample of the main crop production systems across Europe identify the key semi-natural habitats according to their potential to provide selected ecosystem services based upon vegetation traits.
2) Verify the potential of semi-natural habitats to deliver the selected ecosystem services through field studies in 16 case studies (Fig. 1) and demonstrate opportunities and trade-offs through mechanistic modelling.
3) To evaluate the economic and non-monetary value of ecosystem services derived from semi-natural habitats and stakeholders' need (and willingness to pay) for these ecosystem services.
4) To analyse and predict with spatially explicit models the effects of spatial allocation and management of semi-natural habitats on the level of selected ecosystem service provided by semi-natural habitats in farming systems from farm to European scales.
5) To produce guidelines and make recommendations to stakeholders and provide a web-based tool for farmers to enhance exploitation of semi-natural habitats for their ecosystem services provision.

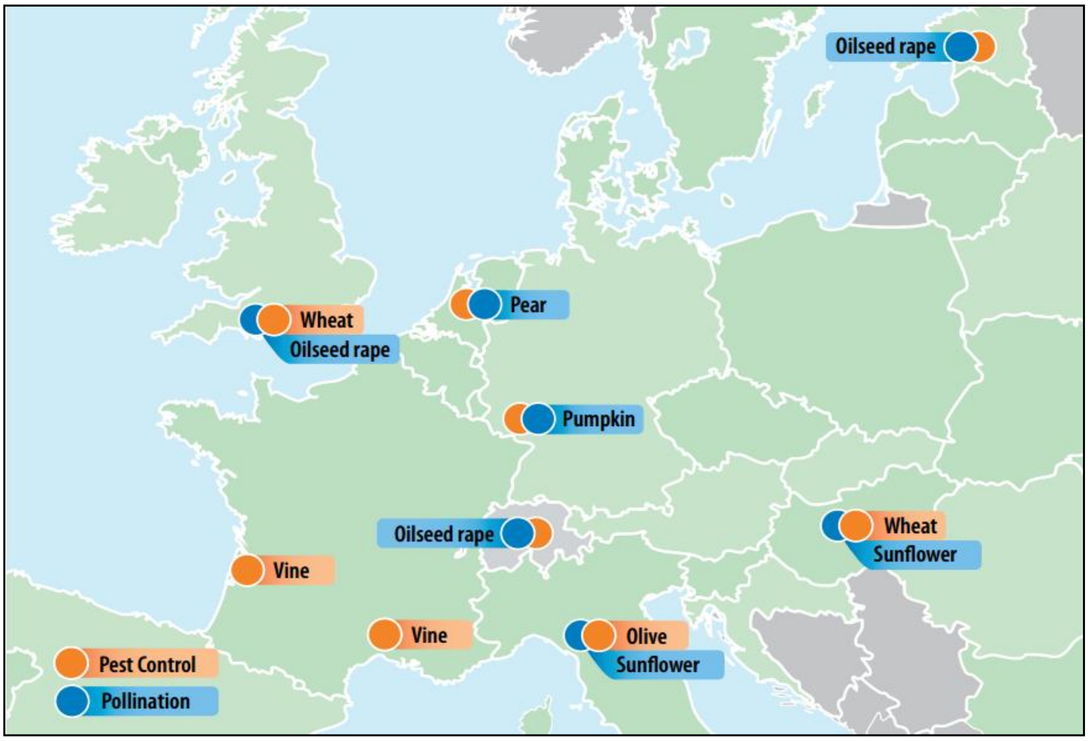


Figure 1. QuESSA Case Studies across Europe (Sites shown in orange have pest control measurements; sites shown in blue have pollination measurements)

The project was structured into three research Work Packages (WP2-4) and one for knowledge exchange (WP5) (Fig. 2). The focus of WP2 was to determine which characteristics (traits) of semi-natural habitats (SNH) determine the ecosystem services provided to the selected agroecosystems and to determine the potential ecosystem services provided and how this is affected by farm and landscape management. In WP3 the aim was to quantify actual delivery of ecosystem services provided by SNH for major European cropping systems across four agro-climatic zones. This included evaluation of the economic and non-monetary value of ecosystem services derived from semi-natural habitats. Data from WP2 and 3 was then used in WP4 to predict, upscale and synthesize the effect of semi-natural habitats on ecosystem service delivery in crop systems at farm, landscape and European level. The role of WP5 was to disseminate the results and inform all relevant stakeholders to utilise and improve semi-natural habitats to enhance ecosystem service provision at local to EU scale.

Main S&T results/foregrounds

1. IDENTIFICATION OF THE KEY SEMI-NATURAL HABITATS ACCORDING TO THEIR POTENTIAL TO PROVIDE SELECTED ECOSYSTEM SERVICES BASED UPON VEGETATION TRAITS (WP2)

1.1 Semi-natural habitat typology and distribution in the QuESSA case studies

The most course level of SNH classification can be made by visual inspection and is based on SNH shape and vegetation structure. Regarding shape, it was decided that SNH that extend over 25 m in all directions were

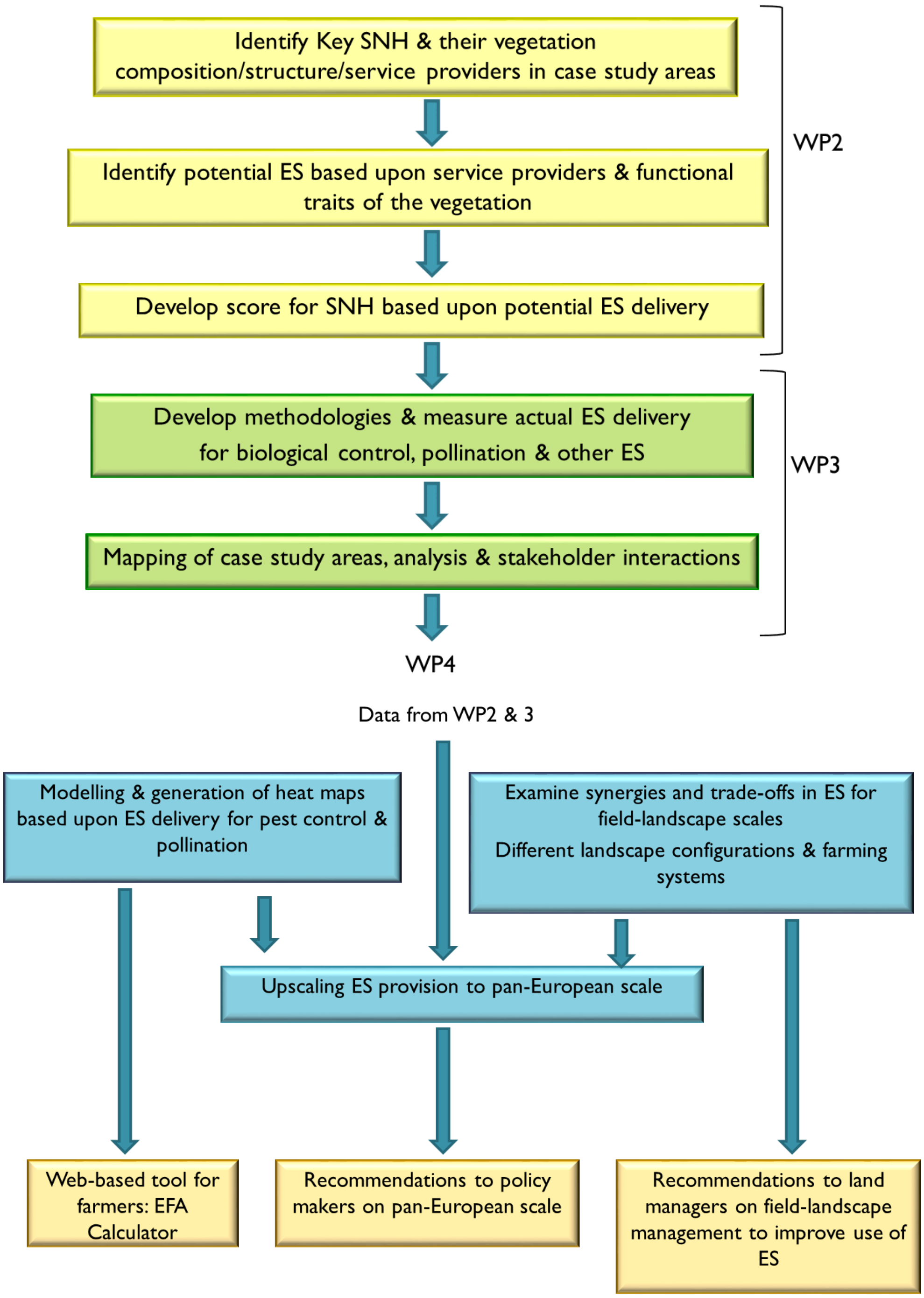


Figure 2. QuESSA Project structure and main information flows

defined as areal elements, whereas any element longer than 50m and between 1.5 and 25 m in width was called a linear element. Smaller elements were discarded. The second criteria was based on the amount of woody features, and if the canopy cover exceeds 30% of the surface of the SNH, it was considered woody, otherwise herbaceous. A last distinction was made based on the disturbance frequency of herbaceous areal elements. This resulted in a fifth class with fallow or temporary semi-natural vegetation in regularly cropped fields. The five resulting SNH types were therefore in-field fallow (FA), herbaceous areal (HA), woody areal (WA), herbaceous linear (HL) and woody linear (WL). The classification diagram is presented in Figure 3. All samplings in the QuESSA project were performed in these five SNH types to test if these vegetation characteristics were determining plant species composition and beneficial insect communities associated with them. To this end QuESSA partners selected 18 landscape sectors (LS) with a 1 km radius. In each landscape 1 SNH element of each type (when present) was sampled determining plant species composition and structure, beneficial insect groups through coloured pan-traps and transect walks to determine the presence of Apoidea often not captured by pan-traps. The QuESSA methodology is described in Deliverable 2.2, Sutter et al., 2017 for part of the Swiss case study (pollinator transects) and in Pfister et al., 2016 for part of the German case study (predatory Diptera from pan-traps) and was similarly applied in the other QuESSA case studies.

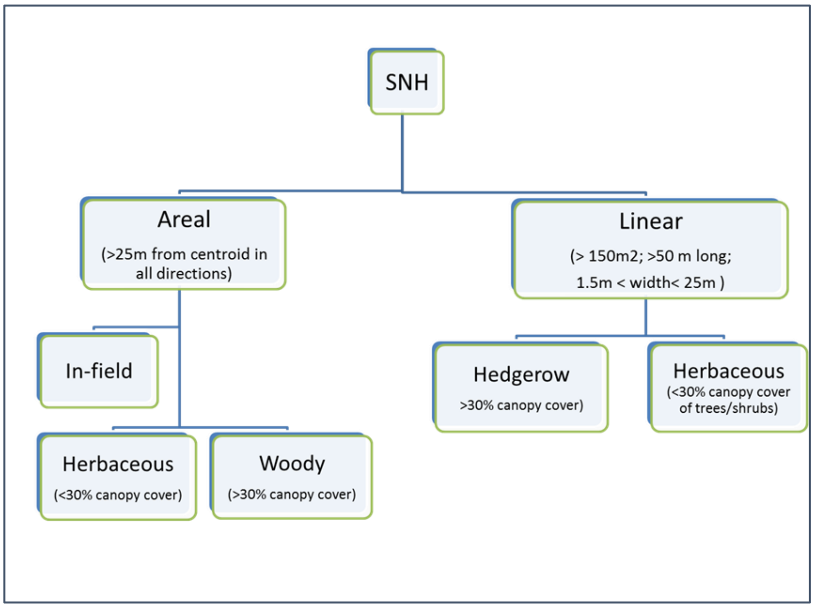


Figure 3. Semi-natural habitat classification resulting in five main SNH types based on shape and vegetation structure: FA, in field fallow; HA, herbaceous areal; WA, woody areal; HL, herbaceous linear; WL, woody linear.

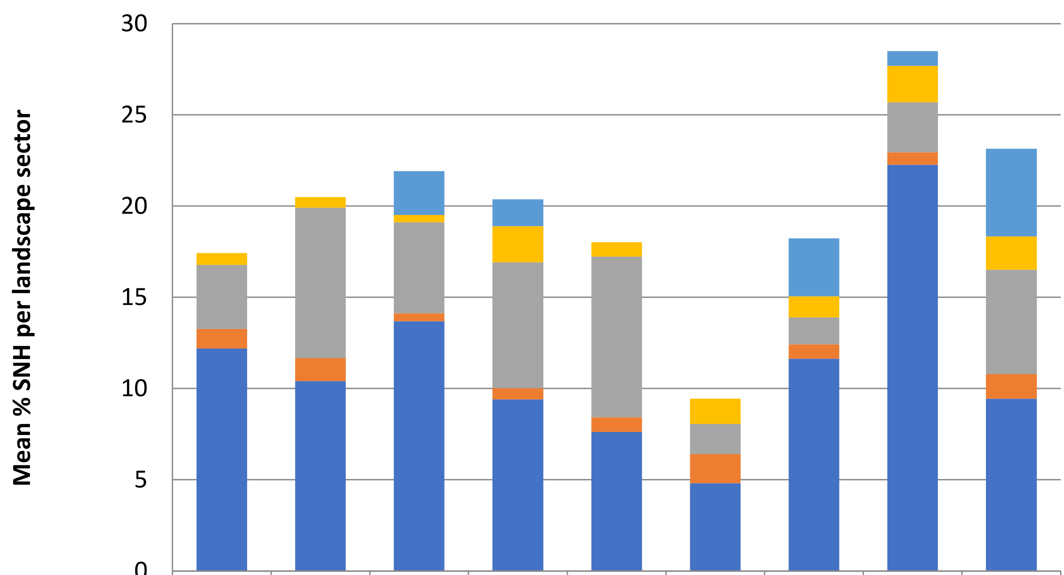
Analysis of the 18 LS in the 8 case study countries showed that SNH occupied at least 4% with the exception of 1 LS in The Netherlands having only 1.5% of SNH. Germany, Hungary and UK have at least 4% of SNH and Switzerland, Estonia, Italy and France show at least 10% of SNH, with a maximum of 89% in the Italian olive grove landscapes. In all countries, the highest percentage of SNH is represented by woodland, varying from an average of 4% in The Netherlands to 36% in Italy. The other four SNH types (woody linear, herbaceous linear, herbaceous areal and fallow land), vary on average between 1 and 10% (Fig. 4).

1.2 Review of knowledge on ecosystem service provisioning by semi-natural habitats in Europe

A systematic map approach has been applied to 1) determine the amount of scientific knowledge on ecosystem services provided by semi-natural habitat (SNH) in Europe, and 2) analyse in detail the knowledge on how various types of SNHs affect conservation biological control and through that, crop yield.

Only published, empirical research was included and searches were carried out using the online database: Web of Knowledge (v.5.10). A scoping process was used to refine and select the final search terms that included review by the partners. 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*)). After a selection process, 270 papers were retained in which results were presented on the delivery of the ecosystem services pollination, biocontrol, soil erosion and carbon storage from SNH. The most extensively studied semi-natural habitats were hedgerows/field margins (150), woodland, shrubland (113) and grassland (135).

Investigations of fallows were reported in 39. Half of the publications (137) investigated more than one habitat type. The majority of publications looked at regulating ecosystem services (250), 28 investigated supporting services, 12 examined provisioning services and three cultural services. The most commonly investigated regulating ecosystem services were pest control (143) and pollination (78). The most extensively studied ecosystem service provider were



	CH	DE	EE	FR	HU	NL	UK	IT_pc	IT_pol
St. dev FA	0.00	0.00	2.39	1.47	0.00	0.00	3.17	0.82	4.81
St. dev HL	0.65	0.58	0.42	1.98	0.78	1.38	1.16	1.99	1.82
St. dev HA	3.52	8.25	4.98	6.90	8.82	1.66	1.48	2.73	5.71
St. dev WL	1.07	1.27	0.43	0.61	0.81	1.59	0.78	0.69	1.35
St. dev WA	12.20	10.41	13.69	9.41	7.62	4.82	11.65	22.27	9.45

Figure 4. Mean percentage land cover and standard deviation in the 18 landscape sectors of 2014 for the 5 SNH types (woody areal - WA, woody linear - WL, herbaceous linear - HL, herbaceous areal - HA and fallow land – FA) in the eight QuESSA case study countries.

invertebrates (217) of which there were 143 publications on pest natural enemies, 78 of pollinators but only 5 of both groups and only two of organisms responsible for nutrient recycling. For pest control 30 publications reported pest levels, 96 levels of pest predators, 35 on parasitism rates and four measured the arthropod community composition. Only two publications reported on yield with one finding a positive and the other a negative effect of SNH. However, in 55 publications there was a positive effect of SNH on pest control although sometimes abundance of predators was used as a proxy for pest control, a negative effect in three and eight reported no effect. Of the 58 publications that provided a recommendation as to the best SNH for enhancing pest control, 32 recommended field boundary habitats such as hedgerows, hedge-base or field margins with 14 specifically mentioning hedgerows. Woodland or forest was recommended in 7 publications and grassy habitats in 6 publications. For pollination, none of these publications provide a recommendation on the best habitat to increase pollination, with 28 providing a recommendation only whether pollinators were more abundant in the studied habitats. Of these, six recommended field boundary habitats such as hedgerows, hedge-base or field margins with some mentioning that floral abundance within these was important. Seven recommended flower-rich strips or margins, a further three recommended flower-rich meadows. The systematic map and the outcomes of the analysis are described in Deliverable 2.3 and were published in Holland et al. (2017).

A detailed review was performed to establish the extent to which the predominant habitat types in Europe support natural enemies, whether this results in enhanced natural enemy densities in the adjacent crop and whether this leads to reduced pest densities. This review was published in Holland et al. (2016). Considerable variation exists in the available information for the different habitat types and trophic levels. Natural enemies within each habitat were the most studied, with less information on whether they were enhanced in adjacent fields, while their impact on pests was rarely investigated. Most information was available for woody and herbaceous linear habitats, yet not for woodland which can be the most common semi-natural habitat in many regions. While the management and design of habitats offer potential to stimulate conservation biocontrol, we also identified knowledge gaps. A better understanding of the relationship between resource availability and arthropod communities across habitat types, the spatiotemporal distribution of resources in the landscape and interactions with other factors that play a role in pest regulation could contribute to an informed management of semi-natural habitats for biocontrol.

1.3 European semi-natural habitats classified based on their vegetation composition and structure

A total of 854 species were registered in 539 SNH during the second sampling period (spring) that was used for the overarching vegetation analysis. For the overarching analysis genus level was used and this reduced the response variables to 355 genera. The Canonical Correspondence Analysis (CCA) performed with CANOCO 5 on the plant genus abundances of the 539 SNHs samples in the 10 case study regions in eight European countries with explanatory variables 'country'', 'SNH type' and their interaction resulted in 17.8% of variability in plant data explained.

Correspondence Analysis (CA) was performed on 355 European SNHs, while the Italian olive grove sites were made supplementary because species composition was so different that these sites became outliers. The four agroclimatic zones were distinct in terms of their plant composition, with the greatest differences between the maritime and Mediterranean regions (Fig. 5). All herbaceous SNH in Europe were fairly similar in terms of genera composition, while the woody sites from the Maritime regions and from the Mediterranean region have a different plant genera composition (Fig. 6).

1.4 A scoring system for pollination and pest control potential of European semi-natural habitats

Assessing whether the presence (or absence) of semi-natural habitats in European landscapes provides the society with detectable positive ecosystem services is a challenge for researchers. Various attempts have been made up to now with this regard but univocal conclusions have not been reached yet: one of the major drawbacks of the approaches taken so far is due to the different methodologies that have been adopted in different European regions (i.e. case studies); these inherently different methodological approaches undermine the chances of obtaining general conclusions which could serve as useful references for policy makers and stakeholders.

One of the main aim of this Task of the QUESSA project was to measure the potential provision of ecosystem services from semi-natural habitat types that are common across the continent (i.e. herbaceous and woody element, both linear and areal ones) using the same methodologies in all the case studies. Two common sampling techniques – coloured pan-traps and transect walks - were thus used in all case studies to sample groups of insects which are known to exert positive effects ('beneficials') on agricultural crops.

A modelling approach was then used to try to disentangle the effects of the various environmental variables at play and assess if 1) semi-natural habitats facilitate the presence of groups of insects that can provide useful services to the farmers, and 2) which variables have the strongest effect on those processes.

The two ecosystem services that were taken into account for the analysis were "pollination" and "pest control" being the two which are considered as the most interesting from a crop-production perspective.

In terms of "potential pollination service", one of the main – and most interesting - results was a common trend found for the abundance of bees (for both *Apis mellifera* and wild bees) across all the European case studies: going from the Mediterranean region (Central Italy) to the north of Europe (UK) we observed a decreasing presence of bees in the central parts of woody areas, i.e. according to our data and models the inner parts of European woods seem to host lower abundances of such pollinators, thus are likely to provide lower levels of pollination services to the surrounding crops.

The same analytical approach was followed to analyse known groups of pest controllers within the semi-natural habitats: in this case results are less clear and make any generalization across groups difficult to obtain; a few interesting points were nevertheless found, e.g. the presence of woody linear elements (e.g. hedgerows) seem to support the presence of some specific groups of pest controllers (e.g. parasitic wasps).

We can thus conclude that there's not a single SNH type that can be considered as the "best" habitat in terms of pollination and pest-control provision, but the "optimal" habitat depends on both the "ecosystem service" and the "service providers" of interest.

Beside the assessment of which SNH could provide higher levels of ecosystem services, we also wanted to get an idea of the potential mechanisms driving those results: given that all the ecosystem providers that we sampled rely on plant species to fulfil some of their biological needs, we analysed the functional traits (flower type, flower colour, flowering time, life history) of the plant species that were sampled within the SNH and analysed the correlation between

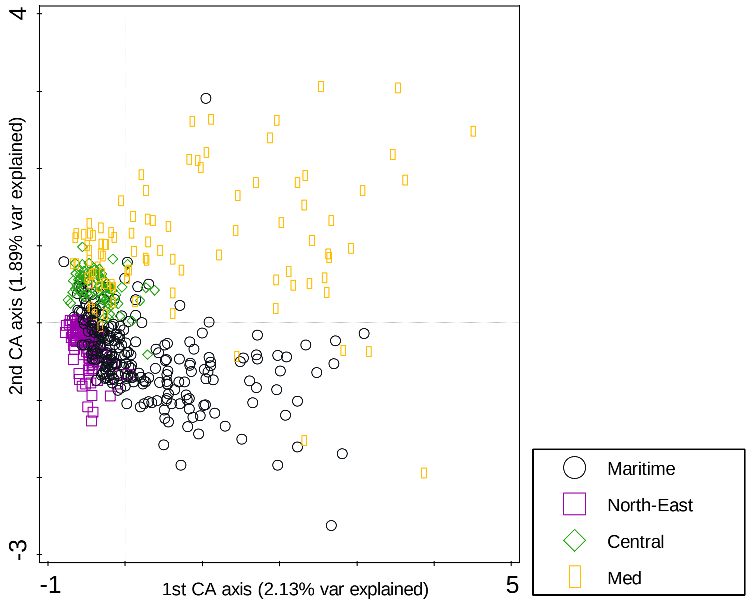


Figure 5. CA of 355 SNH based on plant genera. In the CA the Italian olive grove sites (IT-OLI) were made supplementary because species composition was so different that it eliminated all differences between the remaining sites. Different colours represent the four agro-climatic zones the case study areas belong to following Bouma (2005).

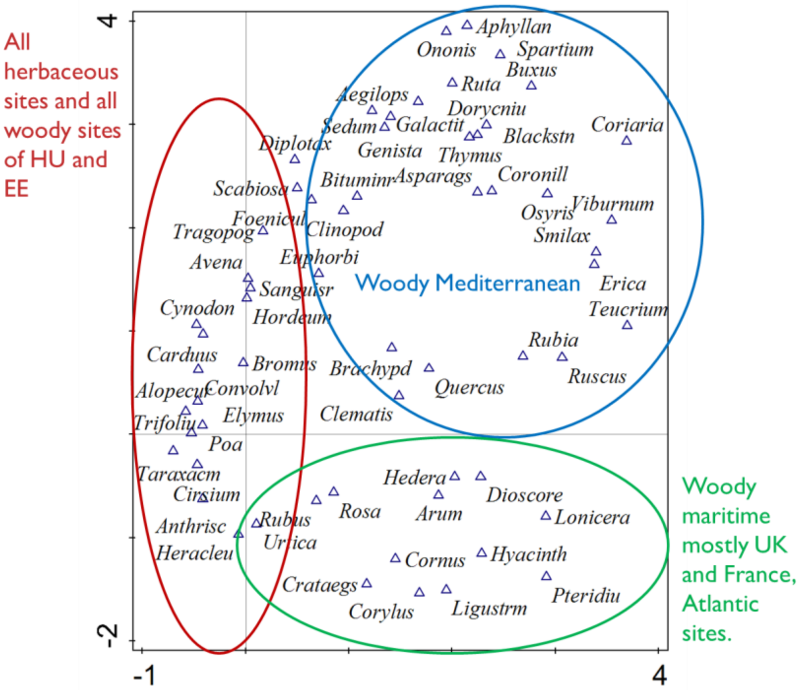


Figure 6. CA of 355 SNH based on plant genera. In the CA the Italian

these traits and the presence of beneficials. We found that there are some groups of specific plant species which, when present, are able to boost the abundances of pollinators: Among the most important ones, we found species belonging to the Rosacea family (*Rubus, Prunus* and *Rosa* genus), the Asteraceae (*Achillea spp.*) and Leguminosae (species belonging to the *Trifolium* genus). The effect of such plants is mediated by the characteristics of their flowering structures which make them more suitable as food sources (pollen and nectar) for pollinators. The full report of these analyses are given in Deliverable 2.4.

1.5 Conclusions and recommendations

1.5.1 Recommendations for policy makers

1. Semi-natural habitat all over Europe provide a rich source for plant and insect species and geographical distribution is an inherent source of diversity that should be respected when formulating policies and management objectives for these areas.
2. Despite the difference in plant species, various SNH typologies have a tendency to provide resources to beneficial insects and pollinators. Pollinating insects respond to the availability of floral resources throughout the year, whereas predatory flies and parasitic wasps respond stronger to habitat structure. They have a preference for woody elements.
3. It can therefore be concluded that policies are needed that promote and sustain DIVERSITY of SNH types on farmland, including diversification of vegetation management in SNH (mowing regimes, reduction or no-use of herbicides…) in and around farmland. Since SNH are not only managed by farmers but also by local administrations, it seems like a wise idea to involve also municipalities and other territorial structures to protect functional biodiversity in SNH.

1.5.2 Recommendations for farmers

1. Diversity of SNH types and management results in spatio-temporal spread of floral resources sustaining a more diverse beneficial insect communities including pollinators. Since different functional groups necessitate different vegetation characteristics, diversification of SNH types on farmland seems like to most promising approach to sustain functional biodiversity, potentially able to provide ecosystem services like crop pollination and pest population reduction.
2. Use of pesticides and herbicides near flowering vegetation puts at risk the health of many beneficial insect populations. Respecting buffer zones around flowering vegetation may be a solution if spraying cannot be avoided.

2. QUANTIFYING THE POTENTIAL OF SEMI-NATURAL HABITATS TO DELIVER THE SELECTED ECOSYSTEM SERVICES THROUGH FIELD STUDIES IN 16 CASE STUDIES (WP3)

2.1 Approach

In QueSSA, the following ecosystem service provision in relation to semi-natural habitats were assessed: natural predation of pest, pollination, landscape aesthetic, soil fertility and organic matter, erosion, and disservices. Assessment was performed following a standardized design in each case study consisting of 18 focal crop fields bordered by semi-natural habitats (SNH) in two categories, ie. either woody SNH or grassy SNH, or another crop field as control. Fields were selected along a gradient of SNH proportion measured in a landscape sector of 1km radius around each field. Vegetation traits were recorded in the adjacent SNH to the crop field as well as the main management practices applied in the field by interviewing the farmer. Habitats and fields in the landscape sector around the focal field were recorded by ground mapping and entered into a GIS system. Generic and simple methods were developed and tested among case studies regardless of the farming systems and the crop under investigation in order to generate general information. The complete methodologies are described in Deliverable 3.1 and the details of the all the measurements conducted in Deliverable 3.2.

2.2 Effects of semi-natural habitats on pollination level of crops

Animal (insect)-mediated pollination corresponds to the processes of pollen grain (male gamete) transport from stamens to female reproductive organs of a plant. This is an essential step of the production of seeds in all spermatophytes (seed plants). It represents a key service of paramount economic importance. Even though the major staples of the human diet do not require insect pollinators, around one-third of global food production comes from crops that are depending on them to some extent. During the last decade, studies have reported worldwide declines in insect pollinators because of habitat losses or fragmentation, land use changes and modern agricultural practices, highlighting the multiple risks of these declines in terms of crop production, food security and ecosystem stability.

QuESSA aimed at evaluating the status of pollination and its implications in terms of crop production, and tried to disentangle how landscape context affects the pollination service delivery. The relationship between provision of insect pollination and semi-natural habitats was measured in four economically important cropping systems – sunflower (two case studies), oilseed rape (three case studies), pumpkin (one case study) and pear (one case study) – several farming intensities and four European agro-climatic zones in seven case studies. In each of the case studies, pollination and semi-natural habitats were investigated in 18 crop fields with standardized methods. Pollination delivery was assessed by a) bagging plants to compare the level of insect pollination with an open pollination treatment; b) assessing the potential for yield gain under optimal pollination (supplementing the pollen deposition on stigmas by hand) compared to the actual level of pollination, and analyse the potential pollination deficiency on yield; c) identifying the flower visitors and measuring the rate of visits; d) recording the pollen deposition on flowers by single pollinators using several techniques, eg. by providing non-pollinated flowers ("mobile bouquet") to pollinators in the field. The insect pollination efficiency on yield was estimated by measuring the fruit and the seed set as well as seed weight and oil content (oilseed rape).

The pollination of the studied crops showed diverging responses across the case studies. Benefits of insect pollination was increased by landscape wide available semi-natural habitats measured in a 1-kilometre radius sector in the Swiss oilseed rape (Fig. 7), the German pumpkin fields and the Italian sunflower crops. Landscape analysis of all the case study data is reported on p19-22 and in Deliverable 3.3.

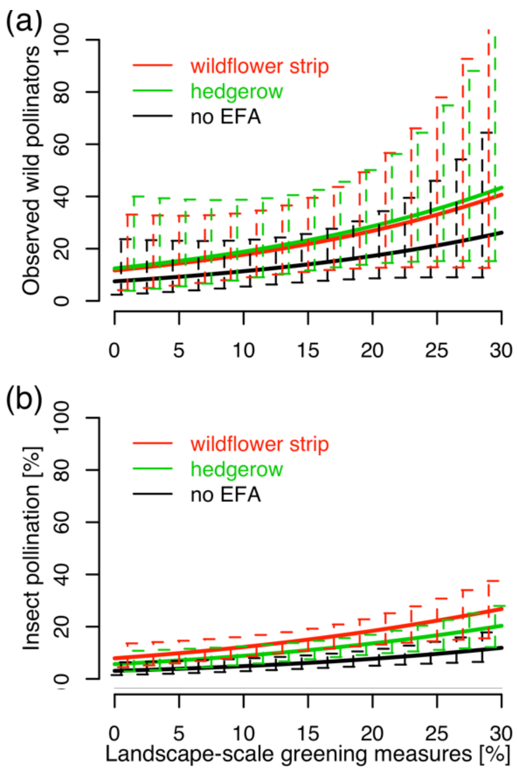


Figure 7. Swiss case study on oilseed rape showing effects of landscape-scale greening measures and adjacent EFA (wildflower strip (red), hedgerow (green), and no EFA (black)) on (a) number of observed wild pollinator, (b) increase of seed set driven by insect pollination (%). Predicted values ± 95% confidence interval for the investigated gradient (6–26%) of landscape-scale greening measures (n = 18 fields). Where no differences between adjacent habitat types occurred, only the average values for all three habitat types is shown (Sutter et al. 2017).

2.3 Effects of semi-natural habitats on natural pest control of crops

Despite the annual use of approximately three million tons of pesticides, pests destroy more than 40 percent of potential global food production. Pest control is estimated to occur mainly through natural enemies (~50%) and host-plant resistance (~40%) and much less through pesticides (~10%). Therefore, development of alternative pest control methods to pesticide application is necessary. Conservation biocontrol is one of them where semi-natural habitats are used by natural enemies of pests for overwintering, as source of alternative prey or hosts.

Pest predation occurs through predators actively (carabids) or passively (spider net) hunting pests or through parasitism from parasitoids. The relationship between provision of pest control and semi-natural habitats was measured in six economically important cropping systems – oilseed rape (two case studies), pumpkin (one case study), pear (one case study), olive (one case study), winter wheat (two case studies) and vine (one case study) that varied in farming intensities. Studies were sited across four European agro-climatic zones. In each of the case studies, pest control dependency on semi-natural habitats was investigated in 18 crop fields using standard methods. Sentinel-preys were exposed in fields (standard fishing baits – *Calliphora* larvae, *Ephestia* eggs, Aphids, plasticine preys, weed seeds, etc.) (Fig. 8). Results of testing allowed determination of the most efficient sentinel-prey techniques that showed variation as well as best practicability for further assessments. Sentinel-preys kept for assessment of general predation overall were the *Calliphora* larvae exposed on the ground, *Ephestia* eggs exposed on the ground and on the plants, *Chenopodium album* and *Poa trivialis* seeds exposed on the ground**.** In addition, the predation rate of crop specific pests was estimated in 18 crop fields of each case study by using sentinels either of the particular pest or by measuring predation directly with predator exclusion methods. Natural enemies were recorded by using pitfalls for ground dwelling predators, and with pan and sticky traps for flying ones. Camera recording was used to identify predators acting on sentinel-preys in one case study. The selected sentinels were used over the following 1-2 years in each case study.

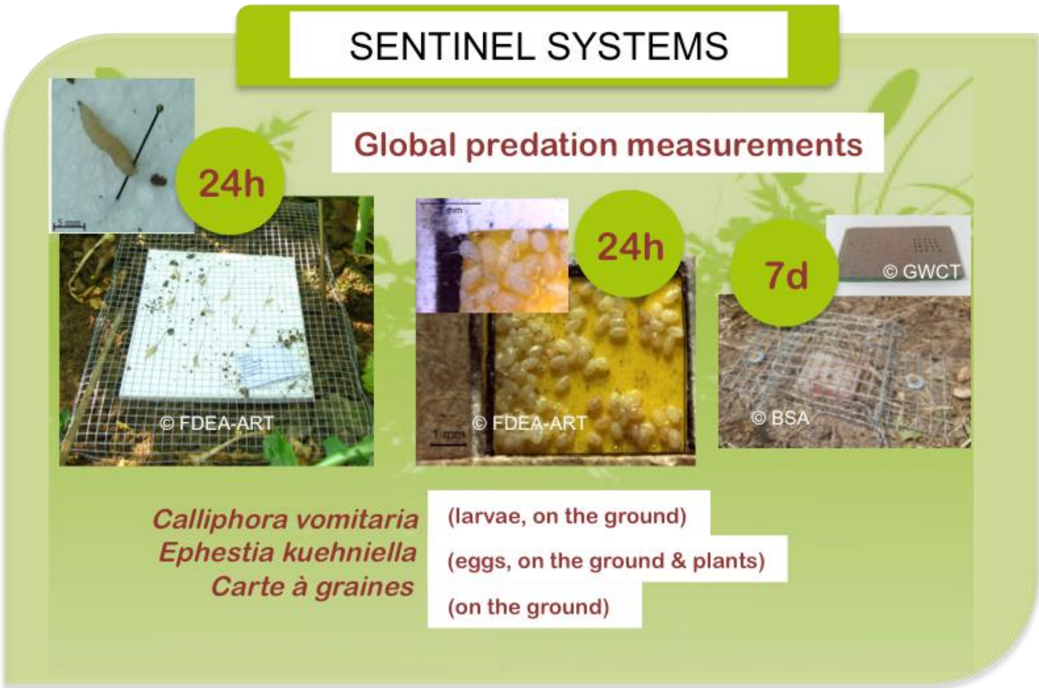


Figure 8. Sentinel systems were used in fields to confirm the presence of predators and estimate the general predation.

The natural pest control in the investigated cropping systems was in some cases more influenced by available SNH at landscape level (i.e. landscape complexity), and in other case studies by locally bordering SNH. Similar to insect pollination no clear European trends appear (Table 1). Three out of eight case studies demonstrated an increase in predation of crop specific pests through bordering SNH. In the Italian case study, the availability of Mediterranean garrigue increased the parasitism of the olive fly in orchards, and bordering herbaceous linear elements increased the parasitism of pollen beetle in Estonia and ground predation in wheat fields in southern England. In four case studies

Table 1. Qualitative summary table of all investigated country-crop-ecosystem service combinations of QuESSA. (+ = SNH increases the ecosystem service, - SNH reduces the ecosystem service, 0 = no effect of SNH on ecosystem service detected, NA = data not available / not measured, values in brackets show effects on service providers if no effect on ecosystem service was found)

ES	cty	investigated crop	Proportion SNH in the surrounding landscape	locally bordering SNH			interaction LS x adj
				WL/WA	HL/HA	others?	
pollination	CH	oilseed rape	+	+	+	NA	+
pollination	UK	oilseed rape	0	0	0	NA	0
pollination	IT	sunflower	WL+ HA-	-	+	NA	0
pollination	DE	pumpkin	+	+	+	NA	0
pollination	EE	oilseed rape	0	(+)	(+)	NA	0
pollination	NL	pear	0	0	0	NA	0
pollination	HU	sunflower	0	0	0	NA	0
pest control	CH	oilseed rape	+	0	0	NA	0
pest control	UK	wheat	HA + WL/WA	-	+	NA	0
pest control	IT	olive	0	0	0	garrigue +	0
pest control	DE	pumpkin	0	0	0	NA	0
pest control	EE	oilseed rape	+	0	+	NA	0
pest control	NL	pear	0	0	0	NA	0
pest control	HU	wheat	0	0	0	NA	0
pest control	FR	vine	0	0	0	NA	0
Landscape aesthetic	EU	diverse	+	+	+	NA	0
Soil erosion	FR	vine	0	0	0	NA	0
Soil fertility	EE	oilseed rape	0	+	+	NA	0
Soil fertility	FR	vine	0	+	+	NA	0
Soil fertility	HU	wheat	0	0	0	NA	0
Carbon sequestration	UK	wheat	NA	+	+	WA+	NA
Carbon sequestration	HU	wheat	NA	+	+	WA+	NA
Carbon sequestration	EE	oilseed rape	NA	+	+	NA	NA
Biodiversity conservation	DE	pumpkin	0	+	+	NA	0
weed invasion	IT	sunflower	0	-	-	NA	0
weed invasion	HU	sunflower	0	-	-	NA	0
Bird damage	NL	pear	0	(+)	0	NA	0

where no direct effect of locally bordering SNH were detected, the total amount of SNH measured in a 1-kilometre radius sector around the studied focal crop fields positively influenced the natural predation of damage-causing pest species.

The proportion of SNH increased the predation on pollen beetles in Swiss and Estonian oilseed rape fields (Fig. 9). In the United Kingdom, the proportion of grassland in the surrounding landscape increased predation rate in wheat fields, whereas woody habitats rather negatively influenced predation. In Germany, the abundance of predators was positively influenced by the flower abundance in the adjacent SNH, but a direct reduction on aphid number, the principal pest in pumpkin production, was not recorded. In the Netherlands, no effect of SNH could be demonstrated on sentinels.

Results suggest that pest control agents rather react to the amount of SNH at landscape level (i.e. landscape complexity/diversity) than to local implementation of current SNH, whilst role of attracting predators into fields for successful natural pest control seems less important than expected (Table 1). For further results see Deliverables 3.3 and 5.8.

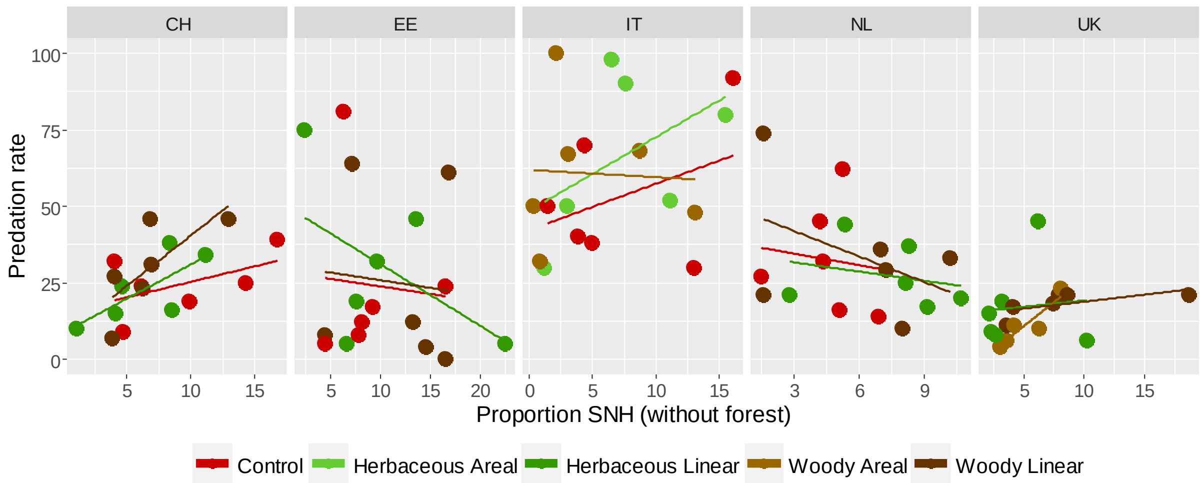


Figure 9. Except for the predation rate of the pollen beetle in the Swiss oilseed rape fields, no significant impact of the SNH proportion around crop fields (1 km radius) could be demonstrated in the case studies. Case studies: CH = Switzerland, EE = Estonia, IT = Italy, NL = The Netherlands, UK = United Kingdom.

2.4 Effects of semi-natural habitats on landscape aesthetics, soil erosion, soil fertility, carbon storage, biodiversity conservation and disservices

Other ecosystem services in QuESSA included landscape aesthetic (eight case studies), soil erosion (one case study), soil fertility (four case studies), organic matter storage (two case studies), and biodiversity conservation. In addition, the impact of semi-natural habitats on so-called disservices was recorded, namely weed invasion (three case studies) and bird damage (one case study).

2.4.1 Landscape aesthetics

Regarding the landscape aesthetic, photographs were taken of element combinations of woody SNH or grassy SNH, or another crop field as control as for pollination and predation assessments. Pictures were taken at three or four different vegetation stages during the season (Fig. A1). First analyses showed a significant positive influence SNH on landscape aesthetics in many cases, particularly woody elements (Table 1). This influence seems to be stronger in landscapes with traditional crops than in landscapes with three-dimensional crop elements as vineyards and olive groves.

Nevertheless, colourful flowering crop elements were significantly preferred to grassy, not flowering elements. This is the case of oilseed rape investigated in Switzerland. An interesting case was the sunflower crops in Hungary flowering at a particular time of the season, and were then depreciated when brownish once wilted to the benefit of green elements. Grassy elements seem to be attractive if they bring additional colour in a (brownish) landscape or if they are flowering. However, flowering grassy SNH are rather seldom because they are often cut. For European crop landscapes, the data suggests that more flowering grassy elements could enhance landscape attractiveness. For the vineyard and the olive landscapes, no clear conclusion can be drawn, as among pictures showed there were no colourful flowering grassy elements. Hedgerows play an important role for landscape attractiveness as being three-dimensional elements. However, preferred woody element should be a regular hedgerow consisting of trees, while a low hedgerow or a hedgerow consisting of trees and bushes is less preferred. First analyses corroborate results from literature showing that colourful flowering, trees and vegetation structures plays an important role for the landscape aesthetics. These hypotheses will be analysed in detail with discrete choice models.

2.4.2 Soil erosion

Soil erosion by water was quantified by using astroturf mats having grass-like features installed on upslope and downslope sides of elements of the four SNH classes bordering vineyards in the vine case study, and inside vineyards with and without green manure crop. No significant effect of herbaceous cover and/or region was found on soil erosion measured using mats. However, soil erosion tended to be higher in vineyard fields without herbaceous cover, though not significant. For reliable conclusions, more replicates and more research would be necessary, in particular when vineyards or other crop systems have steep slopes.

2.4.3 Soil fertility

Soil fertility was assessed in Estonia, France and Hungary by taking soil samples from focal fields and from woody linear and herbaceous linear SNH. Soil organic carbon content was measured with dry combustion method with a Carbon/Nitrogen analyser. Decomposition rate was also measured by burying tea bags in France and Hungary. Soil fertility (C:N ratio, soil organic matter and soil organic carbon) was higher in woody linear SNH compared to adjacent crop fields in Estonia but not in grassy strips (Table 1). In Hungary, results were less general as the total nitrogen content showed no significant difference between SNH and crop fields. Organic matter decomposition of tea bags in France and Hungary showed no difference between SNH and crop fields, yet a higher decomposition rate could be observed at a higher distance from the field margin than at a lower distance. Differences also occurred between the two French regions (Mediterranean or Oceanic).

2.4.4 Soil carbon storage

Organic matter storage was calculated using loss on ignition from soil samples collected in the SNH classes and crop fields of Estonia, Hungary and UK. Overall the SNH habitats contained 35-50% more soil carbon than the fields. There was some variation between countries, with herbaceous and linear habitats containing similar levels of carbon in Estonia, but higher levels in woody compared to herbaceous in Hungary whilst the reverse was found for the UK. However, when taking into the area occupied by fields and SNH, the vast majority of soil carbon in the top 30 cm of soil is stored in fields rather than SNH in agricultural landscapes. Further carbon will be stored in the above and below ground vegetation of SNH and this is likely to be highest for woodland, potentially storing up to 20.2 kg C m-2. Overall up to ~60% of the carbon in forest ecosystems may be stored within live and dead stands of trees. Of the all the SNH types the greatest variability between sites occurred for woodland. In addition, the highest level of soil carbon was recorded in for a woodland site (317.653 t C ha-1) showing there is potential to make improvements. The variation may be due to differences in the age, level and composition of tree cover. The implications of these findings are that future policy must recognise that both fields and SNH are important for carbon sequestration. Research on carbon sequestration has traditionally focused on agricultural fields, which are important for carbon sequestration, as the results from this study have shown. Techniques to improve carbon sequestration in fields are already known, including low or no tillage, improving carbon sequestration in agricultural soils would also bring a secondary benefit of improving crop yield. This has been referred to as a “win-win” policy, which could mitigate climate change and aid global food security for a growing global population. SNH, however, are also important for provisioning carbon sequestration. Research is needed on how carbon sequestration can be improved in SNH as well as to understand the effects of management techniques on carbon sequestration from SNH.

2.4.5 Biodiversity conservation

While recording the vegetation, the predators and the pollinators to characterize SNH, a large part of biodiversity was simultaneously assessed (vegetation, pan, sticky and pitfall traps). All collected organisms put together provide the basis for a biodiversity conservation value of the SNH. Preliminary analysis of carabid communities showed that SNH had a significant effect on species richness, temporal beta diversity, spatial beta diversity and the number of red list species. Species richness, temporal beta diversity and number of red list species were higher in herbaceous SNH than in woody ones. In contrast, spatial beta diversity (community variation) was higher in woody SNH than in herbaceous ones. Our preliminary analysis showed that SNH contain several species including species of conservation concern. Therefore, SNH are important for species conservation in agricultural landscapes. Interestingly, landscape composition had no effect on species richness, beta diversity and the number of endangered species. Hence, even in simple landscape SNH have a high conservation value for carabids. Further analysis will be performed for other taxa.

2.4.6 Disservices

As disservices, weed populations and bird damage were recorded. Weed composition was determined by scoring density and percentage cover of the species in sunflower fields in Italy and Hungary. Bird damages were estimated by quantitative observation of damages on fruits at harvest in pear orchards in the Netherlands, and by interviewing farmers. Important findings are:

- Weed abundance is higher only at 1m distance from the field margin. From 2 m onwards, weed cover is not affected by distance from the SNH.
- The % of SNH in the landscape sector has no effect on weed species richness in sunflower but does affect species composition (2.5% variability accounted for).
- Weed species richness in sunflower is not affected by adjacent SNH type.
- SNH typology affects weed species composition and abundance in sunflower fields:
    - Fields adjacent to woody elements have a lower abundance of pernicious weed species, especially of annual dicots and rhizomous species, and weed cover is lower.
    - Fields adjacent to grassy elements are less likely to be responsible for invasions of *Digitaria sanguinalis* and in Hungary for *Ambrosia artemisiifolia* and *Hibiscus trionum*.

Overall, the potential disservice provided by SNH in terms of weed abundance is very limited and woody elements seem to decrease weed cover. On the other hand, woody elements may have a negative effect on crop yield in the first few meters due to root competition and shading. However, if fields are sufficiently large, this may not have a huge overall impact on total yield, and the slight negative effect may be compensated by reduced weed abundances.

Damage on fruits caused by birds is a severe disservice in Dutch fruit orchards. For many growers this caused a negative perception of SNH like forest and hedgerows close to their orchards. Although growers strongly relate bird damage to the presence of woody vegetation, this was not reflected by the percentage of woody SNH in the 1 km landscape sector (Table 1).

2.5 Perception of benefits by stakeholders and on-farm demonstration

Farmers as primary land users have the most power to interact with the land. Therefore, understanding **farmers' perception of ecosystem services** (hereafter ESs) through farmers' eyes is of primary importance: their assessments of ESs and their ideas about the possibilities of maintenance will be crucial for land management decisions. This comparative analysis presents how farmers understand the benefits and non-monetary value of on-farm ESs provided by SNHs in main cropping systems (arable, orchard, vegetable and vines) across four European agro-climatic zones in 8 European countries (the UK, Germany, France, Netherlands, Italy, Switzerland, Estonia and Hungary).

Our methodology relied on previous successful engagements with farmers in focus group discussions with a special emphasis on their perceptions on local ESs, as well as what kind of values they attribute to ESs, and how they understand benefits derived. Evaluation of private and public economic benefits and non-monetary value of selected ESs requires special socio-economic expertise and moderation/communication skills to be successfully delivered in the selected field studies. Therefore, ESSRG provided the case study partners with appropriate standardised methods (semi-structured interviewing, focus groups with farmers, mind-mapping) to assess farmers' evaluation of on-farm ESs provided by SNHs in the case study areas (Fig. A2). We recorded rich and complex set of perceptions about ESs, linked to multiple attitudes and values. Some (e.g. directly economic) aspects of ESs are frequently considered; other cultural or holistic aspects are not at all mentioned. Case studies were heterogeneous according to farmers' knowledge and belief system which influenced their perceptions and understanding of ESs and in this sense well-represented the heterogeneity of farming in the EU. The mind-mapping exercise produced a comprehensive and detailed set of farmers' perceptions of most important local ESs. Perceptions are strongly embedded in the agricultural context; less abstract and more emotion-based, connected to everyday farming lives. It shows that farmers normally do not think out of their agricultural contexts. Essentially, the analysis on the interrelatedness of ESs showed that farmers perceived many interrelations with a focus on economic ESs. In fact, farmers recognised that their agricultural practices had a direct impact on ESs and ESs were calculated in their farming decisions.

Attitudes are ambivalent: they usually build on personal feelings and ethical considerations and at the same time use rational economic arguments. Farmers appreciated ESs in multiple ways (e.g. enjoying aesthetics and sense of peace, benefiting from ESs, etc.) and valued it against the harm caused by pests, diseases and weeds (an indication of their success as agriculturalists). Positive attitudes typically go for yield and associated ESs including pollination; whereas negative attitudes are recorded towards Functional Biodiversity. Farmers have their own personal and ethical considerations, but these become *dissonant with economic rationale* and capacities in maintaining the farm. As a result, farming ideals and the real world requirements are often in conflict.

What constitutes ES benefit is very much **context-dependent**: ESs have different relative values according to the ecological and social conditions of a given case study setting. In essence, the economic are most appealing in farming. The perceived economic benefits are mostly related to farm management practices (especially how ESs relate to farm economics) and farmers' livelihood and identity as "Good Farmers". As a most important insight from these group discussions, it became clear that the concept of ESs is very well received in a given local contexts of farming. The valuation exercise also highlighted that the concept of ES is reinterpreted when farmers are involved in the discussions on the local scale. Therefore, understanding farmers' perceptions is crucial to invite them to maintain ESs. Furthermore, generating local level social learning processes (through extension and local study/action groups) can be as much important as supportive policies and subsidy schemes to shape the understanding of ESs. The exercise also pointed to the limits of monetary valuation in ES valuation, as they restrict benefits to economics which are seemingly important for maintaining the farm enterprise but less as an ideal for agriculturalists. Farmers mention 'yields' as the most important as this is the main success criteria represented by the CAP towards farming – however, according to farmers, this is problematic as yields are not equal with the money gained in exchange. Methodologies and results are further reported in Deliverable 3.4.

2.6 On-farm demonstrations

The "on-farm demonstrations" aimed at increasing farmers' awareness of ecosystem services, ecological functions and biodiversity and should improve capacity of farmers' communities to benefit from these services by future training activities (Fig. A3). On-farm demonstrations and farmers training were conducted in 8 countries by project Partners from 2013 to 2016 (see Deliverable 3.5).

Though key targeted stakeholders were farmers, several partners invited broader range of stakeholders (advisory people), or the events were sometimes linked to other ongoing research and development activities. In some cases, the press has been invited to increase advertising. One message from this is that linking specific demonstrations to other typical farmers' events may result in a win-win case, thus might be considered in the future.

Reports by partners showed that SNH and functional biodiversity in general may be interesting for farmers but specific problems (for instance dealing with an economic pest, weeding potential of flowering strips, etc.) that are usual relevant topics for farmers attract them to such demonstration meetings. This corroborates findings of the perception of the benefit study. If (as expected in co-innovation programs) farmers are involved in the project preparations, problem formulations, can contribute to field trial development, etc., they will feel themselves as important participants of and contributors to the knowledge and capacity development process. The participatory components (active involvement of farmers in the training and learning process, smaller group work and discussions, inputs by farmers in terms of topic selection, etc.) of the on-farm demonstrations were strengthened.

Based on reports by partners, it is likely that direct and immediate/short term solutions to problems and benefits are more attractive for farmers than long term perspectives. However, ESs by SNHs and farming system approach (including off crop SNHs) should be placed into a broader temporal and spatial context, as medium or longer term benefits can be expected only in such a context. Therefore, certain institutionalization of on-farm demonstrations and capacity development of farming communities is desirable in the future.

3.0 ANALYSIS AND PREDICTION WITH SPATIALLY EXPLICIT MODELS THE EFFECTS OF SPATIAL ALLOCATION AND MANAGEMENT OF SEMI-NATURAL HABITATS ON THE LEVEL OF SELECTED ECOSYSTEM SERVICE PROVIDED BY SEMI-NATURAL HABITATS IN FARMING SYSTEMS FROM FARM TO EUROPEAN SCALES (WP4)

3.1 Introduction

Farmers and policy makers need information on the strength and spatial extent of ecosystem services radiating out from semi-natural habitat as a result of movement of the insects (natural enemies, pollinators), providing those services. Such information would help to plan landscapes for optimal service provisioning, and it would also assist in developing incentive programs for semi-natural habitats. We developed a 2-D, landscape level, mathematical kernel approach to weigh contributions of different semi-natural habitats across a landscape, and predict the level of biological control in a focal field on the basis of contributions from different habitats (e.g. semi-natural habitats) in the surrounding landscape. This was conducted for two key ecosystem services (pest control and pollination) that are reliant on mobile ecosystem service providers (invertebrates).

3.2 Pest control

3.2.1 Approach

Employing a kernel, we used a rotationally symmetric 2D t-distribution with two parameters, one for the distance scale of service provisioning, and a second one for the relative delivery of services at very far distances from the source ("fat" tails). The mathematical formula for the kernel is given in Equation 1.

Using this kernel approach, contributions from sources of the same kind scattered at different distances from a focal field in a landscape are combined. Furthermore, kernels representing the contributions from different sources can be super-imposed, resulting in a calculation of landscape-wide delivery of ES from multiple sources. Regression models are used to quantify the strength of service provided by each type of habitat, taking into account how much of it occurred, scattered across the landscape.

Data analyses were conducted for individual case study data sets. Based on these analyses, heat maps were made depicting relative strength of ecosystem service over landscapes (Fig. 10). Overarching analysis, combining data from different case studies across Europe, were also made (Table 2).

Table 2. Land uses that affect *Poa* predation in each case study. Results are based on model selection with dredge in *R* for the optimal length scale *u* of the kernel model (Eq. 1) and the set of at maximum 3 land uses that can explain the observed predation rates the best (selection based on lowest AIC). Land uses written in green increase *Poa* seed predation, whereas land uses written in red decrease *Poa* seed predation. Estimates for α are marked red if the resulting basic predation level is smaller than 0.5 and green when the resulting basic predation rates are larger than 0.5 (high basic predation). The optimal length scale *u* is marked with a dash if there was no effect of distance within the 1 km radius. SNH are in bold.

Case study	Key habitats			α	*u*	AIC
Estonia		wheat		-0.4	-	186.2
France M.	**in-field SNH**		orchards (vineyard)	-1.2	400	172.7
Germany			orchards	-4.1	200	105.3
Hungary		wheat	roads	-1.4	-	183.3
Italy	**herbaceous linear**	wheat		-7.7	500	124.7
Netherlands	**herbaceous linear**	maize	roads	-2.6	200	116.3
Switzerland	**herbaceous linear**	**forest edges**	grasslands	-0.4	100	175.6
UK	**forest edges**	maize	grasslands	-4.9	50	104.6

3.2.2 Results

We found that semi-natural habitats were overall positively associated with biocontrol services, but the relationships were rather weak. On the other hand, differences in biological control between case studies were very large, and these could during the time frame of QuESSA not be explained by data collected within the case studies (Fig. 11). Further data analysis will continue after QuESSA, focusing especially on the interactions between ecological factors at landscape level and management factors, both at landscape and field level. Further results are given in Deliverable 4.1.

3.2.3 Main conclusions

3.2.3.1 For stakeholders

Greater quantities of semi-natural habitats in landscapes supported higher levels of biological control services. However, the responses of biological pest control to the amount of semi-natural habitat were rather shallow, and different kinds of semi-natural habitats were important in different case studies. Furthermore, length scales of the service provisioning differed across case studies. Overarching analyses for combined data sets for different case studies showed large differences in the level of service provisioning between countries, but these differences were not related to the landscape variables measured. A main conclusion for stakeholders is therefore that the effect of semi-natural habitats is moderate and context-dependent and needs to be measured in a specific landscape setting. Within QuESSA, we were not able to identify a single model that would give good predictions of biological control across Europe.

3.2.3.2 For policy makers

The differences in the level of service provisioning between case studies and the absence of a satisfactory statistical explanation for these differences indicates that different regions in Europe experience different levels of biological control, and landscape factors provided an insufficient explanation for these differences. Further analysis of landscape-wide or within-field management factors may perhaps elucidate causes of the differences, and was not completed at the end of QuESSA. The data also indicate that semi-natural habitats alone will not guarantee a sufficient level of pest control in farmers' fields, and the benefits of semi-natural habitats to farmers should therefore be articulated with caution. Further data analysis will continue after QuESSA, focusing especially on the interactions between ecological factors at landscape level and management factors, both at landscape and field level.

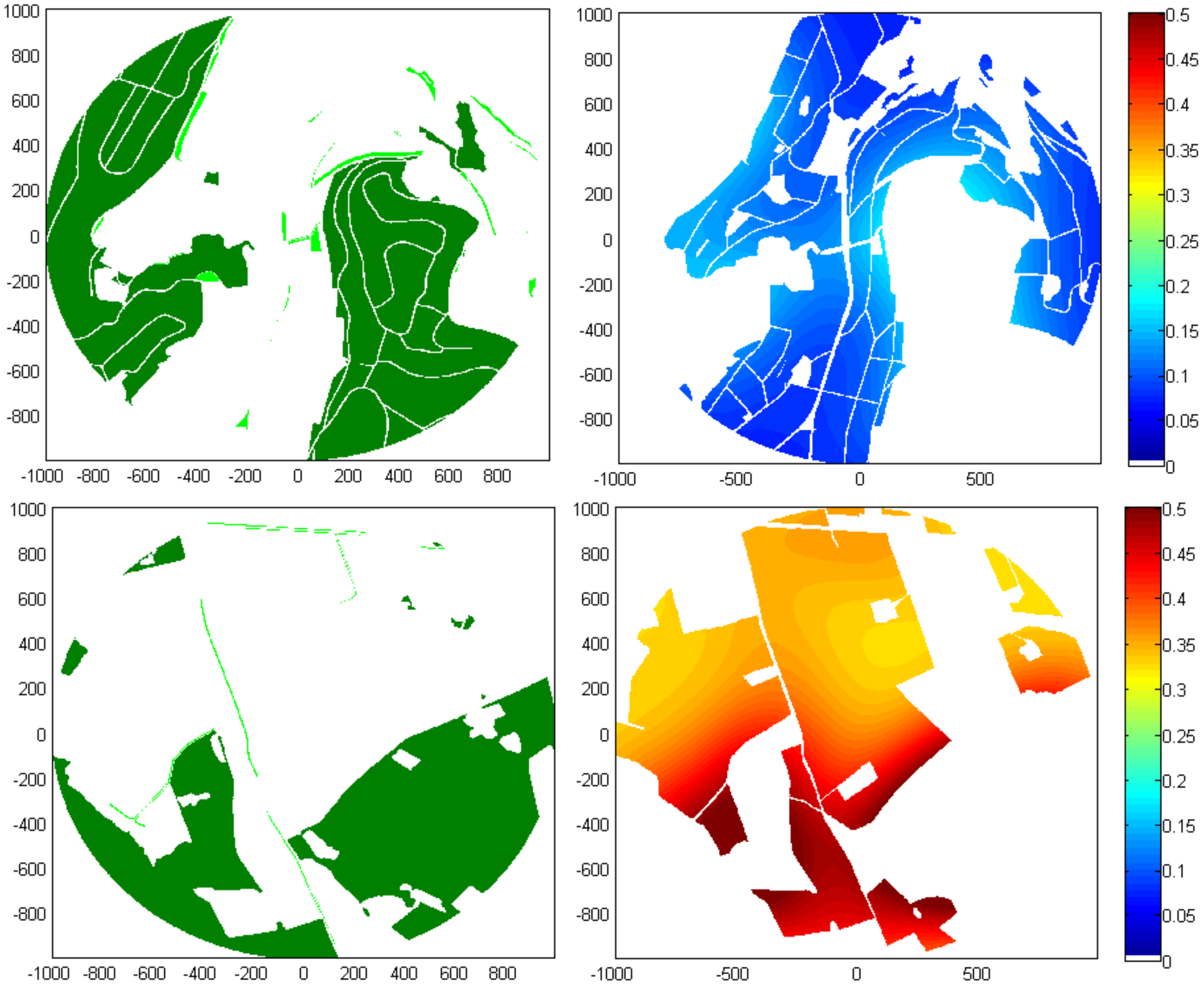


Figure 10. Predicted effect of herbaceous linear elements (light green) and forest (dark green) in a landscape sector of Switzerland (top left) and a landscape sector of Estonia (bottom left) on larval parasitism rates (proportion) of the rape pollen beetle in agricultural fields, taking into account the differences in basic parasitism rates between Switzerland (top right) and Estonia (bottom right). The colour bar depicts the range of the predicted parasitism rates and is expressed in units of proportion parasitization.

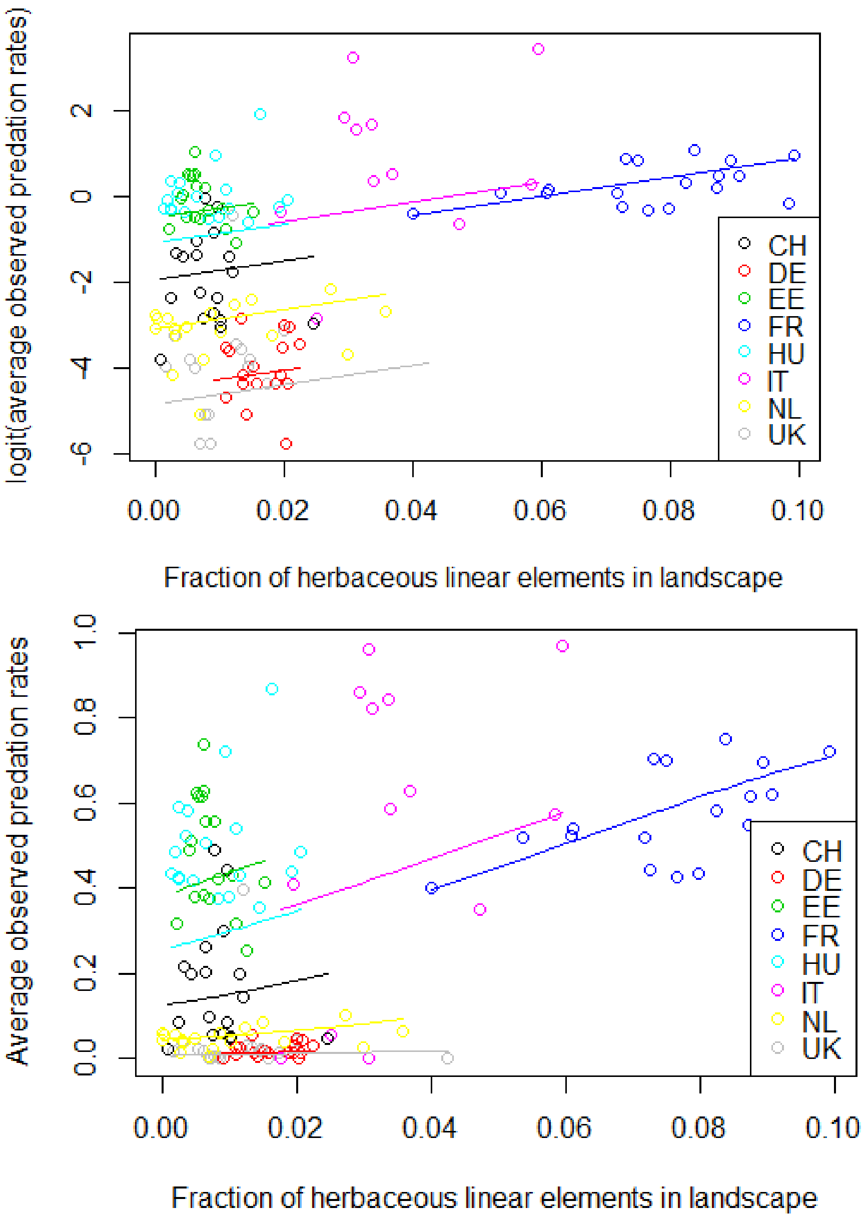


Figure 11. Variation in the relationship between predation on the seeds of Rough-meadow grass, *Poa trivialis,* and the proportion of herbaceous linear elements in the landscape. The figure exemplifies the large variability in predation rate between case studies that is not explained by landscape factors. Panel a shows data (open circles) and fitted relationship using a logit scale to plot predation proportion. The bottom panel has predation rate back transformed to the original proportion scale of measurement.

3.3 Pollination

Recently, there has been widespread concern over the decline of bees, with high rates of extinction during the twentieth century and in extant species there is evidence both of range contraction and of falloffs in abundance. Besides pollinating wildflowers, bees are economically important contributors to agricultural production.

3.3.1 Approach

Among entomophilous crops (i.e. those with flowers architecturally suited for insect pollination), the extent to which yield depends on insect pollinators is conventionally quantified by an index of 'pollinator dependence', which is the proportional decrease in yield when insects are excluded from the crop's flowers, here denoted ΔY_{insect} (Fig. 12). However, given current concerns over bee declines it is important also to consider the extent to which yields are already constrained below their maximum by deficiencies in insect pollination (Lautenbach et al. 2012). We use the term 'pollination deficit', denoted ΔY_{open}, to refer to the difference between the observed yield of a crop under open pollination (i.e. ambient conditions) and its maximum when fully pollinated, Y_{max} (Fig. 12).

Figure 12. Pollinator dependence and pollination deficits in four hypothetical crop species, A, B, C and D. In each column, black fill indicates the percentage of maximum yield that is achieved in the absence of visits by animal pollinators. Open fill indicates the realised contribution of insects to yield under ambient conditions (denoted ΔY_{insect}) and grey fill indicates unachieved yield, or the pollination deficit (denoted ΔY_{open}). In this case, crop A has received the greatest contribution from animal pollinators (ΔY_{insect} = 80%) and B has the highest deficit (ΔY_{open} = 50%) and would benefit most from more frequent pollinator visits. If we assume that a saturating level of pollination is delivered by hand-pollination, the difference in yield between open-pollinated and hand-pollinated flowers estimates the pollination deficit. Using standard nomenclature (Klein et al. 2007), crops A and B are 'highly' pollinator-dependent, C has 'modest' dependence, and D has 'little' dependence.

We tested the proposition that patches of SNH influence the pollination deficit of a focal field by delivering ecosystem service or disservice (see p12). We assume that the influence of a patch of SNH depends on its type and spatial proximity to focal field. Specifically, we assume that influence attenuates monotonically with intervening distance and that the relative effect of distance is the same for all types of SNH (i.e. a single kernel describes any distance-attenuation relationship). We assume that SNH patches act independently, each having an independent and additive effect on the pollination deficit in a focal field subject only to the intervening distance and without regard to the type(s) of intervening habitat patches. We assume that the distance-attenuation relationship follows a negative exponential decay, which is the Lonsdorf kernel. Based on these three assumptions, the kernel can be estimated from a dataset comprising observed pollination deficits and landscape maps from multiple focal fields by tuning its parameters through least-squares regression. We formalise this mathematically as follows.
In each country, there are *k* focal fields. Around each field, the surrounding area (within 1 km radius) comprised *i* pixels (quadrats of equal shape and area) that could each be occupied by one of *j* SNH types.
Let A^*_j denote the distance-weighted area of the j^{th} type of semi-natural habitat in the locality of the focal field. The distance-weighted sum of the area of SNH type *j* in the landscape is given in Equation 2.

In Equation 2, *a* denotes the area of each pixel (m^2) and α governs the strength of the distance-weighted attenuation of influence on the field's pollination deficit. Specifically, α serves as an ecologically meaningful tuning parameter, because it relates to the radial distance at which a patch of habitat type *j* has half the influence of a similar quadrat adjacent to the focal field, denoted D_{50}. Formally

$$D_{50} = 0.69 \text{ x alpha}$$

The importance of each type of SNH in influencing the focal field is given by $E_{0,i}$, which denotes the effect on pollination deficit of one unit area of SNH situated immediately adjacent to the focal field (i.e. at $r = 0$). Therefore, the total influence of SNH on the pollination deficit, delta *Y*, is given in Equation 3.

For each country, we analysed the variation in pollination deficits among the 18 focal fields in relation to the representation and dispersion of the four types of SNH in their localities. Specifically, we adjusted the degree to which SNH's influence attenuated with distance (α) until the landscape-based model (Eqn 3) provided the best explanation (largest *r*-squared) for the field-to-field variation in pollination deficits (ΔY_i). Using the kernel based on this best-fit value of α, we then treated Eqn 3 as a General Linear Model and the SNH types as independent predictor variables.

Specifically, we conducted ANOVA-based model simplification by sequentially eliminating the model component with the largest non-significant *p*-value until we obtained the minimal adequate model.

3.3.2 Results

3.3.2.1 Pollinator visits

In sunflower (Italy) and pumpkin (Germany), flowers could expect to receive more than 100 visits by bees during their receptive phase (Fig. 13a). By contrast, in the oilseed rape crops (Estonia, Switzerland, and United Kingdom) less than 10% of flowers could expect even a single bee visit (Fig. 13a). In the United Kingdom, our observations imply that only approximately 1% of receptive flowers were visited by an insect pollinator. In pear orchards (Netherlands), our observations suggest that most, if not all, flowers were visited by a bee.

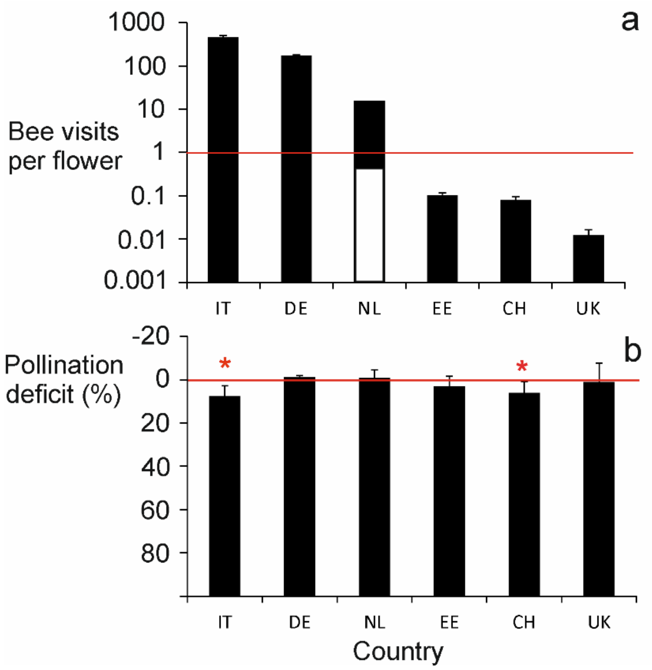


Figure 13. Rates of visits to flowers by eusocial bees (a) and pollination deficits (b) in bee-attractive crops in six European countries. Key to countries and crops:- IT: Italy (sunflower); DE: Germany (pumpkin); NL: Netherlands (pears); EE: Estonia (oilseed rape); CH: Switzerland (oilseed rape); UK: United Kingdom (oilseed rape);.

3.3.2.2 Pollination deficits

Regionally, we detected pollination deficits (c. 7%) in sunflower crops (Italy) and oilseed rape (Switzerland) (Fig. 13b).

Locally, field-to-field variation in the levels of pollination deficit could not be attributed to the representation of SNH in the surrounding landscapes, except in two cases. We found a statistical pattern consistent with short-distance ameliorating influences of linear woody features on the pollination deficits in Dutch pear orchards (*Yield percentage* = 93.1 + 17.4**area* (*woody linear*), α = 155 m, *r*-squared = 0.46, P < 0.01; Fig. 14). In Italian sunflower fields, by contrast, the proximity of linear woody features was associated with greater pollination deficits (*Yield percentage* = 95.9 - 226.1**area* (*woody linear*), α = 69 m, *r*-squared = 0.28, P < 0.05; Fig. 14).

We found that pollination deficits were generally small (<5% of yield under full pollination) in bee-attractive crops across Europe. If the deficits that we observed are representative across Europe, then their removal is worth €1.8 billion, which would be associated almost exclusively from increased production in sunflower.

In pumpkin and sunflowers, the pollination deficits were small probably because flowers received hundreds of insect visits during their receptive phase. In oilseed rape, by contrast, we estimated that only a small proportion of the crop's flowers were visited by bees. Instead, pollination was probably accomplished by flower-to-flower collisions when

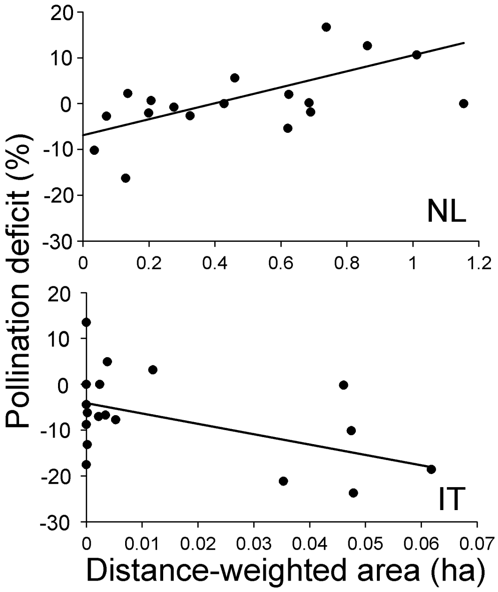


Figure 14. Site-to-site variation in pollination deficit (relative yield of open-pollinated and fully-pollinated flowers) in pear orchards in the Netherlands (upper panel: NL) and sunflower fields in Italy (lower panel: IT) in relation to the distance-weighted area (ha) of woody linear features in the surrounding landscape up to 1 km radius.

the plant stems were agitated by wind and, additionally, a small amount of pollen delivery through airborne transmission by wind. Taken together, our findings suggest that the pollination systems of entomophilous crops of Europe are performing adequately despite recent concerns over bee declines.

However, the variety of means by which the crops are pollinated makes their yields differentially vulnerable to the threat of future bee declines. Oilseed rape is virtually immune from the effects of bee decline by virtue of its capacity for autonomous pollination. Pumpkin is vulnerable only to a universal bee decline because it receives visits from a mixed pollinator fauna comprising both honey bees and wild bumble bees. Even though it is entirely dependent on insects to transmit pollen between its separate male and female flowers, provided that the landscape does not become bereft of bees, wild bees provide ecological insurance against a loss of honey bees, and vice versa. We speculate that sunflower yields are the most vulnerable to bee declines, depending on the variety used, the crop may be heavily dependent on insect visits for maximum seed set and their flowers are reliant almost exclusively on visits from honey bees, which presumably originate from local apiaries. The agricultural varieties used in Italy are both self-compatible and capable of self-pollination, but they typically achieve only half of their maximum yield without bees. If the supply of honey bees was threatened either biologically (e.g. by a newly emerging disease) or economically (e.g. by a change in the value of honey that discouraged local apiarists from maintaining their hives), the lack of wild pollinators makes the crop vulnerable.

3.2.3.3 Landscape effects on pollination

We observed that the nearby presence of rows of trees (i.e. woody linear features) was associated with site-to-site variation in pollination deficits in both sunflower fields and pear orchards. It is possible that the association results from direct causality, because previous studies have indicated that the foraging activities of bees are affected by the presence of intervening trees. However, the apparent effects that we observed differ in direction (trees are associated with improved yields in pears and reduced yield in sunflowers), so they may be correlation around an unstudied cause. In any case, our results do not provide support for a single pan-European approach to improve pollination by landscape management of woody semi-natural habitats. Further results are given in Deliverable 4.2.

3.3 Confronting synergies and trade-offs in ecosystem services at field, farm and landscape levels – a multi-criteria analysis (from field to landscape scale – ecological and socio-economic dimension)

3.3.1 Introduction

In WP4, task 2, synergies and trade-offs between different ecosystem services were explored. This approach is based on the perspective that agricultural land use does not only provide feed and food, but a range of other desirable outputs. In addition, a range of ecosystem functions are required to enable the provisioning of those outputs. Conceptually this combines perspectives of multifunctionality of agriculture and Ecosystem Services. The degree to which the various ecosystem services unfold depends on landscape structure and composition, in QuESSA with special attention for the role of SNH. The requirements for the methodology are thus that it is spatially explicit, allows evaluation at landscape level of different ecosystem services and is able to construct trade-off frontiers as well as showing the position of the current landscape with respect to these frontiers.

3.3.2 Approach

We developed the Landscape IMAGES framework to generate, evaluate and explore alternative landscape configurations. The framework generates a large number of alternative landscape configurations using an evolutionary algorithm, assesses the provisioning level of the five focal ecosystem services for each landscape configuration, and selects well-performing landscape configurations using a Pareto optimization procedure. The Pareto optimality front shows the trade-off that ultimately needs to be stricken if one ecosystem service cannot be increased without a decreasing another ecosystem service. However, current landscapes may be far removed from this Pareto optimality front, and thus win-win situations exist before trade-offs occur. Also, ecosystem services may be improve jointly, resulting in synergies. Which ecosystem services to address was elaborated in 3 workshops with local researchers representing the actors in the various case studies in QuESSA. Based on a long-list of objectives at the landscape level, the procedure narrowed down the list to 5 indicators representing (i) biological pest control, (ii) biodiversity conservation, (iii) carbon sequestration, (iv) landscape aesthetics, and (v) erosion prevention. The indicator for biocontrol potential was based on habitat suitability of the focal arable fields and the surrounding landscape elements for natural enemies. Habitat suitability of semi-natural habitats was informed by a literature review on habitat suitability for woody linear, woody areal, grassy linear, and herbaceous habitats (Holland et al., 2016). The indicator for biodiversity conservation estimated the number of species in SNH using a species accumulation curve approach, and was informed by spider samples collected by pitfall traps in herbaceous and woody habitats in 18 landscape sectors in Germany. The carbon sequestration indicator was based on land use specific organic matter contents of the top soil, which were then weighted by the area of each land use type. The indicator for landscape aesthetics was based on topographic indicators that are positively or negatively associated with aesthetic value. Finally, soil erosion was modelled using the RUSLE equation (Renard et al., 1997), which estimates the amount of sediment load out of a spatially defined landscape unit.

3.3.3 Results

We illustrate the method using two case studies in Germany and Hungary. Results indicated that ultimately trade-offs occur between aesthetic value and conservation value, whereas synergies were observed between aesthetic value and carbon sequestration, aesthetic value and prevention of soil erosion, and carbon sequestration and biocontrol (Fig. 15). While the trade-off/synergy curves have similar shapes in the German and Hungarian case study, clear differences in ecosystem service provisioning levels were observed in the two case studies, with generally greater potential in the German landscapes. The results of this study can help stakeholders to make informed decisions on ecosystem management in the case studies and as such contribute to the design of multifunctional landscapes.

As previously shown a landscape scale approach is needed to achieve actionable knowledge for stakeholders aiming for ecological intensification of agriculture. In addition, attention for biodiversity as a basis for ecosystem services, trade-offs among ecosystems services and active engaement with stakeholders is needed to bridge the think-do gap. In QuESSA attention has been focused on pest control and pollination, leaving only little room to develop indicators for other ecosystem services, let alone test these out with stakeholders. At the same time, QuESSA results make clear that biocontrol and pollination are not 'technologies' that have guaranteed returns on investment. Identification of synergies with other ecosystem services may thus be essential to facilitate transition to ecologically intensive rather than external-input intensive production systems. The approach developed in this project at the scale of small landscapes is well suited for this purpose. In a parallel Dutch Science Foundation project, interactions with stakeholders in a case study were possible and were received well. In addition, various publications are pending, which will also create impact in the

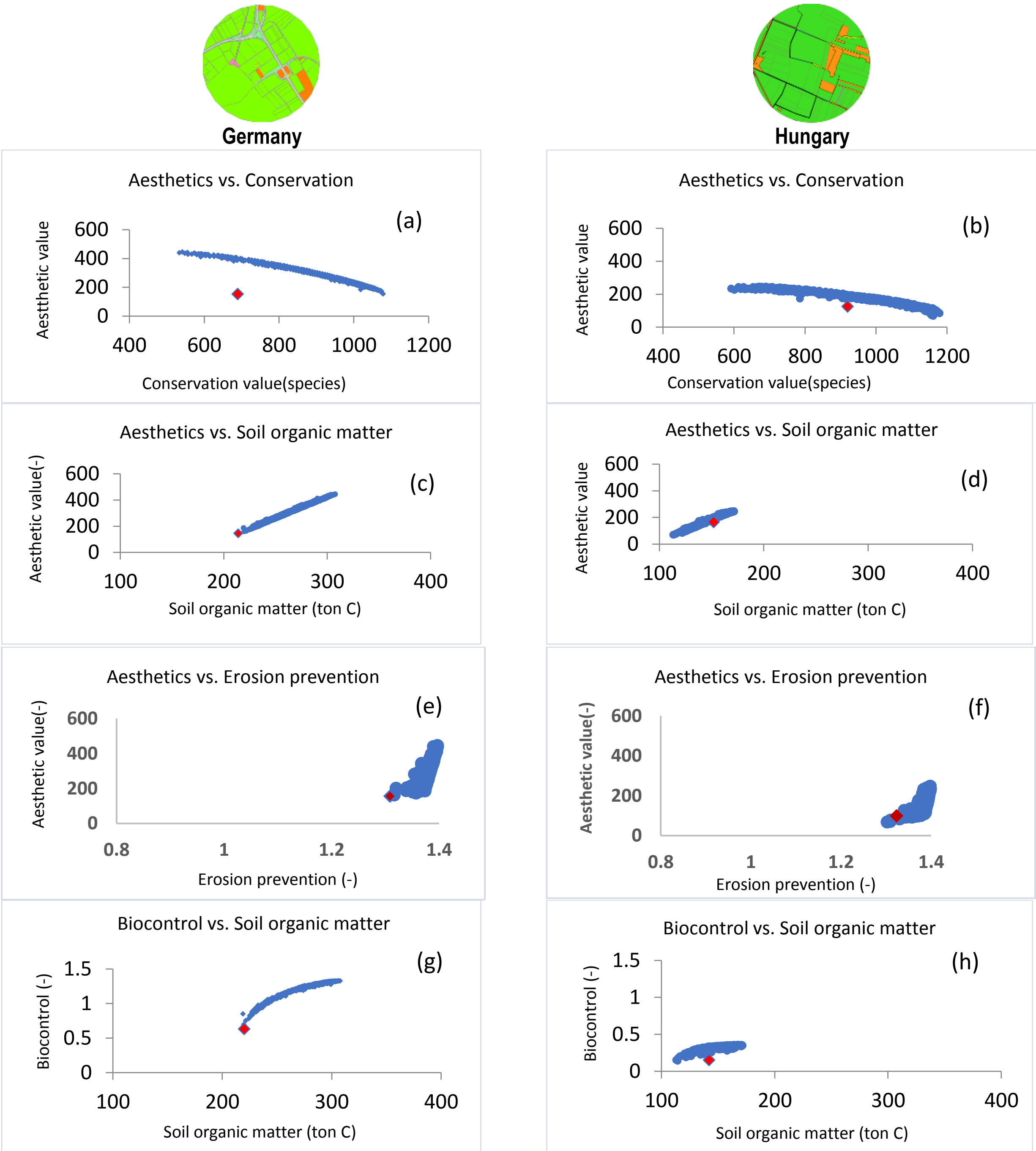


Figure 15. Trade-off/synergy curves for five ecosystem services in the German (left) and the Hungarian case study (right). The red diamonds show the ecosystem service provisioning level of the current landscape configuration, while blue dots show ecosystem service provisioning levels for alternative (Pareto-optimal) landscape configurations.

scientific domain. We now expect projects in which the approach developed in QuESSA can be mobilized in an action-research approach to support stakeholders in concrete landscape-level redesign endeavours. Fur further details see Deliverable 4.3.

3.4 Report on spatially explicit "heat maps" that show the intensity of selected ES over Europe, using existing data bases for land use, agricultural practices and natural habitat and making use of simplified "meta-models" that calculate ES from these available inputs.

3.4.1 Introduction

In WP4, task 3, we developed two spatially-explicit, fine-resolution models with whole European coverage to measure the pollination and pest control ecosystem services provided by semi-natural vegetation in agricultural land. The overall architecture and the main assumptions of the pan-European models are the same of the landscape models described in the previous sections. Patches of (semi) natural habitats in agricultural land were conceptualised as sources of beneficial insects (pollinators and predators) that disperse in the surrounding landscape according to a probability function, monotonically decreasing with distance from the source. We maintained the assumption that each SNH has an independent and additive effect on the pollination and pest control service, only depending on distance and the broad SNH type (woody areal, woody linear or herbaceous areal).

3.4.2 Approach

We processed recently available layers providing both high resolution and complete European coverage to derive the abundance of SNH habitats in the landscape, in particular the Copernicus Forest High Resolution Layer for woody SNH and the map of semi-natural grasslands in Europe developed previously for herbaceous areal vegetation. No suitable dataset representing herbaceous linear vegetation with European extent is currently available, so this SNH type was not included in the analysis. We combined these dataset with information from Corine Land Cover (2012) and on management intensity in agriculture from the CAPRI model (2008). A morphological spatial pattern analysis was carried out on the woody SNH layer to distinguish between woody linear and woody areal SNH and, within the latter, between edges and cores areas (Fig. 16).

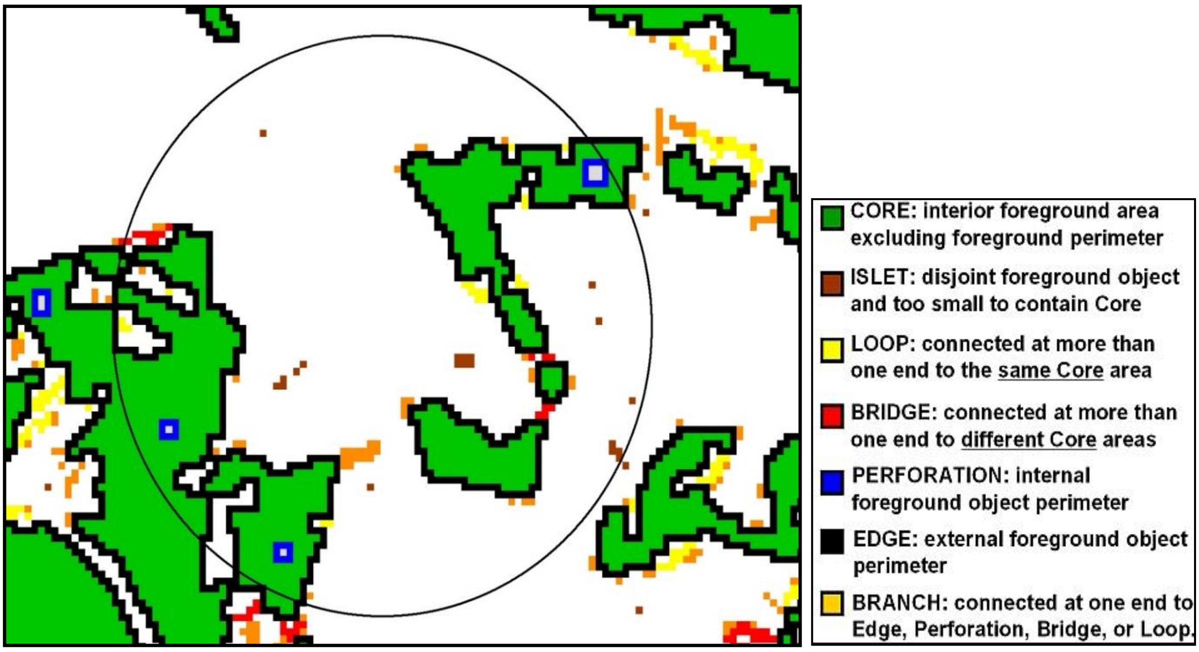


Figure 16. Example of Morphological spatial pattern analysis in a QUESSA landscape sector (black circle, 1 Km radius) to identify core (green) and edgy (black) woody areal SNH and Woody linear features (other colours) in agricultural land.

The denominator of the equation is a scalar used to normalize the output value to 0-1. Once the potential capacity to supply the service is determined with equation 4, a further processing step is carried out to match this with the demand side. By using again the same kernel function, an index of the abundance of the service delivered to each cell is calculated as described by Equation 5.

The obtained values are adjusted by taking account the activity potential of wild bees (i.e. the average time spent by a bee foraging outside the nest) that depends on ambient temperature, so that the general trend is a north-south gradient of bees' activity, also confirmed by the analysis of field data carried out in WP2)

The pest control model has the same conceptual structure, the only difference being that in this case the only characteristic of landscape cells considered when running the models is the presence and abundance of the different types of semi-natural habitats defined in QUESSA.

3.4.3 Results

The main novelty of the proposed models is that we used field-survey information generated in QUESSA to parameterized the models' equations; in particular, we used the scoring system developed in WP2 to weight the different capabilities of SNH in supporting the presence of wild bees and flying predators. The main results of this exercise are the two maps (Figs. 17a & b). Further details are available in Deliverable 4.4.

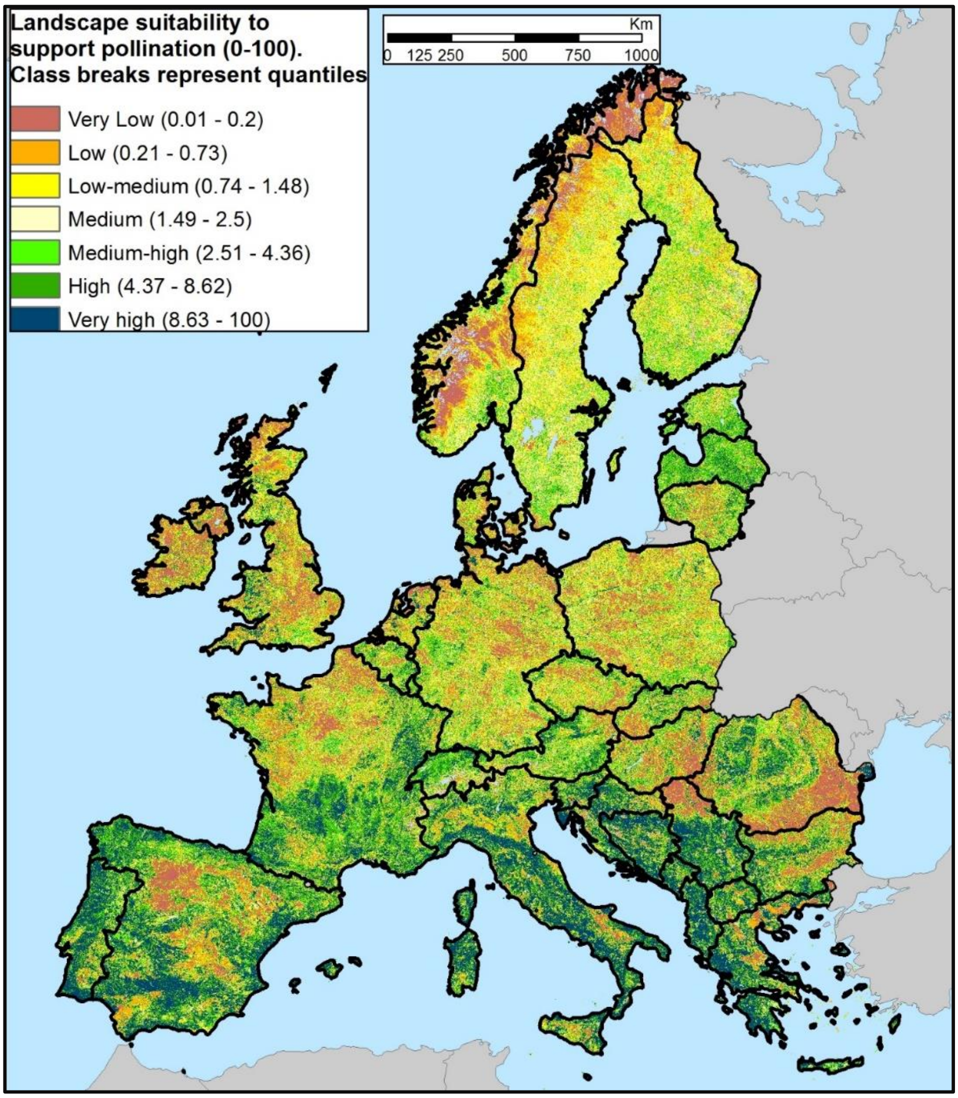
The approach described here allows for further refinements to be easily implemented, in case more detailed input layers become available (e.g herbaceous linear SNH). Results do not represent the actual ecosystem service provided, but the potential of the landscape, in its current configuration, to provide it. As such, they can be used to inform policy makers and relevant stakeholders in identifying areas were improvements can be achieved by enhancing the presence and spatial distribution of SNH, for example through the implementation of Ecological Focus Areas or agri-environmental schemes.

3.5 Development and running of web-based tool

In 2015 the Agriculture and Environment Research Unit (AERU) at the University of Hertfordshire in the UK developed a software application for the European Commission's Joint Research Centre (JRC) known as the Ecological Focus Areas (EFA) Calculator. This application calculates the potential impact on ecosystem services and biodiversity of different EFAs on a farm. Given the compatibility of QuESSA outputs with the EFA Calculator tool, the QuESSA partners agreed that a greater impact would be achieved by utilising the EFA Calculator software as a delivery vehicle for the QuESSA project outputs. AERU were commissioned to conduct this integration and this was successfully achieved. The EFA calculator is freely available at http://sitem.herts.ac.uk/aeru/efa/

The QuESSA impact categories that were integrated in the EFA Calculator included soil erosion, pollinators, pest control and aesthetics. Carbon sequestration was not a priority but has also be included. QuESSA also has techniques that could be used to assess impacts on biodiversity. This is not an ecosystem service in itself, but clearly impacts upon and/or is related to some ecosystem services. However, to avoid confusion with the biodiversity indicators that are already in the EFA Calculator (and which look at species groups) and as the diversity index was calculated using SNHs, this impact category was titled 'Habitat diversity'. A description of the full process in provided in Deliverable 4.5.

a) Pollination



b) Pest control

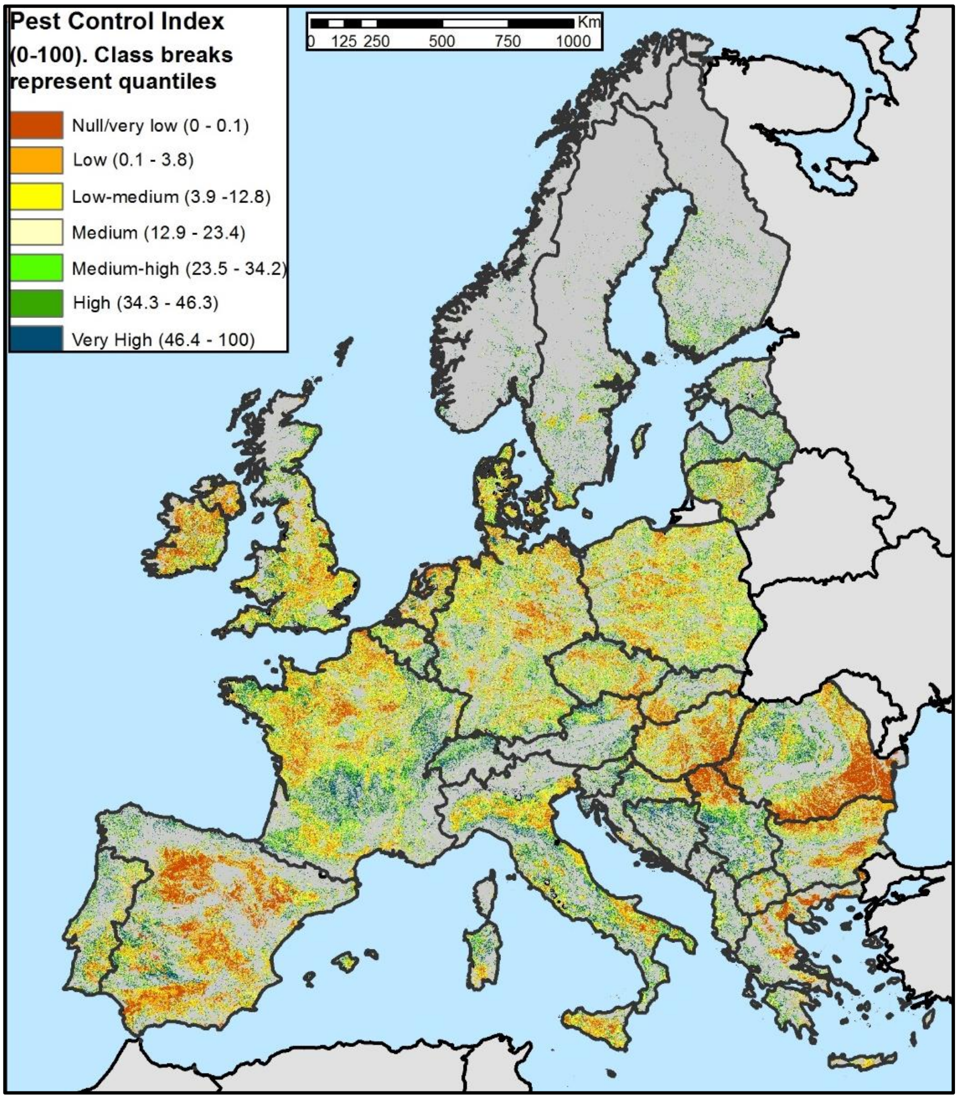


Figure 17. a) The potential of the landscape to provide pollination by wild bees **b)** the potential abundance of beneficial flying predators providing pest control in agricultural land. The values are expressed on a 0-100 scale and represent an index score.

Potential impact and main dissemination activities and exploitation of results

SUMMARY

The 4-year long QuESSA project included three years of field-based research conducted in 16 case-studies in eight European countries. As part of the process new standardised methodologies were developed and applied in each case-study which represents a true Europe-wide collaboration. Methodologies and protocols were developed that can be universally applied in future research and monitoring of semi-natural habitats, biological control, pollination, landscape mapping and measurement of some other ecosystem services.

a) Protocol for typing semi-natural habitats into five categories applicable across Europe.
b) Protocol for measuring the plant species composition and structure of semi-natural habitats.
c) Protocol for mapping the composition of agricultural landscapes at fine scales.
d) Protocols for measuring levels of biological control using sentinel systems comprised of insect prey or seeds.
e) Protocols for measuring pollination deficit across a range of crops.
f) Protocols for measuring a range of other ecosystem services including: aesthetic value of the agricultural landscapes using standardised landscape photographs; soil erosion using astroturf mats, soil decomposition using T-bags.

A huge amount of novel biological, geographical and crop management data was collected that provides a legacy for future evaluations of semi-natural habitats and their impacts. This included:

a) Vegetation composition and structure and functional traits of 539 semi-natural habitats.
b) Beneficial insects comprised of 7,253 honeybees, 14,519 wild bees, 20,087 parasitic wasps, 58,777 predatory diptera found both by transect and pan traps in semi-natural habitats.
c) Detailed description of the landscape composition of 450 sectors of 1 km^2.
d) Evaluations of sentinel systems to test for generic insect and weed seed predation and for plant-specific pests.
e) Measurement of biological control levels from 6,400 sentinel systems. Sentinel preys were placed either on the soil or on plants to measure predation of pests or weed seeds. Tests were carried out with standard sentinels and with preys corresponding to plant-specific pests.
f) Measurement of the pollination deficit of 3,500 plants.
g) Visitation rates of pollinators on 2,300 plots.
h) Feed-back of 352 persons were evaluated.

Novel analytical approaches were further developed and applied that included:

a) Scoring systems for evaluating the contribution of semi-natural habitats to pest control and pollination.
b) Kernel method of identifying the zone of influence and impact of landscape features on pest control and pollination and the generation of landscape heatmaps that identify the strength of these ecosystem services across the landscape.
c) Landscape IMAGES approach for identifying synergies and trade-offs between ecosystem services.
d) Application of scoring systems and scaling up to generate European maps depicting levels of pollination and pest control by flying predators.

Experts and stakeholders identified key recommendations, in the farm and semi-natural habitats management, offering room for improvement in terms of biodiversity and ecosystem services provided.

Six important issues were identified:

1) Knowledge transfer since a huge amount of work on semi-natural habitat and biodiversity was done. Scientists, farmers, food industries, consumers and policy makers are the main targets already identified.
2) Enhancing biodiversity to enhance ecosystem services.
3) Promoting the environmental friendly farming practices and SNH management.

4) Reinforcing green payments for certain Ecological Focus Areas.
5) Promoting the diversity and connectivity of SNH.
6) Promoting the multifunctionality of the SNH.

QuESSA results and particularly some outputs have been introduced to improve the Ecological Focus Area calculator, a standalone PC based tool for evaluating ecosystem services provided by the EFAs, developed for JRC by University of Hertfordshire (http://sitem.herts.ac.uk/aeru/efa/index.htm).
The project besides involving farmers in evaluations of non-monetary values of SNH also included a wide variety of communication and awareness-raising activities in order to reach key stakeholders such as farmers, advisors, and professional associations (see deliverables 2.5, 5.8, 5.9 and 5.10).

OVERARCHING CONCLUSIONS AND RECOMMENDATIONS – DRAWING IT ALL TOGETHER

One of the key aims of the QuESSA project was to evaluate the contribution of semi-natural habitats (SNH) to ecosystem service (ES) provision and at the same time to evaluate whether there were consistencies across Europe that could then be applied to inform policy, especially the CAP. The project used 16 case studies to evaluate the common methodologies for measuring ES delivery (see Deliverable 3.1). The crops differed across the case studies with relatively little replication of individual crops between case studies. This design introduced considerable inherent variability into the data which meant that if the impact of SNH was to be detected with an over-arching analysis of all case studies, it would be a strong effect. The experimental design, however, also had sufficient replication (18 sites per case study) that also allowed ES to be measured for individual case studies and for levels to be compared between case studies. This generated many findings on individual crops in the CS countries which are too numerous to describe here, but they are reported in Deliverable 5.8 Online and hard copy fact-sheets of recommendations for stakeholders (available at www.quessa.eu). The focus in the remainder of this section will be on the over-arching findings, recommendations and implications for European agricultural policy and agriculture, focussing predominantly on pest control and pollination which formed the major part of the QuESSA research programme.

The value of SNH for ES provision predominantly relies on the plant composition and vegetation structure. In particular, the ability of plants to provide resource for beneficial invertebrates that contribute to pest control and pollination. Resources include food, breeding sites and shelter from harmful agronomic practices. In QuESSA the plant composition of SNH was extensively investigated and in some cases also included measurements of beneficial insects (see Deliverable 2.2). These revealed that the SNH investigated supported an extensive diversity of plants and invertebrates, with some of conservation status (see Deliverable 2.4). One of the key findings was that herbaceous SNH were more similar at plant genus level between countries and agro-climatic zones whereas the herbaceous understory of woody SNH differed between Maritime, Mediterranean and Atlantic zones. This subsequently had a knock-on effect generating variability across the case studies for the ES quantification. Despite this variation in plant genus level the abundances of pollinators and flying predators and parasitoids was similar. A database of the functional traits of these plants was also compiled and attempts were made at determining simple SNH descriptors able to predict potential ecosystem service provisioning. The complexity of the data and scenarios prevented the link between plant traits and ES provision being used to develop a scoring system at the time of the project end, although the analyses are on-going. On the other hand, a scoring system for SNH types was developed based upon the levels of pollinators and flying natural enemies that contribute to pest control within each SNH type. This was subsequently linked to existing land use data allowing Europe-wide maps of 100m resolution to be compiled that predict levels of pollination and pest control (see Deliverable 4.4). This was the first time that predictive maps for pest control have been compiled. Further improvements in the resolution of the geospatial data for SNH, particular for narrow linear features, would aid in improving the accuracy of predictions and thereby their use for testing the future landscape scenarios.

For policy makers the inherent variation in the plant and invertebrate composition of SNH is an asset and therefore policies should aim to preserve and enhance this.

The scoring system and European-wide maps have many potential uses for both policy makers, agricultural strategists and sustainable farming.

a) Knowing the potential value of individual SNH habitats can help farmers and regional advisors on how to supplement or better manage such areas to improve ES delivery.
b) At larger scales, identification of areas where levels of these ES are low and interventions through provision of additional SNH habitats or targeted agri-environment schemes may be most beneficial. It was proposed that interventions for ES delivery would be most effective in intermediate compared to simple or complex landscapes.
c) Knowing the likely levels of ES such as pest control and pollination can also help at a more local scale when identifying whether localities are suitable for particular crops, for example those highly dependent on insect pollination. Similarly, such knowledge can aid with identifying the causes of lower productivity.

BIOLOGICAL CONTROL OUTCOMES

The evaluations of levels of pest control using the sentinel systems and crop specific pests revealed many varied and contrasting results (see Deliverable 3.3.) Individual case study and crop specific pest outcomes are discussed in more detail in D5.8. The over-riding conclusion though was that the results were very context specific and it was not possible to provide Europe-wide guidelines on the most valuable SNH or their spatial configuration in the landscape. Overall though the statistical analysis of the data generated using the kernel approach revealed a positive relationship between SNH and levels of biological control, but the relationships were weak (see Deliverable 4.1). In addition, although SNH were sometimes shown to have a positive impact on pest control as measured using sentinels, these effects were sometimes negative. similar results for parasitism on pollen beetle larvae in Estonia and Switzerland, significant landscape effects, but substantial differences between case studies. Parasitism of pollen beetle larvae in both countries depended on herbaceous linear elements and forests, but the level of predation in Estonia was much higher than in Switzerland. This difference cannot be explained by differences in the level of SNH in the landscape. Herbaceous linear elements, in combination with herbaceous areas, affected predation on the summer fruit tortrix in Dutch pear orchards. Furthermore, we found that forest edges had a negative effect on the number of earwigs found in Dutch pear orchards (Figure 19). This is a disservice, as earwigs are a generalist predator in pear orchards that predate on summer fruit tortrix. Overall, there was considerable variation between and within the case studies in levels of sentinel predation and the heatmaps generated in WP4, with some showing much higher levels, which indicated that there are opportunities for improvement. With respect to the type of SNH that contributed most to biological control there were some consistent trends with herbaceous linear elements, forest and wheat frequently having a positive effect.

In some cases it was possible to identify the natural enemies foraging on the sentinels and these were sometimes scavenging species. It is also likely that the generic sentinels attracted more scavenging species rather than pest specific ones. Scavaging species would provide background levels of control that may prevent pest outbreaks, but may not be the key species responsible for controlling faster developing outbreaks, which is usually delivered by specialist predators (e.g. Syrphidae) or parasitoids. In addition, having further information on the relationship between sentinel predation and actual pest control would have been valuable and is a topic for future research. The strength of relationships between landscape composition and seed predation were often stronger for individual case studies rather than with the overarching analysis including all case studies. This has implications for scaling up as this could not be achieved using Europe-wide scoring.

Recommendations for policy makers

The recommendation is that the strong differences in predation level between case studies and weed seed species imply that local data are crucial to identify greening policies that are beneficial in specific contexts. Differentiation between countries will be needed. Further research is also needed to evaluate how the quality and spatial distribution of SNH determines levels of biological control, some of which may be achieved through more intensive investigations of the QuESSA data.

The heatmap approach and scaling-up studies developed in QuESSA could also be used to explore how the collective management for plant protection could be employed and the scale over which this is implanted. Such an approach could also be employed to aid management of wild flora and natural enemies together.

The value of managing landscapes beyond those of individual farms is already being employed in water management through catchment sensitive farming initiative in the UK and Territorial Agriculture Plan in France. This can be achieved through the establishment of farmers' focus groups that take ownership of the objectives and decide on the actions to be implanted. In the UK the concept of cluster farms in which groups of farmers co-operate on a wide range of environmental issues an biodiversity management is gaining momentum.

Recommendations for farmers, advisors, trainers and for policy makers that would encourage more effective use of biological control

1. Shifting from the curative to a preventive approach to manage pest damage below an economic threshold on a long-term perspective.
2. Promoting conservation biological control as an important driver for preserving functional biodiversity in farming landscapes.
3. Dissemination of important host plants and indigenous natural enemies information for each crop by ecological zone through an online interactive tools such as Herbea, http://www.herbea.org/, an online platform to promote and inform on conservation biological control.
4. By providing free training for farmers and agronomists on conservation biological control.
5. Improve the management and the implementation of ecological focus areas to increase their diversity at farm scale (See D5.8-Semi-natural habitats and ecological focus areas management).
6. Promoting the environmental friendly farming practices (D5.8-Olive fly and Aphids on Pumpkin).

Contribution towards integrated pest management at farm and landscape scales

QuESSA revealed different responses according to crops, pests and agro-climatic zones; between and among predators, parasitoids and pollinators and linked or not to SNH. This indicated that rather relying on a single protection method a range of pest management options should be implemented as according to the IPM principles. This may involve combination of methods such as biocontrol, physical (insect-proof net, mulching) or cultural (tolerant variety, crop rotations, drilling dates, etc). It may also involve modification of agrochemical inputs some of which may be harmful to beneficial invertebrates and the plants within SNH. Data on management inputs was collected for some of the case study sites, yet owing to insufficient time and resources, remains to be fully explored. Whether this had impacts on SNH vegetation composition and ES, especially pest control and pollination may offer some novel and relevant findings. Data from the Italian pollination case study showed that pesticide use intensity decreased with increasing percentage of SNH, but no coherent effect on the abundance of pollinating insects in SNHs was found.

POLLINATION OUTCOMES

Much attention has been focussed on bee declines across the world and the potential implications for insect pollinated crops. Yet information about the levels to which pollination limits yield has previously been uncertain for most crops. A step forward in this process was achieved by QuESSA as the pollination-limitation of yield (harvestable mass per flower) in four crops (oilseed rape, sunflower, pears, and pumpkin) was measured in seven European countries (Estonia, Germany, Hungary, Italy, Netherlands, Switzerland, and the United Kingdom). Data from Hungary was not included in analyses. The total value of these crops from the EU was €35 billion in 2014 (Eurostat statistics). Pollinator activity (rates of flower visitation) was also recorded at each site. Additionally, we tested whether levels of pollination limitation were influenced by the presence and spatial dispersion of semi-natural habitats (patches of woody or herbaceous vegetation) around fields at distances up to 1 km radius, using the kernel approach. The findings are based on yield measurements in >1000 hand-pollinated flowers, >2800 open-pollinated flowers and approximately 300 h of pollinator observations.

Yield deficits

The yield deficit attributable to a lack of insect pollination (determined by comparing the yield from hand-pollinated with those of open-pollinated flowers) differed by an average of 3% over six case studies and a pollination limitation was statistically different in two cases: sunflowers in Italy (8%) and oilseed rape in Switzerland (6%), although power analysis indicated that differentials of up to 10% (average = 6%) may have gone undetected in the other four cases (see Deliverable 4.2). In the future, the threats to yield from bee declines depend largely on their dependency on insect pollination. Oilseed rape varieties are increasingly self- or wind-pollinated, whilst pumpkin receives visits from wild and honey bees so as long as ones is abundant their pollination is ensured. Sunflowers are the most vulnerable because they rely on pollinators, especially honey bee for maximum seed set. Although some varieties are capable of self-pollination, the yields are lower as shown by QuESSA research (see PhD Thesis by Miquel-Bartual, 2016).

The pollination deficits although small when scaled up are of economic value at even the farm scale and for the EU are worth €1 billion. In addition, they are worth rectifying if agricultural land is to increase in productivity to match population growth.

In addition, the area of SNH across the QuESSA sites typically exceeded 10%, with the exception of the Netherlands, and thus habitat provision for pollinators may be sufficient. There are however, other areas where SNH provision is inadequate as shown by the European maps for pollination and may require improvement.

Field-to-field variation in pollination limitation was linked with semi-natural habits but opposing effects were found; the nearby presence (within approximately 100 m) of woody vegetation was associated with relatively higher yields pears (Netherlands) but the opposite occurred with sunflowers (Italy). Both crops were foraged relatively intensively by honey bees. If SNH contain flowers more attractive to pollinators at the time the crop is flowering, then this may reduce pollination. Consequently, habitats designed to provide floral resources for pollinators should not include plant species whose flowering periods coincide with that of the crop. On the other hand though, the reverse may be needed if crops are likely to be treated at flowering with insecticides harmful to pollinators.

Overall the QuESSA results do not provide support for a single pan-European approach to improve pollination by landscape management of woody semi-natural habitats.

Pollinator visitation rates

Rates of visits to flowers by insect pollinators varied among crops by over three orders of magnitude, but they did not coincide with levels of pollination limitation. Whether wild pollinators were supplemented with honeybees also had an impact, as occurred with sunflowers in Italy, yet despite this there was pollination limitation. The lowest rates of pollinator activity occurred in the three case studies involving oilseed rape, where we estimate that less than 10% of flowers received even a single bee visit. Nevertheless, oilseed rape exhibited detectable pollination limitation in only one case (Switzerland), which we attribute to the efficacy of non-insect pollination in this crop.

Main conclusions for stakeholders

Our findings show that bee-attractive crops examined in this study may be currently experiencing pollination limitation at low levels, which nevertheless may significantly affect the profit margins for farmers. In the absence of honeybees these deficits may be larger, especially for sunflowers and pears. For oilseed rape growers, the level of self-fertility in the variety should be considered in conjunction with the surrounding landscape features if maximum pollination is to be ensured, although the impact of insecticides on bees must also be considered.

Main conclusions for policy makers

It is important to implement land-management strategies to sustain populations of farmland bees to maintain and improve services to crops and ensure food security, whilst ensuring pollination of wild plants. More detailed studies on pollen use by honeybees from the Italian case study, showed that woody features offer important pollen resources early in the growing season and other studies have shown the importance of these pollen resources for wild bees (D'Albore & Intoppa, 2000). However, woody linear features had a negative impact on sunflower yields in adjacent fields, therefore before implementing any SNH enhancement strategy it is essential to understand the impact it may have on pollinators and pollination. Manipulation of SNH, especially newly created habitats to increase or decrease bee visitation to crops has potential to increase production and mitigate for the environmental impact of insecticides.

Specific recommendations for farmers, advisors and trainers

1. For wild and honey bees, herbaceous elements with some shrubs seemed most attractive, especially from the Rosaceae family.
2. Do not cut flowering herbs like *Achillea, Leucanthemum, Hypericum* and *Trifolium* whilst flowering.
3. It is more beneficial to create small woodlots and herbaceous elements with diverse flower resources and to ensure floral resources are available for periods when beneficial insects are active.
4. Ensure that pesticides are used only when needed and that bee safe products are used to maintain bee health.
5. Maintain spontaneous flowering species in field margins (nutritive resources) to support energy needs of pollinators.
6. Introducing some early and late flowering species around crop fields, which will provide nutritive resources at the beginning of spring and during the autumn when resources are becoming scarce. Woody linear elements with early flowering species are very relevant in this context.
7. Honeybees need pollen as protein resource for their brood all through the year and pollens offered by wild species are very important, beside nectar.

OTHER ECOSYSTEM SERVICES AND THEIR INTERACTIONS

Agriculture relies on multiple ecosystem services that are often associated with semi-natural habitats. In QuESSA, a range of other ES were investigated including how SNH influence our perceptions of landscapes and their beauty (aesthetic value), the capacity of SNH to store carbon, soil fertility in SNH, soil erosion and biodiversity conservation. Some dis-services such as weed ingress and bird damage were also measured (see Deliverable D3.1).

Overall SNH enhanced most of these ES confirming that they play a useful, multi-functional role in agricultural landscapes. There was also little evidence of dis-services. Most of these ES have no perceived economic value for the land owner yet provide tangible benefits to society and the environment. For this reason protecting and improving SNH using CAP funding could be justified.

Some of the most important findings concerned soil properties. SNH contained between 35-50% more carbon than fields indicating that they make a contribution to carbon sequestration. However, when total carbon stored in the landscape sectors was calculated that included fields, more than 80% was contained within fields. The intensity and frequency of tillage is known to effect soil organic matter levels and thereby carbon sequestration, thus policies aimed at conserving soil organic matter (conservation tillage, minimum tillage) should form a part of any climate change policy.

SNH were also more fertile, however, this may not be advantageous to the flora as it can encourage aggressive, less valuable plants such as grasses, that then outcompete the flowering herbaceous plants providing resources for beneficials.

Synergies and trade-offs between ES delivery

QuESSA also investigated how SNH influenced the prevention of soil erosion, conservation value for biodiversity, carbon sequestration, landscape aesthetics, and biocontrol and whether there were synergies or trade-offs between them (see Deliverable 4.3). For this purpose maps were created of the spatial distribution of these five ES for landscapes in Germany and Hungary. The maps indicated that ecosystem service provision levels can differ markedly between and within landscapes and are strongly associated with semi-natural habitats. For instance, woody and herbaceous semi-natural habitats sequestered carbon in the soil, supported populations of natural enemies that can provide pest suppression services in crops, played an important role in the conservation of spiders, prevented soil erosion, and also contributed to the aesthetic value of the landscapes. Soil organic matter in arable fields can be increased by adding green manures, for instance by growing a cover crop in winter, which can not only increase carbon sequestration, but also improve soil fertility, soil structure, water infiltration and water holding capacity. Hence, the attained ES levels depend on characteristics of the landscape (e.g. proportion of semi-natural habitats) and management (e.g. application of green manure). The analysis of multiple ecosystem services in the German and Hungarian landscape revealed that the current configuration/management of the Hungarian landscape was quite favourable, while there was much room for strengthening ecosystem services in the German landscape. Collaboration between actors offers scope for the redesign of agricultural landscapes that better support multiple ecosystem services.

Main conclusions for policy makers on interactions between ecosystem services

a) Research frequently concentrate on evaluations of single ES (Holland et al., In press) but it is also important to consider non-additive interactions among ESs when evaluating, mapping or predicting them. This has fundamental implications for ecosystem management and policy when aiming at maximizing ES for sustainable agriculture.
b) For some ES it is the management of the fields that it is most important. The majority of carbon sequestration occurs within the organic matter of fields and therefore policies aimed at enhancing these levels through support for reduced intensity and frequency of cultivations would provide the most rapid impact. Of the SNH, conversion to grasslands would also encourage rapid carbon sequestration.

SEMI-NATURAL HABITAT AND ECOLOGICAL FOCUS AREA MANAGEMENT

From a long time, evidence has been accumulating on the important role of semi-natural habitats (SNHs). The value of SNHs was recognised by IOBC more than 20 years ago, defining them as ecological infrastructures. They are also present in the Agri-Environmental Measures in most of the EU countries, in cross compliance (e.g. France, Switzerland, UK) and since 2015 in the greening payments where specific SNH are defined as Ecological Focus Areas. Nevertheless, EFAs requirements are only calculated from SNH adjacent to arable crops for CAP greening measures.

Breaking some ideas: “evidence” vs. “perception” How SNH are perceived can vary amongst the farming community with some seeing them as potential sources of pests, weeds, damaging wildlife (e.g. birds) or inoculum reservoirs for viruses, fungi or bacteria e.g. dis-services. But, QuESSA results show that birds are responsible for only 0.2% of damages in Dutch pear orchards. For weeds, they were only present in higher abundance within 1 m of field edge.

QuESSA results also showed that there was no negative effect of SNHs for crop production except for a slight competitive aspect with sunflower. Nevertheless, this effect could be easily avoided by choosing specific species with early flowering compatible with the crop rotation so that they did not attract pollinators away from the focal crop during flowering.

Although the focus of QuESSA was not on biodiversity, some evaluations were conducted, especially of plants and revealed that SNH in agricultural areas support a wide diversity of plants and invertebrates including species of conservation concern. QuESSA was unable in the time available to identify those plants that most support functional biodiversity although with further interpretation of the database such relationships may be detected. The invertebrate species that contribute most to functional biodiversity are the common species, because these are the only ones numerous enough to provide services such as pest control and pollination. However, conservation policies are typically targeted at preserving rare or declining species. Agricultural policies should there aim to preserve and enhance SNH quality and associated species, in particular they should aim to prevent contamination with fertilizers and herbicides that can change the plant composition. Insecticides are directly damaging and can contaminate SNH either from spray drift or from contaminated run-off or soil water movement. Policies can also be supported through the multifunctional role of SNH. Their contribution to landscape aesthetics and thereby human well-being, contribution to climate change through carbon sequestration and prevention of erosion are some of the main motivators.

In addition, QuESSA demonstrated that high levels of biological control occur mid-field provided by beetles and spiders. Such groups are vulnerable to agricultural operations, especially intensive tillage and insecticides. Field-based EFAs can therefore contribute to their preservation provided they remain insecticide free.

There were considerable differences in the quality of SNH, yet only weak relationships were detected between SNH in the landscape and biological control and pollination using the kernel analytical approach. It may be that the quality of existing SNH for beneficial insects is insufficient and more targeted habitats are needed designed with plant species known to provide the resources for beneficial insects. Such habitats have already been designed and implemented for pollinators and have been proven to be successful, but for biological control some habitats have been developed, although their effectiveness remains to be proven. The QuESSA methodologies may help in this process of evaluating the value of engineered habitats.

The EFA calculator developed initially developed by University of Hertfordshire, UK was modified to incorporate QuESSA findings (see Deliverable 5.7). The calculator allows the user to enter information about the features on their farm to determine if they have sufficient amounts to meet EFA rules. The software also calculates the potential impact on ecosystem services and biodiversity of different EFAs on a farm. The calculator is currently only available in English although the user can select their country and thereby the relevant rules will apply. Translating the calculator into other languages would ensure wider use of this valuable and powerful tool. We therefore recommend that further funding is provided to facilitate this process.

Recommendations for farmers, advisors and trainers

a) Results are context-dependent, for a better adoption, farmers' expectations in terms of ESs (mainly soil fertility and support to crop production) should be considered. For instance, the inclusion of herbaceous elements in cropping systems as in-crop SNHs (e.g. as companion crops in facilitative intercropping design, or more generally as cover crops in crop rotations) could be more attractive for farmers willing to increase biodiversity in their farms and to support at the same time soil fertility and crop productivity.
b) Systemic analysis should be adopted to help in visualizing that in agroecosystems, each component is interconnected (e.g. impact of intercropping and cover crops on preservation of nesting or overwintering sites for beneficial arthropods).
c) Promote the implementation of the Green Infrastructure through the « Nature-based solutions », that improve and enhance habitats to support beneficials in farming landscapes. As promoted by EU (COM(2013)249), the idea is to promote a strategically planned network of natural and semi-natural areas, food webs to achieve goals of conserving and enhancing biodiversity, ecosystem processes and ultimately landscape scale delivery of ecosystem services.

Recommendations for policy makers

a) Field-based EFAs should aim to preserve pest natural enemies that reside within fields and therefore should remain insecticide free.
b) Reinforcing greening payments through certain EFAs depending on the contribution to ecosystem services.
c) Improve legislation to better protect SNH to ensure they are not polluted by agrochemicals (e.g. guarantee a minimum of buffer zones in the surrounding of SNHs) and apply this across the EU. For regions in which the landscape is dominated by small, fragmented properties, this requirement may need to be modified due to the high boundary to field ratio.
d) Promote research to fill gaps on the host plants to be supported at farm level to enhance beneficial arthropods.
e) Support research to develop new habitats designed to provide resources for service providers e.g. wildflower areas to encourage pollinators and pest natural enemies.
f) Consider the real surface area of EFAs and not the converted and weighted surface area. Indeed, one linear meter of hedge is currently equivalent to 10 m^2 of EFA (with a conversion coefficient equal to 5 and a weighting coefficient equal to 2). In the same way, one linear metre of field margin is currently equivalent to 9 m^2 of EFA (with a conversion coefficient equal to 6 and a weighting

coefficient equal to 1.5). This calculation with conversion and weighting coefficients tends to underestimate the benefits of hedges.

g) Promote Conservation Biological Control. Indeed, by combining the two approaches: “top down” by implementing/maintaining/well managing SNH adjacent to crop field to favour beneficial populations and “bottom up” by introducing more diversity inside the crop field to push away the pests (intercropping, cover crops), functional biodiversity is improved through plant diversity.
h) Promoting agroforestry systems, not studied in the QuESSA project, but best way to introduce herbaceous and woody SNH within the cropped field.
i) More funding for research and training programs, especially encourage focus groups, participatory research that encourage collective decisions at the territory scale (e.g. watershed).
j) Promote collective and coordinated crop management at a landscape level (farmers’ focus groups).
k) Promoting preventative approach by managing both the diversity of wild flora and beneficials: conservation biological control could be an important driver for preserving functional biodiversity in farming landscapes.
l) Promoting and disseminating rules of Integrated Pest Management (IPM) based on a range of management options since results were shown to be very context-dependent, rather than depending on a single protection method.
m) Supporting research and dissemination on ecological dynamics of the food chain in specific crops and its surrounding. This would encourage farmers to reach a greater sustainability of their cultivation, inspiring new reasoning and thoughts and more sustainable approaches to crop management, consistent with the main current direction of the European agricultural policy in increasing the sustainability of pesticides use.

WORKING WITH FARMERS

In QuESSA the case study partners worked closely with farmers and investigations were conducted to understand the benefits and non-monetary value of on-farm ESs provided by SNHs (see Deliverable 3.4). This was achieved using appropriate standardised methods (semi-structured interviewing, focus groups with farmers, mind-mapping) to assess farmers’ evaluation of on-farm ESs provided by SNHs in the case study areas. The "on-farm demonstrations" also aimed at increasing farmers’ awareness of ecosystem services.

One of the most important insight from these group discussions was that the concept of ESs was very well received in the local contexts of farming. The valuation exercise also highlighted that the concept of ES is reinterpreted when farmers are involved in the discussions on the local scale. Therefore, understanding farmers’ perceptions is crucial to invite them to maintain ESs. Furthermore, generating local level social learning processes (through extension and local study/action groups) can be as much important as supportive policies and subsidy schemes to shape the understanding of ESs.

Perceptions of ES were always are strongly embedded in the agricultural context and showed that farmers normally do not think out of their agricultural contexts with a focus on economic ESs. In fact, farmers recognise that their agricultural practices have a direct impact on ESs and ESs are calculated in their farming decisions. Farmers appreciated ESs in multiple ways (e.g. enjoying aesthetics and sense of place, benefiting from ESs, etc.) and valued it against the harm caused by pests, diseases and weeds (an indication of their success as agriculturalists). Positive attitudes typically go for yield and associated ESs including pollination; whereas negative attitudes were recorded towards Functional Biodiversity. Farmers have their own personal and ethical considerations, but these become dissonant with economic rationale and capacities in maintaining the farm. As a result, farming ideals and the real world requirements are often in conflict.

The exercise also pointed to the limits of monetary valuation in ES valuation, as they restrict benefits to economics which are seemingly important for maintaining the farm enterprise but less as an ideal for agriculturalists. Farmers mention ‘yields’ as the most important as this is the main success criteria represented by the CAP towards farming – however, according to farmers, this is problematic as yields are not equal with the money gained in exchange.

The interactions with farmers also highlighted the dis-connect between research and farming requirements. Researchers were not involving farmers in the development of research ideas. Research results were not being communicated to stakeholders. Research findings were not accessible to farmers, they don't have access to journals and often such publications do not present findings in a user-friendly, knowledge exchange format.

Recommendations for policy makers in relation to farmers

a) Promoting co-innovative framework between farmers, advisors, researchers and trainers to help in the development of ES research and ecological transition. Collaborating with farmers from the start through participative methods (focus groups, interviews, on-farm demonstration) to involve them in the process from the beginning encourages them to take ownership of the concepts of ES, functional biodiversity and SNH.
b) Further research is needed because scientific knowledge is still insufficient: lack of predictable response of organisms (complex interactions), of management indications for multiple ES and of the services provided by individual plant and insect species is limiting uptake by stakeholders.
c) Knowledge transfer: too little dissemination of the "success stories" to stakeholders.
d) Technical solutions are needed, especially for SNH management. For example, there is a lack of adapted machinery for small scale vegetation management.
e) Financial and technical support is needed for farmers and SNH managers to develop and implement locally adapted SNH management.

FINAL CONCLUSIONS

The QuESSA project was challenging since it aimed at exploring complex landscapes and ecosystems (various crops, management and agro-climatic contexts) and many partners interacted with a wide range of stakeholders. It is the first project that investigated the contribution of different types of semi-natural habitats to ecosystem services at field to landscape levels. New methodologies had to be developed and were then applied across many countries and cropping systems to assess ecosystem services, a scoring system was also developed and applied to upscale the results.

Concerning the biological control, the observed level varied much between and within case studies. The SNH type and the distance from SNH into the field had a positive impact but not in all cases. It was shown that herbaceous linear elements and forest can have a positive effect on this service. Nevertheless, over-arching analyses revealed that no general predictions could be made across landscapes.

Concerning pollination, regionally, two (CH, NL) of the six countries we analysed (EE, CH, UK, DE, IT, NL) had a statistically detectable pollination deficit that limited crop yield. Field-to-field variation in levels of local pollination deficit was associated with the quantity and distribution of semi-natural habitat in two countries (EE, IT).

Soil erosion prevention, conservation value for biodiversity, carbon sequestration, landscape aesthetic value and biocontrol differed between & within landscapes. Strong associations with semi-natural habitats and between some ecosystem services were shown for carbon sequestration, aesthetics and biocontrol as well as for prevention of soil erosion and aesthetics. Nevertheless, some trade-offs need to be adjusted between aesthetic and conservation values.