QuESSA

Quantification of Ecosystem Services for Sustainable Agriculture

This project received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 3111879

Preface

"FAO partnership with Academia to strengthen quantification of Ecosystem Services"

Kakoli Ghosh
Coordinator, Academia and Research Partnerships,
Food and Agriculture Organization of the United Nations

To meet rising global food demands, agricultural systems need to produce greater quantities of more diverse and nutritious food in a sustainable way. FAO has developed an approach aimed at enhancing the contributions of agriculture, forestry and fisheries to sustainable development and to address sustainability issues across these sectors. Based on a set of principles for **Sustainable Food and Agriculture** (http://www.fao.org/3/a-i3940e.pdf), FAO promotes policy dialogue and the development of joint and coordinated actions involving governmental bodies, the private sector and civil society and academia and research institutions.

This inclusive approach through dialogue and partnerships is the cornerstone of FAO's commitment to elimination of hunger and it is convinced that knowledge, skills, influence and voice of all relevant sectors need to bring together to achieve sustained food security. In this regard, Academia has a major role and FAO is partnering with academia and research institutions in diverse ways to mobilize existing knowledge, spread innovations, strengthen capacities and generate evidence to support policy processes. FAO is working with academia to engage at the local levels, shares experiences, motivate future practitioners, combine synergies and capacities for results on the ground.

The QUESSA project which held its final meeting at FAO, exemplifies this approach. The meeting allowed dissemination of project result, as well as exchange of global and local experiences. The methodology that has been developed by the project to quantify the key semi-natural habitats that provide essential ecological services for cropping systems in the European context agro-climatic zones, can be adapted for testing in other agro climatic zones. FAO shared its field knowledge working with smallholders on ecosystem services ranging from watershed management, pollination services and cropping systems. This type of focussed and productive interactions must continue for achieving a common understanding of what sustainable food and agriculture means, and agree on the most appropriate strategies and approaches to its implementation, in different contexts and at different scales.

Lukáš Víšek
Economist and policy analyst from European Commission
DG Agriculture and Rural Development

Agriculture and food production are fully dependent on natural resources and farming greatly influences environment. Farmers and their approach to farming can be both a problem and a solution for environment. A good example comes from combat with climate change - while EU agriculture is responsible for 10% of GHG emissions in Europe (and there has been a substantial decrease in the past two decades), it also tackles climate change by producing renewable resources and by sequestering carbon, as well as by sharing and recycling resources. Another example is linked to biodiversity where agriculture can help maintaining valuable habitats that owe their existence to past farming practice that have lost over time their economic profitability while still being essential for preserving the biodiversity once created.

As such, the Common Agricultural Policy remains an important driver of natural resource management. As of 2015, farmers receive more than EUR 12 billion every year in exchange for carrying out the prescribed greening practices, including maintenance of landscape features and crop diversification. In addition, 17% of agricultural and 3% of forest land is expected to come under management contracts contributing to biodiversity before 2020. In parallel, 14% of agricultural and 3% forest land should come under management contracts for improving soil management, and 15% of agricultural and 4% of forest land for improving water management. All farmers receiving direct payments and all farmers taking on these contracts have to manage their land in a way that respects the rules of cross-compliance.
Nevertheless, it is only via the continuous creation, spreading and application of knowledge that the most effective and resource-efficient production techniques can be applied. To that end, the CAP supports farmers in getting help from advisors as well as from other farmers. In addition, the European Innovation Partnership for Agricultural Productivity and Sustainability (www.eip-agri.eu) provides a platform for building and sharing knowledge across the EU.

Contents

Introduction

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 ecosystem services and are worth billions of euros every year in each European country. Semi-natural habitats 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, shaping our perceptions of landscapes and sequestering carbon.

The European reasearch project QuESSA aimed to quantify the key semi-natural habitats (hereafter SNH) providing these essential ecosystem services (hereafter ES) across a range of economically important cropping systems, farming intensities and four European agro-climatic zones. This was achieved by bringing together 14 European research, education and extension organisations, a European stakeholder advisory board and 16 local stakeholder groups to contribute to regional case studies. The research was conducted simultaneously in eight European countries (England, the Netherlands, Estonia, Germany, Hungary, Switzerland, Italy and France) between February 2013 and January 2017.

The contribution of SNHs such as hedgerows, grass strips, woodland, extensive pasture to key ESs for sustainable agriculture was achieved by first identifying vegetation traits responsible for supporting ecosystem services and making predictions about their value. Actual ES provision was then measured in 16 case studies. The ES investigated focused on control of crop pests by natural enemies, crop pollination, but also included services such as erosion mitigation, soil organic matter accumulation, crop yield, weed control and landscape aesthetics whilst also addressing possible disservices. Investigations of private and public economic benefits, and non-monetary value of selected ES were also conducted.

Data have been used to develop mathematical models for mapping ecosystem services at multiple levels of scale: from farm to the whole EU. Models have also been used to explore synergies and trade-offs among ES by SNH from habitat to landscape scale and identify unused opportunities to better exploit ES.

The research was targeted at the requirements of local and national stakeholders and provided valuable outputs that can be used to improve ES provision from SNH. Practical guidelines and policy recommendations have also been produced.

Focus on definitions:
Ecosystem services (ES): include supporting, provisioning, regulating and cultural services whose benefits are appreciated by humans. QuESSA focussed on pest control and pollination but also investigated erosion mitigation, soil organic matter accumulation and landscape aesthetics.
Semi-natural habitat (SNH): any habitat where human induced changes can be detected or that is human managed but which still seems a natural habitat in terms of species diversity and species interrelation complexity.

The project received funding from the European Commission through the Seventh Framework Programme and was coordinated by the **Game and Wildlife Conservation Trust** (GWCT), a UK charity that has been working for 80 years promoting nature conservation and sustainable farming practices. The partners included organizations, private or public, with extensive experience in farming, biodiversity and ecological services.
In France, **Solagro** has been a reference in sustainable farming, energy and natural resources management since its creation in 1981.
Scuola Superiore Sant'Anna (Italy) is a public university since 1986. The Agroecology Group of the Institute of Life Science focuses its work on the development of sustainable cropping and farming systems based on agroecological principles mainly by managing the vegetation aimed at introducing and supporting functional biodiversity.
Universita di Pisa (Italy) is a public university since 1343. The Centre for Agri-environmental Research "Enrico Avanzi" is the experimental station of the departments of Agriculture and Veterinary Medicine, focusing its work on sustainable farming systems and agri-environmental issues, in close collaboration with Scuola Superiore Sant'Anna.

Agroscope (Switzerland) is the Swiss centre of excellence for agricultural research which contributes to a sustainable agriculture and food sector as well as to an intact environment.
Wageningen University & Research (the Netherlands) is collaboration between Wageningen University and the Wageningen Research foundation (Stichting DLO). It is a leading life science university in Europe focusing on research and education in sustainable food production, health, and quality of life.
Bordeaux Sciences Agro (France) is a public higher education institute and agronomic research facility under the authority of the French Ministry of Agriculture, Agrifood and Forestry. Founded in 1962, Bordeaux Sciences Agro works with 40 permanent teaching staff including 15 professors, experts in several domains in particular agroecology and relationships between crop and vine fields, pest insects and landscape effects on functional biodiversity.
The **Szent Istvan University** (Hungary), Gödöllő is the largest one of this kind in Hungary covering broad range of rural development related sciences. The university runs BSc, MSc and PhD programs with more than 18 000 students on 7 campuses. The Plant Protection Institute (PPI) consists of five groups: Phytopathology, Agric. Entomology, Weed management, Integrated Pest Management (IPM), Diagnostic and innovation management. PPI covers all relevant fields of plant protection but has been focusing on development of IPM in its activities.
University of Koblenz – Landau (Germany) is a young university with a special focus in Environmental Sciences. The Ecosystem Analyses group focuses on the structure and function of ecosystems under agriculture and other human influences.
University of Exeter (United Kingdom) Biosciences at the University of Exeter is a research-intensive department and a rapidly expanding international centre for research and teaching across the spectrum of the biological sciences. The academic community is actively involved in producing world-class and groundbreaking research. Consequently it isone of the foremost research departments for Biosciences anywhere in the UK.
Estonian University of Life Sciences (Eesti Maaülikool, Estonia) became independent from Tartu University (Est. 1632) in 1951 under the name of the Estonian Academy of Agriculture and received its present name in November 2005. It is the only Estonian university that is focusing on sustainable development of agriculture, natural resources, preservation of heritage and habitat.
The **Join Research Centre (JRC)** is the European Commission's science and knowledge service, its mission is to support EU policies with independent evidence throughout the whole policy cycle. As one of its fields of research, the JRC helps the European Commission and EU Member States to understand how agriculture and the environment are interlinked by providing scientific knowledge gained from geospatial and modelling-based assessments.
ESSRG (Hungary) is an R&D SME working on the boundaries of environmental and social sciences with a transdisciplinary approach.

Sixteen case studies were conducted across eight countries, four agro-climatic zones and seven crops (olive, sunflower, oilseed rape, winter wheat, pear, vine and pumpkin) focussing either on pollination and/or pest control (*Figure 1*). For each case study, 18 focal fields were assessed.

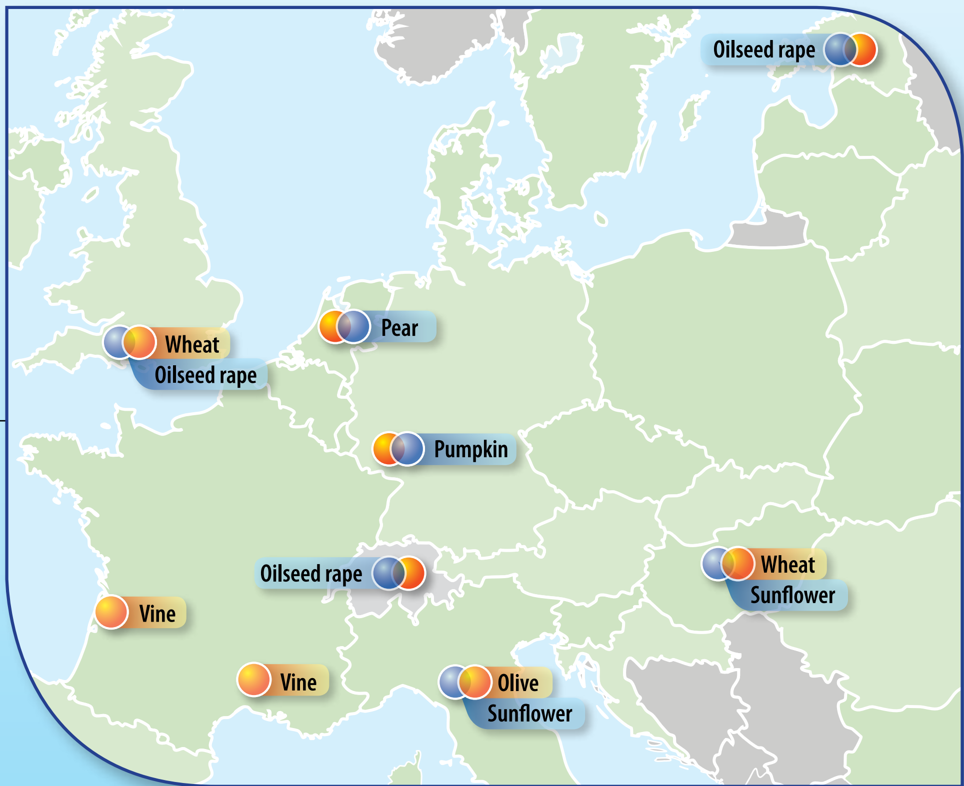


Figure 1. Sixteen case studies conducted across Europe for QuESSA project.

Pest Control

Pollination

QuESSA in numbers

Focus on what was done during field experiments:

- 539 "SNH" were sampled with a description of vegetation composition and structure and functional traits
- for QuESSA Scoring System, 7,253 honeybees, 14,519 wild bees, 20,087 parasitic wasps, 58,777 predatory Diptera were sampled both by transects and pan traps in SNH
- 450 sectors of 1 km^2 were mapped,
- 6,400 sentinel systems were set up. Sentinel preys were placed either on the soil or on plants to measure predation of pests or weeds. Tests were carried out with standard sentinels and with preys corresponding to plant-specific pests.
- the pollination deficit of 3,500 plants was measured
- the visitation rates of pollinators were measured on 2,300 plots
- feed-back of 352 persons were evaluated
- on-farm demonstrations were organized

Experts developed some methods to measure ecosystem services at field and landscape levels. Together, 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.
Seven important issues were identified:

- 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.
- Enhancing biodiversity to enhance ecosystem services.
- Promoting the environmental friendly farming practices and SNH management.
- Reinforcing green payments for certain EFAs.
- Promoting the diversity and connectivity of SNH.
- Promoting the multifunctionality of the SNH.

QuESSA results and particularly some outputs have been introduced to improve the EFA 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 also included various communication and awareness-raising activities in order to reach key stakeholders such as farmers, advisors, and professional associations.

In conclusion, the objective of the QuESSA project was to contribute to making the European farming sector an international leader in terms of protection of farmland biodiversity, ecosystem services delivery, considering the key role of farmers in a sector that serves different purposes not only food production but also climate risk mitigation and adaptation, soil protection, cultural heritage, landscape aesthetics and conservation value.

Methodology

Measurement of ecosystem services

Potential ecosystem services

The objective was to build a tool for easily predicting how good a semi-natural habitat should be in supporting pollination or pest control ecosystem services. This tool is called **Quessa Scoring System**. It is based on spatial traits, features of the SNH that can be easily mapped in a GIS environment to be up scaled at the Pan-European level.

A **typology** was defined to describe the vegetation composition and SNH structure with **5 SNH types**:
Field Area (FA), Woody Areal (WA), Herbaceous Areal (HA), Woody Linear (WL) and Herbaceous Linear (HL) as described in Figure 2.

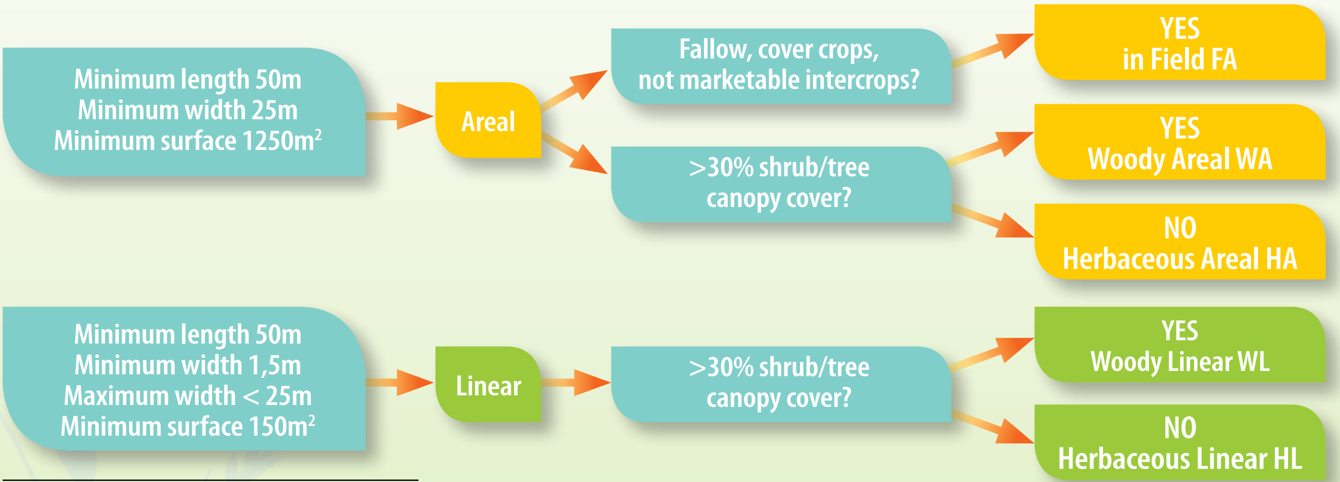


Figure 2. SNH typology for QuESSA project

Natural enemies, pollinators and pests were collected or observed using a series of techniques including coloured pan traps, pitfall traps and transect walks (*Figure 3*).

Coloured pan traps

A pitfall trap

A transect walk for pollinators counting

Figure 3. Sampling methods to measure ES providers

Pollination and pest control scores were calculated with models using the abundance of the service providers in relation with two SNH descriptors:

- The type (WL or WA and HL or HA) described above.
- And the position where service providers were measured (edge or interior).

Analysis was run at two levels: both at the Pan-European and at the Country level. Scoring system was based on data from the 4 countries Italy, Germany, UK and Switzerland since data from the other countries were not sufficient.

Pollination score was based on **bee abundance**[1] (*Apis mellifera* and all wild bee species[2]) from pooled data gathered from pan traps and transect walks (4 sampling periods in a year).

Pest control score was based on flying predators (Parasitica[3], Syrphidae and other predatory flies[4]) from pantrap data.

Scores were calculated by using generalized linear mixed models[5].

For more details, please contact:
moonen@sssup.it

[1] *Syrphids* or Lepidoptera were not taking into account in this analysis.
[2] *Bombus, Eucera*…
[3] Chalcidoidea, Ichneumonoidea
[4] Empididae, Dolichopodidae, Asilidae

[5] Generalized linear mixed models (or GLMMs) are an extension of linear mixed models to allow response variables from different distributions, and are built to include both fixed and random effects (hence mixed models). In QuESSA case studies, random effects are related to plot, field crop, temporal replicate, spatial replicate, year…

General design

In each CS, 18 landscape sectors (LS) of 1 km radius based around a focal field were selected that varied in the proportion of SNH from low to high for the region. Focal fields were selected with an adjacent SNH that was either woody, herbaceous or control (no SNH or grassy strip), with 6 LS of each SNH type. Measurements of pollination or pest control using sentinels were conducted along two transects extending from the SNH to the field centre (*Figure 4*). The abundance of beneficial arthropods was also evaluated along the transects by combining destructive and non-destructive methods. Pitfall traps, and pan or sticky traps were set up for ground dwelling and flying arthropods, respectively. Sweep nets, pan traps and observations were used for pollinators (this included Syrphidae whose larva are important predators of aphids). Videos were also used to visualize the predators and parasitoids communities attracted by the sentinel systems.

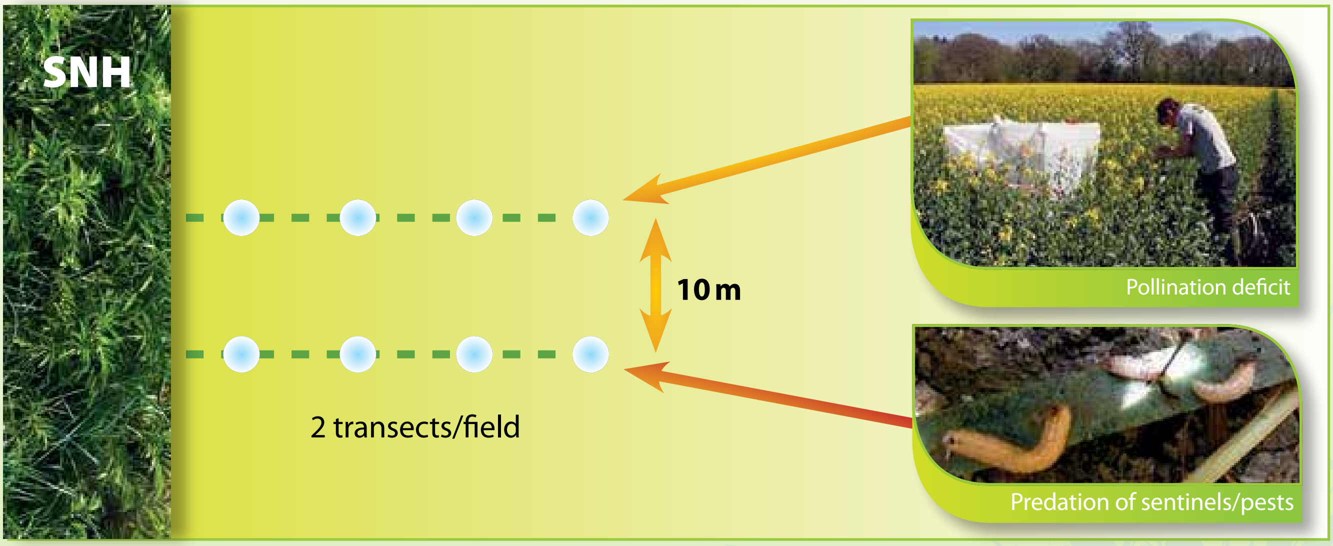


Figure 4. Experimental design – Focal field.

The type of adjacent SNH, the distance from the field margin and the proportion of SNH in landscape (1 km buffer around focal field) are the explanatory variables assessed in the case studies (*Figure 5*).

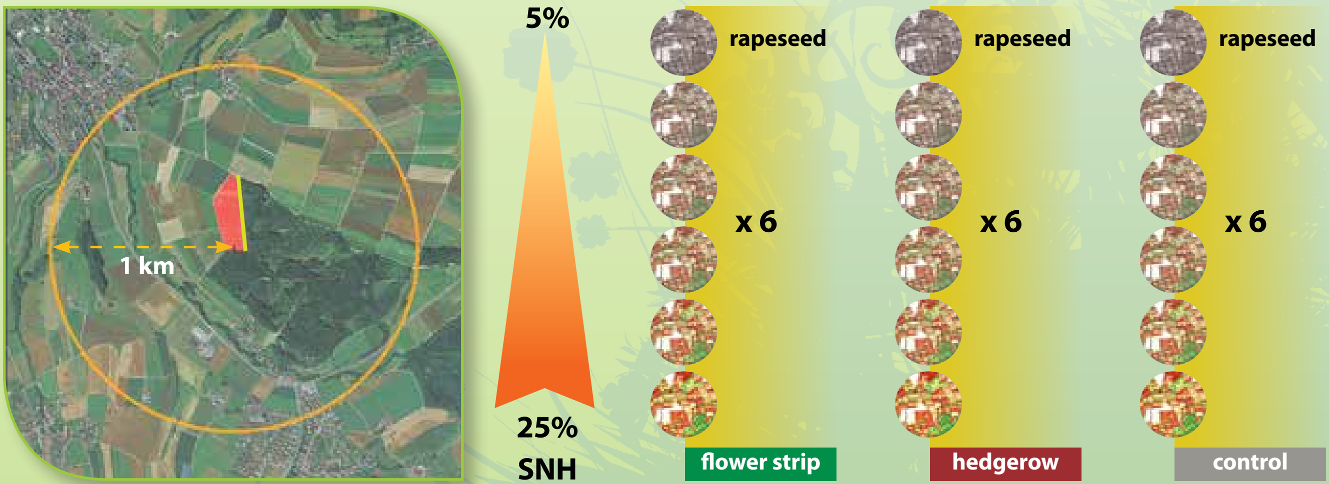


Figure 5. Experimental design – Focal field (red polygon), key semi-natural habitat adjacent to focal field (green line) and landscape sector (orange circle; left). 18 such landscape sectors were investigated each with one SNH type 1 or type 2 or a control (crop-crop). Sectors varied along a gradient of landscape complexity (6 per bordering SNH type; here the example of oilseed rape in Switzerland case study; right).

Farming practices to estimate the management intensity (number of insecticides, herbicides and fungicides, synthetic nitrogen fertilizer, plant density, sowing and harvest dates, yields) were assessed by conducting interviews with farmers. Characteristics of the focal fields were also recorded (field size, length of crop rotation and number of crops per rotation).

For more details, please contact: philippe.jeanneret@agroscope.admin.ch

Pollination deficit study

Pollination was measured through the pollination deficit and the pollen delivered by insects to the crop. Details on the methodology are given in the table 1.

How to measure?	Method	Analysis
Level of insect pollination	Comparison between open, bagged and hand pollination (*Figure 6*) • Hand pollinated: maximum pollination • Bagged or isolated: only self-pollination • Open: insect, wind and self-pollination	Dependence of a crop to insect pollination could be assessed quantitatively (seed set) and/or qualitatively (oil content). If seed set is strongly affected (e.g. % of fully developed seeds significantly lower for isolated flowers than for hand pollinated), crop is considered to be dependent on insect pollination.
	Single visit deposition (SVD) of honey, bumble and halictid bees was recorded in 2015 on pumpkin flower. Videos of pollinators on female pumpkin flowers in 18 fields (3 times, 4 distances and during 15') were recorded in 2014.	Videos to analyse bee visits and handling time.
Proxy of pollination success	Seed set (%) increase due to insect mediated cross-pollination.	Averaged value of seed set of open plants present in each plot minus the baseline level due to within-head selfing of each cultivar.
	Pollen yield dose response was investigated by using hand pollination in 2015 on pumpkin. Pollen delivery to female pumpkin flowers in 18 fields was measured 2 times at 4 distances on 4 stigmas in 2014.	To determine the minimal quantity of pollen necessary for the maximum yield.
Pollination deficit (in terms of productivity)	Difference of seed set or oil content between 'Open' and 'Hand' pollination.	Generalized Linear Mixed Model (GLMM, beta error distribution).
Abundance of pollinators	Pan traps and number of crop flower visits	Generalized Linear Mixed Model
Local SNH influence on pollination service	Effect of the type of adjacent SNH on seed set and/or oil content.	
Landscape SNH influence on pollination service	Proportion of herbaceous and/or woody areal and/or linear present in the landscape.	Analysis of soil cover in a radius of 1 km around the focal field.

Table 1. Synthesis of variables, methods and analysis performed in QuESSA project.

Figure 6. Hand, bagged and open pollination, a simple method to evaluate the pollination deficit.

Some studies examining pollination by different taxa have used cage experiments in which pollinators have no choice about where to forage. The main drawback of this method is that it may not reflect what occurs in the field where pollinators can choose whether to forage on the crop or on the SNH. In QuESSA experiments, the natural levels of foraging and the impact on pollination were examined.

For more details, please contact:
philippe.jeanneret@agroscope.admin.ch

[6] Jauker F, Bondarenko B, Becker HC & Steffan-Dewenter I, 2012. Pollination efficiency of wild bees and hoverflies provided to oilseed rape. Agricultural and Forest Entomology 14: 81-87.

Pest control study

The general predation potential was measured with sentinels systems. Sentinels are targeted and comprised of introduced prey items exposed to predation within fields. Sentinel could be adult, larvae, and eggs of insects or seeds. In the QuESSA project, several sentinels were investigated and their predation rate measured in the field (*Figure 7*):

- *Calliphora vomitaria* (larva) and *Ephestia kuehniella* (egg) to assess the potential predation by generalist predators
- Seeds of *Poa trivialis* & *Chenopodium album* to assess the potential predation by seed-eating insects
- Caterpillar baits to evaluate the potential predation by birds

Sentinels were stuck or pinned on plastazote or polystyrene plates (10 per plate) that are placed on the ground or on the vegetation depending on the final targeted predators. By quantifying the sentinel consumption during a given exposure time (24 hours or 7 days), the general predation potential was assessed.

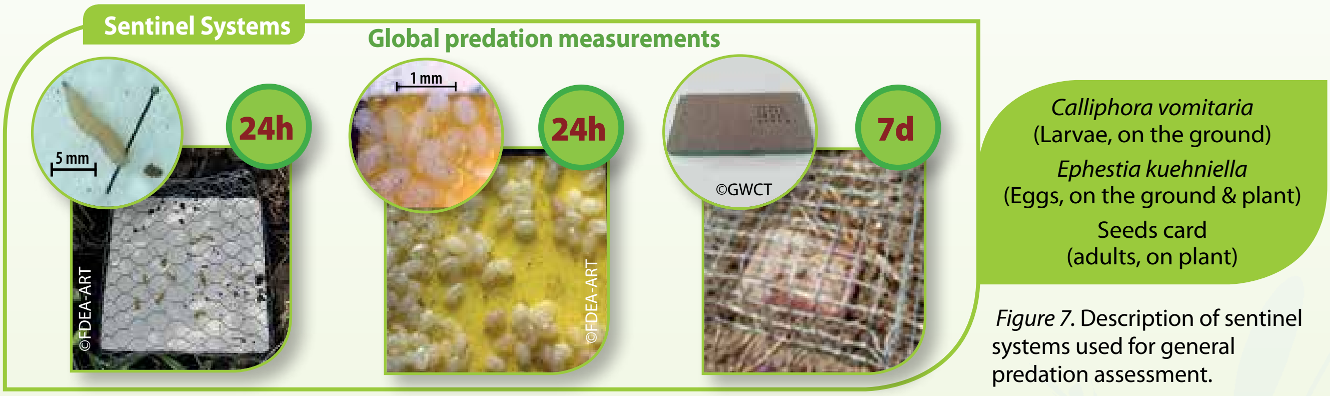


Figure 7. Description of sentinel systems used for general predation assessment.

The specific pest predation could also be evaluated by measuring the consumption of the adults, pupae or larvae of the specific pest. In QuESSA project, the predation of pests was measured by:

- Exposure of sentinels of the crop specific pest:
  - European Grapevine Moth *(Lobesia botrana)* in vineyards of France
  - Aphids *(Sitobion avenae)* in wheat fields of UK
  - Cereal leaf beetles (*Oulema* spp.) in Hungary
  - Olive fruit fly *(Bactrocera oleae)* in olive orchards of Italy
  - Pear psylla *(Cacopsylla pyri)* in pear orchards of the Netherlands
- Direct measurement of the predation:
  - Pollen beetle *(Meligethes aeneus)* larvae in oilseed rape fields of Estonia and Switzerland.
  - Assessing naturally occurring pest levels in the fields.

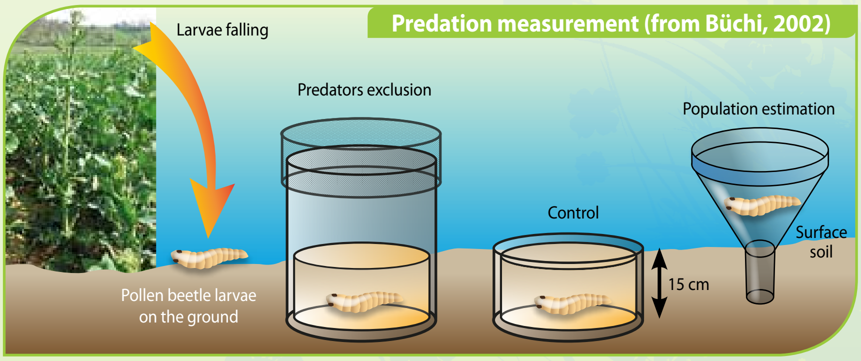


Figure 8. Protocol to measure the predation of pollen beetle larvae

Figure 8 details the protocol to measure the predation of pollen beetle larvae. The control was used to assess the predation by all predators (ground dwelling predators, spiders but also small mammals such as rodents). The exclusion cage was used to assess the natural mortality of the pollen beetle larvae. Table 2 summarizes the main advantages and inconvenient of the sentinel systems.

Advantage	Inconvenient
Cheap Duplicable (in the time & space) Standardized at European scale Educational ("make the invisible visible")	Evaluation of a potential pest control, but not systematically related to crop specific pests Sentinel systems needs to be connected to service provider sampling (e.g. pitfall traps) and observation (e.g. videos) to provide full information.

Table 2. Assessment of QuESSA partners on the use of sentinel systems in the case studies.

For more details, please contact: philippe.jeanneret@agroscope.admin.ch

Farmers' perception

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 eight 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. 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 (*Figure 9*) 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.

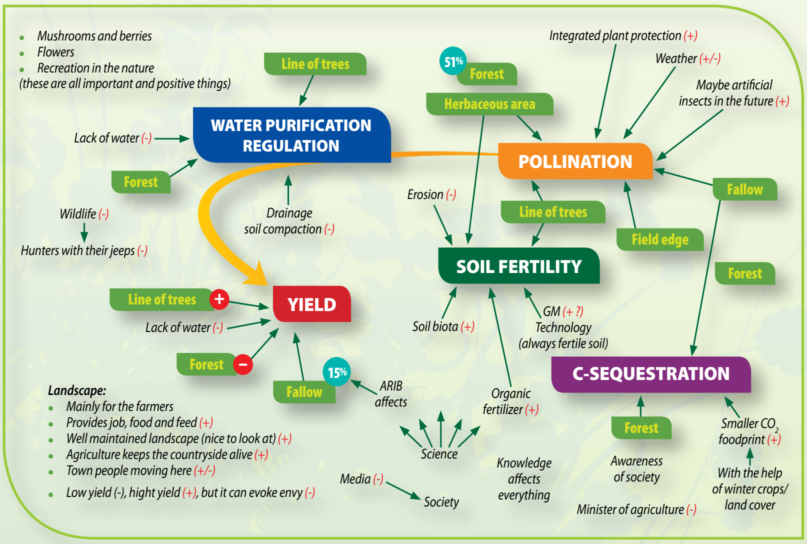


Figure 9. Example of mind-map from focus group.

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.

For more details, please contact: balazs.balint@essrg.hu

Extension activities: on-farm demonstration

Farmers and farming communities are the key actors of implementation of innovations, new approaches and technologies related to sustainable rural development, food and feed safety, IPM of crops, etc. including the preservation and improvement of ecosystem services on their farms. Based on surveys, farmers are more likely to introduce new approaches, to apply new technologies, if they not just hear it during in hall meetings, but if they have possibility to experience the effect of those technologies in their daily life. To be able to use it properly, farmers have to understand the idea behind the innovation, the operating principle of the new approach or technology. This is why knowledge and capacity development of farmers is key element of realization of innovations in actuality.

In QuESSA project the "on-farm demonstrations" aimed at increasing farmers' awareness of selected ecosystem services (pest control, pollination, soil fertility etc. improvement), ecological functions and biodiversity should improve capacity of farmers' communities to benefit from these services by future training activities and offered unique possibilities to work with stakeholders including farmers and learn from this cooperation for future improvement. On-farm demonstrations and farmers training were conducted in 8 countries by project partners from 2013 to 2016 (*Figures 10-14*). 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 publicity.

As a result of activities it become clear, that semi-natural habitats (SNHs) 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. If (as expected in co-innovation programs) farmers are involved in the project preparations and problem formulations, they can contribute to field trial development, they will feel themselves as important participants of and contributors to the knowledge and capacity development process of both side (ie. farmers and researchers) as well. 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) of the on-farm demonstrations were strengthened.

Figure 10. On-farm demonstration event visiting several flower strips and other semi-natural habitats to discuss their potential and practical challenges with respect to the promotion of pollination and pest control services in Swiss agricultural landscapes (Switzerland).

Figure 11. Excursion to flower strips on the organic farm of Ralf Gensheimer (standing right; Germany).

Figure 12. Observing QuESSA experimental field and sentinel traps in flowering field edges (Hungary).

In Italy, two main events of dissemination with farmers were jointly organized by University of Pisa and Scuola Superiore Sant'Anna, following the discussion held within the focus group meetings. Then, the farmers had expressed their interest much more on in-crop SNHs (e.g. cover crops) than on others, and on soil fertility and nutrient supply as target ESs. A first field day was organized to demonstrate farmers how a cover crop can improve several aspects of soil fertility. Special focus has been given to physical and biological soil fertility and also to the available empirical methods (i.e. spade test, visual soil profile, pitfall traps, teabags test, mat traps, hand sorting of earthworms) for measuring it. The farmers were pretty much impressed by how effective the cover crops can be in modifying soil structure and biological activity as well as how easy could be to assess these modifications by themselves.

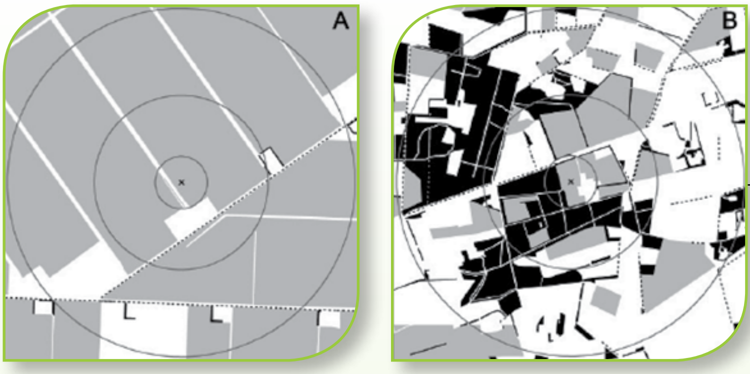
In a second field event, farmers' attention has been drawn to the role of cover crops as SNH for wild pollinators. Two neighbour cover crop fields, one grown with clovers, one with vetches, were kept flowering in the demonstration farm of University of Pisa. The presence, the diversity and the functional traits of many specimens of wild pollinators were demonstrated by researchers to farmers and beekeepers, who were actively involved in sampling.

For more details, please contact:
Jozsef.Kiss@mkk.szie.hu

Figure 13. Field day with farmers assessing soil structure as modified by cover crops through the test.

Figure 14. Field day with farmers sampling wild pollinators by transect walk observation.

Mapping of ecosystem services
Pest control



Semi-natural habitats (SNHs) in agricultural landscapes affect pest control.
Landscape composition affects predation rates depending on the shape, area and placement of SNH (*Figure 15*).

Figure 15. Example of an organic Brussels sprouts fields in a landscape with a small (A) and a largest (B) forest area. Gray indicates agricultural areas, black indicates forest and hedges and dottes lines represent tree lines. Parasitism rates in (A) and (B) were 7% and 94%, respectively[7].

QuESSA project intended to answer these four questions corresponding to four steps for mapping:
- Habitat identification: What are key habitats that affect pest control?
- Distance identification: Over which distance(s) do these habitats affect pest control?
- ES strength identification: What is the strength of the service coming from different habitats?
- Heat maps: What is the ecosystem service provided at landscape level?

First, we developed a modelling approach to generate "heat maps" for biocontrol and pollination from farm to European scales. Modelling ES delivery in landscapes was based on contributions from multiple sources.
We fitted models to data collected in fieldwork of our QuESSA partners to enable an integrated assessment of ESs at field, farm and landscape level. Data sets consisted of ES measured in focal fields (sentinels) and amount of source habitats at different distance from the focal field, along with maps of land use in a radius of 1 km around the field.
We calculated the ES strength in the focal field as the sum of contributions of ES from source habitats across the landscape, using a spatial weight function (kernel) to account for a decreasing effect of source habitats with distance to the focal field. This work focused on estimating the scale and the shape parameters of the dispersal kernel around the focal field and on estimating the source strength in relation with the semi-natural habitat types (woody areal, woody linear; herbaceous areal, herbaceous linear or within field).

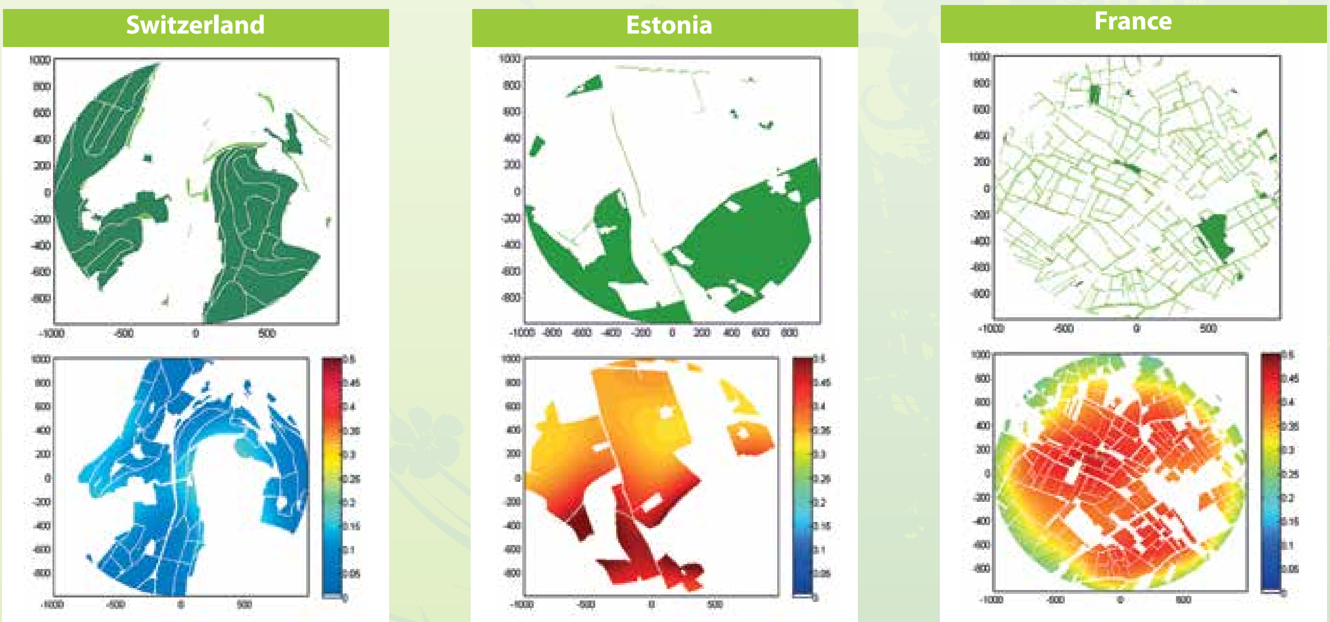


Figure 16. Heatmaps for parasitism rate of pollen beetle larvae (in blue, low and in red high parasitism rate, respectively) supported by herbaceous linear (green light) and woody areal SNHs (dark green) in Switzerland and Estonia. In France, a fine-scaled landscape with many linear herbaceous elements close to the fields potentially could give a better pest control service.

[7] Bianchi FJJA, Goedhart PW & Baveco JM, 2008. Enhanced pect control in cabbage crops near forest in the Netherlands. Landscape Ecology 23: 595-602.

Seven partners studied predation on seeds of weedy plants (*Poa annua* and *Chenopodium album*). Semi-natural habitats in the landscape had significant effects on seed predation, but the size and direction of effect varied between the case studies, species of seed, and habitat type.

Landscapes also affected the biological control of crop pests (slope lines, *Figure 17*), but there were large differences in the level of predation among case studies. We found 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 (*Figure 18*). 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.

In conclusion, semi-natural habitats were significantly associated with pest control services across European but the quantitative relationships depended strongly on the context with substantial differences between case studies. 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.

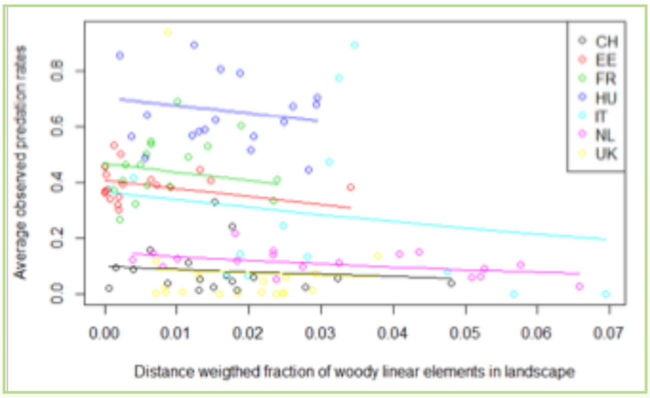


Figure 17. *Chenopodium* seed predation decreases with increase of woody linear elements in the landscape. However, differences between case studies are larger than the effect of SNH.

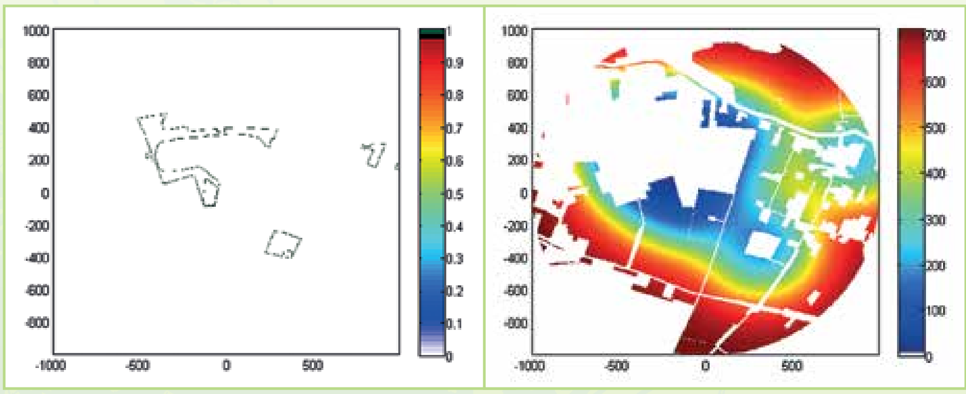


Figure 18. Heatmap for predicted number of earwigs (right) depending on forest edges (left) in the landscape. Earwig density decreases in close proximity of forest edges.

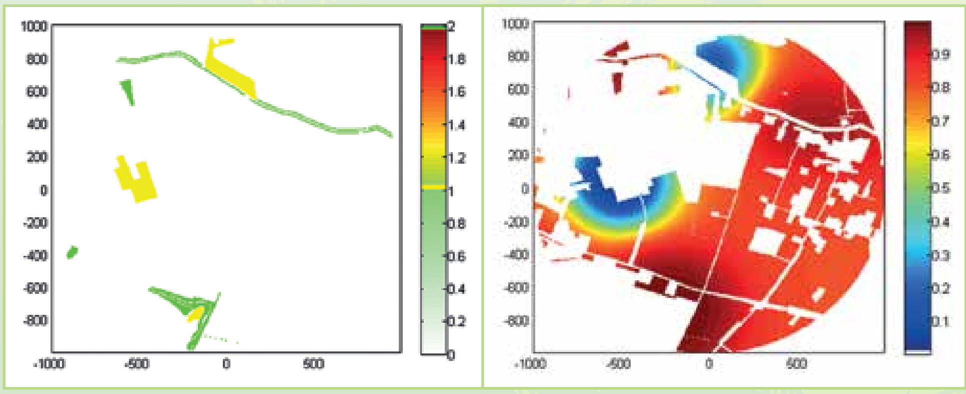


Figure 19. Heatmap for predicted predation on summer fruit tortrix (*Adoxophyes orana*) based on distance weighted fraction of herbaceous linear (light green) and herbaceous area (yellow) in the landscape.

For more details, please contact:
wopke.vanderwerf@wur.nl
marjolein.lof@wur.nl

Trade-off and synergies

There is an increasing interest in multifunctional agriculture that not only provides food and fibre, that not only provides food and fibre, but also supporting, regulating and cultural ES. Depending on landscape composition and the spatial arrangement of semi-natural habitats (SNH) in the landscape, the provisioning levels of the various ecosystem services may differ, and synergies and/or trade-offs between ecosystem services may arise. In this QuESSA project we studied synergies and trade-offs between

- biological pest control,
- biodiversity conservation,
- carbon sequestration,
- landscape aesthetics,
- and erosion prevention.

For this purpose we first developed evidence-based indicators for each of the five ecosystem services, and then explored synergies and trade-offs between these ecosystem services using the multi-objective optimization framework Landscape IMAGES. We illustrate the method using two case studies in Germany and Hungary.

The indicator for biocontrol potential is based on the habitat suitability of the focal arable fields and 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[8]. The indicator for biodiversity conservation estimates the number of species in SNH using a species accumulation curve approach, and is informed by spider samples collected by pitfall traps in herbaceous and woody habitats in 18 landscape sectors in Germany. The carbon sequestration indicator is based on land use specific organic matter contents of the top soil, which are then weighted by the area of each land use type. The indicator for landscape aesthetics is based on topographic indicators that are positively or negatively associated with aesthetic value. Finally, soil erosion is modelled using the RUSLE equation[9], which estimates the amount of sediment load out of a spatially defined landscape unit.

Synergies and trade-offs between these ecosystem services were explored using Landscape IMAGES. 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 (*Figure 20*). 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, thus resulting in synergies.

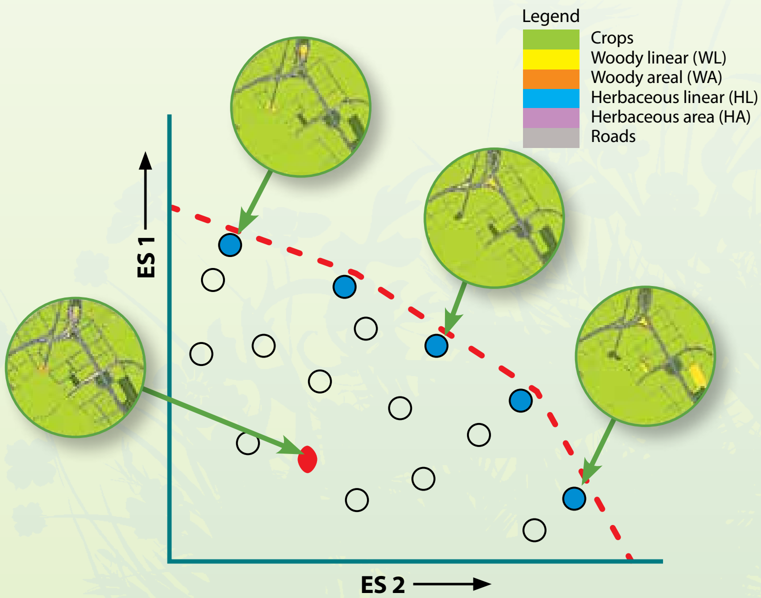


Figure 20. Pareto curve showing trade-offs/synergy analysis between two ESs (ES1 and ES2). The original landscape configuration is indicated by the red diamond, generated landscapes are shown as circles and Pareto-optimal landscape configurations are indicated by the blue dots.

The Landscape IMAGES analysis for the German and Hungarian case study 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 (*Figure 21*). 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. 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.

[8] Holland JM, Bianchi FJJA, Entling MH, Moonen AC, Smith BM & Jeanneret P, 2016. Structure, function and management of semi-natural habitats for conservation biological control: a review of European studies. Pest Management Science 72: 1638-51.

[9] Renard KG, Foster GR, Weesies GA, McCool DK & Yoder DC, 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture-Agriculture Handbook N°. 703.

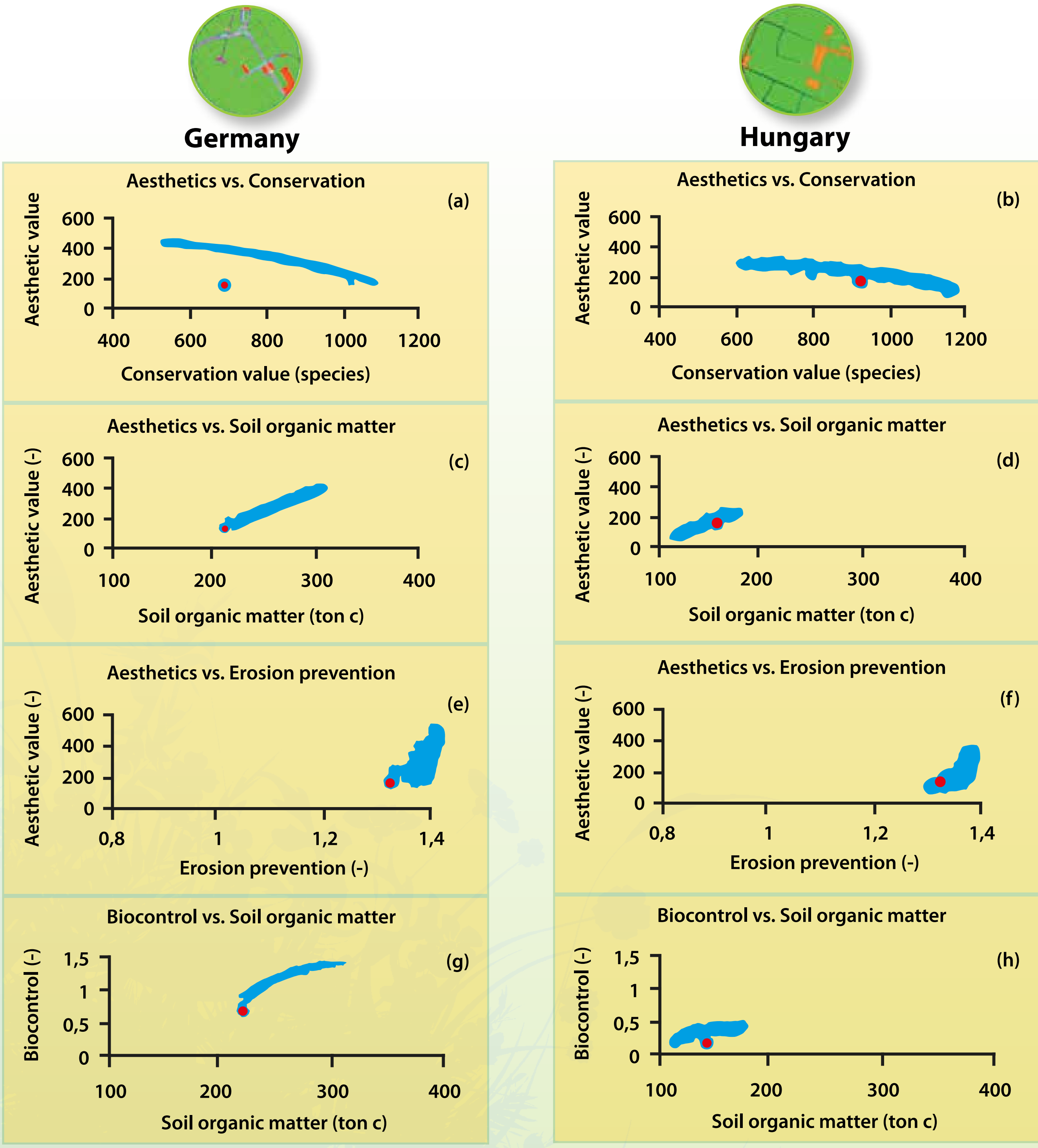
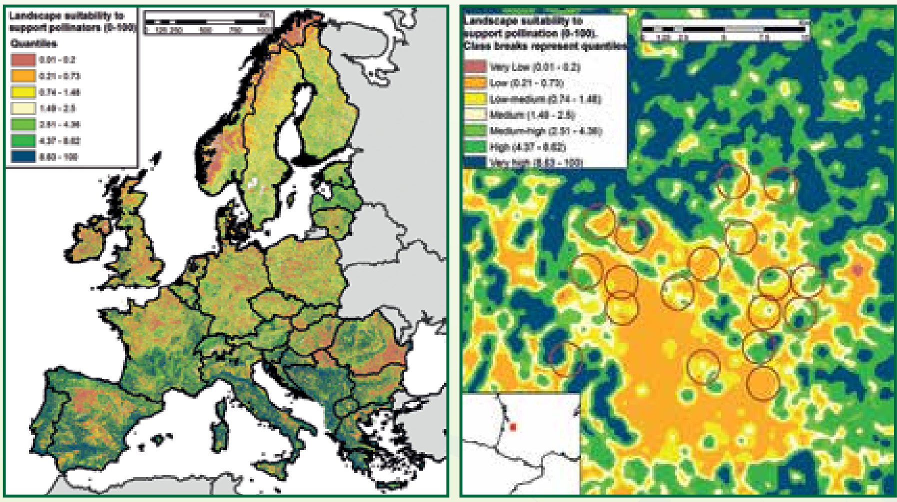


Figure 21. Trade-off/synergy curves for five ecosystem services in the German (left) and the Hungarian case study (right). The red diamonds show the ecosystem service provisioning level of the current landscape configuration, while blue dots show ecosystem service provisioning levels for alternative (Pareto-optimal) landscape configurations.

For more details, please contact:
seleshi.yalew@wur.nl
walter.rossing@wur.nl
felix.bianchi@wur.nl

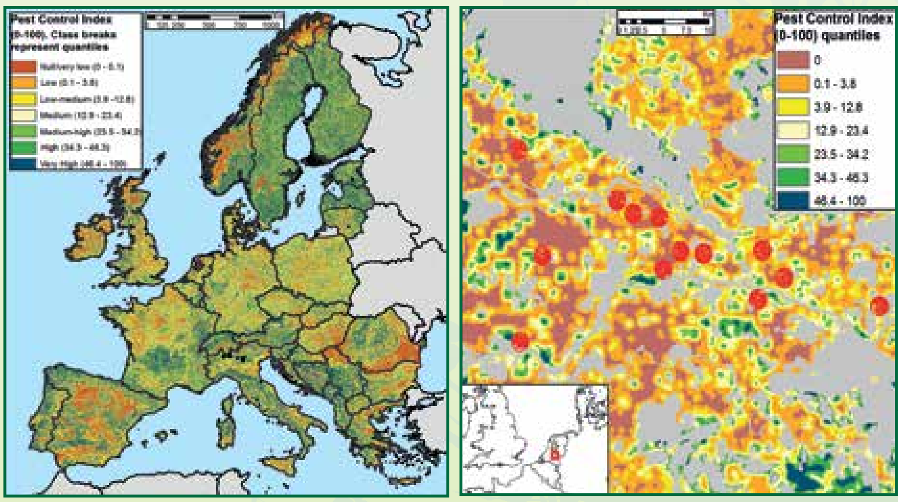
Upscaling at EU level

Two Europe-wide, spatially explicit models for pollination and pest control ecosystem services at fine-grained resolution (100 m) were developed in the project. The pollination model assesses the potential suitability of the entire landscape to support wild bees, the pest control model maps the contribution of SNH to support flying pest predators. Both models are based on the main assumptions of the corresponding landscape sectors models described earlier.
First, pan-European layers that are suitable to represent the abundance of SNH in agricultural land were identified and their reliability was validated using statistical techniques. To this purpose we used recently available High Resolution Layers on tree cover, as well as Corine Land Cover 2012 and the map of semi-natural vegetation in agricultural land developed by Garcia-Feced et al. (2014)[10]. Models were also parameterised with inputs from ground-based surveys carried out in WP2 and WP3 to quantify the potential of different SNH types to support bees and flying predators (scoring system). In both models, SNH are considered to exert an influence on the measured levels of ecosystem services in agricultural land, depending on their types and distance in space.
The pollination model is a development of the original model elaborated by Zulian et al. (2013)[11] whilst to the authors' knowledge, there is no Europe-wide model on pest control on which to build on, therefore the developed one can be considered the first attempt.



The models can be easily adapted once more detailed input information is available, and input layers can be easily modified to include more recent findings whenever available. By coupling the resulting pollination and pest control maps with information of distribution of crops depending on pollination and needing pest predators, areas subject to underprovision of these services can be identified to inform policy action (i.e. foster collective EFA implementation).

Figure 22. Map of landscape suitability to support pollinators in Europe (left) and at regional level (right).



Possible future developments include considering emerging relationships between ES and different types of SNH as identified by landscape sector models; improve the geospatial data used as descriptors of SNH to take into account, for example, herbaceous linear elements; and further elaborate on the role of landscape configuration and composition in supporting pollination and pest control.

Figure 23. Map of pest control in agricultural areas in Europe (left) and in the Netherlands (right).

For more details, please contact:
luisa.paracchini@ec.europa.eu
carlo.rega@ec.europa.eu

[10] Garcia-Feced C, Weissteiner CJ, Baraldi A, Paracchini ML, Maes J, Zulian G et al., 2014. Semi-natural vegetation in agricultural land : European map and links to ecosystem service supply. Agron Sustain Dev 35: 273-83.

[11] Zulian G, Maes J & Paracchini ML, 2013. Linking land cover data and crop yields for mapping and assessment of pollination service in Europe. Land 2: 472-92.

Results & Recommendations

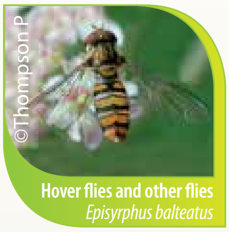
Pollination

Description of underlying ecological function

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[12].

Insect pollination increases and stabilizes the yield of more than three quarters of the world's most important food crops[13]. 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 to some extent dependent on them[14].

Pollinator groups *Species*



Main groups of pollinators with name of species encountered in QuESSA project

Some species of beetles, flies, thrips and birds could also contribute to a lesser extent to crop pollination.

Advantage

Environmental	Agronomical	Socio-economical
↗ Biodiversity Maintenance of wild flora	↗ Productivity: crop yield quantity and quality	↗ Food production and food diversity Beekeepers' activity ↘ Operating expenses: less hives per hectare due to wild pollinators.

Class of pollinator-dependent crop system (adapted from Klein et al. 2007)[13]

Class of pollinator-dependence	Description	QuESSA crops for pollination case study	Type of pollinators
Essential	Pollinators are essential for most varieties: **production reduction by 90% more,** comparing experiments (with and without animal pollinators)	Pumpkin	Honey bees (*Apis cerana, A.mellifera*), Bumblebees (Bombus sp.), Solitary bees Solitary
High	Animal pollinators are extreme **(40 to less than 90% reduction)**	Pear	Honey bees (*Apis mellifera*), Bumble-bees (Bombus sp.), Solitary bees (Osmia sp…), Flies (Eristalis sp.)
Modest	Animal pollinators are clearly beneficial: **10 to less than 40% reduction**	Oilseed rape, Rapeseed, Sunflower	Honey bees (*Apis mellifera*), Bumblebees, Solitary bees (Andrena sp., Osmia cornifrons, lignaria…)
Little	Some evidence suggests that animal pollinators are beneficial: **greater than 0 to less than 10% reduction**	(Tomato)	Honey bees (*Apis mellifera*), Bumble bees (*Bombus hypnorum, B.pascuorum, B.terrestris…*), Solitary bees (*Amegilla chlorocyanea, A.holmesi…*)
No increase	**No production increase** with animal-mediated pollination	Olive	Honey bees visit flowers occasionally

[12] Gallai N, Salles JM, Settele J & Vaissière BE, 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological economics 68: 810-821.
[13] Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C & Tscharntke T, 2007. Importance of pollinators in changing landscapes for world crops. Proc R Soc B-Biol Sci 274: 303-313; Aizen MA, Garibaldi LA, Cunningham SA et al, 2009. How much does agriculture depend on pollinators? Lessons from long-termtrends in crop production. Ann Bot 103:1579-1588.
[14] Kearns CA, Inouye DW & Waser N, 1998. Endangered mutualisms: the conservation of plant–pollinator interactions. Annu Rev Ecol Syst 29: 83-112; Klein et al., 2007.

Results

The pollination of the studied focal crops showed diverging responses across the case studies. Case studies are more detailed hereafter in the document. In only one case (pears in the Netherlands), we found an association between crop performance and the presence of SNH features in the area surrounding a focal field. Specifically, pollination deficits decreased with the presence of woody linear features. The strong positive influence of woody linear features reduced in strength by half roughly every 100 m further from the edge of the focal field.

The importance of wild pollinators was shown across some case studies such as pumpkin in Germany (importance of bumblebees). Fewer pollinators were found in the internal part of WA elements, same trend for all pollinators and by groups (honey vs. wild bees). There were more flying predators in external than in internal part of woody elements, while it was the same for herbaceous elements. Some differences were noticed between parasitic wasps (very abundant in external but still abundant in internal in WL but less in WA elements) and predatory flies (present in external part of woody elements but not in internal). Bee abundance was best predicted by describing herbaceous vegetation cover and flower resource traits. SNH type alone is not a very precise indicator. On the contrary, flying predator abundance was well predicted by SNH type and distance in SNH (especially for woody areal element). For both groups, it is recommended to count only the edge area of WA element as functional. Groups of insects are connected to different elements. No effect of landscape context was observed on honeybees. Nevertheless, beekeepers are aware that the environment of the beehives will be determinant for the health of their bees.

Recommendations for farmers, advisors and trainers

- For wild and honey bees, herbaceous elements with some shrubs seemed most attractive, especially from the *Rosaceae* family.
- Do not cut flowering herbs like *Achillea*, *Leucanthemum*, *Hypericum* and *Trifolium*.
- It is more beneficial to create small woodlots and herbaceous elements with diverse flower resources throughout the year for beneficial insects.
- Taking into account the environment of the beehives (less pesticide use) for bees' health.
- Use less herbicide so more weeds (nutritive resources) are available for pollinators.
- 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.
- Honeybees need pollen as protein resource for their breed all through the year and pollens offered by wild species are very important, beside nectar.

Recommendations for policy makers

- Policies promoting and sustaining different SNH types on farmland, diversified and integrated vegetation management in SNH (mowing regimes, reduction or no-use of herbicides…) in and around farmland and involving not only the farmers but also municipalities and other territorial structures to protect functional biodiversity.
- Enhancing biodiversity to enhance ecosystem service of pollination: proposal of "Nature-based solutions" to increase the biodiversity conditions and the potential home of beneficials in farming landscapes. Working with nature rather than against it by integrating some interesting measures issued from FP7, BiodivERsA and future H2020 projects.

Sunflower

Context
Sunflower (*Helianthus annuus*) is an economically important crop in the EU. It was historically considered as a highly self-incompatible crop, but nowadays, with the use of current commercial cultivars, it is claimed to be highly self-fertile. This is the most important oil crop in Hungary and its acreage has been increased by 50% in the last decade.

Did you know?
Honey bees and wild pollinators can contribute to approximately 5-25% of the yield depending on the varieties (or hybrids).

Figure 24. Bumblebees on sunflower in Hungary.

Objectives
Evaluating the current status of pollination, and its implication in terms of crop production, trying to disentangle
- how landscape context affects the pollination service delivery
- the contribution of SNHs to this ecosystem service as they provide an alternative source of nectar and pollen for insect pollinators.

Results
Commercial cultivars, despite their different degrees of self-fertility, still need conspicuous amounts of cross-pollination which boosts seed set and oil content. Conversely, oil chemical composition was not affected by the insect-mediated level of cross-pollination. Honey bees represented the vast majority of pollinators in the area ensuring an overall adequate pollination. Beehives in the surrounding landscape positively affected yield, as well as the presence of early flowering crops, urban areas and woody linear elements. On the contrary, herbaceous elements reduced sunflower productivity by acting a sink for pollinators.

In Hungary, no pollination deficiency was recorded in 2015, but higher fertility rates (+4.7%) were measured in 2014. Insect pollination rate was on average 7.5%.
A higher proportion of SNH in the investigated landscape did not result in higher ES levels.

Recommendations for farmers, advisors and trainers
- Knowledge support to allow them to understand pollinators (in particular wild ones) and the impacts of management practices on them → extension officers, agro-environmental NGOs need to be equipped with such information to learn how to identify them and preserve their important habitats (overwintering refuges, nesting sites, floral resources…).
- Promote none or fewer pesticides (insecticides but also herbicides due to their lethal effect on wild flora but also because they may negatively affect fitness of many insect species), avoid systemic insecticides (e.g. neonicotinoids) whenever possible and prevent spray drift into nearby flowering SNH.
- Avoid cutting or mowing before flowering.
- Maintain a diversity of SNH types (herbaceous vegetation, flowering species with spatial and temporal diversity in particular).
- Promote woody linear or small woodlots since pollinators uptake nutritive resources from external parts.
- Establish floral strips closer or within field crops:
- Attract wild pollinators early in the late winter and beginning of spring (e.g. *Trifolium pratense, Medicago sativa*…) and encourage early flowering broad-leaved weeds
- Promote a positive image towards consumers through a labelling and media indicating that they adhere to a charter preserving biodiversity

Recommendations for policy makers

- Commercial cultivars are self-fertile but insect-mediated pollination could still improve crop production. Promoting a cultivar diversity at landscape level.
- Coordination of these cultivars, SNH management (late mowing or cutting) and SNH diversity at landscape level to maintain pollinators population.
- Avoid co-flowering SNHs and crop production. Encourage early and late flowering in the hedgerows (trees and shrubs) to attract the pollinators (honey bee and wild pollinators) as early as possible so that they can be present when focus crop is flowering and support them for future years
- Develop policies to support pollinators across landscapes through protection and enhancement of flowering plants in semi-natural habitats.
- Continue research to develop suitable floral mixtures
- Need to better understand the importance of pollen resource in the surrounding landscape for health of honey bees. Identify key species in early flowering trees and shrubs, legume crops and herbaceous vegetation in SNHs that provide floral resources. This has been reported by others as well but importance for health of bees not yet quantified although beekeepers do take floral diversity into account when placing apiaries in the landscape.

For more details, please contact:
moonen@sssup.it
a.miquelbartual@sssup.it
Szalai.Mark@mkk.szie.hu

Figure 25. Sunflower field in Hungary, with forest edge in the background.

Focus on overarching analysis on pollination deficit

Pollination deficits were detected in two countries only: Switzerland (CH, oilseed rape) and Italy (IT, sunflower)(*Figure 26a*). In Switzerland, the pollination deficit may have occurred because the canola varieties did not fully self-pollinate in the absence of bees, unlike varieties in Estonia and the United Kingdom (*Figure 26b*). In Italy, the deficit occurred despite a very high rate of visitation by honey bees, which suggests that managed bees are ineffective pollinators.

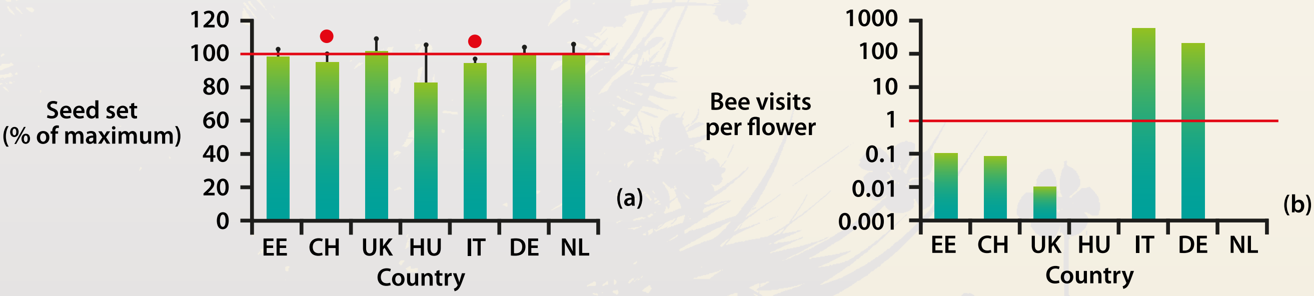


Figure 26. Pollination deficits and visits to flowers by bees in seven countries. Upper panel (a): Seed set in open-pollinated flowers relative to hand-pollinated flowers (%). Asterisks indicate statistically detectable deficits. Lower panel (b): estimated number of bee visits to each flower (or per head for sunflower) in the crop. Rates of visitation were unavailable for HU and NL.

For more details, please contact:
d.wallis@exeter.ac.uk
j.e.cresswell@exeter.ac.uk

Oilseed rape

Context

Oilseed rape (*Brassica napus*; hereafter OSR) is amongst the most important food, fodder and biofuel crop worldwide. OSR is now the third largest source of vegetable oil in the world (http://faostat3.fao.org), it is used for human consumption but also as a high-protein animal feed. The area of OSR has vastly increased in prominence over the past 10 years. This crop is self-fertile and mainly wind pollinated, although recent studies have shown that it also benefits from insect pollination that can increase seed quality and yield[15]. Synergistic effect of insect pollination and pest control on yield and farmer's gain were also shown in an other study in Switzerland[16].

OSR is a mass flowering crop:

- Important food source for honeybees and wild pollinators.
- Potential competition on pollination service between focus crop and adjacent semi-natural habitats.

Main pollinators of OSR

Honey bees, bumblebees, solitary bees and hoverflies are known to pollinate OSR, but there are differences in their efficiency depending on the number of pollen grains they can transfer, visitation rates and their abundance.

Figure 27. Honey bee (*Apis mellifera*) on an oilseed rape (*Brassica napus*) flower.

Objectives

To investigate the effect of adjacent ecological focus areas (hereafter EFAs) and landscape-scale greening measures on pollination, two interrelated hypothesis were tested:

- The local establishment of two commonly implemented types of EFAs (ie sown wildflower strips and hedgerows in Switzerland) enhances pollination service delivery in adjacent OSR crops
- The effectiveness of these adjacent EFAs in promoting pollination is reinforced by increasing the proportion of greening measures implemented at the landscape level

Results

No insect pollination deficit was shown in the UK case study as neither the number of seeds per pod nor the 1000 seed weight differed between the open and hand pollinated treatments.

Yield deficit observed in Estonia, was shown to be positively influenced by the presence of herbaceous areal habitats around focal fields (smaller deficit) but negatively by woody linear habitats. No yield increase was shown according to the adjacent SNH type or distance.

The number of oilseed rape flower visitations by wild pollinators in focal fields synergistically increased with higher proportions of landscape-scale greening measures and the local presence of perennial wildflower strips and hedgerows.

Flower visitation by wild pollinators was dependent on the local presence of the type of SNH adjacent to the focal field: it increased with an adjacent wildflower strip or hedgerow in comparison with no adjacent SNH.

Both the presence of an adjacent SNH and landscape-scale greening measures increased the effect of insect pollination on seed set in focal fields.

In UK, a low number of visits was recorded but mainly by wild pollinators (solitary bees from *Andrena* species). A significant effect of the adjacent woody areal in comparison with herbaceous linear habitat was shown on the abundance of hoverflies in focal field.

In Estonia, wild bees and especially solitary bees were more important in OSR than was expected.

Adjacent SNHs increased the abundance of pollinators, and especially the herbaceous and woody linear ones. Bumblebees were more abundant in the sectors with intermediate (16–26%) and high (≥ 27%) proportions of SNH at landscape level than those with low proportion (< 15%).

[15] Bommarco R, Marini L & Vaissière BE, 2012. Insect pollination enhances seed yield, quality and market value in oilseed rape. Oecologia 169: 1025-32; Hudewenz A, Pufal G, Bogehölz AL & Klein AM, 2013. Cross-pollination benefits differ among oilseed rape varieties. J Agric Sci 152: 770-8.

[16] Sutter L & Albrecht M, 2016. Synergistic interactions of ecosystem services: florivorous pest control boosts crop yield increase through insect pollination. Proc R Soc B 283: 20152529.

Recommendations for farmers

- Providing habitats for pollinators (honey and wild bees, hoverflies) such as nesting or overwintering sites as well as nutritive resources (pollen, nectar): combining perennial herbaceous elements with diverse vegetation, architecture and ensuring a spread of flowering times (especially early or late flowering so as to not compete with the mass-flowering crop and provide resources in these periods when less flowers are naturally present).
- Awareness that some practices might affect pollinators in their field.
- To encourage ground nesting solitary bees, leave patches of bare ground in sheltered, south-facing areas and especially banks. Keep these uncultivated until the following summer. Avoid areas prone to erosion.
- During flowering periods, it is important to coordinate pest and pollinator management by encouraging farmers to use natural products or at least to use insecticides that have less impacts on pollinators and by respecting the recommendations to spray (time and methods of application).
- Promoting the introduction of adjacent elements (e.g. wildflower strip or hedgerow) when no adjacent SNH exists to increase crop flower visitation by wild pollinators.

Recommendations for policy makers

- Importance to preserve nesting sites for wild pollinators to maintain and sustain local populations through agri-environmental schemes
- Promoting research on identification of nesting sites for wild pollinators and on environmental friendly farming practices to preserve these sites (conservation agriculture, cover crops).
- Promoting the understanding of the function of pollinators in agro-ecosystems and the interactions with other practices adopted by farmers: pollination requirement of the crop/variety, the effective pollinators, pollinator guild and the minimum requirement for the crop.
- Enhancing policies enabling agroecological practices that capture synergistic benefits for both pollinators and natural enemies.
- Promoting local and landscape SNH management since an interactive effect was shown, suggesting that adjacent SNH on their own do not provide enough food, overwintering and nesting resources for wild pollinators.
- Encourage farmers through support mechanisms to increase semi-natural habitats beyond the 5% ecological focus areas required by the CAP.
- The pollination of the studied focal crops showed diverging responses across the case studies. Results are context-dependent. Further research is needed to investigate how EFAs and other greening measures can be improved to make them more effective in achieving their multiple goals (trade-offs and synergies).

For more details, please contact:
louis.sutter@agroscope.admin.ch
matthias.albrecht@agroscope.admin.ch
Eve.Veromann@emu.ee
jholland@gwct.org.uk

Focus on weeds in Italy and Hungary (disservices)

he usual four distances foreseen in the QuESSA protocol (§ General design) were not considered relevant for measuring weed invasions from the adjacent SNH into the field and therefore more plots were added especially in the crop edge, summing up to a total of seven distances from the border to the field centre (1, 2, 10, 15, 25, 50 and 75 m).
Weed abundance was higher only at 1 m distance from the field margin. From 2 m onwards, weed cover was not affected by distance from the SNH. The % of SNH in the landscape sector had no effect on weed species richness in sunflower but did affect species composition (2.5% variability accounted for).
The disservice provided by SNH in terms of weed abundance was very limited and woody elements appearing to decrease weed cover (annual dicots and rhizomous species). 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 (see pollination case study in same fields). 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 for by reduced weed abundances.

For more details, please contact:
moonen@sssup.it

Pumpkin

Context

Pumpkin (*Cucurbita maxima*) is a suitable study plant for pollination services because it is obligate cross-pollinated by insects and has local economic value. Pumpkin has a long flowering period (on average 72-80 days), with a short lifetime of the single flowers (6 h – 1 day). Rapid and effective pollinator visits are thus vital to crop yield[16,17].

Objectives

Evaluating the current status of pollination, and its implication in terms of crop production, trying to disentangle

- how landscape context affects the pollination service delivery.
- the contribution of SNHs to this ecosystem service as they provide alternative source of nectar and pollen for insect pollinators

Did you know?

To produce a marketable fruit, a flower required > 500 pollen grains on its stigma and fruit mass increased up to an accumulation of c. 3000 pollen grains.

To reach full pollination every female flower needs 3.5 bumblebee visits, 12 honey bee visits or 190 halictid bee visits between sunrise and ~11 :00 am.

Crop yield is most sensitive to declines in bumblebees.

Results

Bumblebees were the most efficient pollinators since the single visit deposition (hereafter SVD) is equal to 3369 grains with a very short handling time (hereafter H, H=12") in comparison with honey bees (SVD = 582; H=144") and halictid bees (SVD = 45; H=191").

Pollen delivery significantly increased with the number of bumblebee visits, but was not significantly related to the visits of all pollinators, honey or halictid bees.

At the extant abundance of bumblebee visits (on average 21 bumblebee visits per flower lifetime) and pumpkin cultivation (9 ha in 1 km radius) there was no pollination deficit in our study region.

Mediated by bumblebee visits proportion of SNH in 1 km radius (0-50%, herbaceous and woody elements) tended to increase pollen delivery.

Recommendations for farmers, advisors and trainers

- Bumblebees are especially important pollinators of pumpkin. Farmers should preferably support wild over commercial bumblebees since they can transfer diseases to local honey, bumble and other wild bee pollinators[18].
- SNHs at the landscape scale enhance the abundance of bumblebees and the delivery of pollen.
- Farmers should provide perennial elements (such as wildflowers strips) composed of species that
  - flower throughout the vegetation period
  - provide nesting sites to bumble bees through the undisturbed soil surface and/or the presence of small mammal burrows[19].

Recommendations for policy makers

- Favouring connectivity and mix between herbaceous and woody elements in a given region for enhancing wild pollinators. Linear woody elements offer important floral resources in spring (*Prunus, Salix, Lamium* …).
- Promoting perennial elements (with wildflowers).

For more details, please contact:

pfister@uni-landau.de
entling@uni-landau.de
schirmel@uni-landau.de

[16] Dmitruk M, 2008. Flowering, nectar production and insects visits in two cultivars of Cucurbita maxima Duch. flowers. Acta Agrobotanica, 61: 99–106.
[17] Nepi M & Pacini E, 1993. Pollination, pollen viability and pistil receptivity in Cucurbita pepo. Annals of Botany, 72: 527–536.
[18] Goulson D, Nicholls E, Botías C & Rotheray EL, 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science, 347: 1255957.
[19] Goulson D, Lye GC & Darvill B, 2008. Decline and conservation of bumblebees. Annual Review of Entomology, 53: 191–208.

Pear

Context

Pear (*Pyrus* sp.) is an increasingly important crop in Dutch fruit production. Besides Italy, Spain and Belgium, the Netherlands belongs to the top four producers of pears in Europe. A large proportion of the pear production is for export. Keeping a top position at the market requests increasingly efficient production systems, providing fruit that meets the highest quality standards.

Main pollinators

Pollination by honeybees, solitary bees, bumblebees and other pollinators is an ecosystem service of major importance in pear growing. Fruit set and fruit quality are positively influenced by successful pollination.

Objectives

In order to quantify the impact of pollination, the abundance of pollinators and the impact of farm and landscape structure on provisioning the ES pollination we aim at answering the following questions:

- Is there a pollination deficit at all?
- Does insect pollination contribute to seed forming in pears?
- Which pollinators are abundant in pear orchards?
- Is the abundance of pollinators influenced by the adjacent SNH?
- Is the abundance of pollinators influenced by % SNH in the surrounding landscape?

Results

There was a pollination deficit. In both years the hand-pollinated pears had significantly more seeds. There was an actual contribution of insect pollination on seed forming in pears. We compared the number of seeds per fruit in open pollinated and bagged flowers. In both years the open pollinated flowers developed significantly more seeds in fruits.
The most abundant pollinators in the orchard were bees, and to a lesser extend bumblebees and hoverflies.
In both years we could not confirm an effect of the adjacent SNH or % SNH in the surrounding landscape on pollination levels. Overall, abundance of pollinators differed considerably between years with more pollinators observed in 2014. This difference was reflected in the number of seeds in fruits.

Recommendations for farmers, advisors and trainers

- Strengthen the awareness that besides commercially available honey bees also other species like bumble bees and solitary bees play an important role in pollination.
- Provide overwintering refuges and nesting sites to support these pollinators in the long run.
- Increase the presence of floral resources within the orchard to provide pollinators with resources they need for reproduction outside the flowering period of the crop.

Recommendations for policy makers

- Not only farmers but also municipalities and other organizations that are in charge of territorial maintenance should be involved in the diversification of public vegetation in order to support pollinator populations on a regional scale.
- Public areas, road edges and dikes near orchards can be turned into flower-rich habitats. In this way, they can support pollinator populations.

For more details, please contact:
karin.winkler@wur.nl

Pest control

Description of underlying ecological function

Biological control of pests (insects, mites, weeds and diseases) is a method that relies on natural predation rather than introduced chemicals. In QuESSA, one focus was on conservation biological control[20]. It represents a key service of paramount economic importance[21]. Overall pest control is estimated to occur mainly through natural enemies (~50%) and host-plant resistance (~40%) and much less through pesticides (~10%)[22].

The principles of conservation biological control are based on two types of regulation hereafter described (Table 3). The top down regulation corresponds to the enhancement of beneficiary arthropods population by creating, managing and diversifying the ecological infrastructures at farm level. The bottom up regulation consists in modifying farming practices at field level so that crop field becomes unfavourable for pests.

	Top down regulation	Bottom up regulation
Target trophic level	Indigenous beneficial arthropods (level III)	Crop (level I)
Aim	Enhancement of its survival, fecundity and longevity (fitness) for a best predation efficacy	Make the crop field unfavourable to pests
Methods	Creation and/or management of existing agroecological infrastructures (hedgerows, floral or grassy strips…)	Modification of farming practices (species or varieties intercropping, trap crops in field margin or inside field crop)

Table 3. Principles of conservation biological control.

For a higher impact, the best would be to **combine these two approaches**, i.e. the push-pull strategy.
Conservation biological control induces a **redesigning** of the crop production system at short, mid and long term. What can be achieved may well be best achieved through brainstorming at field, farm and landscape levels with different stakeholders groups (farmers, advisors, managers of the countryside…).

This concept is coherent with guidelines of **Integrated Production** from International Organization of Biological Control[23] in which, ecological infrastructures should represent at least 5% of the total UAA and are extensively managed. In the guidelines, two or more indigenous natural enemies for each crop should be protected and enhanced.
This concept, by promoting ESs, genetic and species diversity and preserving natural resources, is in adequation with the agroecological principles[24].

Advantages

Environmental	Agronomical	Socio-economical
↗ Biodiversity Maintenance of wild flora ↗ Diversified habitats at farm and landscape levels	↗ Productivity: crop yield quantity and quality ↘ Pest outbreaks ↗ Soil Biodiversity (due to change in farming practices)	↗ Landscape aesthetics (floral strips and woodlots) ↘ Pesticide use ↗ Knowledge on functional biodiversity and its interests Recognition of the farmers as landscape managers

What are the categories of beneficial arthropods?

- Parasitoids, specialist- or generalist or predators

Specialist predators actively search for its prey, which they kill and consume.
Generalist predators prey on pest and other insects and provide background control.
Parasitoids actively seek out their prey (can be specialist or generalist) and lay their eggs within them, their larval stages then consume the prey.

[20] G There are two other basic types of biological pest control strategies. Importation (sometimes called classical biological control), in which a natural enemy of a pest is introduced in the hope of achieving control; and augmentation, in which locally-occurring natural enemies are bred and released to improve control.
[21] Oerke EC, 2005. Crop losses due to pests. Journal of Agricultural Science 144: 31-43; Gallai N, Salles JM, Settele J & Vaissière BE, 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol Econ 68: 810-21.
[22] Pimentel D & Burgess M, 2014. Environmental and economic costs of the application of pesticides primarily in the United States. In : Pimentel D, Peschin R (eds) Integrated pest management. Springer, Dordrecht pp 47-71.
[23] El Titi A, Boller EF & Gendrier JP (Eds), 1993. Integrated Production Principles & Technical Guidelines (in English, French, German). Bulletin IOBC/WPRS 16; Boller FE, Häni F & Peohling HM, 2004. Ecological Infrastructures - Ideabook on Functional Biodiversity at the Farm Level. 220p.
[24] Altieri, 1995 ; Gliessman, 1998 ; Solagro, osez l'agroécologie http://www.osez-agroecologie.org

Examples of specialist predators

Larva of lacewing

Larva of hoverfly

Larva of lady bird

Adult of lady bird

Examples of generalist predators

Ground beetles

Rove beetles

Predatory flies

Spiders

Conservation biological control is also based on the **food web concept**, in which the importance of weeds is increasingly stressed out [25].

Recommendations for farmers, advisors, trainers and for policy makers

From a curative to a preventive pest management

- Shifting from the curative to a preventive approach to manage pest damage below an economic threshold on a long-term perspective.
- Promoting conservation biological control as an important driver for preserving functional biodiversity in farming landscapes.
- 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. The impacts of farming practices and landscape context on these food webs are also taken into account. This website is for farmers and advisors (an english version will be online soon). It capitalizes information from literature (article, technical review, books…) but also on feedbacks from farmers.
- By providing free training for farmers and agronomists on conservation biological control.

Examples of parasitism

Golden beige to brown mummy: characteristic of genus Aphidius

White mummy characteristic of genus Praon

[25] Pocock MJO, Evans DM & Memmott J, 2012. The Robustness and Restoration of a Network of Ecological Networks. Science 335: 973-77.

Agroecological management of vegetal & animal communities at local and landscape scales

- By increasing plant diversity (crop and/or semi-natural habitats), pest control is ensured by a diversity of natural enemies which gives a certain resilience to the system.
- Improving the management and the implementation of ecological focus areas to increase their diversity at farm scale. (See §Semi-natural habitats and ecological focus areas management).
- Promoting the environmental friendly farming practices (§ Olive fly and § Aphids on Pumpkin).

Reconsidering the time and space scales to manage

- The proportion of SNH in the surrounding landscape had more impact on natural enemies and pest control. Promote collective management for plant protection at a landscape level as well as a preventive approach by managing the diversity of wild flora and natural enemies together (e.g. consider the implementation of SNH through farmers' focus groups inside a same territory to reach specific objectives as is already done for the water quality e.g. Territorial Agriculture Plan in France).

Towards an Integrated Pest Management at farm and landscape scale

- 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, mulch…) or genetic choices (tolerant variety…).

Non-additive but synergistic consideration of ecosystem services

- Importance of 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.

Pollen beetle on Oilseed rape

Oilseed rape (hereafter OSR) is attacked by several insect pests but the pollen beetle (*Meligethes aeneus*) is considered to be one of the most important and yield limiting pest throughout Europe.

The pollen beetle is univoltine. It emerges from overwintering sites in the spring when air temperature exceeds 10°C and feeds on pollen. When temperatures exceed 12°C, they start to seek cruciferous plants for mating and oviposition. They lay eggs in the OSR buds. First instar larvae feed on pollen inside the bud and second instar larvae eat pollen from open flowers. Mature larvae drop from the flowering canopy to the soil and pupate below the soil surface. The major damage to oilseed rape plants are caused by the feeding adults during the bud stage of plants; larval feeding inside the buds can also cause damage.

©EULS, Kovacs G.

Figure 28. Pollen beetle (*Meligethes aeneus*) larvae on oilseed rape in Estonia.

Figure 29. Oilseed rape (*Brassica napus*) fields in Switzerland.

©Tschumi M.

Did you know?

In France, but also in Northern countries of Europe (Sweden and Denmark), and in Switzerland, since 1997-2000, higher populations of pollen beetles were observed. After monitoring and assessment, some phenomenon such as resistance to synthetic pyrethroids insecticides was revealed. Studies to find alternatives to control pollen beetles were thus conducted. The population size of pollen beetles can be controlled by naturally occurring enemies – hymenopteran parasitoids and predatory arthropods. The eggs and larvae of pollen beetles are attacked by at least nine species of hymenopteran endoparasitoid. Pollen beetle larvae are also vulnerable to ground dwelling predatory arthropods after dropping on the ground for pupation.

Objectives

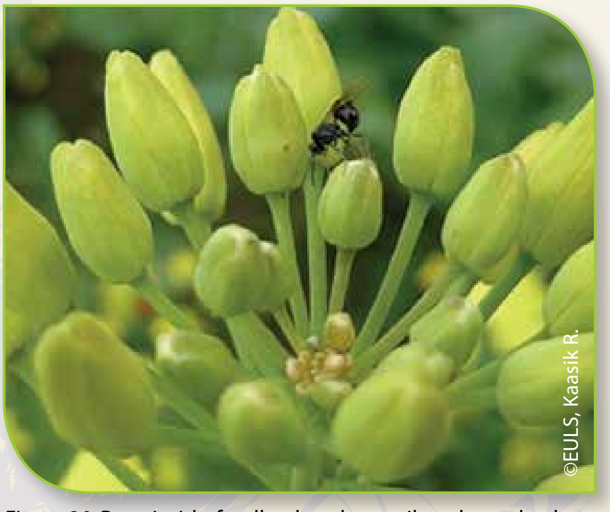
In Switzerland and Estonia, to investigate the effect of adjacent EFAs and landscape-scale greening measures on pest control in OSR, two interrelated hypotheses were tested:

- the local establishment of two commonly implemented types of EFAs (sown wildflower strips and hedgerows) enhances pest predation (insects and weeds) service delivery in adjacent OSR crops.
- the effectiveness of these adjacent EFAs in promoting pest predation is reinforced by increasing the share of greening measures implemented at the landscape level.

Results

Interestingly, contrasting results were observed between the two countries.

In Estonia, the density of *Meligethes aeneus* was influenced by the distance from the field edge with more insects in the crop edges than in the centre of crops but also by the bordering landscape element type with more beetles in fields bordered by woody linear habitats. Herbaceous linear SNH or another crop fields did not increase the abundance of the main pest. The parasitism rate of pollen beetles was very high, 68–85% on average in 2014. The pooled data of 2014 and 2015 showed that herbaceous linear (hereafter HL) SNH had positive effects on the parasitism rates of M. aeneus larvae: it increased significantly with increasing proportion of HL habitats within the 1 km radius landscape sectors. Proportion of green areas (woody areal and linear, herbaceous areal habitats and permanent grasslands) higher than 45.6% within the 1 km buffer increased the parasitism rate of M. aeneus larvae (+ 15%).



©EULS, Kaasik R.

Figure 30. Parasitoid of pollen beetle on oilseed rape buds.

In Switzerland, pollen beetle predation increased significantly with landscape-scale greening measures from 10% at 6% to 23% at 26% landscape-scale greening measures but no effect of the adjacent SNH could be detected. Parasitism of pollen beetle larvae (8% on average) was independent from adjacent SNH and did not change with increasing landscape-scale greening measures.
An increase of predatory ground beetle abundance was shown along the gradient in landscape-scale greening measures but was not affected by the adjacent SNH types or control habitats.

Pollen beetle predation significantly contributed to crop yield after accounting for crop management with a predicted increase in OSR yield by 0.4 t/ha (+9%) when predation increases from 0 to 50%.
Synergistic effects of insect pollination and pest control on yield and farmer's gain were shown in another study in Switzerland[26].
As expected yield increased with stronger pest control and thus lower pest levels, insect pollination also significantly increased yield and farmers gain but interestingly **these effects were not simply additive but rather synergistic**. So pollination increased yield and farmers gain much more at high levels of pest control, compared to low levels of PC. This phenomenon seems to be explained by the fact that **pollen beetles reduce the flower lifetime** (*Figure 31*) and ultimately **pollinator visitation per flower lifetime** (*Figure 32*).

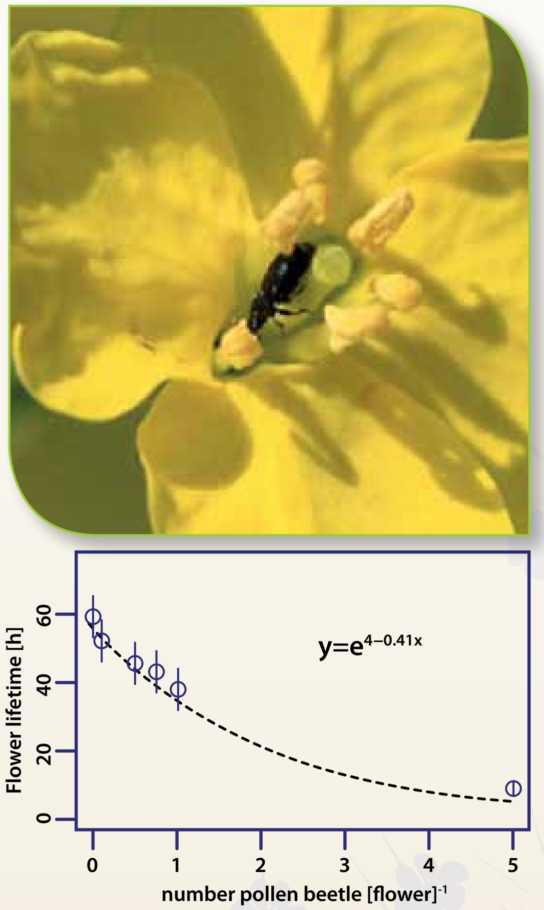


Figure 31. Negative relationship between pollen beetle density on the oilseed rape flowers and its lifetime in Switzerland.

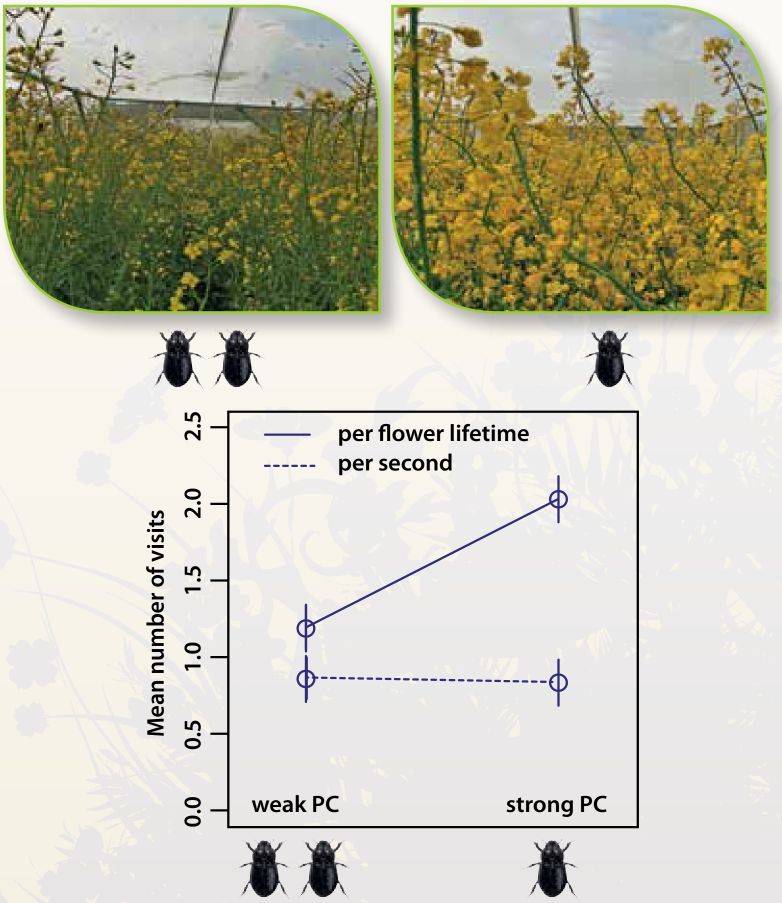


Figure 32. Increase of number of pollinator visits per flower lifetime at strong pest control of pollen beetle in Switzerland.

[26] Sutter L & Albrecht M, 2016. Synergistic interactions of ecosystem services: florivorous pest control boosts crop yield increase through insect pollination. Proc. R. Soc. B. 283: 20152529.

Recommendations for farmers, advisors and trainers

- Knowledge transfer on synergistic effects between predators and pollinators.
- Disseminating key messages such as that herbaceous linear habitats do not encourage pollen beetles in OSR fields: SNH implementation does not systematically induce disservices (pests including weeds).
- Promoting conservation agriculture or at least no tillage to preserve the ground dwelling seed-eating arthropods.
- Promoting pesticide reduction (herbicide and insecticide).

Recommendations for policy makers

- Encouraging neighbouring farmers to work together at a landscape scale when implementing SNH to improve the population of parasitoids and ground dwelling predators.
- The beneficial effects of greening measures on the regulatory ES pest control in conventional OSR production only became relevant when increases in the proportions of EFAs was higher than the currently required 5% in the EU.
- Both the local creation of SNHs, such as species-rich, perennial wildflower strips and hedgerows, nearby OSR crops and a considerable landscape-scale augmentation of greening measures can promote multiple regulatory ES to sustain crop yield even in conventional production systems.
- Promoting integrated and organic pest management since local and landscape SNH implementation could have a greater impact on crop yield.

For more details, please contact:
louis.sutter@agroscope.admin.ch
matthias.albrecht@agroscope.admin.ch
Eve.Veromann@emu.ee

Aphids on Pumpkin

Context

First, pumpkin (*Cucurbita maxima*) is highly suitable to apply conservation pest control of aphids because pumpkin has a long residence time in the field for a vegetable culture and thus there is sufficient time to build up natural enemy populations. Secondly, there is a potential to reduce insecticide applications that are used by some farmers to control aphids and the viruses they transmit. Thirdly, the marketable pumpkin fruit is not infected with aphids or beneficials, thus the use of natural enemies for aphid suppression in pumpkin does not result in problems with consumer acceptance.

Objectives

Evaluating the current status of natural pest control, and its implication in terms of crop production and trying to disentangle:

- How landscape context affects this service delivery.
- The contribution of SNHs to this ecosystem service as they provide alternative source of nectar and pollen for natural enemy populations during a part of their life cycle.

Results

In 2014, all aphidophaga (aphid gall midges, lady beetles, parasitic wasps, spiders and syrphid flies), except for lacewings, were positively related to the abundance of aphids. The economic threshold for pumpkin corresponds to 150 aphids per leaf at peak infestation. It rarely occurred in this region. Moreover, virus infestation did not increase with aphid infestation. Aphid growth rates in June were higher in organic than in conventional fields, inducing higher aphid abundances by the end of July. At this time, aphids were seen to be unproblematic. Field margins with abundant flower resources tended to reduce the density of aphids and increased total natural enemy density and in particular densities of lady beetles, lacewings, parasitic wasps and aphid gall midges in the field.

Recommendations for farmers, advisors and trainers

- Reduction of pesticide use since it is rarely necessary
- Promoting conservation pest control
- Promoting herbaceous margin with perennial floral resources
- increase of lady beetles, lacewings and parasitic wasps abundance in the field
- higher densities of spiders (tendency) & of aphid gall midges (Aphidoletes; significant) in the field bordering herbaceous margins
- Training to transfer knowledge on identification of beneficial arthropods
- Field margins should offer floral resources to increase the abundance of natural enemies and thereby reduce in-field densities of aphids.
- Pesticides should be used at a minimum to avoid interference with pollination and natural pest control.

Recommendations for policy makers

- Promoting conservation pest control through implementation of field margins with abundant flower resources.
- Knowledge transfer on economic threshold for pumpkin and the risk about virus infestation
- Supporting training on identification of beneficial arthropods for farmers and advisors

For more details, please contact:

entling@uni-landau.de
schimler@uni-landau.de
pfister@uni-landau.de

Psylla on Pear

Context

Pear psylla (mainly *Cacopsylla pyri*) is the main insect pest in European pear orchards. It has multiple generations per year, a large reproductive capacity, and it readily develops resistance to pesticides. The main damage is due to the production of large amounts of honeydew on which sooty moulds develop, leading to soiled and russeted fruits. Furthermore, pear psylla is a vector of pear decline Candidatus *Phytoplasma pyri*, the causing agent of the pear decline disease.

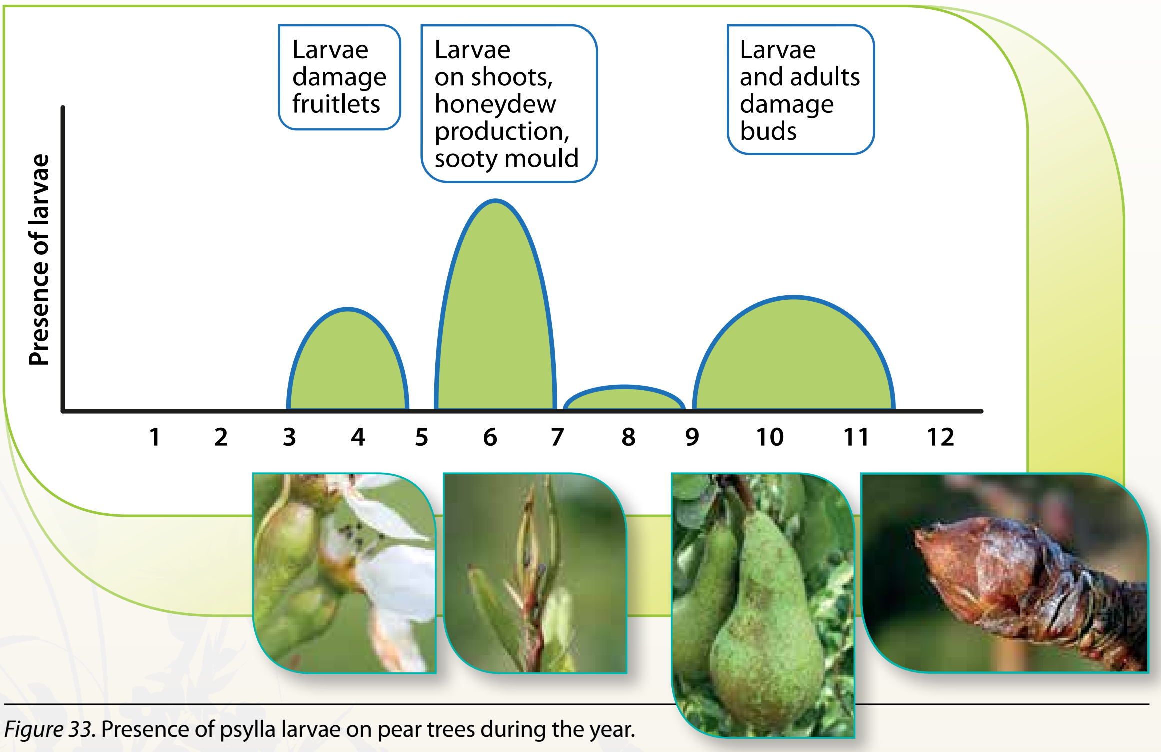


Figure 33. Presence of psylla larvae on pear trees during the year.

In North-western Europe, pear psylla has three to four generations annually (*Figure 32*). Larvae generally have the highest densities in May or June, but can reach pest status before bloom or in autumn as well.

Objectives

This study aims at assessing the level of natural pest control in pear orchards in relation to:

- The composition of the surrounding landscape and the nearby presence of SNHs
- The presence of natural enemies inside the orchard

Results

Our study shows that natural enemies heavily prey on small animal food such as insect eggs. Most of the insect eggs in the sentinel system (§ methodology) exposed in pear trees were eaten within 24 hours. However, there were large differences between orchards. Also the pear psylla densities strongly varied between orchards. These differences could not be related to the percentage of SNH in the surrounding landscape. However, we found a strong effect of earwigs (*Forficula auricularia*), both on our sentinels and on natural pear psylla densities. In orchards with high numbers of earwigs more insect eggs were eaten in summer. And a higher earwig density resulted in significantly less pear psyllids of the autumn generation. Additionally, we found a slightly lower natural psylla infestation in autumn in pear trees near woody linear SNH (i.e. hedgerows), indicating that these hedgerows might be a source of natural enemies.

In summary:

- The ES of pest control was confirmed.
- Predation was not significantly related to type of SNH or % SNH in the landscape surrounding the orchard.
- Predation on sentinels was strongly related to presence of earwigs as a predator.
- Pest density was strongly related to presence of earwigs as a predator.
- There was a large variation in earwig numbers between orchards. Some orchards had very few earwigs.
- Pear trees near hedgerows had less pear psylla as compared to pear trees away from the hedgerow.
- Near dense and high hedgerows, growers observed damage on ripening fruits caused by small birds.

Did you know?
The earwig is a generalist predator that can contribute to the natural pest control in orchards. An important part of the earwigs' life is spent in the soil. In autumn, the earwig adults move from the canopy to the soil for overwintering. In early spring, females build a nest where they lay their eggs and take care of their young. From May onwards, the young earwigs forage in the trees, where they feed on animal and plant tissue.

Recommendations to farmers, advisors and trainers

- IPM strategies should aim at keeping the psylla populations at an acceptably low level throughout the year.
- Provide optimum condition for earwigs. This includes:
  - an earwig-friendly spray regime.
  - a good soil drainage and structure, to prevent water saturation during the earwig's overwintering and nesting phase.
- Hedgerows near the orchards are a potential source of natural enemies that contribute to the natural control of pear *psylla* and other pest species. At the same time, these hedgerows provide shelter to birds that may damage the ripening pear fruits. The latter is a potential disservice of dense and high hedgerows bordering orchards.

Recommendation to policy makers

- Facilitate the registration of selective "green" pesticides such as pheromone mating disruption.

For more details, please contact:
herman.helsen@wur.nl

Aphids and Oulema on Winter Wheat

Cereal aphids and cereal leaf beetle (*Oulema melanopa, O. lichenis*) can become serious pests of cereal crops in Europe. Cereal aphids cause most damage by transmitting viruses to crops in the autumn but summer feeding can also reduce yields (typically 0.25-1 t/ha) if they are sufficiently abundant and encourage fungal diseases. *Oulema* cause damage by feeding on leaves and especially on the flag leaf. Both pests are controlled by a range of generalist (beetles and spiders), specialist natural enemies (hoverflies, lady beetles and lacewings) and parasitic wasps. These natural enemies are supported by semi-natural habitats which they provide overwintering sites, refuges from adverse agricultural operations and food resources.

Figure 34. Cereal leaf beetle larva (*left*) and its damage on winter wheat leaves (*right*).

Figure 34. Aphid sentinel.

Objectives

To evaluate the contribution of semi-natural habitats neighbouring fields and in the landscape to cereal aphid and *Oulema* control. This was achieved using generalist and aphid sentinels and measurements of naturally occurring pest levels in the UK and damage by *Oulema* in Hungary. Both countries have large fields and intensive farming systems with a reliance on insecticides for pest control.

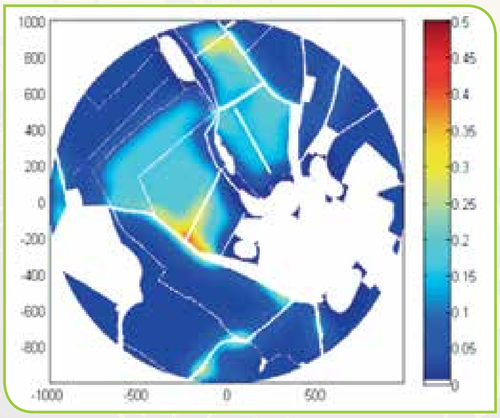


Figure 34. Heatmap of predation from low (blue) to higher (red).

Results

The ground based sentinels showed high levels of predation in the UK indicating that aphids falling from the crop, which is a regular occurrence, would be heavily predated before they can climb back up the crop. Having more herbaceous habitats in the landscape had a positive effect on predation levels in the UK. Predation of aphid sentinels on the crop was relatively low indicating that approaches to encourage crop-active natural enemies are needed. The overall proportion of SNH in the landscape helped reduce natural aphid infestation levels in the UK. *Oulema* damage in Hungary was unaffected by the type of field margin or proportion of SNH in the landscape. Damage was however highest close to the crop edge.

Mapping levels of pest control revealed areas of low and higher predation suggesting these are opportunities to improve across the landscape.

Recommendations for farmers, advisors and trainers

Encourage crop-active natural enemies such as such as hoverflies, lacewings and parasitic wasps by:

- Providing overwintering habitats by establishing tussock forming grasses on raised banks (Beetle Banks)
- Encourage and maintain areas with flowers. Simple, open structured flowers are best (e.g. *Apiaceae*). Avoid cutting hedgerows every year to allow flowering.
- To preserve natural enemies use crop scouting and pest spray thresholds to reduce insecticide usage and avoid broad-spectrum insecticides.
- Avoid intensive soil cultivations that damage beetle predators overwintering within fields.

Recommendations for policy makers

- Agri-environmental policies should provide financial support for the establishment and management of habitats that support pest natural enemies.

For more details, please contact:

jholland@gwct.org.uk
szalai.mark@mkk.szie.hu

Focus on carbon sequestration by SZIE in Hungary and GWCT in UK

Based on the chemical analyses, that we carried out to estimate other ecosystem services provided by soils (soil fertility), we can state that the pH(H2O); pH(KCl) values and the humus quality (E4/E6 ratio) of the examined soils did not differ among different sites, however, the carbon (C) content did. In Hungary and UK the soils of the herbaceous SNHs (SNH-H) contained the highest amount of C (4,3%), which was followed by the woody SNHs (SNH-W) (3,4%), then the Focal Field (FF) sites (2,6%). The nitrogen (N) content showed the same trend. According to the low physical disturbance (tillage, etc.) and high raw organic matter input (leaf litter, plant debris, etc.) of these SNHs, these soils can physically capture, protect, and store the highest amount of carbon (high humus %) in these areas compared to arable lands, which provides an ecosystem service, i.e. carbon sequestration. High total carbon (higher humus %) content in these SNHs provides higher water and nutrient holding capacity, better soil fertility and quality, thus, larger plant biomass. This relates to other ecosystem services, such as pest control, crop pollination, decreasing soil erosion, etc. The total below ground carbon stored in each landscape sector was also calculated in the UK by multiplying the soil carbon levels by the area occupied by each habitat. This revealed that on average most carbon (82%) is stored in the soil within fields because they occupy most of the area, rather than in the SNH. Furthermore, increasing soil organic matter in fields from 1-2% to 6% would double the amount of carbon stored on a farm. Thus persuading farmers to switch to conservation tillage is the most effective way of increasing soil carbon sequestration on farms, although having a higher the ratio of SNHs among arable lands, can also contribute to global C storage.

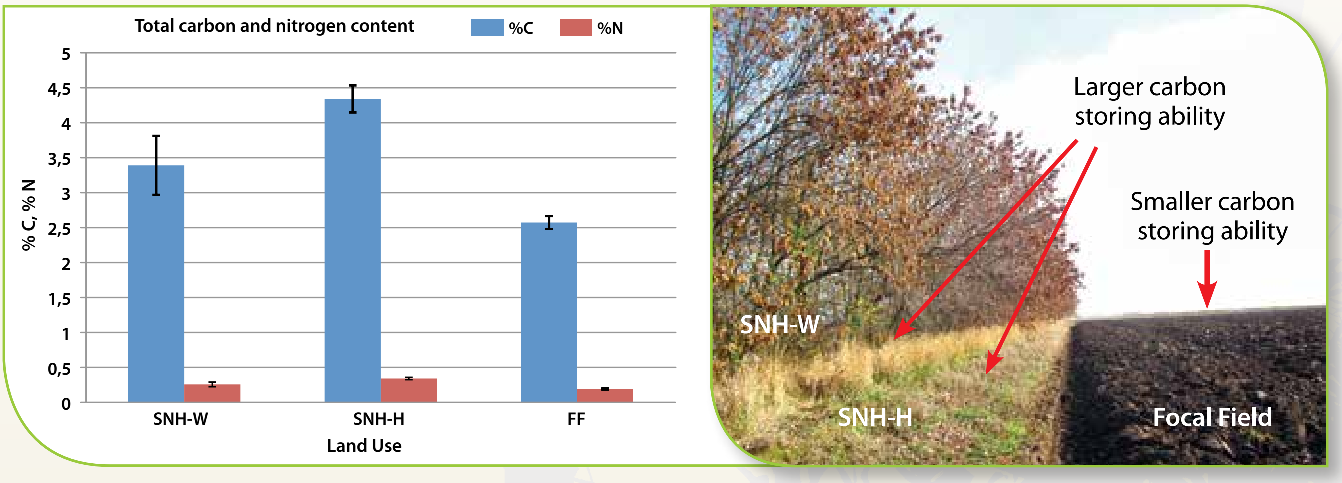


Figure 37. Total carbon and nitrogen content (%) in relation with the land use (SNH-W, H and FF represent semi-natural habitat-woody, herbaceous and focal field, respectively).

For more details, please contact:
Simon.barbara@mkk.szie.hu
jholland@gwct.org.uk

Olive fly on Olive

Olive is a perennial crop typical of Mediterranean area

Figure 38. Olive grove in South of France.

Figure 39. Olive fruit fly (*Bactrocera oleae*)

Olive fruit fly (*Bactrocera oleae*) is the key pest in olive orchard. It is a widespread, monophagous pest that feeds exclusively on wild and cultivated olives[27].

Lifecycle of *Bactrocera oleae*

The size of the olive fly population increases during the summer, after blooming and pit-hardening, and the flies thrive throughout the summer and fall[28]. In most parts of the Mediterranean region population levels decline over the winter, with very little to no trapping of adult flies during the cold months. Substantial numbers of adults usually re-appear mid-spring[29]. Depending on temperature conditions, two to six generations per year are expected in the Mediterranean region[30]. The olive fly is sensitive to high temperatures and temperatures above 31°C induce mortality of all stages of the fly and significantly reduce its reproductive activity. Temperatures between 25 and 29°C are optimal for reproduction, flying and development.

Main crop damages

Uncontrolled olive fly populations may cause up to 90% damage in commercial groves[30]. In summer, the olive fly lays eggs under the surface of ripening drupes and the development of the hatched larva cause pulp consumption and premature fall of olives. This damage takes the form of fruit loss and a decrease in olive oil quality[31]. Farmers and processors are describing 2014 as the worst year for olive oil production in living memory, with overall yields down by nearly 40%, due to above average winter temperature and relatively humid and cool summer.

Did you know?

Genetic studies suggest that this fruit fly is native to Africa, where its original host plants were wild precursors of the cultivated olive. The widespread distribution of this pest is likely due to the geographical spread of olive growing operations. In late spring and summer, adults of olive fly spend more of their time looking for mates and fruits, exposing them to natural enemies. Before overwintering, most larvae leave the fruit to pupate in the soil where ground dwelling natural enemies could attack them[32]. Depth of pupation is related to soil texture and moisture content with 90% of pupae found between 1 and 4 cm of topsoil.

Canopy spiders and their spiderwebs could be consider as a warning signal for the olive fruit fly in summer and could be linked to a reduction of the pest damage, while the predation by ground dwelling predators may be helpful after the harvest of olives, when pupae abundance in soil is at its maximum. Spiders have developed different hunting strategies: web-building and cursorial spiders. They have a complementary role in pest suppression.

Mediterranean garigue is a dry and warm habitat[33], typical of the Mediterranean landscape that consists of a mix of sylviculture (*Quercus* sp., *Pinus* sp. and *Castanea* spp.) and a mosaic pattern of closed and open habitats.

Objectives

This study aims at assessing pest control as an ES mediated by SNHs, and particularly at measuring the potential effect of spiders and ground dwelling predators on the olive fly.

The type of agriculture management, the type of adjoining SNH as well as the proportion of SNH types in the landscape were assessed on the pest control of olive fly by these beneficial communities.

[27] Daane KM &Johnson MW, 2010. Olive fruit fly: managing an ancient pest in modern times. Annu Rev Entomol 55: 151-69.
[28] Ragaglini G., Tomassone D., Petacchi R., 2005 – Can spring-preventive adulticide treatments be assumed to improve Bactrocera oleae (Rossi) management? 2nd European Meeting of the IOBC/WPRS Study Group "Integrated Protection of Olive Crops". Florence, Italy, October 26-28 (2005): 87-92.
[29] Tzanakakis ME, 2003. Seasonal development and dormancy of insects and mites feeding on olive: a review. Netherland Journal of Zoology 52: 87-224.
[30] Katsoyannos P, 1992. Olive pests and their control in the Near East. FAO Plant Production and Protection Paper 115. FAO, Rome.
[31] Baldoni L & Belaj A, 2009. Chapter oil crops Vol 4 of the series Handbook of Plant Breeding pp 397-421.
[32] Tremblay E, 1994. Entomologia Applicata Volume III parte 2 Napoli Liguori Editore.
[33] Polunin O & Walters M, 1985. A guide to the vegetation of Britain and Europe, Oxford University, New York.

Detrimental effect of chemical applications on in-field natural enemy guilds was observed. Organic management increased the potential endemic pest control agents with an increase in the abundance and richness of spiders and on predation rate of ground dwelling predators.
Regulation of the olive fruit fly daily density could be due to the predation activity or to the repellent effect of spider webs[34] that could be seen as a warning signal by potential prey and thus, reduce pest damage[35].
Among the SNH types (olive fields, woods, Mediterranean garigue), the Mediterranean garigue seemed to play the most important effect at local and at landscape level.

Mediterranean garigue had a differential effect on beneficial arthropods:

- Reduction of abundance of spiders (*Linyphiidae* family) by the proportion of garigue in the landscape (1 km sector buffer)
- As adjacent SNH type to olive, garigue seems to increase the predatory pressure mediated by ground dwelling predators.

The abundance of flies (potential spider prey) increased with increasing percentage of wood in the landscape.
Olive fruit fly densities were negatively correlated with cursorial and sheet web spiders' abundance. In canopies with greater abundance of spiders, the activity of olive fruit fly decreased. When pest density was low, the negative correlation was among olive fruit flies and sheet web spider family (*Linyphiidae*). At the peak of infestation, the assemblage of cursorial spiders had a negative correlation with the daily activity density of the olive fruit fly.

Recommendations for farmers

- Results suggested that there is a potential for integrated pest control programs in olive tree that can be based on a range of management options aimed at limiting olive fruit fly abundances, rather than depending on a single protection method.
- Organic management increases the conservation biological control
- No upper layer soil tillage so as to not disturb the ground dwelling activity and predation of pupae.
- To manage weeds, mowing is recommended. Avoid herbicide application.
- Improve harvesting techniques in order to eliminate the residual olives from trees, also in areas with accessibility difficulties[36].
- Regular monitoring of their own field from the beginning of spring through visual estimation of the olive fruit fly presence in order to hasten decision-making and then applying the appropriate pest control methods.
- Key role of the Mediterranean garigue on beneficial arthropods. Potential opposite and controversial role on spiders and ground predators to be taken into account in conservation biological control techniques and need further studies to determine its role on service provider communities.

Recommendations for policy makers

- Supporting research on the effect of Mediterranean garigue on the pest complex of B. oleae in order to support biological control in the field.
- Improve the monitoring of the pest infestation in the territory through evaluation of the pest damage in olives (June till October) and that weekly pest management assessments are adopted by farmers in the landscape (www.agroambiente.info) and to assess the government investment programs
- Improve the low input management of olive fields with the aim of reducing the abandonment and enhancing the conservation of terracing, dry walls and the accessibility to olive fields.
- A sustainable rural development program to support the maintenance of rural elements that contribute to the conservation of aesthetic landscapes.

For more details, please contact:
m.picchi@sssup.it

[34] Picchi MS, Bocci G, Petacchi R & Entling MH, 2016. Effects of local and landscape factors on spiders. Agriculture, Ecosystems and Environment 222: 138-47.
[35] Rypstra AL & Buddle CM, 2013. Spider silk reduces insect herbivory. Biol Lett 9 : 20120948.

[36] A partial collection of olives or abandonment of some part of the olive field could increase the risk of infestation for the following season: leftover olives works as the larval feeding substrate for the first annual generation of olive fruit fly in spring.

Green leafhopper, Grapevine moth and Vine

Figure 40. Vineyard from French case study.

Context

Perennial crops such as vineyards, differed greatly from annual cropping systems in terms of disturbance for natural enemy communities: high inputs of pesticides are used but they are also more stable habitats in space and time (no crop rotation and lower levels of soil disturbance).

Pests studied in France

Grapevine moth (*Lobesia botrana*)

Figure 41. Adult of European vin moth (*Lobesia botrana*) (*Left*).

Figure 42. Damages of European vine moth on grape: glomerulus and punctures that facilitate the development of microorganisms: risk of gray mold (*Botrytis cinerea*), black rot from *Aspergillus* and fruit flies that lay eggs in wounds and initiate the installation of the acid rot, (*Right*).

Vine leafhopper (*Empoasca vitis*)

Figure 43. Adult of vine leafhopper (*Empoasca vitis*) (*Left*).

Figure 44. Main symptoms of vine leafhopper on red vine.

Objectives

In both Atlantic and Mediterranean vine regions of France, the effects of landscape and local complexity on biodiversity (measured both on pests and on natural enemies) and their associate ecosystem services (measured on sentinel systems) were assessed.

Results

Interestingly, the two pest species associated with vineyards showed a different response to the presence or the cover of SNH at the local and landscape levels. The abundance of moth species L. botrana was significantly and negatively influenced by the presence of woody habitats at the local level and of SNH cover at the landscape level. The leafhopper species was unaffected.

Further analyses of landscape composition are necessary for the Mediterranean site.

There were few effects of SNH cover on abundances of insectivorous predators in the vineyards.

Carabids, staphylinids and opiliones were negatively influenced by vine monoculture (i.e. increase of vine cover at the landscape scale).

The abundance of different groups of service providers at different scales was negatively affected by vine monoculture.

Figure 45. Potential of predation on the ground through consumption of eggs of *Ephestia kuehniella*, located under the vine row during 1 day. (*Left*)

Figure 46. Potential of predation through consumption of eggs of *Ephestia kuehniella*, located on the vine during 1 day. (*Right*)

Figure 47. Living larvae of *Calliphora vomitaria* during 1 day. (*Left*)

Figure 46. Artificial caterpillar on vine during 7 days. (*Right*)

Recommendations for farmers

- SNH cover and presence of woody habitats around vineyards at local level strongly decreased the pest abundance of *Lobesia botrana*.

Recommendations for policy makers

- Encourage the diversity of habitats at a landscape levels.

For more details, please contact:
brice.giffard@gmail.com

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.*: disservices. 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 showed that there is 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 to implement in the flower strips, species with early flowering compatible with the crop rotation so that they did not attract pollinators away from the focal crop during flowering.

Recommendations for farmers, advisors and trainers
- 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.
- Systemic analysis should be adopted to help in visualizing that within agroecosystems each component is interconnected (e.g. impact of intercropping and cover crops on preservation of nesting or overwintering sites for beneficial arthropods).

Enhancing biodiversity to enhance ES

Little knowledge is available on the relationship between plants and the provided services, but some elements from QuESSA results on the complementary vegetation functional traits and plant diversity in the SNH (herbaceous, shrubs…) could be a best guarantee for the potential ES delivery.

Recommendations for farmers, advisors and trainers and for policy makers
- Promoting the implementation of the Green Infrastructure through the « Nature-based solutions », that improves and enhances habitats to support beneficials in farming landscapes. As promoted by EU (COM(2013)249)[37] and by the recent study of Harvey et al. (2016)[38], 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.
- Need to take care of biodiversity for several reasons: biodiversity as a guarantee for food production, conservation value, landscape aesthetics and adaptation to climate change with the example of SNH network. To help in implementing and managing the SNH, having a multifunctionality goal could be a motivator.
- Promoting research to fill gaps on the host plants to be supported at farm level to enhance beneficial arthropods' populations.
- Developing new habitats designed to provide resources for service providers e.g. wildflower areas to encourage pollinators and pest natural enemies.

[37] http://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF
[38] Harvey E, Gounand I, Ward C L & Altermatt F, 2016. Bridging ecology and conservation: from ecological networks to ecosystem function. J Appl Ecol. doi:10.1111/1365-2664.12769.

Figure 49. A wildflower strip adjacent to a winter wheat plot in Switzerland.

Reinforcing the ecological focus areas green payments

Previous EU projects (Bio-Bio) underlined the SNH diversity as a guarantee for local functional biodiversity (beneficials).

Recommendations for policy makers

Go further on the EFA requirements by taking inspiration from the IOBC guidelines.

- Calculate the ecological infrastructures area in the whole farm perimeter (all crops are included, not only the arable crops),
- Consider the real surface area of EFAs and not the converted and weighted surface area. Indeed, and to over-estimate the benefits of field margins 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 meter 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.
- 5% to 7% of real agricultural surface area in SNH.
- Foster collective EFA implementation.
- 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. The QuESSA project has highlighted the need for a herbaceous understory and vegetation complexity that can only develop with lower agrochemical contamination. For regions in which the landscape is dominated by small, fragmented properties, this requirement may be accomplished only with some costs for farmers (take into account potential subsidies in case of significant gain loss).
- Forbid pesticides and fertilized used on the cover crops and legumes, which are included as EFA. They crucially support honey and wild pollinators as well as predators and parasitoids by providing essential resources, therefore no agrochemicals should be permitted.
- 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. This could be achieved by promoting a diversity of EFAs.
- Promoting agroforestry systems, not studied in the QuESSA project, but best way to introduce herbaceous and woody SNH within the cropped field.

Promoting the environmental friendly farming practices and SNH management

As previously mentioned, QuESSA results could help to change postures and attitudes.

Recommendations for policy makers

- Reinforcing greening payments through certain EFAs, such as introducing a maximal threshold for legumes and cover crops (1% of the required % of EFA) and a minimal threshold for perennial features (at least 2,5% of required % of EFA).
- Strategies promoting Organic Farming could contribute to re-establish heterogeneity of farmland habitats, thereby enhancing farmland beneficial diversity.
- More funding for research & training programs: "Keep up with the ecological transition".
- Promoting focus groups, participatory research, collective decisions at the territory scale (e.g. watershed).
- Promoting collective and coordinated crop management at a landscape level (farmers' focus groups).

- 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.
- 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.
- 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 (EU Directive 2009/128/EC).
- Increasing the efficacy of natural enemies should start from the study of the functioning of biological control in agroecosystems and it could be reached through the identification of the key aspect of diversity to promote new sustainable strategies such as habitat manipulation[38].
- Such alternative strategies should take into account the seasonality of natural enemies and the composition of the surrounding landscape.
- Promoting the development and dissemination of decision support tools to help farmers to implement or manage their SNH. Such decision support tools could be complementary to Herbea (http://www.herbea.org/) that is an interactive tool that propose a list of key plants and SNH to implement to favour beneficials (including parasitoids, predators and pollinators) and not pests according to your ecological zone and the selected crop (or rotation) (an English version is coming soon).

Promoting diversity and connectivity of the SNH

The scoring system of potential ES provisioning by the SNH underlines the importance **of the edge effect**: pollinators are more abundant at the edge than inside woody areal elements.
Moreover, groups of beneficial invertebrates are connected to specific elements. The structure as well as the functional traits are important determinants to attract some beneficials (flower colour, early/late flowering, nectar availability…). Flying predators respond differently to vegetation structure: parasitic wasps are very abundant at the edge of woody and herbaceous areal and linear elements, and still present inside these elements. Predatory Diptera are only very abundant at the edge but not inside woody elements.

Recommendations for farmers, advisors and trainers

- Promoting **diversity and connectivity** of SNH elements to enhance beneficial populations.
- Supporting research on land sharing, delivery of ESs beneficial and/or resilience of agricultural systems to climate change and pest outbreaks.
- Knowledge transfer on the benefits of increasing plant diversity at farm scale:
  - Global resources are better used when numerous species are present (different ecological niches): this corresponds to the **functional complementarity hypothesis**.
  - By increasing the number of species, « best » ones are expected to occur: **sampling effect hypothesis**.
  - Functional similarities in the landscape allow functional redundancy and stability of the environment (resilience): **redundancy-resilience effect hypothesis**.

Promoting the multifunctionality of the SNH

QuESSA project was interested in evaluating other ESs such as conservation value, carbon storage, soil erosion, landscape aesthetics and soil fertility. They highlight the multiple functions provided by SNH. People particularly like landscapes with flowering and woody elements (included perennial crops such as vineyard or olive orchards). Soil fertility was shown to be higher in SNH than in crop fields as well as carbon storage (more C / ha for SNH). Carabids species richness Red List species were shown to be higher in herbaceous elements in Germany, demonstrating the conservation value of these SNH types. This multifunctional character could be helpful for farmers to find an attachment point for addressing ecosystem services, biodiversity and SNH.

Recommendations for policy makers

- Policies promoting and sustaining different SNH types on farmland, diversified vegetation management in SNH (mowing regimes, reduction or no-use of herbicides…) in and around farmland and involving not only the farmers but also municipalities and other territorial structures.

[38] Eilenberg J, Hajek A & Lomer C, 2001. Suggestions for unifying the terminology in biological control. Biocontrol. 46: 387-400; Paredes D, Cayuela L & Campos M, 2013. Synergistic effects of ground coer and adjacent vegetation on natural enemies of olive insect pests. Agriculture, Ecosystems and Environment 173: 72-80.

Working with the farmers

Recommendations for policy makers

- Promoting co-innovative framework between farmers, advisors, researchers and trainers to help in the ecological transition.
- QuESSA underlines the importance of collaborating with farmers on these topics, at a local scale, through participative methods (focus groups, interviews, on-farm demonstration) to involve them in the process from the beginning so that they take ownership of the concepts of ES, functional biodiversity and SNH.
- As mentioned previously, the multifunctionality of SNH could be helpful.

Gaps and lacks were identified during focus groups and/or on-farm demonstration:

- **Scientific knowledge**: 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.
- **Knowledge transfer**: too little dissemination of the "success stories"
- **Technical solutions**: lack of adapted machinery to small scale vegetation management.
- The more the farmers are involved, the better they can participate and propose some farming practices or SNH management that fit the ES desired and needed locally.
- This implies that financial and technical support is needed for farmers and SNH managers to develop and implement locally adapted SNH management.

Conclusion

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, none of the five countries we tested (ES, CH, UK, DE, IT) 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 (ES, 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 biocontrôle as well as for prevention of soil erosion. Nevertheless, some trade-offs need to be adjusted between aesthetic and conservation values.

Acknowledgement

The partners of the QuESSA project would like to warmly thank all the farmers who voluntarily joined the case studies in France, Italy, Switzerland, Germany, United Kingdom, Hungary, the Netherlands and Estonia. Their commitment was essential to the assessment of ecosystem services provided by semi-natural habitats in much diversified regions. Their interest and understanding of the issue allowed constructive exchanges.
We would like to warmly thank the members of the stakeholder advisory board for their accurate recommendations and expectations with regard to the outcome of the project and the requirements regarding semi-natural habitat management.
Finally, we would like to warmly thank all the members of the Food and Agricultural Organization of the United Nations with a special mention to Kakoli Ghosh, for the fruitful discussion occurring during the Final Conference.

Content:
Partners of the QuESSA project
Redaction:
Dr Caroline Gibert (Solagro)
caroline.gibert@solagro.asso.fr

Graphic design, illustrations:
Eric Péro (spyro) – www.imageric.fr

QuESSA
Quantification of Ecosystem Services for Sustainable Agriculture

www.quessa.eu

https://www.facebook.com/Quessa-129370957261348/

Contact (co-ordinator):
Dr John Holland – Game & Wildlife Conservation Trust (GWCT)
Fordingbridge, Hampshire SP6 1EF, United Kingdom
jholland@gwct.org.uk

Partners

Game & Wildlife Conservation Trust; Solagro; European Commission; Schweizerische Eidgenossenschaft, Confédération suisse, Confederazione Svizzera, Confederaziun svizra, Swiss Confederation, Federal Department of Economic Affairs, Education and Research EAER, Agroscope; essrg; Wageningen University & Research; www.emu.ee Eesti Maaülikool Estonian University of Life Sciences; Universität Koblenz · Landau; Institute of Life Sciences, Scuola Superiore Sant'Anna; University of Exeter; Università di Pisa; Bordeaux Sciences Agro; Szent István University