LIBERATION

LInking farmland Biodiversity to Ecosystem seRvices for effective eco-functional intensificATION

7th Framework Programme Theme KBBE.2012.1.2-02
Managing semi-natural habitats and on-farm biodiversity to optimise ecological services

Collaborative Project
Grant Agreement No.: 311781 – LIBERATION – CP – FP

Deliverable 3.2: Report on the effectiveness of a range of landscape management practices

Deliverable date: 25.01.2016

Lead Participant: UPAD
Contributing participant(s): ALTERRA, UREAD, MTA-ÖK

The research leading to these results has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 311781.

NON TECHNICAL SUMMARY

Ecological intensification aims to enhance important ecosystem processes that contribute to the delivery of the ecosystem services that underpin agricultural production allowing us to reduce our reliance on synthetic inputs. The potential of ecological intensification will depend on many factors, among the most important of which are off-field management and landscape context. These factors, and importantly the interaction between them, are likely to vary across regions and countries. Identifying off-field management approaches that are successful in enhancing ecosystem services will require assessing a range of strategies. The empirical work carried out in task 3.2 provided original data on the effectiveness of three off-field interventions (hedgerow, set- aside and flower strips) on the delivery of biocontrol and yield in winter cereals across different European countries. For hedgerows we found that the quality of the hedgerow (flower diversity) generally increased biodiversity of several beneficial groups of insects (e.g. butterflies, tachinids, carabids, spiders), while the delivery of ecosystems services such as pollination and pest control tended to respond more to landscape factors (proportion of hedgerows or semi-natural habitats in general in the surrounding). For set-aside we found that this intervention increased locally the biodiversity of several beneficial insect groups (literature) but the spillover to winter wheat fields was small with no apparent benefit on the delivery of aphid biocontrol. Finally, we found that wildflower strips helped to reduce aphid pests in winter wheat fields, which, in turn, enhanced crop yield. However, this potential may only be reached in case strips are properly managed, in a way that optimizes floral diversity, and may only be relevant in agricultural landscapes with a low availability of habitat area for natural enemies. Irrespective of the intensity of the agricultural systems, the two most promising interventions to foster biocontrol and support yield in winter wheats are hedgerows and flower strips, but their effect appeared to be stronger in landscapes with low cover of existing semi-natural habitats.

POLICY RELEVANCE

Our findings highlight the potential contribution that hedgerows and flower strips can make to ecological intensification in several European countries. In several cases we demonstrated that investing in the creation of hedgerows and flower strips can improve the delivery of pest control and pollination with benefits on yield provisioning, while set-aside did not provide any benefit to biocontrol or yield. The different responses among countries, ecosystems services and biodiversity groups indicate that each intervention should be tailored according to local conditions and existing semi-natural habitats in the landscape. This suggests that multiple ecosystem services can most effectively be enhanced by conservation or restoration of off-field landscape elements at relatively large spatial scales. Currently, few agri-environmental programs in Europe provide instruments for coordinated conservation action at the landscape level. If the objective is to enhance ecosystem services investments in these off-field interventions should be concentrated in landscapes with existing low cover of semi-natural habitats. The threshold for low cover of existing semi-natural habitats can be different in the different countries and we cannot provide a single figure. Future agri-environment schemes to foster biocontrol in simple landscapes could focus on hedgerow and flower strips in both low- and high-intensity farming systems. Combined with the results from D3.1, D3.3 and the modeling exercises in WP4 and 5 we will provide farmers and land managers with concrete options for how to close potential yield gaps using semi-natural habitats, with the support of clearly defined ecosystem services, that will be based on a much improved understanding of economic opportunities and consequences.

Liberation Deliverable 3.2

Report on the effectiveness of a range of landscape management practices

Lorenzo Marini[1], Réka Ádám[2], András Báldi[2], Krisztina Bereczki[2], Gergely Boros[2], Duncan J. Coston[3], Matteo Dainese[1], Wim Dimmers[4], Zoltán Elek[2], Mike P.D. Garratt[3], Stijn van Gils[4], Arjen de Groot[4], Ruud van Kats[4], Anikó Kovács-Hostyánszki[2], Dennis Lammertsma[4], Silvia Montecchiari[1], Simon Mortimer[3], Simon G. Potts[3], Deepa Senapathi[3], Maurizia Sigura[5], László Somay[2], Ottó Szalkovszki[6], Tommaso Sitzia[7], David Kleijn[4, 8]

[1] DAFNAE-Entomology, University of Padova, viale dell'Università 16, 35020, Legnaro, Padova, Italy

[2] Institute of Ecology and Botany, Centre for Ecological Reserach, Alkotmány utca 2-4, H-2163 Vácrátót

[3] Centre for Agri-Environmental Research, School of Agriculture, Policy and Development, University of Reading, UK

[4] Animal Ecology, Alterra – Wageningen UR, P.O.Box 47, 6700 AA Wageningen, the Netherlands

[5] Department of Agricultural and Environmental Science, University of Udine, via delle Scienze 208, 33100, Udine, Italy

[6] Department of Botany, Center for Plant Diversity, Külsőmező út 15, H-2766 Tápiószele

[7] Department of Land, Environment, Agriculture and Forestry, University of Padova, Viale dell'Università 16, 35020 Legnaro, Padova, Italy;

[8] Plant Ecology & Nature Conservation, Wageningen University, P.O. Box 47, 6700 AA Wageningen, the Netherlands

1. GENERAL INTRODUCTION

A huge amount of ecological research conducted during the last two decades provides support for the impact of landscape composition and configuration on biodiversity patterns in agricultural landscapes world-wide (e.g. Tscharntke et al. 2012). On the contrary, the evaluation of the impact of landscape on the delivery of biodiversity-based ecosystem services in agriculture was only recently addressed by ecologists. Actually, studies addressing this topic in realistic cropping systems have mainly been carried out in the last five-six years in North America and Europe (Klein et al. 2012; Rusch et al., 2013).

Besides these limitations, studies generally agree on the beneficial effects of landscape complexity and connectivity and on the positive effect of semi-natural habitats on ecosystem service delivery in the landscape surrounding crops. For example, connectivity loss negatively affects pollination and pest control (Mitchell et al., 2013), while fruit set increases with increasing percentage of natural habitats in the surrounding of cultivated areas (Klein et al. 2012; Kremen et al. 2004). This suggests that the effective flow and stability of biodiversity-based ecosystem services in agro-ecosystems would require the conservation of heterogeneous landscapes with a high proportion of semi-natural habitats (Rusch et al., 2013) that provide refuge and food sources for beneficial organisms.

Some studies also indicate an interactive effect between landscape features and local management (Fischer et al. 2011), indicating that the delivery of biodiversity-based ecosystem services in agricultural landscapes relies on different factors simultaneously acting at different spatial scales. For example, organic farming combined with high landscape complexity enhances biological control (Winqvist et al. 2011) and pollination (Andersson et al. 2014). This suggests that a combination of insect habitat and decreased management intensity is needed to improve and stabilize biodiversity-based ecosystem services.

In general, current scientific knowledge indicates that the increasing simplification of agricultural landscapes would negatively affect the provision and the spatial-temporal stability of the most important ecosystem services. However, most studies focus on a single ecosystem service, especially pollination (Klein et al. 2012) and pest control (Rusch et al., 2013), while only a few studies simultaneously address multiple ecosystem services (e.g., Mitchell et al., 2015), hindering the identification of trade-offs between services (Mitchell et al., 2013). The simultaneous effects of landscape on multiple ecosystem services is therefore a topic that would deserve further research in the future.

In LIBERATION, we examine the benefits of both existing and new semi-natural habitats on the provision of multiple ecosystem services in a number of different studies across Europe. We focused on the effect of hedgerows, set-aside and flower strips on biocontrol and yield provisioning in winter cereals.

2. EXISTING SEMI-NATURAL HABITATS: SHORT REVIEW

Over the past half-century, agricultural intensification has dramatically increased, transforming agricultural landscapes into simplified monocultures with low cover of semi-natural habitats (DeFries et al. 2010). This trend, often called ‘landscape simplification’, has led to severe biodiversity losses and to the deterioration of key ecosystem services to agriculture (Tilman et al. 2001). Amongst ecosystem services, pest and weed control and pollination have been demonstrated to have a valuable impact on crop production worldwide. Therefore, several interventions have been suggested to enhance ecosystem services in farmland (Bommarco et al. 2013).

Field-margin diversification through the conservation and restoration of hedgerows is becoming a prominent intervention for promoting biodiversity and ecosystem services in intensive agricultural landscapes. Recent studies have shown that hedgerows can help mitigating the negative effects of agricultural intensification on biodiversity. In particular, hedgerows can promote pollinator populations and export wild bees to adjacent fields (Morandin & Kremen 2013), as well as enhance natural enemies (Morandin et al. 2014). Increasing environmental heterogeneity within farms can be also an effective way of decreasing the abundance of problematic weeds by shifting the species abundance distribution (Dornelas et al. 2014). However, current understanding of the effects of off-field interventions on the provision of ecosystem services is mainly based on studies at the local scale, even though the surrounding landscape context can play a relevant role in shaping plant and insect assemblages in agro-ecosystems (Tscharntke et al. 2012). In addition, studies addressing the impact of such interventions have mostly focused on one particular ecosystem services, while there is a lack of studies that use multiple experiments to capture the impacts of hedgerows on multiple ecosystem services simultaneously.

In LIBERATION, we assessed the effects of field-margin diversification at the local and landscape scale on multiple ecosystem services in Italy and UK.

2.1 Italian case study: Complex hedgerow networks support multiple ecosystem services

Matteo Dainese, Silvia Montecchiari, Tommaso Sitzia, Maurizia Sigura, Lorenzo Marini

Summary

Field-margin diversification through conservation and restoration of hedgerows is becoming a prominent intervention for promoting biodiversity and associated ecosystem services in intensive agricultural landscapes. Here, we assessed the effect of increased field margin complexity at the local and landscape scales on the provision of pest control, weed control, and potential pollination. Three types of field margin were compared (standard grass margin – simple hedgerow – complex hedgerow) along two independent gradients of hedgerow cover and arable land cover in the landscape. At the local scale, we found that increased field margin complexity did not enhance ecosystem services' delivery. However, complex hedgerow networks in the landscape enhanced the provision of aphid parasitism and potential pollination irrespective of local margin quality. The cover of arable land in the landscape instead reduced the abundance of vegetation-dwelling predators and weed diversity but did not affect the delivery of the investigated ecosystem services. Our results highlight the key importance of the surrounding landscape context, rather than local factors, to ecosystem services' delivery. This suggests that multiple ecosystem services can most effectively be enhanced by conservation or restoration of hedgerows at relatively large spatial scales. Currently, few agri-environmental programs in Europe provide instruments for coordinated conservation action at the landscape level. If the focus is on enhancing ES, policy should primarily target simplified landscapes and increase the cover of hedgerow.

Publications

Dainese M., Inclan D.J., Sitzia T., Marini L. (2015) Scale-dependent effects of semi-natural habitats on farmland biodiversity. Ecological Applications 25, 1681–1690.

Dainese M., Montecchiari S., Sitzia T., Sigura M., Marini L. Complex hedgerow networks support multiple ecosystem services. Submitted to Journal of Applied Ecology on the 12-12-2015 (currently under review)

Methods and approach

The study was conducted in 2014 in the Venetian-Friulian Plain (north-eastern Italy: 46°09′−45°16′ N, 11°45′−13°22′ E). Our study design consisted of 26 field margins adjacent to winter wheat fields. Three types of field margins were chosen to represent different levels of structural complexity: (i) grass margin (n = 10), (ii) simple hedgerow (n = 8), and (iii) complex hedgerow (n = 8) (Fig. 1). The three types of field margin with different levels of structural complexity were selected along two independent gradients of hedgerow cover and arable land cover in the landscape (in a 1 km buffer).

Fig. 1 Examples of a (a) grass margin, (b) simple hedgerow, and (c) complex hedgerow.

In all the selected field margins we measured multiple ecosystem services. Natural pest control of cereal aphids was measured using an exclusion experiment and the sampling of natural enemies in the field. In the field, the sampling of natural enemies was carried out by visual inspection of winter wheat shoots and by pitfall traps. Ground-dwelling predators (carabid beetles, rove beetles, and cursorial spiders) were caught with three plastic pitfall traps per field (9.5 cm in diameter and 13 cm deep). The diversity and abundance of weeds were recorded once in the second half of May. Sampling was conducted in a plot of 10×10 m within the crop adjacent to the selected field margins. Pollinator activity and their effects on plant reproductive success were quantified using a phytometer experiment. Radish, *Raphanus sativus* L. (Brassicaceae), was selected as phytometer species on the basis of its growth characteristics (quick germination and fast growth). For each site, insect visitation rate was quantified three times between 28th May and 11th June. On the 19th of June 2014, at the end of the flowering period, the potted plants were taken back to a screen house to complete fruit maturation.

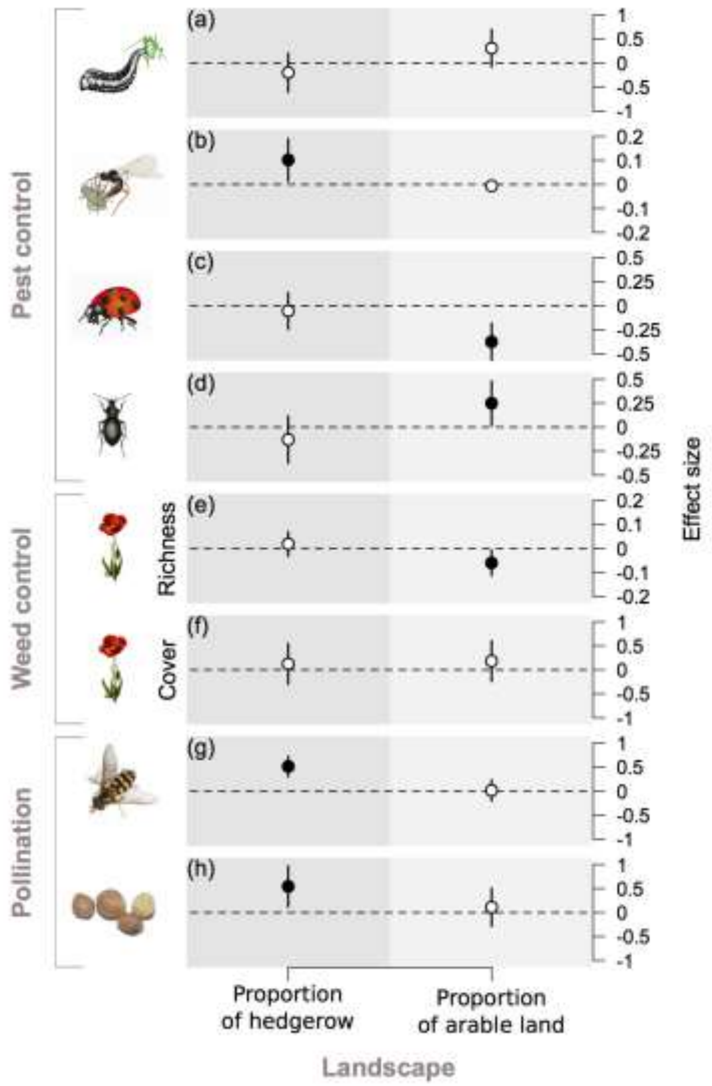

Fig. 2 Model-averaged effect sizes and 95% confidence intervals for the landscape parameters included in strongly supported models (ΔAICc ≤ 7) explaining (a) predation index, (b) parasitism rate, (c) abundance of vegetation-dwelling predators, (d) abundance of ground-dwelling predators, (e) weed species richness, (f) weed cover, (g) visitation rate, and (h) Δ seed set. Open and closed symbols reflect estimates model averaged confidence intervals that include and did not include 0.

Main findings and implications

At the local scale, our results confirm previous studies showing a strong reduction in aphid populations in cereal fields due to natural enemies. We observed high potential pest control (> 90%) in all fields irrespective of the local margin complexity. Surprisingly, we did not find any effect of field margin complexity on both parasitism rate and abundance of vegetation- and ground-dwelling predators. Considering weed control and pollination service we found similar weed diversity, pollinator visitation rate, and seed set among the three types of field margins. Field margin had a significant effect only on pollinator abundance of some pollinator guilds.

Despite no apparent effect of local field-margin diversification on the delivery of ecosystem services, the benefits from hedgerows were evident considering a landscape perspective. Landscapes with complex hedgerow networks supported more abundant communities of beneficial arthropods than landscapes with low hedgerow cover improving natural pest control by parasitoids, as well as potential pollination service (Fig. 2). Although we hypothesised that field-margin diversification could compensate the lack of semi-natural habitats in the landscape, our results indicate no interaction between local complexity and landscape processes. Likewise, we found no interaction between the cover of hedgerow and arable land in the landscape suggesting that a complex hedgerow network can enhance the provision of ecosystem services in landscapes dominated by arable land, as well as in landscapes with large proportion of non-linear semi-natural habitats.

Until now, hedgerow-related interventions have mainly focused on local measures. While these measures are certainly beneficial for conserving farmland biodiversity (Dainese et al. 2015), our results suggest that there is a need to promote the conservation of hedgerows at larger spatial scales for supporting multiple ecosystem services. Specifically, the development of ecological corridor networks through, for example, the conservation or restoration of hedgerows, can be an effective measure. Such interventions may be a ‘low cost-high benefit solution', since farmers can create or conserve high-quality habitats taking little or no land from crop production and without the need to change their crop management. The ecological production functions and the economic analyses that will be performed in WP4 and WP5 will elucidate the cost-benefit of introducing these interventions. However, successful implementation of such measures at large spatial scales requires well-designed landscape-scale schemes that support and coordinate the participation of farmers and landowners. However, these off-field interventions cannot be considered a unique solution to enhance ecosystem services’ delivery in farmland and other measures may be necessary to achieve, for instance, the desired level of pest control or pollination service. The integration of innovative interventions in modern farming systems can represent, therefore, a major challenge for future policy strategies.

2.2 English case study: Hedgerow benefits for ecosystem services depends on hedge quality and is moderated by landscape

Mike P.D. Garratt, Duncan J. Coston, Deepa Senapathi, Simon Mortimer, Simon G. Potts

Summary

Hedgerows are common linear semi-natural features in arable cropping systems and are particularly common in the UK. In fact there are more than 450,000 km of hedgerows in England alone (Norton et al. 2012). Hedgerows provide a valuable habitat and food resource for biodiversity including invertebrates (Amy et al. 2015), plants (Critchley et al. 2013) and birds (Staley et al. 2012) and may provide an important mechanism for increasing the permeability of agricultural landscapes and increasing the abundance of functionally important taxa (Hanley & Wilkins 2015; Sardiñas & Kremen 2015; Amy et al. 2015). In light of this, hedgerows are a priority habitat in the UK and support for their management is provided through agri-environment schemes (Natural England, 2013). The aims of the present study were to; 1) measure to what extent the abundance of functionally important taxa spill over from hedgerow habitats in the UK; 2) understand the role of hedgerow quality and 3) how hedgerows and surrounding semi-natural landscape components interact to influence the abundance of functionally important taxa. Our study shows that hedgerows provide an important source of natural enemies which spill over into neighbouring fields and the abundance of some natural enemies including Staphylinids and Lycosids is greater in good quality hedges. Hedges also provide a valuable forage resource for pollinators. In particular, hedgerows that contained more than three woody species, a good solid structure with no gaps supported greater numbers of bumblebees and hoverflies. Landscape context moderates the benefits of hedgerows for some taxa and wild bee abundance on hedgerows was greater in landscape with low semi-natural habitat. In conclusions, hedgerows have a more important role in supporting wild bee abundance in areas with low semi-natural habitat than in areas with high semi-natural habitat.

Publications

Garratt M.P.D., Coston D.J., Senapathi D., Mortimer S., Potts S.G. Hedgerow benefits for ecosystem services depends on hedge quality and is moderated by landscape. Manuscript in preparation

Methods and approach

The aims of the present study were to; 1) measure to what extent the abundance of functionally important taxa spill over from hedgerow habitats in the UK; and 2) how hedgerows and surrounding semi-natural landscape components interact to influence the abundance of functionally important taxa found in crop fields.

Sixteen field sites were selected in four 15km*15km regions in Southern England. Each field site represented a hedgerow adjacent to a crop of winter wheat. These hedgerows had been classified as "Good" or "Poor" quality based on several hedgerow factors included as part of a DEFRA conditional assessment carried out during a previous study (Defra 2007). Good quality hedges contained more than three woody species, a good solid structure with no gaps bigger than two meters and were well maintained. Poor quality hedges had fewer species, a poor overall structure in both height width and gaps and showed little maintenance. The landscape surrounding these hedgerows was characterized at a 500m radius considering the % area of semi-natural landscape based on the Priority Habitat Inventory (http://jncc.defra.gov.uk/page-5706). Within each study region there were four hedgerows, two good quality and two poor quality with one located in an area of high semi-natural (>5%) and one in an area of low semi-natural (<5%) (Fig. 3). These thresholds were chosen considering the low cover of semi-natural habitats in the study area although other authors reported different classes for simple and complex landscapes (e.g. Tscharntke et al. 2005).

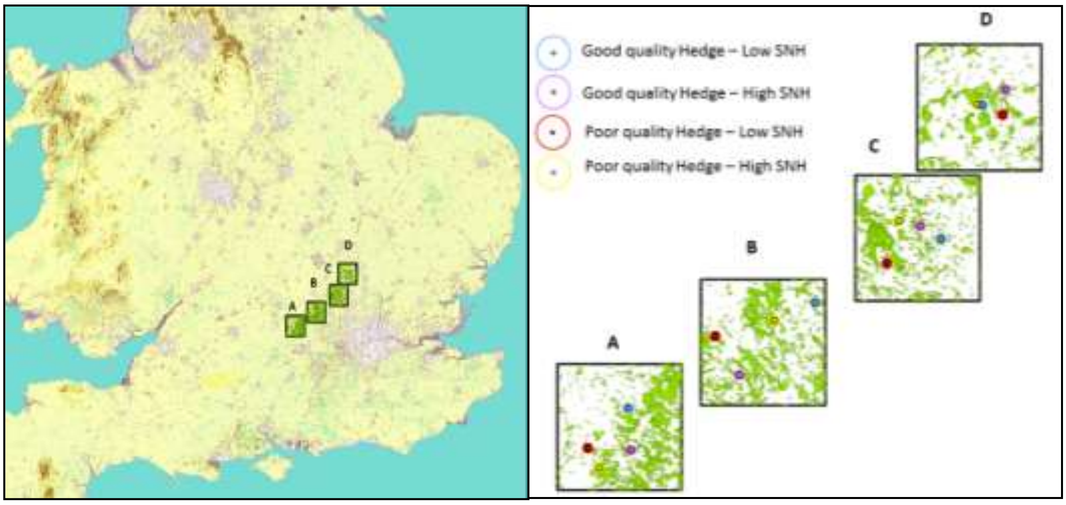

Fig. 3 Study sites used to investigate effects of hedgerow quality and landscape context (500 m) on functionally important taxa in UK arable landscapes. The four regions were 15 x 15 km large.

At each study hedge, three transects perpendicular to the hedge and 25m apart were marked out. Invertebrates where sampled at different sampling stations along each transect a number of times through the season. To assess abundance (activity density) of ground active natural enemies, pitfall traps were placed out for 10 days at sampling stations located 0, 10, 25 and 50m into the wheat field. Two rounds of pitfall sampling were carried out, the first in late April and early May and the second in mid-June. After collection, pitfall trap contents were stored in a freezer at -20^{o}C and then natural enemies were identified to broad functional groups.

Aphid population density was sampled in the wheat crop at stem elongation in early May, flowering in early June and dough development in early July. As with pitfall trapping, aphid populations were sample at 0, 10, 25 and 50m along each transect. At each sampling location, 25 tillers were examined and the number and species of aphids recorded. The number of parasitoid mummies was also counted.

The abundance of pollinators was recorded along transects running parallel to the hedgerow, at 0m, and at 10m and 50m into the field. Each transect was 75m long divided into 3, 25m sub-sections. On the day of pollinator surveys, each sub-section was walked slowly for a period of 5 minutes and all bees and hoverflies 2m either side of the observer was recorded. All surveys were carried out in low wind conditions and in temperatures in excess of 15 ^{o}C. Three surveys were carried out at each field site, the first in mid-May, the second in mid-June and the final survey in mid-July.

Data analysis

Generalised linear mixed effects models were used to investigate effects of hedge quality, landscape and distance into the field on natural enemies caught in pitfall traps, aphid counts per 25 tillers and percentage parasitism. Sampling point within 'transect', within 'site', within 'block' were included as nested random effects. A stepwise deletion of the least significant interaction effects was carried out until only main effects and significant interactions remained in the model. A poisson error structure was used to deal with count data and binomial error structure for proportion data and if a model was over-dispersed then an observation level random effect was included (Harrison, 2014). For analysis of pollinator survey data, counts were combined by broad taxonomic groups (honeybees, hoverflies, bumblebee and other bees) and a total wild bee response was also analysed. Generalised linear mixed effects models were used with the same fixed and random effects as earlier models. However, distance was no longer a continuous variable due to the nature of surveys and was considered a three level categorical variable (hedge, 10m and 50m). Solitary bee, bumblebee and honey bee counts were lumped, combining counts from the 3 transects associated with each field site and transect was no longer included as a random effect. All statistical analysis was carried out in R version 3.2.2 (R Core Development Team, 2013).

Main findings and implications

Significant effects of distance from hedgerow, hedge quality, landscape and survey round on pests and natural enemies were found. A significant effect of survey round and distance on all aphid groups was found and a significant positive effect of semi-natural area on *S. avenae* was apparent (Table 1, Fig. 4, 5). The abundance of Lycosids and Linyphiids was affected by distance, with abundance decreasing with increasing distance from the hedgerow (Fig 4). A significant hedge quality:distance interaction on Staphylinids was also found as well as a survey round effect on Lycosids and percentage parasitism (Table 1). Some natural enemy groups were more abundant next to the hedge and that the abundance of Linyphids and Staphylinids was also greater next to good quality hedges indicates that some hedges provide a better habitat or refuge for some natural enemies than others. Aphid numbers declined further into the field, this could be because hedgerows act as a source of aphid populations or the chemical control used by growers reduced aphid populations in the field but not in the unsprayed field edge. Ground active predators can have a significant impact on reducing cereal aphids particularly in conjunction with areal predators (Schmidt *et al*. 2003), therefore maintaining a high density of good quality hedgerows in agricultural landscapes could improve natural pest control in cereal crops and reduce the need for pest control chemicals. The direct impact of hedgerows on pest populations also needs to be considered however.

Table 1. Effects of hedgerow quality, % semi natural landscape within 500m, distance from hedgerow effects on aphids, natural enemies and pollinators. F and p values following analysis with generalised mixed effects models. Significant p value (<0.05) shown in bold. The model included also survey round.

	Hedge quality			*% Semi-natural*			*Distance*			*Hedge quality x distance*		
	n	*F*	*P*	*n*	*F*	*P*	*n*	*F*	*P*	*n*	*F*	*P*
Total aphids	*1-576*	*0.04*	*0.97*	*1-576*	*0.55*	*0.29*	*1-576*	*5.16*	***0.021****			
M. dirhodum	*1-576*	*0.27*	*0.49*	*1-576*	*0.01*	*0.71*	*1-576*	*5.85*	***0.015****			
S. avenae	*1-576*	*0.13*	*0.93*	*1-576*	*2.98*	***0.047****	*1-576*	*2.96*	***0.047****			
Carabids	*1-384*	*0.71*	*0.41*	*1-384*	*0.23*	*0.64*	*1-384*	*0.82*	*0.360*			
Staphylinids	*1-384*	*1.18*	*0.28*	*1-384*	*0.20*	*0.15*	*1-384*	*4.28*	*0.880*	*2-384*	*4.59*	***0.032****
Lycosids	*1-384*	*2.63*	*0.07*	*1-384*	*5.49*	***0.006*****	*1-384*	*139.32*	***<0.001*****			
Linyphiids	*1-384*	*4.09*	***0.044****	*1-384*	*0.44*	*0.50*	*1-384*	*8.92*	***0.003*****			
% parasitism	*1-576*	*0.13*	*0.67*	*1-576*	*1.36*		*1-576*	*1.31*				
Wild bees	*1-432*	*1.60*	*0.09*	*1-432*	*3.97*	***0.024****	*3-432*	*31.07*	***<0.01*****			
Honey bees	*1-144*	*0.01*	*0.57*	*1-144*	*0.10*	*0.55*						
Solitary bees	*1-144*	*0.07*	*0.71*	*1-144*	*0.22*	*0.41*						
Hoverfly	*1-432*	*0.19*	***0.018****	*1-432*	*1.54*	*0.23*	*3-432*	*33.08*	***<0.001******	*3-432*	*3.21*	***0.042****
Bombus sp.	*1-432*	*4.1*	***0.0089*****	*1-432*	*2.59*	*0.06*	*3-432*	*7.83*	***<0.001******			

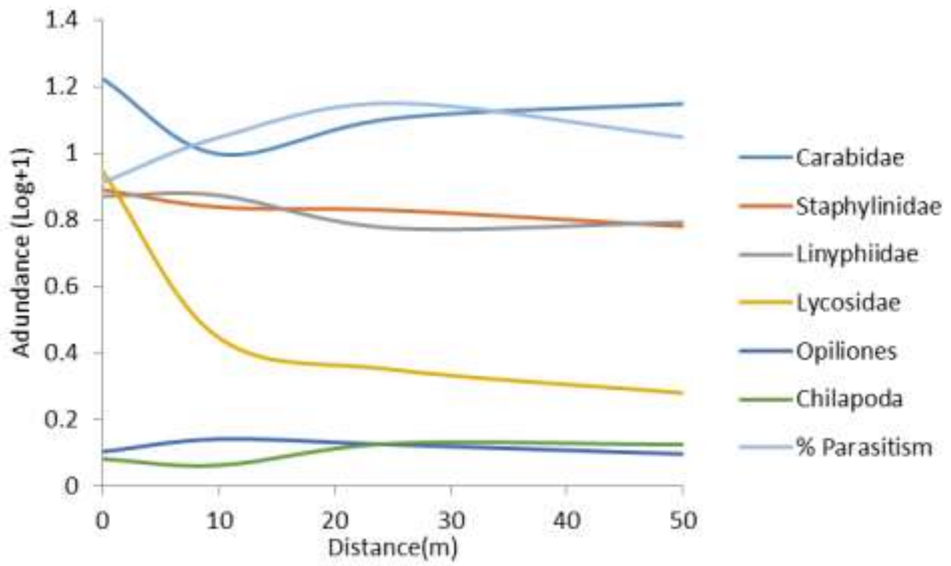

Fig. 4 Natural enemy abundance in wheat fields at increasing distance from hedgerows. Data shows log +1 abundance per pitfall trap. Analysis with generalised linear mixed effects models. Taxonomic groups significantly affected by distance into the field shown.

The abundance of Lycosids in wheat fields increased in areas of high local semi natural (Fig. 3), semi-natural areas are known to benefit these species (Sunderland and Samu, 2000). Given the importance of spiders as natural enemies in cereal cropping systems (Sunderland et al. 1986; Lang, 2003) there is a clear benefit to maintaining semi-natural habitat in arable landscapes, particularly considering the wider benefits of semi-natural landscape for pest control (Chaplin-Kramer et al. 2011). However, greater S. avenae numbers were also associated with high local semi-natural areas (Fig. 5), perhaps by acting as a refuge and source population for these pests. A trade-off exists based on the potential benefit to natural enemies and cost of increased pest species and this needs to be understood to ascertain the true value of semi-natural areas for pest control. Importantly, the additional benefits of semi-natural landscapes for other functionally important taxa as well as taxa of conservation concern must also be considered.

Significant effects of hedgerows and landscape on pollinators were found. Wild bee, hoverfly and bumblebee abundance was significantly greater on the hedgerow when compared to 10m and 50m away from the hedge. A significant effect of hedge quality on hoverfly and bumblebee abundance was apparent with abundance greater on good quality hedges (Table 1). A significant negative effect of semi-natural area on wild bee numbers found foraging on hedges was also found (Fig. 4). Hedgerows provide an important forage and dispersal resource for pollinators (Morandin and Kremen, 2013; Hanley and Wilkins, 2015) and in our study, bumblebees and hoverflies were found foraging on hedgerows in greater numbers than in wheat fields. The value of these hedgerows, however, depends on hedgerow quality with greater abundance of both taxonomic groups found on good quality hedgerows. The utility of hedgerows as forage resources or movement corridors for pollinators also depended on landscape context with greater abundance of wild bees on hedgerows in areas of low local semi-natural habitat indicating hedgerows are more valuable for bees in more intensive landscapes. Given the importance of many bee and hoverfly species as pollinators of crops, including beans and oilseed, in arable UK landscapes (Garratt *et al*. 2014), investment should be made in increasing the number and quality of hedgerows in these regions to support crop pollinator communities.

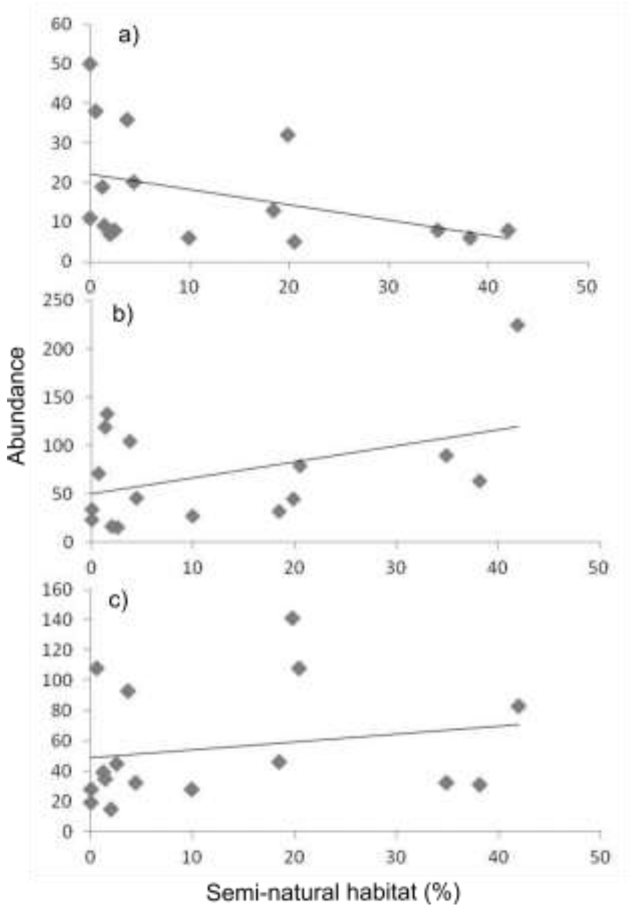

Fig. 5 Relationship between % semi-natural landscape within a 500m radius and the abundance of a) wild bees (Estimate -0.022, $F_{1\text{-}432}$ = 3.97, p = 0.024) b) wolf spiders (Estimate +0.024, $F_{1\text{-}432}$ = 5.08, p = 0.006) and c) *S. avenae* (Estimate +0.019, $F_{1\text{-}576}$ = 3.20, p = 0.047). Data shows raw abundance summed by site.

In summary, the benefits of hedgerows as a refuges or forage resource for beneficial organisms in arable landscapes is clear and the activity of these taxa can spill over from hedgerows into adjacent crop fields providing potential benefits to pest regulation or crop pollination. Hedgerows supported more pollinators in landscapes with few compared to many hedgerows. However, it is unclear how this works for pest control since both pests and predators were found in larger numbers in landscapes with more semi-natural enemies. As our understanding of the value of functionally important taxa to crop production increases the true value of hedgerows and what contribution they can make to ecological intensification will become clearer.

3. NEW SEMI-NATURAL HABITATS: SHORT REVIEW

Modern agriculture in Europe has simplified the traditional agro-ecosystems and replaced the ecosystem services with increased external inputs of energy and chemicals. In order to search targets of sustainable development, agriculture needs to be more productive, while minimizing its negative environmental impact. The aim of task 3.2b was to achieve such ecological intensification by enhanced invertebrate communities and related ecosystem services through reduced level of management intensity adjoining to newly established semi-natural habitats. To quantify the impacts of ecological intensification on winter-wheat production in fields adjoining to newly established semi-natural habitats, we tested how pest organisms and their natural enemies were affected by landscape properties and by local field management such as experimentally manipulated fertilizer use in Hungary and the Netherlands. The landscape properties were estimated by a common GIS protocol between countries focusing on the proportion of semi-natural and arable areas in the landscape. The local mitigation effect of semi-natural habitats was estimated by a distance based survey from the habitat edge toward the core of the winter-wheat fields. In Hungary, one of the major concerns was that the increasing cover of semi-natural habitats in the landscape can mitigate the negative effect of pathogen fungi as rust, and pests such as aphids and grain thrips. Fertilizer application had no consistent effects neither on the phenology of the crops (including yield), nor on the pests due to the nitrogen rich soils in Hungary. The transect-based observations did not reveal effect of the set-aside fields on the direct promotion of ecosystem services in Hungary. In the Netherlands, the partners conducted an integrated study comparing biocontrol potential, aphid abundance and wheat yield in eight fields with and eight fields without an adjacent wildflower strip, while taking effects of landscape structure, soil organic carbon and agrochemical applications into account. They observed strong interactions between the effects of both strip presence and quality (floral diversity) and the percentage of semi-natural habitat (SNH) in the surrounding landscape. In landscapes with low percentage of SNH, aphid abundances were reduced by the presence of flower strip and high floral diversity. In contrast, in landscapes with relatively high percentage of SNH, aphid abundances were low also in the absence of such local floral resources. Wheat yield was strongly affected by fertilizer input, but was significantly reduced by increasing aphid numbers, even though aphid abundances remained relatively low and patchy throughout the entire experiment.

3.1 Hungarian case study: Low-input farming practices and landscape attributes support better pest control through higher abundance of natural enemies in Hungary

Contributors: Zoltán Elek, Gergely Boros, Réka Ádám, Anikó Kovács-Hostyánszki, László Somay, Krisztina Bereczki, Ottó Szalkovszki, András Báldi

Summary

At European scale Hungary is among the countries where agricultural practices are less intensive. However, the effects of extensive practices on the farmland biodiversity and ecosystem services are sparsely known (Kovács-Hostyánszki et al. 2013). In order to move toward a more sustainable agriculture there is a demand to explore the possible role and contribution of beneficial diversity (ecosystem services) for agricultural production. The concept of ecological intensification is based on the enhanced role of invertebrate communities and related ecosystem services through reduced level of management intensity in agriculture. To quantify the impacts of ecological intensification on winter-wheat production, we tested how pest organisms and their natural enemies were affected by landscape properties and by local field management such as experimentally manipulated fertilizer use in Hevesi-sík Region, Hungary, Central Europe. We stratified 7 winter wheat and set-aside field pairs according to the proportion of semi-natural habitats in the landscape. The fertilizer application had no consistent effects neither on the phenology of the crops nor on the pests. In the exclusion experiment, we found that the closed cages were able to keep more aphids (*Sitobion avenae*) than the open cages, but no consistent treatment effect (fertilizer application) was found. The transect-based observation did not reveal any consistent effect of the adjacent set-aside fields on the promotion of ecosystem services in the wheat fields in the Hungarian case study.

Publications

Elek Z., Boros G., Ádám R., Kovács-Hostyánszki A., Somay L., Bereczki K., Szalkovszki O., Báldi A. Low-input farming practices and landscape attributes support better pest control through higher abundance of natural enemies in Hungary. Manuscript in preparation

Methods and approach

The Hungarian partner contributed to the task 3.2b where the main objective was to study the effect of newly-established semi-natural habitats on the effectiveness of off-field management practices for promoting ecosystem services. We selected 7 study sites (winter wheat fields) with an adjacent newly-established set-aside field (1-3 years old), and additional 7 winter wheat fields without adjacent set-aside fields in Hevesi-sík Region, Hungary. These sites were allocated in a region where state-supported agro-environmental scheme (AES) had a high take up rate, which resulted in a high ratio of AES set-aside fields and certain management restrictions for e.g. chemical input. Therefore we had to reduce the experimental treatments within the winter wheat fields excluding the insecticide treatment, and only the fertilizer treatment was applied. we reported this issue to partners of task 3.2b. We recorded the landscape attributes in a 1 km-radius around all the field pairs in Hungary. The proportion of the arable fields, semi-natural areas, urban areas, and water bodies was estimated. The urban areas and water surfaces did not exceed 5% cover in the landscape.

Biological control of aphids was estimated by using a cage experiment (Jonsoon et al. 2014) We inoculated ca. 50-100 aphids (*Sitobion avenae*) per plot at BBCH 40-50 with a pitfall trap per inoculation place to remove aphid predators. In each treatment we established one cage and one open control. Cages consisted of plastic net with 5×5mm mesh size (30cm diameter and 100 cm high) inserted in a plastic barrier (20 cm high, 32 cm diameter) to prevent ground-dwelling predators from entering the cages. The cages were sprayed by sticky glue to prevent access by flying predators. Aphids were counted non-destructively in each plot on 10 randomly selected tillers after 10 and 15 days when the experiment ended. Unfortunately inoculation of aphids was not successful, due to unexpected weather conditions. The treatments in plots included inorganic fertilizer application in each plot of minimum 10 × 12 m size. Fertilizers were NPK, or ammonium nitrate and the amount of fertilizers was applied according to the regionally recommended rates of 90 kg/ha.

The abundance of pests and flying predators and activity-density of ground-dwelling predators was estimated in a transect design 0, 5, 10 and 20 meters from the edge of winter wheat fields adjacent to the set-aside fields into the core of the plot. We visually assessed the prevalence of major pathogens such as leaf spots (*Septori*a spp.), *Fusariu*m spp., mildew and rust *(Puccini*a spp.). We visually surveyed the abundance of aphids, predators (Coccinellids (adults and larvae); Syrphids (larvae); Chrysopids (larvae), and parasitized aphids (mummies) on 50-100 randomly selected shoots per plot along the transect three times at BBCH 35+, 40-50 and 55+. Four pitfall traps were installed in every plot in a transect-design, 0, 5, 10 and 20 meters from the edge towards the core of the plots. The traps consisted of ~114mm diameter plastic cups; each containing approximately 250 ml of a 50% - solution of propylene glycol and water, saturated with salt and with a drop of odourless detergent to reduce surface tension. A green plastic roof protected the solution from litter and rain.

Winter wheat in all treatment plots was hand-harvested along the transect having two subsamples at each distance (0, 5, 10 and 20 m), resulting in a 1 m^2 plot in total. Dry weight (kg/ha) was used as a measurement of yield. We interviewed farmers to obtain background information on the yield, fertilization and crop protection inputs in the experimental fields.

The response of the major indicators (pathogens, pests, ground dwelling predators, and harvest data) were tested by negative binomial models in order to handle the overdispersion in the observation data, where the response variables were the abundance data of the observed indicators, except for the harvest data where the dry grain weight was considered. Explanatory variables were the fertilizer treatment (0 vs. 1; control and treatment respectively), the distance from the edge of the plot (0, 5, 10 and 20 m) and the proportion of the semi-natural habitat in the landscape. The models were implemented in R 3.2.2 (R Core Team, 2015) using the MASS (Venables and Ripley, 2002) package for negative binomial models.

Main findings and implications

Local management effects

We revealed that the fertilizer application slightly increased the occurrence of rust in the plots (theta=0.23, z=1.72, p=0.08). The carabids as one of the major groups of ground dwelling predators were more abundant in the control plots than in the fertilized ones (theta=0.45, z=-2.06, p=0.03), while the abundance of spiders was unaffected by the application of fertilizers. Similarly to the carabids the ants occurred in higher abundance in the control plots (theta=0.29 , z=2.2, p=0.02) than in the treatment. We found no treatment or transect effects on the dry weight of the yield.

Set aside effect

The distance from the edge of the set aside field was not related to any of our response variables.

Landscape scale effects

In the case of pathogens we found that the occurrence of the rust negatively correlated with the increasing cover of semi-natural habitats in the landscape (theta=0.23, z=-2.61, p=0.008). We revealed that the abundance of pests such as thrips (marginally significant, theta=0.10,z=-1.78, p=0.07) and aphids (theta=0.19, z=-3.78, p=0.0001) negatively correlated with the increasing proportion of semi-natural habitats in the landscape. Other abundant insect groups such as orthopteras (theta=0.9, z=-2.39, p=0.01) and soldier beetles (theta=0.07, z=-2.19, p=0.02) showed the same pattern. However, other major ground dwelling taxa such as ants showed that their occurrence was promoted by the increasing proportion of semi-natural habitats in the landscape (theta=0.29, z=2.2, p=0.02). Based on the sample harvest data, we did not find any effect of landscape properties on the yield.

Farmers' opinion

The rapid survey by the first version of the farmer's questionnaire showed that 30% of the farmers think that nature conservation activities promoted the better status of the natural environment in the region, while 30% disagree with this statement and other 40% did not report any opinion. Similarly, 30% of the farmer thinks that the state supported agro-environmental schemes (AES) have positive effects on nature conservation. These results were based on the opinion of 15 farmers, ten of whom had land that was partly included in AES programs or Natura 2000 areas.

Conclusions

Although a meta-analysis of 127 published studies found that land withdrawn from conventional production unequivocally enhances biodiversity in North America and Europe (Van Buskirk and Willi 2004), we found no effect of set-aside on yield, pests and natural enemies in the adjoining fields indicating small spill-over of beneficial insects from the set-aside field to the crop.

3.2. Dutch case study: Do wildflower strips enhance crop yield through improved aphid pest control in Dutch winter wheat fields?

Contributors: Arjen de Groot, Stijn van Gils, Ruud van Kats, Dennis Lammertsma, Wim Dimmers, David Kleijn

Summary

Agricultural landscapes in the Netherlands are relatively intensively managed compared to those in Hungary. Furthermore, newly established semi-natural habitat patches are relatively small, and almost exclusively concern 2-4 meter wide strips of extensively managed land along field edges. Wildflower strips are the most common example and in the Netherlands (Fig. 6), as well as other European countries, are increasingly promoted and implemented as a component of integrated pest management (IPM) strategies. Yet, under which conditions wildflower strips are effective as a biocontrol measure, remains unsure. Multiple studies have shown that both landscape structure and on-field management may influence biocontrol potential in agricultural fields, but less is known about the ways in which these factors may interact with the effectiveness of wildflower strips. Moreover, only few studies have tested if and how this potential actually translates into higher yields. Within WP3.2b, ALTERRA therefore conducted an integrated study comparing biocontrol potential, aphid abundance and wheat yield in eight fields with and eight fields without an adjacent wildflower strip, while taking effects of landscape structure, soil organic carbon and agrochemical applications into account. As a study system we adopted winter wheat fields in the Flevopolders, the most intensively managed agricultural area in the Netherlands. We observed strong interactions between the effects of both strip presence and quality (in terms of floral diversity) and the percentage of semi-natural habitat (SNH) in the surrounding landscape. In landscapes with low percentages of SNH, aphid abundances were reduced in the presence of a strip and when floral diversity was high. Yet, in landscapes with relatively high amounts of SNH, aphid abundances were equally low in the absence of such floral resources. Wheat yield was strongly affected by levels of fertilizer, but was significantly reduced with increasing aphid numbers, even though aphid abundances remained relatively low and patchy throughout the entire experiment. We show that wildflower strips may help to reduce aphid pests in winter wheat fields, which, in turn, may enhance crop yield. However, we also show that this potential may only be reached in case strips are properly managed, in a way that optimizes floral diversity, and may only be relevant in agricultural landscapes with a low availability of habitat area for natural enemies. These restrictions have important implications for the implementation of wildflower strips as a management option in agri-environmental schemes.

Publications

de Groot A., van Gils S., van Kats R., Lammertsma D., Dimmers W., Kleijn D. Do wildflower strips enhance crop yield through improved aphid pest control in Dutch winter wheat fields? Manuscript in preparation

Methods and approach

Sixteen study sites were selected, all of which were located on clayey soil, with the exception of one site located on sandy soil. Eight sites consisted of a wheat field bordered by a standard field boundary, usually a ditch bank, with vegetation dominated by coarse grass species. At the other eight sites, the wheat field bordered a wildflower strip. Here, a mixture of perennial flowering plant species had been sown in a 2-4 m wide strip next to the pre-existing field boundary, at least one year before the experiment. The exact composition of the flower mixture varied per strip, but typically included *Trifolium repens, Lotus corniculatus, Cichorium intybus, Medicago sativa, Achillea millefolium* and *Leucanthemum vulgare*. In early July 2014, we assessed the flower composition in the pre-existing boundaries of the control sites and in the wildflower strips by recording the number of flowering species along a 25m transect. For each site, we characterized the surrounding landscape within a circle with 2 km radius around the centre of the site by calculating the percentage cover of semi-natural habitat (SNH), which was defined to include forests, heathlands, orchards, roadsides, dikes and hedgerows.

Fig. 6: example of a wildflower strip along a winter wheat field in the Dutch Flevopolder area.

Each experimental site consisted of an area of 80 x 25m adjacent to the field boundary (Figure 7a). Farmers were asked to avoid the application organic or mineral fertilizer and the spraying of insecticides in this area, while otherwise maintaining all regular management practices. To assess the impact of fertilizer application, two experimental plots of 20x25m were randomly placed in this experimental area (Figure 7a). One plot received nitrogen fertilization (two gifts of calcium ammonium nitrate (CAN), in mid-March and early April, containing 80 and 90 kg N per hectare respectively), while the other plot did not.

Measurements conducted throughout the season in each plot resembled those conducted in the Hungarian experiment. Abundances of aphids, flying predators and parasitoids on wheat shoots were visually assessed during three inventory rounds, in April (stem elongation stage; BBCH 35), May (heading stage; BBCH 50) and June (flowering stage; BBCH 60). Each time, inventories were conducted at distances of 5, 10 and 20 meters from the field margin (Figure 2b; 34 shoots per distance resulting in a total of 102 shoots per plot per round). Just before the fields were harvested by the farmers, 1 m2 of wheat was harvested per distance per plot (Figure 2b) to assess total yield in kg grains per m2. To assess biocontrol potential in each field, an inoculation experiment was conducted. In each plot, aphids were inoculated at two random spots. After a successful 5-day establishment period under a fibre web dome), aphids at one spot per plot were excluded from predation by a cage, while aphids in the other spot could be freely predated. Over the next five days, the changes in aphid abundance was recorded in both the caged and open treatment, to calculate the local predation rate while accounting for contemporary population changes due to natural reproduction. The data were analyses using generalized linear mixed model R.

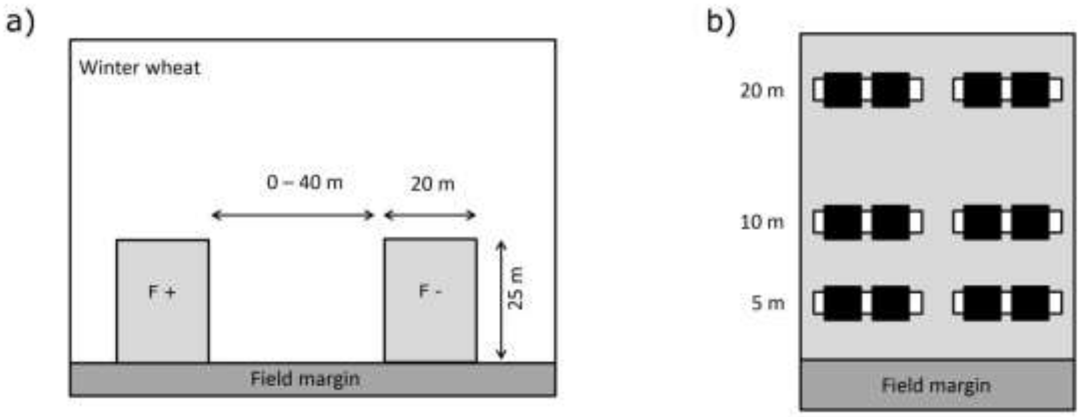

Fig. 7: experimental set-up of the Dutch WP3.2b experiment.

Data analysis

To test for effects on aphid abundance (total number of aphids per plot, averaged over the last two inventory rounds), we applied generalized linear mixed models (GLMM's) as implemented in the R package lme4, using a negative binomial distribution with log link and a square root transformation for the aphid counts. In a first model, we used wildflower strip presence, semi-natural habitats, and fertilizer application as fixed factors and field site as random factor. Insecticide application on the surrounding field was added as a covariate. In a second model, wild flower strip presence was replaced by floral diversity. This approach was chosen because of a strong relation between the presence/absence of a wildflower strip and the floral diversity in the field boundary (as assessed via one-way ANOVA). The same two types of models were used to test for effects on BCP, but applying a more simple linear mixed model as implemented in the R package nlme. To check for direct effects of field margin composition on wheat yield, the same two models were also applied while using wheat yield as dependent variable and adding wheat variety as a covariate. In a third model (linear mixed model via the nlme package) we tested for the effect of the fixed factors fertilizer application, and aphid abundance on wheat yield, while using wheat variety as covariate. In this model, for wheat yield and aphid counts we used the values from the three distances per plot as replicates. Therefore, in this model both plot and field site were added as random factors. We first ran all models while including all interactions between the fixed factors, and then re-ran the model including only the interactions that showed a significant result for at least one of the dependent variables (see e.g. Tamburini et al. 2015). Observed abundances of natural enemies were too low for valid statistical analysis (see results).

Main findings and implications

Only very low numbers of potential predators and limited evidence for parasitoid activity (parasitoids or mummified aphids) were observed in the field inventories. These limited observations did not allow us to statistically relate abundances of natural enemies to aphid counts or on-field and off-field conditions. Yet clear and significant differences in aphid population growth were observed between the two treatments of the inoculation experiment, which showed that predation by natural enemies did in fact occur at all sites (average biocontrol potential of 0.748, meaning that about ¾ of the local aphid population was predated within a five day period).

Floral diversity varied both among field margins characterized as wildflower strips and among control margins, although wildflower strips generally harboured a larger floral diversity. Aphid abundances were low and patchy, but average values did differ between the 16 sites. We observed a significant interaction between the effects of percentage semi-natural habitat in the surrounding landscape and either the presence/absence of a wildflower strip in the field margin or the floral diversity of the margin ($z = 2.475$, $P = 0.013$). Aphid abundance decreased with increasing percentage of semi-natural habitat in the surrounding 2000m, but only in the absence of a wildflower strip and/or when the margin had a low floral diversity; At low percentages of semi-natural habitat in the surrounding landscape, aphid abundances were lower in the presence of a high-diversity flower strip (Fig. 8).

Fertilization was by far the most important factor explaining differences in wheat yield values ($z = 109.3$, $P < 0.001$). Yield was almost twice as high in the fertilized plots compared to the non-fertilized plots. Yet, between site differences in yield were also related to aphid abundance ($z = -2.739$, $P = 0.006$), with lower yield occuring at higher aphid densities.

In conclusion, our results show that sowing wildflower mixtures in the margins of agricultural fields may help to reduce aphid pests which, in turn, may enhance crop yield. However, this potential may only be reached under certain conditions. First, the added value of wildflower strips seems relevant only in landscapes with a very low overall availability of habitat area for natural enemies. Even in the highly intensive agricultural lands in the centre of the Netherlands, a relatively low availability of semi-natural habitat in the direct surroundings of the crop field already seemed sufficient to result in low levels of aphids, thereby limiting the added value of a local flower-rich margin. This indicates that it will be important to target 'simple' landscapes before selecting wildflower strips as the measure of choice in the local implementation of agri-environmental schemes. Second, the effect of wildflower strips does not depend only on their establishment, but also on a proper management afterwards, at least with respect to optimizing their floral diversity. This observation urges for the inclusion of management targets in agri-environmental schemes when adopting wildflower strips as an option to enhance ecosystem services related to aphid pest control.

The potential of wildflower strips for aphid pest control will, however, be different during years with stronger aphid outbreaks as well as in other study areas or study years experiencing a higher overall presence of aphids and their enemies. A comparison of results from similar studies across different landscapes and study years will be required to allow exact predictions of the local benefit of flower-rich margins as a management option for aphid pest control.

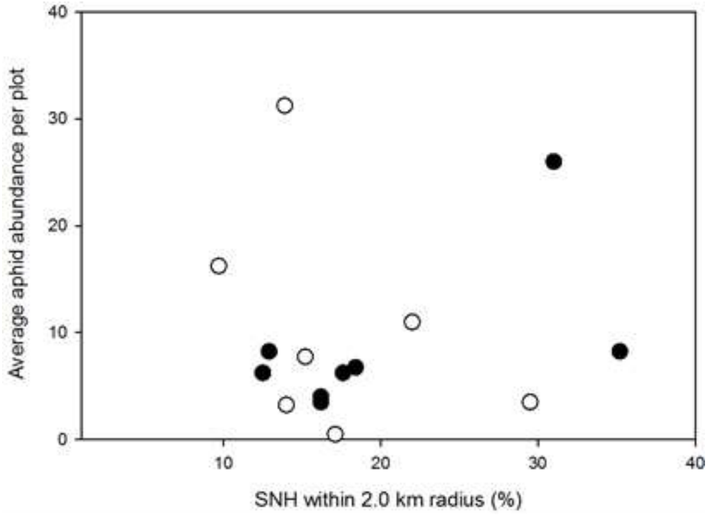

Fig. 8 Relations between percentage of semi-natural habitat (SNH) in the surrounding landscape (2.0 km radius around the study site) and the average aphid abundance per plot. Dots in the graph represent averages per site. Open dots represent sites without a wildflower strip, closed dots represent sites with a wildflower strip.

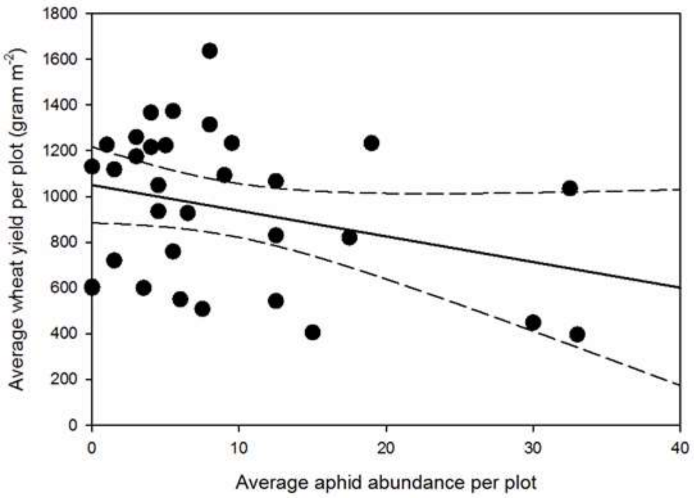

Fig. 9: Relationship between aphid abundance and wheat yield

4. GENERAL DISCUSSION

4.1 Findings across studies

The empirical work carried out across different European countries provided original data on the effectiveness of three off-field interventions on the delivery of multiple ecosystem services in winter cereals. The interventions tested were usually different according to the local relevance and feasibility.

Considering the effect of existing semi-natural habitats, the presence of hedgerows has been demonstrated to improve the provisioning of multiple ecosystems services. In Italy, we found that increased field margin complexity (i.e. increased flower diversity and structural heterogeneity) did not enhance ecosystem services' delivery, while a complex hedgerow networks in the landscape enhanced the provision of aphid parasitism and potential pollination irrespective of local margin quality. A similar result was reported by Sardiñas & Kremen (2015) who found that neither hedgerow presence nor distance from the field edge impacted sunflower seed set despite hedgerows supported richer and more diverse pollinator communities. In UK, hedgerows were important source of natural enemies which spill over into neighboring fields compared top standard field margins. Similar effect was detected by Morandin, Long & Kremen (2014) and Alignier et al. (2014) who found more predatory lady beetles and higher parasitism rate in fields adjacent to hedgerows. In general, landscape context moderated the benefits of hedgerows, i.e. pollination and wild bee abundance and biocontrol on hedgerows was greater compared to standard field margins only in landscapes with low cover of semi-natural habitats.

Considering the effect of new semi-natural habitats, we tested the effect of set-aside fields (Hungary) and flower strips (the Netherlands) on the delivery of multiple ecosystem services in neighboring winter wheat fields. In the Netherlands, we showed that wildflower strips may help to reduce aphid pests in winter wheat fields, which, in turn, may enhance crop yield. However, we also show that this potential may only be reached in case strips are properly managed, in a way that optimizes floral diversity, and may only be relevant in agricultural landscapes with a low availability of habitat area for natural enemies. However, a recent study indicates that flower strip effects on natural enemies, pests and crop damage in winter wheat were largely independent of landscape complexity (8–75% non-crop area) (Tschumi et al. 2015). This study demonstrates a high effectiveness of annual flower strips in promoting pest control, reducing pest levels below the economic threshold. Among the few studies that have previously assessed pest density response to flower strips in other crops, effects were frequently inconsistent or weak (e.g. Baggen & Gurr 1998; Pfiffner et al.2009; Winkler et al. 2010; Balzan & Moonen 2014). In Hungary, we did not detect any benefit from the presence of a set-aside field close to a winter cereal field. No other study has tested this intervention on ecosystem services while a meta-analysis of 127 published studies found that set-aside unequivocally enhances biodiversity at the local scale (Van Buskirk and Willi 2004).

In spite of the different soil and management properties between Italy, UK, Hungary and the Netherlands, the partners revealed that the increasing ratio of semi-natural habitat at the landscape scale can mitigate the negative effect of pests such as aphids. This indicate that any increase in semi-natural habitats in simple landscape can provide multiple benefits. In general, we found that the effectiveness of the local intervention to enhance ecosystem service delivery was maximized in simple landscapes characterized by low cover of semi-natural habitats. Hence, ecosystem services are currently limited only under these extreme conditions. The thresholds to define a landscape 'simple' may vary drastically between regions and a single figure cannot be provided. Once locally these thresholds are known, the next step would be to perform a cost benefit analysis to implement our interventions in existing conventional farms. A recent study (Pywell et al. 2015) tested this idea and found that removing between 3 and 8% of land at the field edge from production to create wildlife habitat (e.g. flower strips or hedgerows) in commercial arable farms in central England did not affect total farm yield after six years since the intervention. As a consequence, yields at the field scale were maintained and, indeed, enhanced for some crops despite the loss of cropland for semi-natural habitat creation.

4.2 Implications for practice

The following implications for practice can be derived from the study cases carried out in the four European countries:

Hedgerows: The quality of the hedgerow (flower diversity) generally increased biodiversity of several beneficial groups of insects (e.g. butterflies, tachinids, carabids, spiders), while the delivery of ecosystems services such as pollination and pest control tended to respond more to the landscape (proportion of hedgerows or semi-natural habitats in general in the surrounding). Investments in the creation of hedgerows should be concentrated in landscapes with low cover of existing semi-natural habitats.

Set-aside: creating set-aside fields increased locally the biodiversity of several beneficial insect groups (literature) but the spillover to winter wheat fields is small with no apparent effect on the delivery of aphid biocontrol.

Flower strips: wildflower strips helped to reduce aphid pests in winter wheat fields, which, in turn, enhanced crop yield. However, this potential may only be reached in case strips are properly managed, in a way that optimizes floral diversity, and may only be relevant in agricultural landscapes with a low availability of habitat area for natural enemies. Investments in the creation of new flower strips should be concentrated in landscapes with low cover of existing semi-natural habitats.

4.3 Implications for policy

Our findings highlight the potential contribution of hedgerows and flower strips can make to ecological intensification in several European countries and inform decision making about the optimal management of these semi-natural habitats. In several cases we demonstrated that investing in the creation of hedgerows and flower strips can improve the delivery of pest control and pollination with benefits on yield provisioning, while set-aside did not provide any benefit to biocontrol or yield. The idiosyncratic responses among countries, services and insect groups indicate that each intervention should be tailored according to local conditions and existing semi-natural habitats in the landscape. Our results highlight the key importance of the surrounding landscape context, along with local factors, to ecosystem services' delivery. A general conclusion from our four studies is that the benefits of implementing single local intervention such as flower strips and hedgerows is higher in landscapes with low cover of existing semi-natural habitats. The thresholds to define a landscape 'simple' may vary drastically between regions and a single figure cannot be provided. Biocontrol appeared to be limited only under these extreme conditions while in landscapes with medium to high cover of semi-natural habitats the delivery of this service is effective. Future agri-environment schemes to foster biocontrol in simple landscapes should focus on hedgerow and flower strips in both low- and high-intensity farming systems.

4.4 Research and policy gaps

The types of measures studied in task 3.2 of LIBERATION include only a part of a large set of novel options that are relevant to the upcoming CAP-reform. The effects on ecosystem service delivery of a series of on-field interventions are being examined in WP3.1. These interventions can be part of agri-environmental measures or compulsory measures that are part of cross compliance. More research is therefore needed to test these options on multiple ecosystem services to test for potential trade-offs and synergies between services. Large knowledge gaps still exist for how to manage regulating and supporting ecosystem services efficiently for ecological replacement or enhancement in agriculture.

Whilst some of the management strategies examined here were tested under different input regimes it would be informative to incorporate a greater number of treatment levels, especially for nitrogen fertilizer to better understand the input-ecosystem service relationship under different management strategies. Furthermore, by incorporating these relationships into cost-benefit analyses it would help set out the economic impacts of these management strategies which will be crucial in informing farmers’ decision making.

Finally, off-field interventions are often treated as separate, and mutually exclusive. Little thought has been invested to understand how on- and off-field mitigation options can be combined to promote multiple services in different farming systems and in different landscapes. An important task is then to map expected trade-offs and synergies for different services from combinations of mitigation interventions. Task 3.3 will address this challenge.

4.5 Conclusions

The impact of mitigation on ecosystem services were explored where different management approaches were examined in stand-alone experiments in countries dominated by either high intensity agricultural systems (UK the Netherlands) or low intensity agricultural systems (Hungary and Italy). Biocontrol appeared to be efficient in landscapes with large to medium cover of semi-natural habitats irrespective of the local intervention (flower strips, set-aside or hedgerow) even in countries with high intensity agricultural systems. On the other hand, in landscapes with low cover of semi-natural habitats the introduction of both hedgerows and flower strips can improve pollinator communities, pollination and biocontrol and in some cases even crop yield. Set-aside did not provide any benefit to biocontrol or yield. In conclusions, the two most promising interventions to foster biocontrol and support yield in winter wheats are hedgerows and flower strips irrespective of the intensity of the agricultural systems.

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