Understanding plant–arthropod interactions in multitrophic communities to improve conservation biological control: useful traits and metrics

Antoine Gardarin, Manuel Plantegenest, Armin Bischoff, Muriel Valantin-Morison

► To cite this version:

Antoine Gardarin, Manuel Plantegenest, Armin Bischoff, Muriel Valantin-Morison. Understanding plant–arthropod interactions in multitrophic communities to improve conservation biological control: useful traits and metrics. *Journal of Pest Science*, 2018, 91 (3), pp.943-955. 10.1007/s10340-018-0958-0 . hal-01778315

HAL Id: hal-01778315

<https://hal-univ-avignon.archives-ouvertes.fr/hal-01778315>

Submitted on 14 May 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Understanding plant-arthropod interactions in multitrophic communities to improve conservation biological control: useful traits and metrics

Antoine Gardarin ¹, Manuel Plantegenest ², Armin Bischoff ³ and Muriel Valantin-Morison ¹

Corresponding author: Antoine.Gardarin@inra.fr. +33 1 30 81 54 40.

¹ UMR Agronomie, INRA, AgroParisTech, Université Paris-Saclay, 78850 Thiverval-Grignon, France

² UMR1349 IGEPP, Agrocampus Ouest, 65 rue de Saint-Brieuc, CS 84215, 35042 Rennes Cedex, France

³ UMR Mediterranean Institute of Biodiversity and Ecology (IMBE), Aix-Marseille University-CNRS-IRD-University of Avignon, IUT Agroparc, 84911 Avignon, France

Acknowledgements

This work was partly supported by the *Agence Nationale de la Recherche* PEERLESS project (ANR-12-AGRO-0006). We thank the reviewers for their helpful comments on the manuscript.

Summary

The role of biodiversity in the delivery of ecosystem services is increasingly being studied by trait-based functional approaches. Here, we review and discuss the contribution of a trait-based approach to understanding plant-arthropod interactions and improving conservation biological control. The stable biological control of multispecies herbivore communities requires functional diversity and a redundancy of natural enemies, including specialists and generalists, with minimal antagonistic interactions. The management of arthropod communities through plant community requires the plant community to perform several functions, including the provision of diversified trophic resources and appropriate physical habitats. Many studies have investigated the ability of plants to provide these functions, but many of the results obtained were limited to single species. The description of communities in terms of traits underlying trophic and non-trophic interactions between plants and animals would make it possible to extrapolate findings to other species. Studies on plant-herbivore and plant-pollinator interactions have identified several traits as important for trophic resource provision, in terms of resource quantity, accessibility, quality and temporal availability. By contrast, traits relating to physical habitat provision and microclimate modification have been little explored. Several metrics describing the functional composition and diversity of communities have been proposed, to extend the trait-based approach to plant community level, but the extent to which multitrophic communities are affected by plant traits remains largely unexplored. The next step will be to identify the combinations of these plant community metrics best explaining their impact on arthropod communities and disentangling the roles of plant functional composition and diversity.

Keywords: entomophagous arthropods; flower strip; functional diversity; functional trait; interaction trait; natural enemy

Key message

- The management of arthropod communities for conservation biological control requires plant communities to provide diversified trophic resources and physical habitats.
- A trait-based approach would provide more generic knowledge.
- Several interaction traits relating to resource provision have been identified, but traits relating to physical habitat provision have been little identified.
- At community level, it remains unclear how multitrophic communities are affected by plant traits.
- A functional description of plant communities might facilitate the management of semi-natural habitats to enhance biological control.

Author contribution statement

AG, AB and MP wrote the paper. MVM provided comments on the manuscript.

Introduction

There is increasing evidence that semi-natural habitats provide a wide range of services (Wratten et al. 2012) dependent on ecosystem functioning and on its interactions with the management of these habitats. The role of biodiversity in ecosystem service provisioning is increasingly being studied by trait-based functional approaches investigating the relationships between environmental variables, including habitat management, and ecosystem functioning, community assembly and structure. Trait-based approaches are widely used in plant ecology (e.g. Lavorel et al. 2011) and have been extended to studies of other taxonomic groups, such as soil invertebrates (Birkhofer et al. 2017; Pey et al. 2014), but studies connecting different trophic levels on the basis of their traits remain rare (Boukal 2014; but see Moretti et al. 2013).

Several ecosystem services, such as herbivore regulation, pollination and biogeochemical cycles, are dependent on multitrophic interactions, and there is an urgent need to improve our understanding of the relationships between plant and animal communities (Wood et al. 2015). The functioning of species-rich assemblages involved in interaction networks has been little studied to date and the mechanisms underlying the functioning of such assemblages remain poorly understood and quantified (Violle et al. 2014). Correlations have recently been found between the functional composition of vegetation and the abundance of phytophagous invertebrates in agroecosystems (Storkey et al. 2013) and natural habitats (Frenette-Dussault et al. 2013). Here, we extend the trait-based framework of Lavorel et al. (2013), which focused on trophic interactions, to non-trophic interactions, and we explain how it applies to conservation biological control in agroecosystems.

Our understanding of interactions between plant and animal communities and their effect on the biological control of pests remains limited. Conservation biological control aims to increase the abundance, diversity and efficacy of natural enemies through environmental management and the adoption of particular agricultural practices. Species-rich habitats, such as linear field margins between crop fields, support populations of the natural enemies of pests, and therefore help to improve the biological control of crop herbivores (Bischoff et al. 2016). Their effects are thought to be mediated by

plant species composition (Haaland et al. 2011). The plant species found in these habitats provide functions not supplied by crop plants. This is obvious in natural enemies of crop herbivores that depend on specific plant resources at particular stages of their life cycle, such as hoverflies and parasitic wasps do. The role of plant species composition is less obvious for groups of natural enemies that do not feed on plants. For ground beetles, spiders and ground-dwelling arthropods, vegetation cover via structure-mediated effects is as important, or more, than resource-mediated effects (Balzan et al. 2016; Diehl et al. 2012).

If the implementation or the management of habitats to enhance functional biodiversity increases natural enemy populations, this does not necessarily result in a significant reduction of crop herbivores. The performance of these populations, in terms of biological control, depends on many other factors and interactions (Jonsson et al. 2008), and we are often unable to understand why some plant species mixtures perform better than other ones. There is also currently no methodology for knowledge transfer concerning the biological control efficiency of a given plant mixture to facilitate the choice of new sets of species adapted to other agronomic and climatic situations. Previous studies on trophic and non-trophic interactions within and between plant and animal communities focused principally on analyses of biological diversity through taxonomic approaches or on the global relationship between species diversity and community functioning (Snyder et al. 2006). Their results depended strongly on the species composition of the plant community studied (Wilby et al. 2013). A functional description of plant and arthropod communities is therefore required, to render findings more general and for the development of predictive agroecology.

Here, we review and discuss the contribution of a trait-based approach to improving our understanding of plant-arthropod interactions in agroecosystems, focusing on both trophic (e.g. arthropods feeding on plants, predators feeding on alternative prey) and non-trophic interactions. We address the following questions: (1) What characteristics of entomophagous arthropod communities are related to the regulation of crop herbivore populations? (2) Which functions and plants traits are involved in plant-arthropod interactions? (3) How could the effects of plants on arthropod assemblages at community and landscape levels be scaled up, and what issues would this raise?

For the preparation of this review, we searched the Web of Science literature database (<http://apps.webofknowledge.com>) with two search strings in the “topic” search field. The first was *[(arthropod* or insect* or pest* or prey* or "natural ennem*" or predator* or parasitoid*) and ("biological control" or biocontrol) and diversity and communit*]*, to target scientific articles investigating the role of arthropod community structure in biological control. The second search string was *[("food web*" or "trophic network*" or "interaction network*") and (multitrophic or interaction*) and (trait* or morpholog* or characteristic*) and (plant* or arthropod* or insect* or flower*)]*, to target articles identifying traits involved in plant-arthropod interactions. Limiting our search to articles published between 2005 and 2017 (last updated 29th November 2017), the two search strings identified 507 and 528 articles, respectively. This first set of articles was analysed, and additional relevant articles cited by these articles were added to the working set, whereas articles considered to be outside the scope of the study were removed. We retained 515 articles for the final analysis (Online Resource 1).

1. The role of natural enemy diversity in controlling crop herbivore communities

The main properties of biological control and their relationship to the characteristics of entomophagous arthropod communities emerging from the selected studies are summarized in Fig. 1 (first two columns). Crops harbour many herbivore species differing in terms of their taxonomic identity and relative importance between years and between crop species. Interannual pest dynamics and crop rotations make it necessary to consider interactions of herbivores and natural enemies at community level. In general, control efficiency, for a large range of herbivore species, increases with the diversity of natural enemies (Jonsson et al. 2017). Studies on predator and prey communities in mesocosms have shown that the niche complementarity of predators is the principal mechanism underlying the higher levels of predation in more diverse predator communities (Northfield et al. 2010; Wilby et al. 2005). The number and complementarity of functional groups of natural enemies, rather than their taxonomic richness, thus appears to be the major determinant of the effect of

diversity, when it exists.

By contrast, the stability of biological control for multispecies herbivore communities requires functional diversity (i.e. diversity in the functions provided) and redundancy of natural enemies, which should include both specialists and generalists (Gontijo et al. 2015), with no antagonistic interactions (Fig. 1). Most relationships between community structure and functioning have been inferred from experiments carried out in mesocosms, and their extrapolation to more complex communities under field conditions is problematic. In croplands, habitat management is often used as a tool to support beneficial insects (conservation biological control). It has been suggested that high levels of plant diversity in non-crop habitats favour the amount of natural enemies, leading to a decrease in herbivore abundance (Letourneau et al. 2011). However, little is known about the plant traits favouring effective biological control and their interactions with arthropod communities. Below, we will review and discuss current knowledge.

2. A trait-based approach to understanding plant–arthropod interactions

2.1 What functions must plant communities provide to promote herbivore regulation within arthropod communities?

Plant community management to improve the efficiency of herbivore control by natural enemy communities should have several objectives (third column in Fig. 1). Here, we focus on the case of the neighbouring environment of the field, but our analysis also applies to within-field plant diversity. The surrounding non-crop vegetation fulfils two main functions for the natural enemies of pests (detailed in Fig. 1): it provides both trophic resources and shelter (Griffiths et al. 2008).

The abundance of several insect groups (e.g. Heteroptera, Syrphidae: Pfiffner and Wyss 2004) increases with the total amount of resources available, whereas other groups of insects also respond to

the diversity of these resources (Carabidae, Harwood et al. 2009). The resources supplied by plant communities and required for completion of the life cycles of several natural enemies include nectar and pollen for adults herbivores (hoverflies, parasitoids), and alternative prey for larval or adult predators. The provision of trophic resources, such as floral nectar, increases the fecundity of some parasitoids and, thus, the parasitism rates (Heimpel and Jervis 2005). Food resources must be abundant, but also accessible and available at different times. Accessibility, such as the matching of nectar depth in the corolla to the size of arthropod mouthparts, can be used as a criterion for targeting specific arthropod natural enemies (Baggen et al. 1999). Plant communities could be designed to improve the regulation of a large range of herbivores through the support of diverse groups of natural enemies. The duration of the resource provisioning period is also crucial for both the maintenance of entomophagous communities throughout the year, and to increase the growth rates of specialists during pest outbreaks (Welch and Harwood 2014).

The role of vegetation in providing shelter has been little studied. Perennial plant communities, such as beetle banks, provide refuges to protect populations of natural enemies against disturbances in the vicinity of cropped habitats (MacLeod et al. 2004; Porcel et al. 2017). The density and complexity of vegetation architecture and litter are important drivers of microclimate affecting vulnerable stages in the life cycles of arthropods (oviposition, estivation, hibernation, Griffiths et al. 2008). Vegetation provides attachment points for spider webs (MacLeod et al. 2004). Vegetation structure also determines habitat complexity, thereby modifying interactions between natural enemies. It may reduce intraguild predation by providing refuges and shelter, and reduce competition between natural enemies from the same guild (Finke and Denno 2006; Wilby et al. 2013). However, studies investigating resource- and structure-mediated effects have suggested that the provision of shelter and a favourable microclimate affect the activity-density of arthropod generalist predators indirectly, by increasing weed-borne resources or alternative prey (Birkhofer et al. 2008; Diehl et al. 2012).

Increases in the quantity and diversity of trophic resources may also affect crop pests, as demonstrated for several lepidopteran herbivores (Balzan et al. 2016; Winkler et al. 2010). Plant communities designed to enhance natural enemies should provide these populations with specific resources and other habitat features not favourable to crop herbivores.

207

208 Overall, plant communities can promote herbivore regulation by supplying diversified trophic
209 resources accessible to various arthropod species with mouthparts of different shapes and sizes. These
210 trophic resources should be available over a long period and should not be exploitable by unwanted
211 herbivores (Fig. 1). Many studies have been performed to investigate the provision, by plants, of floral
212 resources for parasitoids (e.g. Sivinski et al. 2011; Winkler et al. 2009) and hoverflies (van Rijn and
213 Wäckers 2010), and of overwintering habitats (Bürki and Hausammann 1992). A few of these studies
214 have shown that arthropod groups tend to be associated with particular functional traits of plant
215 resources (e.g. Wäckers and van Rijn 2012). Most of the studies cited above focused specifically on
216 particular species, and their results cannot be directly extrapolated to other plant-arthropod pairs.
217 Given the large number of possible interactions within and between arthropod communities,
218 alternative approaches are required to predict the functioning of these communities.

219

220 ***2.2. Use of interaction traits to analyse relationships between plant and*** 221 ***arthropod communities***

222 The mechanisms underlying community assembly processes involve morphological, physiological,
223 phenological and behavioural traits (sensu Pey et al. 2014; Violle et al. 2007). A role for
224 morphological traits has been demonstrated in several plant-insect studies. For instance, pollination
225 depends on the existence of a good match between insect proboscis length and the nectar holder depth
226 of the corolla (Ibanez 2012; Stang et al. 2006). Grasshopper herbivory is mediated by a match between
227 the toughness of plant leaves and insect mandibular strength (Ibanez et al. 2013).

228 Pairs of response-and-effect traits must be identified, to improve resource provisioning to beneficial
229 arthropods (Lavorel et al. 2013): plants modify arthropod performance via their effect traits, and the
230 response of arthropods to the vegetation depends on their response traits. We will use the term
231 “interaction traits” to denote all traits mediating interactions between plants and animals.

232

233 Interaction traits include not only trophic (Lavorel et al. 2013), but also non-trophic interactions, such
234 as shelter functions, with all of them having an effect on overall performance. Non-trophic interactions

can modify feeding parameters (escape from predation), non-feeding parameters (mortality, reproduction) and dispersal. A well-known example of a non-trophic interaction is the presence of domatia in some plant species, providing specific habitats for arthropods, such as ants, to increase predation on herbivores and enhance plant defences (Agrawal and Karban 1997).

A trait-based approach, such as that recently used to predict the effect of various flower strips on hoverflies (van Rijn and Wäckers 2016), might improve the understanding and prediction of assemblages of invertebrate communities as a function of plant community composition (weed communities, semi-natural habitats, flower strips). Many studies have assessed the attractiveness of individual plant species to insects, but the identification of plant and animal interaction traits would make it possible to extrapolate findings to untested plant species. Despite the known effects of traits in mediating interactions, most ecological networks are still built on a taxonomic basis. Improvements in our understanding of interaction traits should facilitate the prediction of the role of these traits in structuring ecological networks and communities (Kissling and Schleuning 2015).

The mechanisms by which invertebrates affect other components of the ecosystem involve several interaction traits (Moretti et al. 2013). This is of great practical importance when the studied organisms are predators or parasitoids of agricultural pests. The relevant effect traits may be related to diet, foraging behaviour, dispersal ability, shelter requirement and longevity.

2.3. What are the key plant traits involved in plant-arthropod interactions?

We will focus here on some key arthropod functional groups involved in biological control (soil dwellers, nectar and pollen feeders, leaf feeders, vegetation dwelling and flying predators).

2.3.1. Plant traits associated with trophic interactions

Studies on plant-herbivore and plant-pollinator interactions have identified several plant traits implied in these interactions related to resource type, attractiveness, accessibility, quality and availability (Fig. 2).

263

264 *Resource type:* Plants provide various food resources, such as leaves, stems, roots, fruits and seeds,
265 sap, floral and extrafloral nectar and pollen. They also indirectly provide honeydew and alternative
266 hosts and prey. Nectar and pollen have been studied mostly as resources for parasitoids, but these
267 resources are also consumed by various other insects and spiders (Chen et al. 2010). The availability
268 over time, quality and quantity of these resources constitute interaction traits that vary broadly among
269 plant species (Kühn et al. 2004). The carbohydrate and protein resources provided by plants increase
270 the longevity, reproduction and dispersal of their consumers (Wäckers et al. 2005). Fitness effects vary
271 considerably with the diet, sex and stage in the lifecycle of the arthropod consumer (Wäckers et al.
272 2007). Plants may act as occasional and supplementary food sources, but the resources they supply
273 may also be of crucial importance, in synovigenic species of parasitoids for instance (Jervis et al.
274 2004), with nectar and pollen proteins have strong effects on adult performance and egg maturation.

275

276 *Attractiveness of the resource:* The presence of trophic resources does not necessarily imply that they
277 are consumed. Olfactory, gustatory and visual signals facilitate the recognition and detection of
278 resources, but may also be repellent, depending on the preferences of arthropod groups. Flowers emit
279 olfactory signals and different species are not equally attractive to parasitoids (Belz et al. 2013).
280 Visual signals, such as plant height, flower height, inflorescence size and colour, are involved in
281 resource detection and a high degree of visual attractiveness increases the abundance of natural
282 enemies (Fiedler and Landis 2007).

283 For phytophagous insects feeding on plant tissues, secondary metabolites have a deterrent effect,
284 defending the plant against attack. In the Brassicaceae, glucosinolates act as defence compounds
285 against generalist herbivores, but may attract specialists (Fahey et al. 2001). This attractiveness to
286 specialists increases with specific glucosinolate content (Kos et al. 2014). Chemical traits are often
287 used to predict the relative attractiveness or repellent effects of plant species and genotypes, although
288 the effect of secondary metabolites on phytophagous insects varies considerably, and their role as
289 defence compounds has been called into question (Carmona et al. 2011).

290 *Resource accessibility:* Flower morphology, including corolla shape in particular, plays a crucial role

in determining the accessibility of floral nectar and pollen (Heimpel and Jervis 2005). In flower-visiting arthropods, head or body size may physically restrict access to floral resources in flowers with a small corolla diameter. In such cases, the plant-arthropod interaction depends on the length of the mouthparts. A correlation between nectar holder depth and the proboscis length of the flower visitor has been observed in several insect groups, especially in pollinators. Short corolla flowers favour hoverflies, whereas bumblebees prefer long corollas (Campbell et al. 2012). As a result, flower size is one of the most important variables determining the abundance and diversity of flower visitors and their size (Ibanez 2012; Stang et al. 2006; van Rijn and Wäckers 2016). By contrast, extrafloral nectar is generally produced on exposed nectaries, with no size constraints on its accessibility. However, extrafloral nectar has a higher sugar content than floral nectar, rendering it more viscous. This high viscosity facilitates the feeding of hymenopteran parasitoids, which have adapted mouthparts, but limits the accessibility of this resource to lepidopterans, which feed only on dilute nectar (Géneau et al. 2012).

In the herbivores serving as alternative prey for the natural enemies of pests, resource provisioning is dependent on plant palatability, which in turn depends on various morphological (e.g. presence of trichomes, Carmona et al. 2011), biomechanical and chemical traits (e.g. silica content, Massey et al. 2006). Plant resistance to chewing insects is positively related to leaf punch strength, work to shear and work to tear (Peeters et al. 2007). The incisor strength of insect mandibles is thus related to the traits of the leaves consumed (like leaf dry matter content and carbon:nitrogen ratio, Deraison et al. 2015). Biomechanical properties are associated with several leaf structure traits, such as cuticle thickness, lignin content, specific leaf area and leaf dry matter content (Pérez-Harguindeguy et al. 2003; Schädler et al. 2003). However, the effect of biomechanical properties may be partly confounded with leaf nutrient quality (nitrogen content, carbon:nitrogen ratio, assimilate content), which is negatively correlated with mechanical resistance (Peeters et al. 2007).

Nutritional characteristics of the resource: Floral nectar, extrafloral nectar and honeydew are composed of sugars, whereas pollen is a source of proteins and free amino acids. The sugar, protein and amino acid composition of these resources varies considerably between plant species (Heimpel

and Jervis 2005). Floral nectar contains mostly sucrose, fructose and glucose (Baker and Baker 1983). The sugar composition of nectar affects pollinator preferences. Parasitoids prefer floral nectar composed predominantly of sucrose (Vattala et al. 2006), partly due to a gustatory response (Cocco and Glendinning 2012). Extrafloral nectar generally has a higher sugar concentration, whereas honeydew has a lower nutritional quality than nectar (Lee et al. 2004).

Temporal availability of resources: The synchrony between the plant and arthropod cycles determines the likelihood of interaction (Welch and Harwood 2014). The circadian rhythm of nectar production must coincide with the timing of flower and extrafloral nectaries visitors. The seasonal availability of resources depends on plant phenology. The phenological match between flowering period and arthropod floral resource requirements is crucial for completion of the life cycles of both herbivores and their natural enemies.

A number of trophic interaction traits have, thus, been clearly identified (Fig. 2), and several traits must be considered simultaneously in the evaluation of trophic interactions between plants and arthropods.

2.3.2. Plant traits associated with the non-resource functions of the habitat

Plants have a number of other effects on invertebrates in addition to providing food (Fig. 2): physical habitat provision, microclimate modification and habitat provision for all life stages, including the most critical, such as reproduction.

The structural properties of non-crop vegetation, such as density, height and litter quantity, are known to influence the distribution of soil-dwelling arthropods (Griffiths et al. 2008). Plant structural traits, such as growth form, height, architecture (density and orientation of branches and leaves, leaf morphology) and the presence of domatia shape arthropod habitats (Parolin et al. 2012). For example, plant morphology influences small-scale invertebrate distribution: plants with a complex morphology have higher invertebrate abundances and biomasses than plants with a simple morphology (Hansen et al. 2010). At a smaller scale, the properties of plant surfaces, such as leaf toughness, epicuticular waxes, pubescence and trichomes, affect the attachment and movement of arthropods, with contrasting

effects on herbivores and predators, either enhancing or impairing biological control (Mitchell 2016; Petersen 2016).

Plants also provide epigeic invertebrates with shelter, particularly during the periods outside the crop growing season. The plant canopy maintains a moist microclimate and reduces wind speed (Norris and Kogan 2005), protecting invertebrates from desiccation and providing favourable sites for aestivation. Conversely, relatively dry sites with little temperature variation, such as grass tussocks, are favourable sites for the overwintering of ground beetles (MacLeod et al. 2004). The role of plants in providing suitable overwintering sites has been evaluated for a large range of plant and soil invertebrate species (Bürki and Hausammann 1992), but the corresponding traits have yet to be identified, making it difficult to draw general conclusions.

Habitat provision for reproduction, such as the choice of oviposition sites, has been analysed principally in relation to adult and larval food distribution in the framework of optimal oviposition theory (Wäckers et al. 2007). The olfactory stimuli emitted by plants, such as kairomones and allomones, seem to predominate in the long-distance attraction or repulsion of gravid female herbivores, whereas visual stimuli drive the choice of specific oviposition sites, limiting oviposition on non-host plants (Hooks and Johnson 2003). Plants associated with higher egg survival rates are suitable oviposition sites for phytophagous and predatory insects, and may be different from the plants on which these insects feed (Norris and Kogan 2005). The physical characteristics of the plant are also important. For example, hollow tree and shrub stems are selected as nesting sites for sphecids wasps (Bitsch and Leclercq 1993). Nentwig (1992) recorded the oviposition preferences of lacewings on a large range of plant species and found that oviposition rates were particularly high on plants of the Papaveraceae and Boraginaceae species, possibly due to the pilosity of these species. However, it remains unclear how plant traits, such as architecture or surface features (wax, pilosity etc.) affect the oviposition behaviour of arthropods.

3. Scaling up to the community and landscape levels

3.1. Overcoming the limitations of single-species approaches

Most studies on conservation biological control have focused on one or a few plant species and their role in the regulation of one or a few herbivore groups by one or a few natural enemies (e.g. Langoya and van Rijn 2008; Laubertie et al. 2012). Several of these studies have involved the screening of plants in controlled conditions to identify the most appropriate species for increasing the biocontrol performance of a particular natural enemy. The most frequently tested species are *Phacelia tanacetifolia*, *Fagopyrum esculentum* Moench and *Lobularia maritima* (L.) Desv.

However, crops are generally susceptible to attacks from several herbivore species. Moreover, in arable fields used for the cultivation of annual crops in rotation, a diverse community of natural enemies is required to regulate the associated communities of herbivores. The surrounding non-crop vegetation must, therefore, also consist of a mixture of plant species if it is to support a diverse community of natural enemies. However, plant effects on arthropod behaviour have been analysed mostly in pure stands, and little is known about the effect of plant assemblages (Pontin et al. 2006). In plant communities, attractive plant species may divert herbivores from less attractive species, resulting in lower visiting rates than for single-species stands. Interactions may also occur within arthropod communities, such as competition between an aggressive species and a less aggressive species (bee vs. hoverflies, Hogg et al. 2011). A greater diversity of plant resources and plant habitats may result in lower levels of competition and other negative interactions between arthropods, promoting a greater diversity of arthropods than would be expected from experimental results obtained for single-species stands. The occurrence of interactions makes it necessary to develop community-level approaches, to identify the characteristics of plant communities most likely to improve conservation biological control. Most studies to date have focused on a particular mixture (e.g. Gillespie et al. 2011; Pfiffner et al. 2009), but a small proportion of studies have compared different mixtures (eight studies out of 40 synthesized in Haaland et al. 2011).

However, there is strong evidence for functional relationships between plant and arthropod

communities. The abundance of phytophagous invertebrates is positively correlated with plant traits related to resistance to community-level disturbances (e.g. low leaf dry matter content), suggesting a functional link between the two communities (Storkey et al. 2013). In addition to the mean trait values for plant communities, trait diversity may also be important. Potts et al. (2004) showed that the diversity of nectar resources was positively related to bee species richness.

3.2. Which metrics provide information about the effects of plant community structure on arthropod assemblages, and what are their limitations?

In this section, we review the characteristics of plant communities relating to arthropod assemblages and their functioning in terms of herbivore regulation.

Several descriptors can be used to characterise communities. The first is species identity. This approach assumes that each species has an idiosyncratic role and that the functioning of the community depends on the particular species it contains. This view may reflect insufficient knowledge or an inadequate description of the mechanisms underlying the processes studied.

The second type of descriptor is based on the functional composition of the community. According to the biomass-ratio hypothesis, ‘the extent to which the traits of a species affect ecosystem properties is likely to be strongly related to the contributions of the species [...]’ to community biomass (Grime 1998). This suggests that the effects of plants on ecosystem functions are determined primarily by mean trait values at community level, weighted by the relative importance of each species. For example, in subalpine grasslands, the mean body mass of grasshoppers responds to the community weighted mean of leaf dry matter content (Moretti et al. 2013). The abundance of nectar- and pollen-feeding arthropods would be expected to increase with the amount of accessible resources provided by the whole plant community, possibly modulated by their nutritional value.

However, interactions between the functional components of the community may result in a community functioning that could not be inferred simply by adding together the effects of individual

species. The ecosystem impact of organisms from higher trophic levels may be less related to abundance or biomass (Grime 1998) as in plants. Non-additive diversity effects can result from functional complementarity, which facilitates niche partitioning, or from synergistic or antagonistic interactions. Functional diversity is often measured as the diversity of functional traits and can be described by functional trait richness, evenness and divergence (Dias et al. 2013). In plant-invertebrate communities, a high diversity of plant resources and microhabitats would be expected to support a high diversity of invertebrates. Podgaiski et al. (2013) found a positive correlation between functional diversity in plant communities (in terms of size and architecture) and functional diversity in spiders (morphology and web-building type). However, this finding was not supported by those of other recent studies analysing the effects of the functional diversity of flower resources on natural enemies (Balzan et al. 2014; Uyttenbroeck et al. 2017). Due to the long generation times of several natural enemies, particularly for generalists, the temporal diversity of resource provisioning (e.g. flowering date and duration) may play an important role than the instantaneous diversity of flower resources.

There is no consensus concerning the relative importance of community species composition and functional structure (Costanzo and Barberi 2014), and the contribution of functional diversity effects to ecosystem functioning remains unclear (Gagic et al. 2015; Garibaldi et al. 2015; Garnier et al. 2016).

Recent meta-analyses have provided evidence that plant species diversity and functional diversity favour generalist predators (Dassou and Tixier 2016), thereby increasing herbivore regulation by natural enemies (Iverson et al. 2014). Several unanswered questions remain concerning the type of functional diversity (i.e. which traits?) and the degree of diversity optimising herbivore regulation.

3.3. How is plant functional diversity related to herbivore regulation?

It is not easy to determine the level of functional diversity required to optimise herbivore control at community level. The biological control of a single herbivore species might be expected to depend principally on the amounts of trophic resources and habitats supporting its main natural enemies

(dominance effects). The plants traits supporting the natural enemies of additional herbivore species may differ, resulting in a need for diverse plant functions to support the entire natural enemy community required to regulate a community of herbivores. As shown by Isbell et al. (2011), the larger the number of ecosystem services required of plant communities, the larger the number of plants with different functions is needed to provide those services. However, in a plant community of fixed size, plant functional diversity cannot be increased in isolation, without modifying other community properties.

First, the generally hump-shaped relationship between the community weighted mean of traits (CWM) and functional diversity (Dias et al. 2013) implies that, for any given trait, functional diversity tends to be lowest at extreme values of CWM. Thus, depending on the plant trait values related to biological control, this interdependence may constrain increases in functional diversity.

Second, evenness, which is a component of functional diversity, reduces dominance effects by diluting the relative contribution of dominant species within the community. For example, combining plant species according to their flowering period, so as to ensure that nectar and pollen are supplied throughout the year, decreases the density of plants flowering at the same time. At peak flowering, more resources are available in communities with a homogeneous phenology than in communities with a heterogeneous phenology, resulting in a trade-off between the diversity of resources and their instantaneous availability. Thus, increasing the diversity of plant traits to increase the diversity of arthropods may result in a lower density of each type of arthropod.

This trade-off between evenness and dominance effects suggests that the functional diversity-biological control relationship may not be monotonous. Provided that plant functional diversity promotes complementarity and positive interactions with natural enemies, this should counterbalance the decrease in plant dominance effects. Thus, the functional diversity-herbivore regulation relationship may not always be positive, and may reach a plateau or an optimum value, depending on the strength of the synergistic interactions at high levels of plant functional diversity. The deciphering of this relationship will require experiments in which the functional composition and diversity of plant

communities are varied, for the simultaneous testing of the two effects, and for quantitative analyses of the relationships between functional trait diversity, composition and ecosystem functions.

Several traits (Fig. 2) and metrics have been proposed to account for the interactions between species or between restricted taxonomic groups. The next step is the identification of combinations of plant community metrics accounting for the effects of the plant community on arthropod communities, and taking into account the effects of functional composition, functional diversity and species identity (when effects cannot be related to functional traits). The level of functional redundancy is another important aspect.

3.4. Taking interactions with surrounding landscapes into account

The management of a given habitat for conservation biological control must be adapted to the characteristics of the neighbouring habitats, such as crop fields and other non-crop structures (Tscharntke et al. 2016). The creation of a new habitat, such as a wildflower strip, provides additional resources and habitats. Plant community management or establishment should therefore be based on i) assessments of the requirements of natural enemies and ii) assessments of the resources already provided in the surroundings, in locally limiting resources or habitats. For instance, the effect of wildflower strips on pollinators depends strongly on their complementarity with the resources already available at landscape scale (Scheper et al. 2015), particularly as concerns synchrony between flowering period and pollinator requirements. Plant traits must be adapted to abiotic conditions, such as climate and soil conditions. In arid climates, arthropods may search for moist shelters protecting them from drought stress (tussocks and creeping plants providing shade and higher levels of humidity), whereas, in humid climates, open habitats with rapid warming may result in higher levels of arthropod activity. A functional characterisation of the surrounding landscape (functional landscape ecology) is therefore required, with an improvement of the metrics of landscape description beyond land use (Vialatte 2017; landscape ecology). Simplified vegetation relevés, stratified by habitat type, can be used to calculate the landscape-wide floral resource availability (Scheper 2015). This approach could be extended to other plant properties, including habitat-related traits, and other metrics, such as

the spatial diversity of plant trait values. In the future, such descriptions of the properties of plant communities at the landscape scale should make it possible to adapt habitat creation and management, to improve spatial functional supplementation and complementation rather than making use of standardised greening infrastructures.

Conclusions and implications for conservation biological control

A trait-based approach opens up exciting new possibilities for improving our understanding of the relationships between plant assemblages and conservation biological control. The well-known influence of morphological and biochemical traits on the interaction between plants and pollinators (Stang et al. 2009) suggests that this approach may also be useful for dealing with other biotic interactions.

We also need to identify the characteristics of arthropod communities associated with efficient biological control. Despite the general finding that the stable biological control of multispecies herbivore communities requires functional diversity and a redundancy of natural enemies, the development of appropriate management practices remains limited by our poor understanding of the functioning of arthropod communities, and of their trophic interaction network, in particular.

We also propose the identification of “interaction traits” specifically involved in plant-arthropod interactions, including the effect traits of plants (traits with an impact on arthropods) and the response traits of arthropods (traits associated with the arthropod response to plants). Interaction traits are correlated with plant features relating to the provision of trophic resources (amount of resource, phenology of production, corolla shape etc.) and habitat (plant architecture) affecting arthropods (Fig. 2). Important interaction traits, such as nectar composition, extrafloral nectar availability, presence of domatia and plant pilosity, are currently poorly documented in botanical databases. The use of such traits would improve our mechanistic understanding of interactions at community level. It might also

make it possible to quantify the diversity and redundancy of interaction traits in plant communities and to determine their relationship to the abundance of natural enemies or herbivore regulation.

We need to scale up our knowledge of plant-arthropod interactions, from the population to the community level. The extent to which arthropod communities are affected by plant traits at community level remains largely unexplored. An intermediate level of plant functional diversity might be expected to maximise the service of herbivore regulation, but experimental designs facilitating the comparison of contrasting plant communities (such as Hatt et al. 2017) will be useful for disentangling the respective roles of plant functional composition and diversity.

The identification of relevant community characteristics should not be limited to additive species traits. It should also take into account the structure of the interaction network, species complementarity and the generalist/specialist ratio.

Over and above the identification of relevant plant traits, the high specificity of certain plant-insect and insect-insect interactions may weaken the trait-based approach. Aphid-parasitoid and plant-aphid interactions are usually species-specific. Consequently, aphid regulation often requires the targeting of a particular aphid species by promoting a particular parasitoid species. Trade-offs may occur between the positive effects of plant traits on one group of natural enemies and negative effects on another. It therefore seems likely that some sets of traits are related to herbivore regulation in general, but we cannot exclude the possibility that these combinations are highly specific and that a trait-based approach is not necessarily more straightforward than a species-based approach. We do not, therefore, recommend the exclusive use of trait-based approaches, and advances in food-web ecology will undoubtedly also improve the understanding and management of trophic interactions. If interactions are idiosyncratic or poorly understood, and if trait attributes are phylogenetically conserved, then phylogenetic parameters may be better predictors of ecosystem functioning than functional traits or groups (Cadotte et al. 2008). However, interaction specificity usually includes a single dimension of a niche, and a trait-based approach may still be straightforward for the other dimensions. For generalist predators, a trait-based approach would remain relevant, but difficulties may arise due to the number

of traits and their interactions to be considered in each situation to predict their functioning. If patterns become too complex and difficult to generalize, then the trait-based approach may be impractical.

In practice, interaction traits may be used to decide on the combinations of plant properties required to guide the formulation of seed mixtures for creating or restoring semi-natural habitats, rather than using standard species lists applied to several biogeographical zones. The identification of plant species from the local flora with the desired trait criteria would make it possible to design seed mixtures with similar functional characteristics based on species adapted to local climatic conditions.

The use of functional traits as proxies for community and ecosystem functioning should not completely supplant other drivers of plant arthropod interactions, such as environmental conditions and habitat management. In addition, the use of plant communities to support biological control must also take into account a diversity of ecological, technical and socio-economic criteria, such as a potential loss of diversity during plant succession.

Problematic weed species cannot be included in the mixtures sown, even if they present ideal trait combinations. Plant species of local origin should be preferred whenever possible, to select locally adapted populations and to prevent genetic pollution. Finally, trade-offs with other ecosystem services should be considered from a multifunctional standpoint, including pollination, species conservation and landscape aesthetics.

Conflict of interest: The authors have no conflict of interest to declare.

References

- Agrawal AA, Karban R (1997) Domatia mediate plant-arthropod mutualism *Nature* 387:562-563
doi:10.1038/42384
- Baggen LR, Gurr GM, Meats A (1999) Flowers in tri-trophic systems: mechanisms allowing selective exploitation by insect natural enemies for conservation biological control *Entomol Exp Appl* 91:155-161 doi:10.1046/j.1570-7458.1999.00478.x
- Baker HG, Baker I (1983) Floral nectar sugar constituents in relation to pollinator type *Handbook of experimental pollination biology*:117-141
- Balzan M, Bocci G, Moonen A-C (2014) Augmenting flower trait diversity in wildflower strips to optimise the conservation of arthropod functional groups for multiple agroecosystem services *J Insect Conserv* 18:713-728 doi:10.1007/s10841-014-9680-2
- Balzan MV, Bocci G, Moonen AC (2016) Utilisation of plant functional diversity in wildflower strips for the delivery of multiple agroecosystem services *Entomol Exp Appl* 158:304-319
doi:10.1111/eea.12403
- Belz E, Kölliker M, Balmer O (2013) Olfactory attractiveness of flowering plants to the parasitoid *Microplitis mediator*: potential implications for biological control *Biocontrol* 58:163-173
doi:10.1007/s10526-012-9472-0
- Birkhofer K et al. (2017) Land-use type and intensity differentially filter traits in above- and below-ground arthropod communities *J Anim Ecol* 86:511-520 doi:10.1111/1365-2656.12641
- Birkhofer K, Wise DH, Scheu S (2008) Subsidy from the detrital food web, but not microhabitat complexity, affects the role of generalist predators in an aboveground herbivore food web *Oikos* 117:494-500 doi:10.1111/j.0030-1299.2008.16361.x
- Bischoff A et al. (2016) Effects of spontaneous field margin vegetation and surrounding landscape on *Brassica oleracea* crop herbivory *Agr Ecosyst Environ* 223:135-143
doi:<http://dx.doi.org/10.1016/j.agee.2016.02.029>
- Bitsch J, Leclercq J (1993) Hyménoptères Sphecidae d'Europe Occidentale, volume I. Faune de France 79. Fédération Française des Sociétés de Sciences Naturelles, Paris, France,
- Boukal DS (2014) Trait- and size-based descriptions of trophic links in freshwater food webs: current status and perspectives *J Limnol* 73:171-185 doi:10.4081/jlimnol.2014.826
- Bürki H-M, Hausamann A (1992) Überwinterung von Arthropoden im Boden und an Ackerkräutern künstlich angelegter Ackerkrautstreifen *Agrarökologie* 7:1-158
- Cadotte MW, Cardinale BJ, Oakley TH (2008) Evolutionary history and the effect of biodiversity on plant productivity *Proc Natl Acad Sci U S A* 105:17012-17017 doi:10.1073/pnas.0805962105
- Campbell AJ, Biesmeijer JC, Varma V, Wäckers FL (2012) Realising multiple ecosystem services based on the response of three beneficial insect groups to floral traits and trait diversity *Basic and Applied Ecology* 13:363-370 doi:10.1016/j.baae.2012.04.003

636 Carmona D, Lajeunesse MJ, Johnson MTJ (2011) Plant traits that predict resistance to herbivores
637 *Funct Ecol* 25:358-367 doi:10.1111/j.1365-2435.2010.01794.x

638 Chen XQ, Chen YC, Wu LB, Peng Y, Chen JA, Liu FX (2010) A survey of nectar feeding by spiders
639 in three different habitats *Bull Insectol* 63:203-208

640 Cocco N, Glendinning JI (2012) Not all sugars are created equal: some mask aversive tastes better
641 than others in an herbivorous insect *J Exp Biol* 215:1412-1421 doi:10.1242/jeb.059832

642 Costanzo A, Barberi P (2014) Functional agrobiodiversity and agroecosystem services in sustainable
643 wheat production. A review *Agronomy for Sustainable Development* 34:327-348 doi:10.1007/s13593-
644 013-0178-1

645 Dassou AG, Tixier P (2016) Response of pest control by generalist predators to local-scale plant
646 diversity: a meta-analysis *Ecology and Evolution* 6:1143-1153 doi:10.1002/ece3.1917

647 Deraison H, Badenhauer I, Loeuille N, Scherber C, Gross N (2015) Functional trait diversity across
648 trophic levels determines herbivore impact on plant community biomass *Ecology Letters* 18:1346-
649 1355 doi:10.1111/ele.12529

650 Dias ATC, Berg MP, de Bello F, Van Oosten AR, Bílá K, Moretti M (2013) An experimental
651 framework to identify community functional components driving ecosystem processes and services
652 delivery *J Ecol* 101:29-37 doi:10.1111/1365-2745.12024

653 Diehl E, Wolters V, Birkhofer K (2012) Arable weeds in organically managed wheat fields foster
654 carabid beetles by resource- and structure-mediated effects *Arthropod-Plant Interactions* 6:75-82
655 doi:10.1007/s11829-011-9153-4

656 Fahey JW, Zalcmann AT, Talalay P (2001) The chemical diversity and distribution of glucosinolates
657 and isothiocyanates among plants *Phytochemistry* 56:5-51 doi:10.1016/s0031-9422(00)00316-2

658 Fiedler AK, Landis DA (2007) Plant characteristics associated with natural enemy abundance at
659 Michigan native plants *Environ Entomol* 36:878-886 doi:10.1603/0046-
660 225x(2007)36[878:pcawne]2.0.co;2

661 Finke DL, Denno RF (2006) Spatial refuge from intraguild predation: implications for prey
662 suppression and trophic cascades *Oecologia* 149:265-275 doi:10.1007/s00442-006-0443-y

663 Frenette-Dussault C, Shipley B, Hingrat Y (2013) Linking plant and insect traits to understand
664 multitrophic community structure in arid steppes *Funct Ecol* 27:786-792 doi:10.1111/1365-
665 2435.12075

666 Gagic V et al. (2015) Functional identity and diversity of animals predict ecosystem functioning better
667 than species-based indices *Proc R Soc B* 282:sous presse doi:10.1098/rspb.2014.2620

668 Garibaldi LA et al. (2015) Trait matching of flower visitors and crops predicts fruit set better than trait
669 diversity *J Appl Ecol* 52:1436-1444 doi:10.1111/1365-2664.12530

670 Garnier É, Navas M-L, Grigulis K (2016) Plant functional diversity. Oxford University Press, United
671 Kingdom,

672 Géneau CE, Wäckers FL, Luka H, Daniel C, Balmer O (2012) Selective flowers to enhance biological
673 control of cabbage pests by parasitoids Basic and Applied Ecology 13:85-93
674 doi:10.1016/j.baae.2011.10.005

675 Gillespie M, Wratten S, Sedcole R, Colfer R (2011) Manipulating floral resources dispersion for
676 hoverflies (*Diptera: Syrphidae*) in a California lettuce agro-ecosystem Biol Control 59:215-220
677 doi:10.1016/j.biocontrol.2011.07.010

678 Gontijo LM, Beers EH, Snyder WE (2015) Complementary suppression of aphids by predators and
679 parasitoids Biol Control 90:83-91 doi:10.1016/j.biocontrol.2015.06.002

680 Griffiths GJK, Holland JM, Bailey A, Thomas MB (2008) Efficacy and economics of shelter habitats
681 for conservation biological control Biol Control 45:200-209 doi:10.1016/j.biocontrol.2007.09.002

682 Grime JP (1998) Benefits of plant diversity to ecosystems: immediate, filter and founder effects J Ecol
683 86:902-910

684 Haaland C, Naisbit RE, Bersier LF (2011) Sown wildflower strips for insect conservation: a review
685 Insect Conservation and Diversity 4:60-80 doi:10.1111/j.1752-4598.2010.00098.x

686 Hansen JP, Sagerman J, Wikstrom SA (2010) Effects of plant morphology on small-scale distribution
687 of invertebrates Mar Biol 157:2143-2155 doi:10.1007/s00227-010-1479-4

688 Harwood JD et al. (2009) Invertebrate biodiversity affects predator fitness and hence potential to
689 control pests in crops Biol Control 51:499-506 doi:10.1016/j.biocontrol.2009.09.007

690 Hatt S et al. (2017) Do flower mixtures with high functional diversity enhance aphid predators in
691 wildflower strips? Eur J Entomol 114:66-76 doi:10.14411/eje.2017.010

692 Heimpel GE, Jervis MA (2005) Does floral nectar improve biological control by parasitoids? In:
693 Wäckers F, van Rijn P, Bruin J (eds) Plant-provided food and plant-carnivore mutualism. Cambridge
694 University Press, Cambridge, UK, pp 267-304

695 Hogg BN, Bugg RL, Daane KM (2011) Attractiveness of common insectary and harvestable floral
696 resources to beneficial insects Biol Control 56:76-84 doi:10.1016/j.biocontrol.2010.09.007

697 Hooks CRR, Johnson MW (2003) Impact of agricultural diversification on the insect community of
698 cruciferous crops Crop Prot 22:223-238 doi:10.1016/s0261-2194(02)00172-2

699 Ibanez S (2012) Optimizing size thresholds in a plant-pollinator interaction web: towards a
700 mechanistic understanding of ecological networks Oecologia 170:233-242 doi:10.1007/s00442-012-
701 2290-3

702 Ibanez S, Lavorel S, Puijalon S, Moretti M (2013) Herbivory mediated by coupling between
703 biomechanical traits of plants and grasshoppers Funct Ecol 27:479-489 doi:10.1111/1365-2435.12058

704 Isbell F et al. (2011) High plant diversity is needed to maintain ecosystem services Nature 477:199-
705 U196 doi:10.1038/nature10282

706 Iverson AL et al. (2014) Do polycultures promote win-wins or trade-offs in agricultural ecosystem
707 services? A meta-analysis J Appl Ecol 51:1593-1602 doi:10.1111/1365-2664.12334

708 Jervis MA, Lee JC, Heimpel GE (2004) Use of behavioural and life-history studies to understand the
709 effects of habitat manipulation. In: Gurr GM, Wratten SD, Altieri MA (eds) Ecological engineering
710 for pest management. CSIRO, Wallingford, UK, pp 65-100

711 Jonsson M, Kaartinen R, Straub CS (2017) Relationships between natural enemy diversity and
712 biological control Current Opinion in Insect Science 20:1-6 doi:10.1016/j.cois.2017.01.001

713 Jonsson M, Wratten SD, Landis DA, Gurr GM (2008) Recent advances in conservation biological
714 control of arthropods by arthropods Biol Control 45:172-175 doi:10.1016/j.biocontrol.2008.01.006

715 Kissling WD, Schleuning M (2015) Multispecies interactions across trophic levels at macroscales:
716 retrospective and future directions Ecography 38:346-357 doi:10.1111/ecog.00819

717 Kos M et al. (2014) Relative importance of plant-mediated bottom-up and top-down forces on
718 herbivore abundance on *Brassica oleracea* Funct Ecol 25:1113-1124 doi:10.1111/j.1365-
719 2435.2011.01871.x

720 Kühn I, Durka W, Klotz S (2004) BiolFlor - a new plant-trait database as a tool for plant invasion
721 ecology Divers Distrib 10:363-365

722 Langoya LA, van Rijn PCJ (2008) The significance of floral resources for natural control of aphids
723 Proceedings of the Netherlands Entomological Society Meeting 19:67-74

724 Laubertie EA, Wratten SD, Hemptinne JL (2012) The contribution of potential beneficial insectary
725 plant species to adult hoverfly (Diptera: Syrphidae) fitness Biol Control 61:1-6
726 doi:10.1016/j.biocontrol.2011.12.010

727 Lavorel S et al. (2011) Using plant functional traits to understand the landscape distribution of
728 multiple ecosystem services J Ecol 99:135-147 doi:10.1111/j.1365-2745.2010.01753.x

729 Lavorel S et al. (2013) A novel framework for linking functional diversity of plants with other trophic
730 levels for the quantification of ecosystem services J Veg Sci 24:942-948 doi:10.1111/jvs.12083

731 Lee JC, Heimpel GE, Leibe GL (2004) Comparing floral nectar and aphid honeydew diets on the
732 longevity and nutrient levels of a parasitoid wasp Entomol Exp Appl 111:189-199 doi:10.1111/j.0013-
733 8703.2004.00165.x

734 Letourneau DK et al. (2011) Does plant diversity benefit agroecosystems? A synthetic review
735 Ecological Applications 21:9-21 doi:10.1890/09-2026.1

736 MacLeod A, Wratten SD, Sotherton NW, Thomas MB (2004) 'Beetle banks' as refuges for beneficial
737 arthropods in farmland: long-term changes in predator communities and habitat Agric For Entomol
738 6:147-154 doi:10.1111/j.1461-9563.2004.00215.x

739 Massey FP, Ennos AR, Hartley SE (2006) Silica in grasses as a defence against insect herbivores:
740 contrasting effects on folivores and a phloem feeder J Anim Ecol 75:595-603 doi:10.1111/j.1365-
741 2656.2006.01082.x

742 Moretti M et al. (2013) Linking traits between plants and invertebrate herbivores to track functional
743 effects of land-use changes J Veg Sci 24:949-962 doi:10.1111/jvs.12022

- 744 Nentwig W (1992) Die nützlingsfördernde Wirkung von Unkräutern in angesäten Unkraustreifen
745 Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz 13:33-40
- 746 Norris RF, Kogan M (2005) Ecology of interactions between weeds and arthropods. In: Annual
747 Review of Entomology, vol 50. Annual Review of Entomology. Annual Reviews, Palo Alto, pp 479-
748 503. doi:10.1146/annurev.ento.49.061802.123218
- 749 Northfield TD, Snyder GB, Ives AR, Snyder WE (2010) Niche saturation reveals resource partitioning
750 among consumers Ecology Letters 13:338-348 doi:10.1111/j.1461-0248.2009.01428.x
- 751 Parolin P, Bresch C, Poncet C, Desneux N (2012) Functional characteristics of secondary plants for
752 increased pest management Int J Pest Manage 58:368-376 doi:10.1080/09670874.2012.734869
- 753 Peeters PJ, Sanson G, Read J (2007) Leaf biomechanical properties and the densities of herbivorous
754 insect guilds Funct Ecol 21:246-255 doi:10.1111/j.1365-2435.2006.01223.x
- 755 Pérez-Harguindeguy N, Díaz S, Vendramini F, Cornelissen JHC, Gurvich DE, Cabido M (2003) Leaf
756 traits and herbivore selection in the field and in cafeteria experiments Austral Ecol 28:642-650
757 doi:10.1046/j.1442-9993.2003.01321.x
- 758 Pey B et al. (2014) Current use of and future needs for soil invertebrate functional traits in community
759 ecology Basic and Applied Ecology 15:194-206 doi:10.1016/j.baae.2014.03.007
- 760 Pfiffner L, Luka H, Schlatter C, Juen A, Traugott M (2009) Impact of wildflower strips on biological
761 control of cabbage lepidopterans Agr Ecosyst Environ 129:310-314 doi:10.1016/j.agee.2008.10.003
- 762 Pfiffner L, Wyss E (2004) Use of sown wildflower strips to enhance natural enemies of agricultural
763 pests. In: Ecological engineering for pest management: advances in habitat manipulation for
764 arthropods. CABI Publishing, Wallingford, UK, pp 165-186
- 765 Podgaiski LR, Joner F, Lavorel S, Moretti M, Ibanez S, Mendonca MD, Pillar VD (2013) Spider trait
766 assembly patterns and resilience under fire-induced vegetation change in South Brazilian grasslands
767 PLoS One 8:11 doi:10.1371/journal.pone.0060207
- 768 Pontin DR, Wade MR, Kehrli P, Wratten SD (2006) Attractiveness of single and multiple species
769 flower patches to beneficial insects in agroecosystems Ann Appl Biol 148:39-47 doi:10.1111/j.1744-
770 7348.2005.00037.x
- 771 Porcel M, Cotes B, Castro J, Campos M (2017) The effect of resident vegetation cover on abundance
772 and diversity of green lacewings (Neuroptera: Chrysopidae) on olive trees J Pest Sci 90:195-206
773 doi:10.1007/s10340-016-0748-5
- 774 Potts SG, Vulliamy B, Roberts S, O'Toole C, Dafni A, Ne'eman G, Willmer PG (2004) Nectar
775 resource diversity organises flower-visitor community structure Entomol Exp Appl 113:103-107
776 doi:10.1111/j.0013-8703.2004.00212.x
- 777 Schädler M, Jung G, Auge H, Brandl R (2003) Palatability, decomposition and insect herbivory:
778 patterns in a successional old-field plant community Oikos 103:121-132 doi:10.1034/j.1600-
779 0706.2003.12659.x
- 780 Scheper J et al. (2015) Local and landscape-level floral resources explain effects of wildflower strips

781 on wild bees across four European countries *J Appl Ecol* 52:1165-1175 doi:10.1111/1365-2664.12479

782 Sivinski J, Wahl D, Holler T, Al Dobai S, Sivinski R (2011) Conserving natural enemies with
 783 flowering plants: Estimating floral attractiveness to parasitic Hymenoptera and attraction's relationship
 784 to flower and plant morphology *Biol Control* 58:208-214 doi:10.1016/j.biocontrol.2011.05.002

785 Snyder WE, Snyder GB, Finke DL, Straub CS (2006) Predator biodiversity strengthens herbivore
 786 suppression *Ecology Letters* 9:789-796 doi:10.1111/j.1461-0248.2006.00922.x

787 Stang M, Klinkhamer PGL, van der Meijden E (2006) Size constraints and flower abundance
 788 determine the number of interactions in a plant-flower visitor web *Oikos* 112:111-121
 789 doi:10.1111/j.0030-1299.2006.14199.x

790 Stang M, Klinkhamer PGL, Waser NM, Stang I, van der Meijden E (2009) Size-specific interaction
 791 patterns and size matching in a plant-pollinator interaction web *Ann Bot* 103:1459-1469
 792 doi:10.1093/aob/mcp027

793 Storkey J, Brooks D, Haughton A, Hawes C, Smith BM, Holland JM (2013) Using functional traits to
 794 quantify the value of plant communities to invertebrate ecosystem service providers in arable
 795 landscapes *J Ecol* 101:38-46 doi:10.1111/1365-2745.12020

796 Tschardt T et al. (2016) When natural habitat fails to enhance biological pest control - Five
 797 hypotheses *Biol Conserv* 204:449-458 doi:10.1016/j.biocon.2016.10.001

798 Uyttenbroeck R, Piqueray J, Hatt S, Mahy G, Monty A (2017) Increasing plant functional diversity is
 799 not the key for supporting pollinators in wildflower strips *Agr Ecosyst Environ* 249:144-155
 800 doi:10.1016/j.agee.2017.08.014

801 van Rijn PCJ, Wäckers FL (2010) The suitability of field margin flowers as food sources for
 802 zoophagous hoverflies *Landscape management for functional biodiversity* 56:125-128

803 van Rijn PCJ, Wäckers FL (2016) Nectar accessibility determines fitness, flower choice and
 804 abundance of hoverflies that provide natural pest control *J Appl Ecol*:n/a-n/a doi:10.1111/1365-
 805 2664.12605

806 Vattala HD, Wratten SD, Phillips CB, Wäckers FL (2006) The influence of flower morphology and
 807 nectar quality on the longevity of a parasitoid biological control agent *Biol Control* 39:179-185
 808 doi:10.1016/j.biocontrol.2006.06.003

809 Violle C, Navas ML, Vile D, Kazakou E, Fortunel C, Hummel I, Garnier E (2007) Let the concept of
 810 trait be functional! *Oikos* 116:882-892

811 Violle C, Reich PB, Pacala SW, Enquist BJ, Kattge J (2014) The emergence and promise of functional
 812 biogeography *Proceedings of the national academy of sciences* 111:13690-13696
 813 doi:10.1073/pnas.1415442111

814 Wäckers FL, Romeis J, van Rijn P (2007) Nectar and pollen feeding by insect herbivores and
 815 implications for multitrophic interactions. In: *Annual Review of Entomology*, vol 52. *Annual Review*
 816 *of Entomology*. Annual Reviews, Palo Alto, pp 301-323. doi:10.1146/annurev.ento.52.110405.091352

817 Wäckers FL, van Rijn PCJ (2012) Pick and mix: selecting flowering plants to meet the requirements

818 of target biological control insects. In: Biodiversity and Insect Pests. John Wiley & Sons, Ltd, pp 139-
819 165. doi:10.1002/9781118231838.ch9

820 Wäckers FL, van Rijn PCJ, Bruin J (2005) Plant-provided food for carnivorous insects. Cambridge
821 University Press, Cambridge, UK,

822 Welch KD, Harwood JD (2014) Temporal dynamics of natural enemy-pest interactions in a changing
823 environment Biol Control 75:18-27 doi:10.1016/j.biocontrol.2014.01.004

824 Wilby A, Anglin LA, Nesbit CM (2013) Plant species composition alters the sign and strength of an
825 emergent multi-predator effect by modifying predator foraging behaviour PLoS One 8:7
826 doi:10.1371/journal.pone.0070258

827 Wilby A, Villareal SC, Lan LP, Heong KL, Thomas MB (2005) Functional benefits of predator
828 species diversity depend on prey identity Ecol Entomol 30:497-501 doi:10.1111/j.0307-
829 6946.2005.00717.x

830 Winkler K, Wackers FL, Kaufman LV, Larraz V, van Lenteren JC (2009) Nectar exploitation by
831 herbivores and their parasitoids is a function of flower species and relative humidity Biol Control
832 50:299-306 doi:10.1016/j.biocontrol.2009.04.009

833 Winkler K, Wackers FL, Termorshuizen AJ, van Lenteren JC (2010) Assessing risks and benefits of
834 floral supplements in conservation biological control Biocontrol 55:719-727 doi:10.1007/s10526-010-
835 9296-8

836 Wood SA, Karp DS, DeClerck F, Kremen C, Naeem S, Palm CA (2015) Functional traits in
837 agriculture: agrobiodiversity and ecosystem services Trends in Ecology & Evolution 30:531-539
838 doi:10.1016/j.tree.2015.06.013

839 Wratten SD, Gillespie M, Decourtye A, Mader E, Desneux N (2012) Pollinator habitat enhancement:
840 benefits to other ecosystem services Agr Ecosyst Environ 159:112-122
841 doi:10.1016/j.agee.2012.06.020
842

843 **Figures and online resource**

844

845 **Fig. 1** Outline of the main objectives targeted for efficient conservation biological control (first
846 column), their effects on arthropod community functioning (second column) and on plant community
847 and habitat management (third column), synthesised from published findings.

848

849 **Fig. 2** Overview of the main plant-arthropod interaction traits recorded in published studies and
850 relevant for managing arthropod communities by conservation biological control. *Heracleum*
851 *sphondylium* image © Pierre Déom – www.lahulotte.fr

852

853 **Online Resource 1.** List of the articles selected with the search equation in the Web of Science
854 literature database and used for the review.

Plant traits

Traits associated with trophic interactions

Resource type (nectar, pollen, seeds, leaves) and quantity

Attractiveness: odour, taste, inflorescence size and colour, secondary metabolites

Accessibility: flower shape

Nutritional quality : sugar composition, leaf structural traits

Phenology: flowering date, duration, timing of resource production

Traits associated with non-resource habitat functions

Physical habitat provision: domatia, hollow stems, pilosity

Architecture: height, growth form, vertical leaf distribution

Arthropod traits

Traits associated with trophic interactions

Trophic level, diet and specific food requirements at different life-cycle stages

Food preferences, ovigeny, mouthparts structure

Body size, head width

Phenology: voltinism, breeding season, emergence season

Traits associated with non-resource habitat functions

Mobility, body size, dispersal mode, hunting strategy, sociality

Ecological preferences for overwintering, aestivation, oviposition

[Click here to view linked References](#)

Understanding plant-arthropod interactions in multitrophic communities to improve conservation biological control: useful traits and metrics

Journal of Pest Science

Antoine Gardarin, Manuel Plantegenest, Armin Bischoff and Muriel Valantin-Morison

Corresponding author: UMR Agronomie, INRA, AgroParisTech, Université Paris-Saclay, 78850 Thiverval-Grignon, France. Antoine.Gardarin@inra.fr.

Online Resource 1. List of the articles selected from the search equation in the Web of Science literature database and used for the review.

- Abbas M, Klein AM, Ebeling A, Oelmann Y, Ptacnik R, Weissberg WW, Hillebrand H (2014) Plant diversity effects on pollinating and herbivorous insects can be linked to plant stoichiometry *Basic and Applied Ecology* 15:169-178 doi:10.1016/j.baae.2014.02.001
- Agelopoulos N et al. (1999) Exploiting semiochemicals in insect control *Pestic Sci* 55:225-235
- Agrawal AA, Karban R (1997) Domatia mediate plant-arthropod mutualism *Nature* 387:562-563 doi:10.1038/42384
- Agustí N, Shayler SP, Harwood JD, Vaughan IP, Sunderland KD, Symondson WOC (2003) Collembola as alternative prey sustaining spiders in arable ecosystems: prey detection within predators using molecular markers *Mol Ecol* 12:3467-3475 doi:10.1046/j.1365-294X.2003.02014.x
- Al-Dobai S, Reitz S, Sivinski J (2012) Tachinidae (Diptera) associated with flowering plants: estimating floral attractiveness *Biol Control* 61:230-239 doi:10.1016/j.biocontrol.2012.02.008
- Alhmedi A, Haubruge E, D'Hoedt S, Francis F (2011) Quantitative food webs of herbivore and related beneficial community in non-crop and crop habitats *Biol Control* 58:103-112 doi:10.1016/j.biocontrol.2011.04.005
- Almeida-Cortez JS, Shipley B, Arnason JT (1999) Do plant species with high relative growth rates have poorer chemical defences? *Funct Ecol* 13:819-827 doi:10.1046/j.1365-2435.1999.00383.x
- Almohamad R, Verheggen FJ, Francis F, Haubruge E (2007) Predatory hoverflies select their oviposition site according to aphid host plant and aphid species *Entomol Exp Appl* 125:13-21 doi:10.1111/j.1570-7458.2007.00596.x
- Alyokhin A et al. (2015) The Red Queen in a potato field: integrated pest management versus chemical dependency in Colorado potato beetle control *Pest Manage Sci* 71:343-356 doi:10.1002/ps.3826
- Amaral D, Venzon M, dos Santos HH, Sujii ER, Schmidt JM, Harwood JD (2016) Non-crop plant communities conserve spider populations in chili pepper agroecosystems *Biol Control* 103:69-77 doi:10.1016/j.biocontrol.2016.07.007
- Amarasekare P (2007) Trade-offs, temporal variation, and species coexistence in communities with intraguild predation *Ecology* 88:2720-2728 doi:10.1890/06-1515.1
- Anderson A, Carnus T, Helden AJ, Sheridan H, Purvis G (2013) The influence of conservation field margins in intensively managed grazing land on communities of five arthropod trophic groups *Insect Conservation and Diversity* 6:201-211 doi:10.1111/j.1752-4598.2012.00203.x
- Andow DA (1991) Vegetational diversity and arthropod population response *Annu Rev Entomol* 36:561-586 doi:10.1146/annurev.ento.36.1.561
- Andrade TO, Outreman Y, Krespi L, Plantegenest M, Vialatte A, Gauffre B, van Baaren J (2015) Spatiotemporal variations in aphid-parasitoid relative abundance patterns and food webs in agricultural ecosystems *Ecosphere* 6:14 doi:10.1890/es15-00010.1
- Aquilino KM, Cardinale BJ, Ives AR (2005) Reciprocal effects of host plant and natural enemy diversity on herbivore suppression: an empirical study of a model tritrophic system *Oikos* 108:275-282 doi:10.1111/j.0030-1299.2005.13418.x
- Araj SE, Wratten S, Lister A, Buckley H (2008) Floral diversity, parasitoids and hyperparasitoids - A laboratory approach *Basic and Applied Ecology* 9:588-597 doi:10.1016/j.baae.2007.08.001
- Arnold SEJ, Le Comber SC, Chittka L (2009) Flower color phenology in European grassland and woodland habitats, through the eyes of pollinators *Isr J Plant Sci* 57:211-230 doi:10.1560/IJPS.57.3.211

- Badenes-Perez FR, Marquez BP, Petitpierre E (2017) Can flowering *Barbarea* spp. (Brassicaceae) be used simultaneously as a trap crop and in conservation biological control? J Pest Sci 90:623-633 doi:10.1007/s10340-016-0815-y
- Badenes-Perez FR, Reichelt M, Gershenson J, Heckel DG (2014) Using plant chemistry and insect preference to study the potential of *Barbarea* (Brassicaceae) as a dead-end trap crop for diamondback moth (Lepidoptera: Plutellidae) Phytochemistry 98:137-144 doi:10.1016/j.phytochem.2013.11.009
- Baggen LR, Gurr GM, Meats A (1999) Flowers in tri-trophic systems: mechanisms allowing selective exploitation by insect natural enemies for conservation biological control Entomol Exp Appl 91:155-161 doi:10.1046/j.1570-7458.1999.00478.x
- Baker HG, Baker I (1983) Floral nectar sugar constituents in relation to pollinator type Handbook of experimental pollination biology:117-141
- Ball SL, Woodcock BA, Potts SG, Heard MS (2015) Size matters: Body size determines functional responses of ground beetle interactions Basic and Applied Ecology 16:621-628 doi:10.1016/j.baae.2015.06.001
- Ballhorn DJ, Godschalx AL, Smart SM, Kautz S, Schadler M (2014) Chemical defense lowers plant competitiveness Oecologia 176:811-824 doi:10.1007/s00442-014-3036-1
- Balmer O et al. (2014a) Wildflower companion plants increase pest parasitation and yield in cabbage fields: experimental demonstration and call for caution Biol Control 76:19-27 doi:10.1016/j.biocontrol.2014.04.008
- Balmer O, Pfiffner L, Schied J, Willareth M, Leimgruber A, Luka H, Traugott M (2014b) Noncrop flowering plants restore top-down herbivore control in agricultural fields Ecology and Evolution 3:2634-2646 doi:10.1002/ece3.658
- Balzan M, Bocci G, Moonen A-C (2014) Augmenting flower trait diversity in wildflower strips to optimise the conservation of arthropod functional groups for multiple agroecosystem services J Insect Conserv 18:713-728 doi:10.1007/s10841-014-9680-2
- Balzan MV, Bocci G, Moonen AC (2016a) Landscape complexity and field margin vegetation diversity enhance natural enemies and reduce herbivory by Lepidoptera pests on tomato crop Biocontrol 61:141-154 doi:10.1007/s10526-015-9711-2
- Balzan MV, Bocci G, Moonen AC (2016b) Utilisation of plant functional diversity in wildflower strips for the delivery of multiple agroecosystem services Entomol Exp Appl 158:304-319 doi:10.1111/eea.12403
- Balzan MV, Moonen AC (2014) Field margin vegetation enhances biological control and crop damage suppression from multiple pests in organic tomato fields Entomol Exp Appl 150:45-65 doi:10.1111/eea.12142
- Banks JE, Gagic V (2016) Aphid parasitoids respond to vegetation heterogeneity but not to fragmentation scale: an experimental field study Basic and Applied Ecology 17:438-446 doi:10.1016/j.baae.2016.01.007
- Barari H, Cook SM, Clark SJ, Williams IH (2005) Effect of a turnip rape (*Brassica rapa*) trap crop on stem-mining pests and their parasitoids in winter oilseed rape (*Brassica napus*) Biocontrol 50:69-86 doi:10.1007/s10526-004-0895-0
- Bartomeus I, Gagic V, Bommarco R (sous presse) Pollinators, pests and soil properties interactively shape oilseed rape yield. doi:10.1101/010181
- Bartomeus I, Gravel D, Tylianakis JM, Aizen MA, Dickie IA, Bernard-Verdier M (2016) A common framework for identifying linkage rules across different types of interactions Funct Ecol 30:1894-1903 doi:10.1111/1365-2435.12666
- Beach JP, Williams L, Hendrix DL, Price LD (2003) Different food sources affect the gustatory response of *Anaphes iole*, an egg parasitoid of *Lygus* spp J Chem Ecol 29:1203-1222 doi:10.1023/a:1023837808291
- Begg GS et al. (2017) A functional overview of conservation biological control Crop Prot 97:145-158 doi:<http://dx.doi.org/10.1016/j.cropro.2016.11.008>
- Begum M, Gurr GM, Wratten SD, Nicol HI (2004) Flower color affects tri-trophic-level biocontrol interactions Biol Control 30:584-590 doi:10.1016/j.biocontrol.2004.03.005
- Bell JR, King RA, Bohan DA, Symondson WOC (2010) Spatial co-occurrence networks predict the feeding histories of polyphagous arthropod predators at field scales Ecography 33:64-72 doi:10.1111/j.1600-0587.2009.06046.x
- Belz E, Kölliker M, Balmer O (2013) Olfactory attractiveness of flowering plants to the parasitoid *Microplitis mediator*: potential implications for biological control Biocontrol 58:163-173 doi:10.1007/s10526-012-9472-0
- Berger J, Jönsson M, Hedlund K, Anderson P (2015) Niche separation of pollen beetle parasitoids Frontiers in Ecology and Evolution 3 doi:10.3389/fevo.2015.00045
- Bertolaccini I, Núñez-Pérez E, Tizado EJ (2008) Effect of wild flowers on oviposition of *Hippodamia variegata* (Coleoptera: Coccinellidae) in the laboratory J Econ Entomol 101:1792-1797 doi:10.1603/0022-0493-101.6.1792
- Bianchi F, Wackers FL (2008) Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids Biol Control 46:400-408 doi:10.1016/j.biocontrol.2008.04.010

- Bilá K, Moretti M, de Bello F, Dias ATC, Pezzatti GB, Van Oosten AR, Berg MP (2014) Disentangling community functional components in a litter-macrodetrivore model system reveals the predominance of the mass ratio hypothesis *Ecology and Evolution* 4:408-416
- Birkhofer K, Diekötter T, Meub C, Stotzel K, Wolters V (2015) Optimizing arthropod predator conservation in permanent grasslands by considering diversity components beyond species richness *Agr Ecosyst Environ* 211:65-72 doi:10.1016/j.agee.2015.05.014
- Birkhofer K, Gavish-Regev E, Endlweber K, Lubin YD, von Berg K, Wise DH, Scheu S (2008a) Cursorial spiders retard initial aphid population growth at low densities in winter wheat *Bull Entomol Res* 98:249-255 doi:10.1017/s0007485308006019
- Birkhofer K et al. (2017) Land-use type and intensity differentially filter traits in above- and below-ground arthropod communities *J Anim Ecol* 86:511-520 doi:10.1111/1365-2656.12641
- Birkhofer K, Wise DH, Scheu S (2008b) Subsidy from the detrital food web, but not microhabitat complexity, affects the role of generalist predators in an aboveground herbivore food web *Oikos* 117:494-500 doi:10.1111/j.0030-1299.2008.16361.x
- Bischoff A et al. (2016) Effects of spontaneous field margin vegetation and surrounding landscape on *Brassica oleracea* crop herbivory *Agr Ecosyst Environ* 223:135-143 doi:<http://dx.doi.org/10.1016/j.agee.2016.02.029>
- Bitsch J, Leclercq J (1993) Hyménoptères Sphecidae d'Europe Occidentale, volume I. Faune de France 79. Fédération Française des Sociétés de Sciences Naturelles, Paris, France,
- Björkman M, Hambäck PA, Hopkins RJ, Rämert B (2010) Evaluating the enemies hypothesis in a clover-cabbage intercrop: effects of generalist and specialist natural enemies on the turnip root fly (*Delia floralis*) *Agric For Entomol* 12:123-132 doi:10.1111/j.1461-9563.2009.00452.x
- Blaauw BR, Isaacs R (2014a) Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop *J Appl Ecol* sous presse:n/a-n/a doi:10.1111/1365-2664.12257
- Blaauw BR, Isaacs R (2014b) Larger wildflower plantings increase natural enemy density, diversity, and biological control of sentinel prey, without increasing herbivore density *Ecol Entomol* 37:386-394 doi:10.1111/j.1365-2311.2012.01376.x
- Blitzer EJ, Dormann CF, Holzschuh A, Klein AM, Rand TA, Tscharnkte T (2012) Spillover of functionally important organisms between managed and natural habitats *Agr Ecosyst Environ* 146:34-43 doi:10.1016/j.agee.2011.09.005
- Bohan DA et al. (2013) Networking agroecology: integrating the diversity of agroecosystem interactions. In: *Ecological Networks in an Agricultural World*, vol 49. *Advances in Ecological Research*. Elsevier Academic Press Inc, San Diego, pp 1-67. doi:10.1016/b978-0-12-420002-9.00001-9
- Botías C, David A, Horwood J, Abdul-Sada A, Nicholls E, Hill E, Goulson D (2015) Neonicotinoid residues in wildflowers, a potential route of chronic exposure for bees *Environ Sci Technol* 49:12731-12740 doi:10.1021/acs.est.5b03459
- Boukal DS (2014) Trait- and size-based descriptions of trophic links in freshwater food webs: current status and perspectives *J Limnol* 73:171-185 doi:10.4081/jlimnol.2014.826
- Brittain C, Bommarco R, Vighi M, Settele J, Potts SG (2010) Organic farming in isolated landscapes does not benefit flower-visiting insects and pollination *Biol Conserv* 143:1860-1867 doi:10.1016/j.biocon.2010.04.029
- Brooks DR, Storkey J, Clark SJ, Firbank LG, Petit S, Woiwod IP (2012) Trophic links between functional groups of arable plants and beetles are stable at a national scale *J Anim Ecol* 81:4-13 doi:10.1111/j.1365-2656.2011.01897.x
- Brose U (2003) Bottom-up control of carabid beetle communities in early successional wetlands: mediated by vegetation structure or plant diversity? *Oecologia* 135:407-413 doi:10.1007/s00442-003-1222-7
- Brousseau P-M, Gravel D, Handa IT Trait matching and phylogeny as predictors of predator-prey interactions involving ground beetles *Funct Ecol*:n/a-n/a doi:10.1111/1365-2435.12943
- Bruno JF, Cardinale BJ (2008) Cascading effects of predator richness *Front Ecol Environ* 6:539-546 doi:10.1890/070136
- Bucher R, Menzel F, Entling MH (2015) Risk of spider predation alters food web structure and reduces local herbivory in the field *Oecologia* 178:571-577 doi:10.1007/s00442-015-3226-5
- Büchs W, Nuss H (2000) First steps to assess the importance of epigeic active polyphagous predators on oilseed rape insect pests with soil pupating larvae. Paper presented at the Bulletin OILB/SROP, Prague, Czech Republic,
- Bukovinszky T, van Veen FJF, Jongema Y, Dicke M (2008) Direct and indirect effects of resource quality on food web structure *Science* 319:804-807 doi:10.1126/science.1148310
- Bürki H-M, Hausamann A (1992) Überwinterung von Arthropoden im Boden und an Ackerkräutern künstlich angelegter Ackerkrautstreifen *Agrarökologie* 7:1-158
- Button L, Elle E (2014) Wild bumble bees reduce pollination deficits in a crop mostly visited by managed honey bees *Agr Ecosyst Environ* 197:255-263 doi:10.1016/j.agee.2014.08.004

- Byrnes JE, Stachowicz JJ (2009) The consequences of consumer diversity loss: different answers from different experimental designs *Ecology* 90:2879-2888 doi:10.1890/08-1073.1
- Caballero-Lopez B et al. (2012) Weeds, aphids, and specialist parasitoids and predators benefit differently from organic and conventional cropping of winter cereals *J Pest Sci* 85:81-88 doi:10.1007/s10340-011-0409-7
- Cadotte MW, Cardinale BJ, Oakley TH (2008) Evolutionary history and the effect of biodiversity on plant productivity *Proc Natl Acad Sci U S A* 105:17012-17017 doi:10.1073/pnas.0805962105
- Campbell AJ, Biesmeijer JC, Varma V, Wäckers FL (2012) Realising multiple ecosystem services based on the response of three beneficial insect groups to floral traits and trait diversity *Basic and Applied Ecology* 13:363-370 doi:10.1016/j.baae.2012.04.003
- Cardinale BJ, Weis JJ, Forbes AE, Tilmon KJ, Ives AR (2006) Biodiversity as both a cause and consequence of resource availability: a study of reciprocal causality in a predator-prey system *J Anim Ecol* 75:497-505 doi:10.1111/j.1365-2656.2006.01070.x
- Carmona CP, de Bello F, Mason NWH, Leps J (2016) Traits without borders: integrating functional diversity across scales *Trends in Ecology & Evolution* 31:382-394 doi:10.1016/j.tree.2016.02.003
- Carmona D, Lajeunesse MJ, Johnson MTJ (2011) Plant traits that predict resistance to herbivores *Funct Ecol* 25:358-367 doi:10.1111/j.1365-2435.2010.01794.x
- Caro G, Marrec R, Gauffre B, Roncoroni M, Augiron S, Bretagnolle V (2016) Multi-scale effects of agri-environment schemes on carabid beetles in intensive farmland *Agr Ecosyst Environ* 229:48-56 doi:10.1016/j.agee.2016.05.009
- Carreck NL, Williams IH (1997) Observations on two commercial flower mixtures as food sources for beneficial insects in the UK *J Agr Sci* 128:397-403 doi:10.1017/s0021859697004279
- Carrié RJG, George DR, Wäckers FL (2012) Selection of floral resources to optimise conservation of agriculturally-functional insect groups *J Insect Conserv* 16:635-640 doi:10.1007/s10841-012-9508-x
- Carval D, Resmond R, Achard R, Tixier P (2016) Cover cropping reduces the abundance of the banana weevil *Cosmopolites sordidus* but does not reduce its damage to the banana plants *Biol Control* 99:14-18 doi:10.1016/j.biocontrol.2016.04.004
- Carvalho LG et al. (2014) The potential for indirect effects between co-flowering plants via shared pollinators depends on resource abundance, accessibility and relatedness *Ecology Letters* 17:1389-1399 doi:10.1111/ele.12342
- Carvell C, Westrich P, Meek WR, Pywell RF, Nowakowski M (2006) Assessing the value of annual and perennial forage mixtures for bumblebees by direct observation and pollen analysis *Apidologie* 37:326-340 doi:10.1051/apido:2006002
- Chailleux A, Mohl E, Teixeira Alves M, Messelink G, Desneux N (2014) Natural enemy-mediated indirect interactions among prey species: potential for enhancing biocontrol services in agroecosystems *Pest Manage Sci* 70:1769-1779 doi:10.1002/ps.3916
- Chamberlain SA, Kilpatrick JR, Holland JN (2010) Do extrafloral nectar resources, species abundances, and body sizes contribute to the structure of ant-plant mutualistic networks? *Oecologia* 164:741-750 doi:10.1007/s00442-010-1673-6
- Chang GC, Snyder WE (2004) The relationship between predator density, community composition, and field predation of Colorado potato beetle eggs *Biol Control* 31:453-461 doi:<http://dx.doi.org/10.1016/j.biocontrol.2004.07.009>
- Chaplin-Kramer R, Kremen C (2012) Pest control experiments show benefits of complexity at landscape and local scales *Ecological Applications* 22:1936-1948
- Chen XQ, Chen YC, Wu LB, Peng Y, Chen JA, Liu FX (2010) A survey of nectar feeding by spiders in three different habitats *Bull Insectol* 63:203-208
- Cocco N, Glendinning JI (2012) Not all sugars are created equal: some mask aversive tastes better than others in an herbivorous insect *J Exp Biol* 215:1412-1421 doi:10.1242/jeb.059832
- Cole LJ et al. (2002) Relationships between agricultural management and ecological groups of ground beetles (Coleoptera : Carabidae) on Scottish farmland *Agr Ecosyst Environ* 93:323-336 doi:10.1016/s0167-8809(01)00333-4
- Coleman D, Fu SL, Hendrix P, Crossley D (2002) Soil foodwebs in agroecosystems: impacts of herbivory and tillage management *European Journal of Soil Biology* 38:21-28 doi:10.1016/s1164-5563(01)01118-9
- Coll M, Guershon M (2002) Omnivory in terrestrial arthropods: Mixing plant and prey diets *Annu Rev Entomol* 47:267-297 doi:10.1146/annurev.ento.47.091201.145209
- Collins KL, Boatman ND, Wilcox A, Holland JM, Chaney K (2002) Influence of beetle banks on cereal, aphid predation in winter wheat *Agr Ecosyst Environ* 93:337-350 doi:10.1016/s0167-8809(01)00340-1
- Cook SM, Smart LE, Martin JL, Murray DA, Watts NP, Williams IH (2006) Exploitation of host plant preferences in pest management strategies for oilseed rape (*Brassica napus*) *Entomol Exp Appl* 119:221-229 doi:10.1111/j.1570-7458.2006.00419.x
- Corbett A, Rosenheim JA (1996) Quantifying movement of a minute parasitoid, *Anagrus epos* (Hymenoptera:

- Mymaridae), using fluorescent dust marking and recapture *Biol Control* 6:35-44 doi:10.1006/bcon.1996.0005
- Corcket E, Giffard B, Sforza RFH (2017) Food Webs and Multiple Biotic Interactions in Plant-Herbivore Models. In: Sauvion N, Thiery D, Calatayud PA (eds) *Insect-Plant Interactions in a Crop Protection Perspective*, vol 81. *Advances in Botanical Research*. pp 111-137. doi:10.1016/bs.abr.2016.10.002
- Costanzo A, Barberi P (2014) Functional agrobiodiversity and agroecosystem services in sustainable wheat production. *A review Agronomy for Sustainable Development* 34:327-348 doi:10.1007/s13593-013-0178-1
- Coudrain V et al. (2016) Temporal differentiation of soil communities in response to arable crop management strategies *Agr Ecosyst Environ* 225:12-21 doi:10.1016/j.agee.2016.03.029
- Coux C, Rader R, Bartomeus I, Tylianakis JM (2016) Linking species functional roles to their network roles *Ecology Letters* 19:762-770 doi:10.1111/ele.12612
- Crea C, Ali RA, Rader R (2016) A new model for ecological networks using species-level traits *Methods in Ecology and Evolution* 7:232-241 doi:10.1111/2041-210x.12471
- Cronin JP, Tonsor SJ, Carson WP (2010) A simultaneous test of trophic interaction models: which vegetation characteristic explains herbivore control over plant community mass? *Ecology Letters* 13:202-212 doi:10.1111/j.1461-0248.2009.01420.x
- Cronin JT, Reeve JD (2005) Host-parasitoid spatial ecology: a plea for a landscape-level synthesis *Proceedings of the Royal Society B-Biological Sciences* 272:2225-2235 doi:10.1098/rspb.2005.3286
- Crowder DW, Jabbour R (2014) Relationships between biodiversity and biological control in agroecosystems: Current status and future challenges *Biol Control* 75:8-17 doi:10.1016/j.biocontrol.2013.10.010
- Crowder DW, Northfield TD, Strand MR, Snyder WE (2010) Organic agriculture promotes evenness and natural pest control *Nature* 466:109-U123 doi:10.1038/nature09183
- Dainese M, Riedinger V, Holzschuh A, Kleijn D, Scheper J, Steffan-Dewenter I Managing trap-nesting bees as crop pollinators: Spatiotemporal effects of floral resources and antagonists *J Appl Ecol*:n/a-n/a doi:10.1111/1365-2664.12930
- Dainese M, Schneider G, Krauss J, Steffan-Dewenter I (2017) Complementarity among natural enemies enhances pest suppression *Scientific Reports* 7:8 doi:10.1038/s41598-017-08316-z
- Damien M, Le Lann C, Desneux N, Alford L, Al Hassan D, Georges R, Van Baaren J (2017) Flowering cover crops in winter increase pest control but not trophic link diversity *Agr Ecosyst Environ* 247:418-425 doi:<https://doi.org/10.1016/j.agee.2017.07.015>
- Damour G, Navas ML, Garnier É (2017) A revised trait-based framework for agroecosystems including decision rules *J Appl Ecol* sous presse:n/a-n/a doi:10.1111/1365-2664.12986
- Dassou AG, Tixier P (2016) Response of pest control by generalist predators to local-scale plant diversity: a meta-analysis *Ecology and Evolution* 6:1143-1153 doi:10.1002/ece3.1917
- Davey JS et al. (2013) Intraguild predation in winter wheat: prey choice by a common epigeal carabid consuming spiders *J Appl Ecol* 50:271-279 doi:10.1111/1365-2664.12008
- Day RL, Hickman JM, Sprague RI, Wratten SD (2015) Predatory hoverflies increase oviposition in response to colour stimuli offering no reward: Implications for biological control *Basic and Applied Ecology* 16:544-552 doi:10.1016/j.baae.2015.05.004
- de Rijk M, Wang QJ, Papagiannaki E, Dicke M, Poelman EH (2016) Herbivore species identity rather than diversity of the non-host community determines foraging behaviour of the parasitoid wasp *Cotesia glomerata* *Entomol Exp Appl* 161:20-30 doi:10.1111/eea.12493
- Delettre YR, Morvan N, Tréhen P, Grootaert P (1998) Local biodiversity and multi-habitat use in empidoïd flies (Insecta: Diptera, Empidoidea) *Biodivers Conserv* 7:9-25
- Denoth M, Frid L, Myers JH (2002) Multiple agents in biological control: improving the odds? *Biol Control* 24:20-30 doi:10.1016/s1049-9644(02)00002-6
- Denys C, Tscharrntke T (2002) Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows *Ecologia* 130:315-324 doi:10.1007/s004420100796
- Deraison H, Badenhauer I, Loeuille N, Scherber C, Gross N (2015) Functional trait diversity across trophic levels determines herbivore impact on plant community biomass *Ecology Letters* 18:1346-1355 doi:10.1111/ele.12529
- DeWitt TJ, Langerhans RB (2003) Multiple prey traits, multiple predators: keys to understanding complex community dynamics *J Sea Res* 49:143-155 doi:10.1016/s1385-1101(02)00220-4
- Dias ATC, Berg MP, de Bello F, Van Oosten AR, Bilá K, Moretti M (2013) An experimental framework to identify community functional components driving ecosystem processes and services delivery *J Ecol* 101:29-37 doi:10.1111/1365-2745.12024
- Dib H, Libourel G, Warlop F (2012) Entomological and functional role of floral strips in an organic apple orchard: Hymenopteran parasitoids as a case study *J Insect Conserv* 16:315-318 doi:10.1007/s10841-012-9471-6
- Diehl E, Mader VL, Wolters V, Birkhofer K (2013a) Management intensity and vegetation complexity affect web-building spiders and their prey *Oecologia* 173:579-589 doi:10.1007/s00442-013-2634-7

- Diehl E, Sereda E, Wolters V, Birkhofer K (2013b) Effects of predator specialization, host plant and climate on biological control of aphids by natural enemies: a meta-analysis *J Appl Ecol* 50:262-270 doi:10.1111/1365-2664.12032
- Diehl E, Wolters V, Birkhofer K (2012) Arable weeds in organically managed wheat fields foster carabid beetles by resource- and structure-mediated effects *Arthropod-Plant Interactions* 6:75-82 doi:10.1007/s11829-011-9153-4
- Ditner N, Balmer O, Beck J, Blick T, Nagel P, Luka H (2013) Effects of experimentally planting non-crop flowers into cabbage fields on the abundance and diversity of predators *Biodivers Conserv* 22:1049-1061 doi:10.1007/s10531-013-0469-5
- Douglas MR, Rohr JR, Tooker JF (2015) Neonicotinoid insecticide travels through a soil food chain, disrupting biological control of non-target pests and decreasing soya bean yield *J Appl Ecol*:n/a-n/a doi:10.1111/1365-2664.12372
- Drieu R, Rusch A (2017) Conserving species-rich predator assemblages strengthens natural pest control in a climate warming context *Agric For Entomol* 19:52-59 doi:10.1111/afe.12180
- Du YJ, Poppy GM, Powell W (1996) Relative importance of semiochemicals from first and second trophic levels in host foraging behavior of *Aphidius ervi* *J Chem Ecol* 22:1591-1605 doi:10.1007/bf02272400
- Duffield SJ, Jepson PC, Wratten SD, Sotherton NW (1996) Spatial changes in invertebrate predation rate in winter wheat following treatment with dimethoate *Entomol Exp Appl* 78:9-17
- Duyck PF, Lavigne A, Vinatier F, Achard R, Okolle JN, Tixier P (2011) Addition of a new resource in agroecosystems: do cover crops alter the trophic positions of generalist predators? *Basic and Applied Ecology* 12:47-55 doi:10.1016/j.baae.2010.11.009
- Ernault A, Vialatte A, Butet A, Michel N, Rantier Y, Jambon O, Burel F (2013) Grassy strips in their landscape context, their role as new habitat for biodiversity *Agr Ecosyst Environ* 166:15-27 doi:10.1016/j.agee.2012.07.004
- Eubanks MD, Finke DL (2014) Interaction webs in agroecosystems: beyond who eats whom *Current Opinion in Insect Science* 2:1-6 doi:10.1016/j.cois.2014.06.005
- Evans DM et al. (2015) The cascading impacts of livestock grazing in upland ecosystems: a 10-year experiment *Ecosphere* 6 doi:10.1890/es14-00316.1
- Evans EW (2016) Biodiversity, ecosystem functioning, and classical biological control *Appl Entomol Zool* 51:173-184 doi:10.1007/s13355-016-0401-z
- Fahey JW, Zalcmann AT, Talalay P (2001) The chemical diversity and distribution of glucosinolates and isothiocyanates among plants *Phytochemistry* 56:5-51 doi:10.1016/s0031-9422(00)00316-2
- Feltham H, Park K, Minderman J, Goulson D (2015) Experimental evidence that wildflower strips increase pollinator visits to crops *Ecology and Evolution* 5:3523-3530 doi:10.1002/ece3.1444
- Feng Y, Kravchuk O, Sandhu H, Wratten SD, Keller MA (2017) The activities of generalist parasitoids can be segregated between crop and adjacent non-crop habitats *J Pest Sci* 90:275-286 doi:10.1007/s10340-016-0775-2
- Ferguson AW, Barari H, Warner DJ, Campbell JM, Smith ET, Watts NP, Williams IH (2006) Distributions and interactions of the stem miners *Psylliodes chrysocephala* and *Ceutorhynchus pallidactylus* and their parasitoids in a crop of winter oilseed rape (*Brassica napus*) *Entomol Exp Appl* 119:81-92 doi:10.1111/j.1570-7458.2006.00404.x
- Ferguson AW, Klukowski Z, Walczak B, Clark SJ, Muggleston MA, Perry JN, Williams IH (2003) Spatial distribution of pest insects in oilseed rape: implications for integrated pest management *Agr Ecosyst Environ* 95:509-521 doi:10.1016/s0167-8809(02)00200-1
- Fiedler AK, Landis DA (2007) Plant characteristics associated with natural enemy abundance at Michigan native plants *Environ Entomol* 36:878-886 doi:10.1603/0046-225x(2007)36[878:pcawne]2.0.co;2
- Finke DL, Denno RF (2006) Spatial refuge from intraguild predation: implications for prey suppression and trophic cascades *Oecologia* 149:265-275 doi:10.1007/s00442-006-0443-y
- Finke DL, Snyder WE (2010) Conserving the benefits of predator biodiversity *Biol Conserv* 143:2260-2269 doi:10.1016/j.biocon.2010.03.022
- Fischbein D, Jofré N, Corley JC (2016) A comparative analysis of host feeding and life-history traits in parasitoid wasps *Entomol Exp Appl* 159:172-180 doi:10.1111/eea.12422
- Frank SD, Wratten SD, Sandhu HS, Shrewsbury PM (2007) Video analysis to determine how habitat strata affects predator diversity and predation of *Epiphyas postvittana* (Lepidoptera : Tortricidae) in a vineyard *Biol Control* 41:230-236 doi:10.1016/j.biocontrol.2007.01.012
- Frank T (1998) Slug damage and numbers of the slug pests, *Arion lusitanicus* and *Deroceras reticulatum*, in oilseed rape grown beside sown wildflower strips *Agr Ecosyst Environ* 67:67-78 doi:10.1016/s0167-8809(97)00108-4
- Freeman Long R, Corbett Z, Lamb C, Reberg-Horton C, Chandler J, Stimmann M (1998) Beneficial insects move from flowering plants to nearby crops *Calif Agric* 52:23-26

- Frei G, Manhart C (1992) Nützlinge und Schädlinge an künstlich angelegten Ackerkrautstreifen in Getreidefeldern. Agrarökologie, bd.4.
- Freier B, Triltsch H, Möwes M, Moll E (2007) The potential of predators in natural control of aphids in wheat: results of a ten-year field study in two German landscapes *Biocontrol* 52:775-788 doi:10.1007/s10526-007-9081-5
- Frenette-Dussault C, Shipley B, Hingrat Y (2013) Linking plant and insect traits to understand multitrophic community structure in arid steppes *Funct Ecol* 27:786-792 doi:10.1111/1365-2435.12075
- Furlong MJ, Zalucki MP (2010) Exploiting predators for pest management: the need for sound ecological assessment *Entomol Exp Appl* 135:225-236 doi:10.1111/j.1570-7458.2010.00988.x
- Fusser MS, Pfister SC, Entling MH, Schirmel J (2017) Effects of field margin type and landscape composition on predatory carabids and slugs in wheat fields *Agr Ecosyst Environ* 247:182-188 doi:<http://dx.doi.org/10.1016/j.agee.2017.06.030>
- Gagic V et al. (2015) Functional identity and diversity of animals predict ecosystem functioning better than species-based indices *Proc R Soc B* 282:sous presse doi:10.1098/rspb.2014.2620
- Gagic V, Hänke S, Thies C, Scherber C, Tomanović Ž, Tscharntke T (2012) Agricultural intensification and cereal aphid-parasitoid-hyperparasitoid food webs: network complexity, temporal variability and parasitism rates *Ecologia* 170:1099-1109 doi:10.1007/s00442-012-2366-0
- Gagic V, Petrovic-Obradovic O, Frund J, Kavallieratos NG, Athanassiou CG, Stary P, Tomanovic Z (2016a) The Effects of Aphid Traits on Parasitoid Host Use and Specialist Advantage *Plos One* 11 doi:10.1371/journal.pone.0157674
- Gagic V, Riggi LGA, Ekbom B, Malsher G, Rusch A, Bommarco R (2016b) Interactive effects of pests increase seed yield *Ecology and Evolution* 6:2149-2157 doi:10.1002/ece3.2003
- Gagic V, Tscharntke T, Dormann CF, Gruber B, Wilstermann A, Thies C (2011) Food web structure and biocontrol in a four-trophic level system across a landscape complexity gradient *Proceedings of the Royal Society B-Biological Sciences* 278:2946-2953 doi:10.1098/rspb.2010.2645
- Gaines HR, Gratton C (2010) Seed predation increases with ground beetle diversity in a Wisconsin (USA) potato agroecosystem *Agr Ecosyst Environ* 137:329-336 doi:10.1016/j.agee.2010.03.003
- Gamfeldt L, Roger F (2017) Revisiting the biodiversity–ecosystem multifunctionality relationship *Nature Ecology & Evolution* 1:s41559-41017 doi:10.1038/s41559-017-0168
- Garibaldi LA et al. (2015) Trait matching of flower visitors and crops predicts fruit set better than trait diversity *J Appl Ecol* 52:1436-1444 doi:10.1111/1365-2664.12530
- Garnier É, Navas M-L, Grigulis K (2016) Plant functional diversity. Oxford University Press, United Kingdom,
- Garratt MPD, Senapathi D, Coston DJ, Mortimer SR, Potts SG (2017) The benefits of hedgerows for pollinators and natural enemies depends on hedge quality and landscape context *Agr Ecosyst Environ* 247:363-370 doi:10.1016/j.agee.2017.06.048
- Geiger F, Wäckers F, Bianchi F (2009) Hibernation of predatory arthropods in semi-natural habitats *Biocontrol* 54:529-535 doi:10.1007/s10526-008-9206-5
- Géneau CE, Wäckers FL, Luka H, Daniel C, Balmer O (2012) Selective flowers to enhance biological control of cabbage pests by parasitoids *Basic and Applied Ecology* 13:85-93 doi:10.1016/j.baae.2011.10.005
- Gilabert A et al. (2017) Influence of the surrounding landscape on the colonization rate of cereal aphids and phyto virus transmission in autumn *J Pest Sci* 90:447-457 doi:10.1007/s10340-016-0790-3
- Gillespie M, Wratten S, Sedcole R, Colfer R (2011) Manipulating floral resources dispersion for hoverflies (*Diptera: Syrphidae*) in a California lettuce agro-ecosystem *Biol Control* 59:215-220 doi:10.1016/j.biocontrol.2011.07.010
- Gillespie MAK, Gurr GM, Wratten SD (2016) Beyond nectar provision: the other resource requirements of parasitoid biological control agents *Entomol Exp Appl* 159:207-221 doi:10.1111/eea.12424
- Gontijo LM, Beers EH, Snyder WE (2015) Complementary suppression of aphids by predators and parasitoids *Biol Control* 90:83-91 doi:10.1016/j.biocontrol.2015.06.002
- Gonzalez E, Salvo A, Valladares G (2015) Sharing enemies: evidence of forest contribution to natural enemy communities in crops, at different spatial scales *Insect Conservation and Diversity* 8:359-366 doi:10.1111/icad.12117
- Grass I, Albrecht J, Jauner F, Diekötter T, Warzecha D, Wolters V, Farwig N (2016) Much more than bees – Wildflower plantings support highly diverse flower-visitor communities from complex to structurally simple agricultural landscapes *Agr Ecosyst Environ* 225:45-53 doi:10.1016/j.agee.2016.04.001
- Grass I, Lehmann K, Thies C, Tscharntke T (2017) Insectivorous birds disrupt biological control of cereal aphids *Ecology*:n/a-n/a doi:10.1002/ecy.1814
- Gravel D, Albouy C, Thuiller W (2016) The meaning of functional trait composition of food webs for ecosystem functioning *Philosophical Transactions of the Royal Society B-Biological Sciences* 371 doi:10.1098/rstb.2015.0268
- Gravel D, Poisot T, Albouy C, Velez L, Mouillot D (2013) Inferring food web structure from predator-prey body

- size relationships *Methods in Ecology and Evolution* 4:1083-1090 doi:10.1111/2041-210x.12103
- Griffiths GJK, Holland JM, Bailey A, Thomas MB (2008) Efficacy and economics of shelter habitats for conservation biological control *Biol Control* 45:200-209 doi:10.1016/j.biocontrol.2007.09.002
- Griffiths GJK, Winder L, Holland JM, Thomas CFG, Williams E (2007) The representation and functional composition of carabid and staphylinid beetles in different field boundary types at a farm-scale *Biol Conserv* 135:145-152 doi:10.1016/j.biocon.2006.09.016
- Grime JP (1998) Benefits of plant diversity to ecosystems: immediate, filter and founder effects *J Ecol* 86:902-910
- Guerrieri E, Poppy GM, Powell W, Rao R, Pennacchio F (2002) Plant-to-plant communication mediating in-flight orientation of *Aphidius ervi* *J Chem Ecol* 28:1703-1715 doi:10.1023/a:1020553531658
- Gunton RM (2011) Integrating associational resistance into arable weed management *Agr Ecosyst Environ* 142:129-136 doi:10.1016/j.agee.2011.05.022
- Gurr GM et al. (2016) Multi-country evidence that crop diversification promotes ecological intensification of agriculture *Nature Plants* 2:1:3
- Gurr GM, Wratten SD, Landis DA, You MS (2017) Habitat management to suppress pest populations: progress and prospects. In: Berenbaum MR (ed) *Annual Review of Entomology*, Vol 62, vol 62. *Annual Review of Entomology*. Annual Reviews, Palo Alto, pp 91-109. doi:10.1146/annurev-ento-031616-035050
- Haaland C, Naisbit RE, Bersier LF (2011) Sown wildflower strips for insect conservation: a review *Insect Conservation and Diversity* 4:60-80 doi:10.1111/j.1752-4598.2010.00098.x
- Haenke S, Scheid B, Schaefer M, Tschardt T, Thies C (2009) Increasing syrphid fly diversity and density in sown flower strips within simple vs. complex landscapes *J Appl Ecol* 46:1106-1114 doi:10.1111/j.1365-2664.2009.01685.x
- Hallem EA, Dahanukar A, Carlson JR (2006) Insect odor and taste receptors. In: *Annual Review of Entomology*, vol 51. *Annual Review of Entomology*. Annual Reviews, Palo Alto, pp 113-135. doi:10.1146/annurev.ento.51.051705.113646
- Hallett RH, Bahlai CA, Xue YG, Schaafsma AW (2014) Incorporating natural enemy units into a dynamic action threshold for the soybean aphid, *Aphis glycines* (Homoptera: Aphididae) *Pest Manage Sci* 70:879-888 doi:10.1002/ps.3674
- Hamon N, Bardner R, Allenwilliams L, Lee JB (1990) Carabid populations in field beans and their effect on the population-dynamics of *Sitona lineatus* (L.) *Ann Appl Biol* 117:51-62 doi:10.1111/j.1744-7348.1990.tb04194.x
- Hansen JP, Sagerman J, Wikstrom SA (2010) Effects of plant morphology on small-scale distribution of invertebrates *Mar Biol* 157:2143-2155 doi:10.1007/s00227-010-1479-4
- Hanson HI, Palmu E, Birkhofer K, Smith HG, Hedlund K (2016) Agricultural land use determines the trait composition of ground beetle communities *Plos One* 11:13 doi:10.1371/journal.pone.0146329
- Hanson HI, Smith HG, Hedlund K (2015) Agricultural management reduces emergence of pollen beetle parasitoids *Agr Ecosyst Environ* 205:9-14 doi:10.1016/j.agee.2015.03.001
- Harmon JP, Ives AR, Losey JE, Olson AC, Rauwald KS (2000) *Colemegilla maculata* (Coleoptera : Coccinellidae) predation on pea aphids promoted by proximity to dandelions *Oecologia* 125:543-548 doi:10.1007/s004420000476
- Harvey JA, Gols R (2011) Population-related variation in plant defense more strongly affects survival of an herbivore than its solitary parasitoid wasp *J Chem Ecol* 37:1081-1090 doi:10.1007/s10886-011-0024-3
- Harvey JA, Snaas H, Malcicka M, Visser B, Bezemer TM (2014) Small-scale spatial resource partitioning in a hyperparasitoid community *Arthropod-Plant Interactions* 8:393-401 doi:10.1007/s11829-014-9319-y
- Harvey JA, van der Putten WH, Turin H, Wagenaar R, Bezemer TM (2008) Effects of changes in plant species richness and community traits on carabid assemblages and feeding guilds *Agr Ecosyst Environ* 127:100-106 doi:10.1016/j.agee.2008.03.006
- Harwood JD et al. (2009) Invertebrate biodiversity affects predator fitness and hence potential to control pests in crops *Biol Control* 51:499-506 doi:10.1016/j.biocontrol.2009.09.007
- Harwood JD, Sunderland KD, Symondson WOC (2005) Monoclonal antibodies reveal the potential of the tetragnathid spider *Pachygnatha degeeri* (Araneae : Tetragnathidae) as an aphid predator *Bull Entomol Res* 95:161-167
- Hatt S et al. (2017) Do flower mixtures with high functional diversity enhance aphid predators in wildflower strips? *Eur J Entomol* 114:66-76 doi:10.14411/eje.2017.010
- Hatt S et al. (2015) Do wildflower strips favor insect pest populations at field margins? *Agriculture and agricultural science procedia* 6:30-37
- Hausamann A (1996a) The effects of weed strip-management on pests and beneficial arthropods in winter wheat fields *Z Pflanzenk Pflanzens-J Plant Dis Prot* 103:70-81
- Hausamann A (1996b) Strip-management in rape crop: is winter rape endangered by negative impacts of sown weed strips? *J Appl Entomol* 120:505-512
- Hawlena D, Hughes KM, Schmitz OJ (2011) Trophic trait plasticity in response to changes in resource availability

- and predation risk *Funct Ecol* 25:1223-1231 doi:10.1111/j.1365-2435.2011.01891.x
- Hector A et al. (1999) Plant diversity and productivity experiments in European grasslands *Science* 286:1123-1127 doi:10.1126/science.286.5442.1123
- Heil M (2008) Indirect defence via tritrophic interactions *New Phytol* 178:41-61 doi:10.1111/j.1469-8137.2007.02330.x
- Heimpel GE, Jervis MA (2005) Does floral nectar improve biological control by parasitoids? In: Wäckers F, van Rijn P, Bruin J (eds) *Plant-provided food and plant-carnivore mutualism*. Cambridge University Press, Cambridge, UK, pp 267-304
- Henry LM, Bannerman JA, Gillespie DR, Roitberg BD (2010) Predator identity and the nature and strength of food web interactions *J Anim Ecol* 79:1164-1171 doi:10.1111/j.1365-2656.2010.01723.x
- Herrault PA et al. (2016) Combined effects of area, connectivity, history and structural heterogeneity of woodlands on the species richness of hoverflies (Diptera: Syrphidae) *Landsc Ecol* 31:877-893 doi:10.1007/s10980-015-0304-3
- Hicks DM et al. (2016) Food for pollinators: quantifying the nectar and pollen resources of urban flower meadows *Plos One* 11:37 doi:10.1371/journal.pone.0158117
- Hillebrand H, Bennett DM, Cadotte MW (2008) Consequences of dominance: a review of evenness effects on local and regional ecosystem processes *Ecology* 89:1510-1520 doi:10.1890/07-1053.1
- Hof AR, Bright PW (2010) The impact of grassy field margins on macro-invertebrate abundance in adjacent arable fields *Agr Ecosyst Environ* 139:280-283 doi:10.1016/j.agee.2010.08.014
- Hogg BN, Bugg RL, Daane KM (2011) Attractiveness of common insectary and harvestable floral resources to beneficial insects *Biol Control* 56:76-84 doi:10.1016/j.biocontrol.2010.09.007
- Holland JM, Bianchi FJJA, Entling MH, Moonen A-C, Smith BM, Jeanneret P (2016) Structure, function and management of semi-natural habitats for conservation biological control: a review of European studies *Pest Manage Sci* 72:1638-1651 doi:10.1002/ps.4318
- Holland JM, Douma JC, Crowley L, James L, Kor L, Stevenson DRW, Smith BM (2017) Semi-natural habitats support biological control, pollination and soil conservation in Europe. A review *Agronomy for Sustainable Development* 37:23 doi:10.1007/s13593-017-0434-x
- Holland JM, Oaten H, Moreby S, Birkett T, Simper J, Southway S, Smith BM (2012) Agri-environment scheme enhancing ecosystem services: A demonstration of improved biological control in cereal crops *Agr Ecosyst Environ* 155:147-152 doi:10.1016/j.agee.2012.04.014
- Holland JM, Oaten H, Southway S, Moreby S (2008) The effectiveness of field margin enhancement for cereal aphid control by different natural enemy guilds *Biol Control* 47:71-76 doi:10.1016/j.biocontrol.2008.06.010
- Hooks CRR, Johnson MW (2003) Impact of agricultural diversification on the insect community of cruciferous crops *Crop Prot* 22:223-238 doi:10.1016/s0261-2194(02)00172-2
- Huang JH, Liu MQ, Chen FJ, Griffiths BS, Chen XY, Johnson SN, Hu F (2012) Crop resistance traits modify the effects of an aboveground herbivore, brown planthopper, on soil microbial biomass and nematode community via changes to plant performance *Soil Biology & Biochemistry* 49:157-166 doi:10.1016/j.soilbio.2012.02.022
- Ibanez S (2012) Optimizing size thresholds in a plant-pollinator interaction web: towards a mechanistic understanding of ecological networks *Oecologia* 170:233-242 doi:10.1007/s00442-012-2290-3
- Ibanez S, Lavorel S, Puijalon S, Moretti M (2013) Herbivory mediated by coupling between biomechanical traits of plants and grasshoppers *Funct Ecol* 27:479-489 doi:10.1111/1365-2435.12058
- Inclan DJ, Dainese M, Cerretti P, Paniccia D, Marini L (2016) Spillover of tachinids and hoverflies from different field margins *Basic and Applied Ecology* 17:33-42 doi:10.1016/j.baae.2015.08.005
- Isaacs R, Tuell J, Fiedler A, Gardiner M, Landis D (2009) Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants *Front Ecol Environ* 7:196-203 doi:10.1890/080035
- Isbell F et al. (2011) High plant diversity is needed to maintain ecosystem services *Nature* 477:199-U196 doi:10.1038/nature10282
- Iverson AL et al. (2014) Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis *J Appl Ecol* 51:1593-1602 doi:10.1111/1365-2664.12334
- Jamont M, Crépeillère S, Jaloux B (2013) Effect of extrafloral nectar provisioning on the performance of the adult parasitoid *Diaeretiella rapae* *Biol Control* 65:271-277 doi:10.1016/j.biocontrol.2013.01.010
- Jansen JP, Chavalle S (2014) A study to assess the parasitism of insect pests in winter oilseed rape in Belgium: preliminary results *IOBC/WPRS Bulletin* 104:53-59
- Jauker F, Bondarenko B, Becker HC, Steffan-Dewenter I (2012) Pollination efficiency of wild bees and hoverflies provided to oilseed rape *Agric For Entomol* 14:81-87 doi:10.1111/j.1461-9563.2011.00541.x
- Jervis MA, Lee JC, Heimpel GE (2004) Use of behavioural and life-history studies to understand the effects of habitat manipulation. In: Gurr GM, Wratten SD, Altieri MA (eds) *Ecological engineering for pest management*. CSIRO, Wallingford, UK, pp 65-100
- Jonsson M et al. (2014) Ecological production functions for biological control services in agricultural landscapes

- Methods in Ecology and Evolution 5:243-252 doi:10.1111/2041-210x.12149
- Jonsson M, Kaartinen R, Straub CS (2017) Relationships between natural enemy diversity and biological control Current Opinion in Insect Science 20:1-6 doi:10.1016/j.cois.2017.01.001
- Jonsson M et al. (2015) Experimental evidence that the effectiveness of conservation biological control depends on landscape complexity J Appl Ecol 52:1274-1282 doi:10.1111/1365-2664.12489
- Jonsson M, Wratten SD, Landis DA, Gurr GM (2008) Recent advances in conservation biological control of arthropods by arthropods Biol Control 45:172-175 doi:10.1016/j.biocontrol.2008.01.006
- Josso C, Le Ralec A, Raymond L, Saulais J, Baudry J, Poinot D, Cortesero AM (2014) Effects of field and landscape variables on crop colonization and biological control of the cabbage root fly *Delia radicum* Landsc Ecol 28:1697-1715 doi:10.1007/s10980-013-9928-3
- Junker RR, Blüthgen N, Brehm T, Binkenstein J, Paulus J, Schaefer HM, Stang M (2013) Specialization on traits as basis for the niche-breadth of flower visitors and as structuring mechanism of ecological networks Funct Ecol 27:329-341 doi:10.1111/1365-2435.12005
- Kagata H, Ohgushi T (2006) Bottom-up trophic cascades and material transfer in terrestrial food webs Ecological Research 21:26-34 doi:10.1007/s11284-005-0124-z
- Kaplan I, Thaler JS (2011) Do plant defenses enhance or diminish prey suppression by omnivorous Heteroptera? Biol Control 59:53-60 doi:10.1016/j.biocontrol.2010.12.005
- Kéfi S et al. (2012) More than a meal ... integrating non-feeding interactions into food webs Ecology Letters 15:291-300 doi:10.1111/j.1461-0248.2011.01732.x
- Kevan PG, Chittka L, Dyer AG (2001) Limits to the salience of ultraviolet: Lessons from colour vision in bees and birds J Exp Biol 204:2571-2580
- Khan ZR, Pickett JA, van den Berg J, Wadhams LJ, Woodcock CM (2000) Exploiting chemical ecology and species diversity: stem borer and striga control for maize and sorghum in Africa Pest Manage Sci 56:957-962 doi:10.1002/1526-4998(200011)56:11<957::aid-ps236>3.0.co;2-t
- Kienzle J, Foell M, Karrer E, Krismann A, Zebitz CPW (2014) Establishment of permanent weed strips with autochthonous nectar plants and their effect on the occurrence of aphid predators. Paper presented at the 16th International conference on organic fruit-growing, Stuttgart-Hohenheim, Germany
- King RA, Vaughan IP, Bell JR, Bohan DA, Symondson WOC (2010) Prey choice by carabid beetles feeding on an earthworm community analysed using species- and lineage-specific PCR primers Mol Ecol 19:1721-1732 doi:10.1111/j.1365-294X.2010.04602.x
- Kissling WD, Schleuning M (2015) Multispecies interactions across trophic levels at macroscales: retrospective and future directions Ecography 38:346-357 doi:10.1111/ecog.00819
- Kopta T, Pokluda R, Psota V (2012) Attractiveness of flowering plants for natural enemies Horticultural Science 39:89-96
- Kos M et al. (2014) Relative importance of plant-mediated bottom-up and top-down forces on herbivore abundance on *Brassica oleracea* Funct Ecol 25:1113-1124 doi:10.1111/j.1365-2435.2011.01871.x
- Kos M, Kabouw P, Noordam R, Hendriks K, Vet LEM, van Loon JJA, Dicke M (2011) Prey-mediated effects of glucosinolates on aphid predators Ecol Entomol 36:377-388 doi:10.1111/j.1365-2311.2011.01282.x
- Koss AM, Snyder WE (2005) Alternative prey disrupt biocontrol by a guild of generalist predators Biol Control 32:243-251 doi:10.1016/j.biocontrol.2004.10.002
- Kranz J (2002) Labor- und Freilanduntersuchungen zur Attraktivität unterschiedlicher Wild- und Nutzpflanzen auf die Adulten verschiedener polyphager Prädatoren. Hohen Landwirtschaftlichen Fakultät der Rheinischen Friedrich-Wilhelms-Universität zu Bonn, Germany
- Kromp B (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement Agr Ecosyst Environ 74:187-228 doi:10.1016/S0167-8809(99)00037-7
- Kühn I, Durka W, Klotz S (2004) BiolFlor - a new plant-trait database as a tool for plant invasion ecology Divers Distrib 10:363-365
- Labuschagne L, Swanepoel LH, Taylor PJ, Belmain SR, Keith M (2016) Are avian predators effective biological control agents for rodent pest management in agricultural systems? Biol Control 101:94-102 doi:<http://dx.doi.org/10.1016/j.biocontrol.2016.07.003>
- Laliberté É, Shipley B, Norton DA, Scott D (2012) Which plant traits determine abundance under long-term shifts in soil resource availability and grazing intensity? J Ecol 100:662-677 doi:10.1111/j.1365-2745.2011.01947.x
- Landis DA, Menalled FD, Costamagna AC, Wilkinson TK (2005) Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes Weed Sci 53:902-908 doi:10.1614/ws-04-050r1.1
- Langer A, Hance T (2004) Enhancing parasitism of wheat aphids through apparent competition: a tool for biological control Agr Ecosyst Environ 102:205-212 doi:10.1016/j.agee.2003.07.005
- Langoya LA, van Rijn PCJ (2008) The significance of floral resources for natural control of aphids Proceedings of the Netherlands Entomological Society Meeting 19:67-74
- Laubertie EA, Wratten SD, Hemptinne JL (2012) The contribution of potential beneficial insectary plant species to adult hoverfly (Diptera: Syrphidae) fitness Biol Control 61:1-6 doi:10.1016/j.biocontrol.2011.12.010

- Lavorel S (2013) Plant functional effects on ecosystem services *J Ecol* 101:4-8 doi:10.1111/1365-2745.12031
- Lavorel S, Garnier E (2002) Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail *Funct Ecol* 16:545-556
- Lavorel S et al. (2011) Using plant functional traits to understand the landscape distribution of multiple ecosystem services *J Ecol* 99:135-147 doi:10.1111/j.1365-2745.2010.01753.x
- Lavorel S, McIntyre S, Landsberg J, Forbes TDA (1997) Plant functional classifications: from general groups to specific groups based on response to disturbance *Trends in Ecology & Evolution* 12:474-478
- Lavorel S et al. (2013) A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services *J Veg Sci* 24:942-948 doi:10.1111/jvs.12083
- Law YH, Rosenheim JA (2011) Effects of combining an intraguild predator with a cannibalistic intermediate predator on a species-level trophic cascade *Ecology* 92:333-341 doi:10.1890/10-0156.1
- Leather SR (1993) Overwintering in six arable aphid pests: a review with particular relevance to pest management *J Appl Entomol* 116:217-233 doi:10.1111/j.1439-0418.1993.tb01192.x
- Lee JC, Heimpel GE (2005) Impact of flowering buckwheat on Lepidopteran cabbage pests and their parasitoids at two spatial scales *Biol Control* 34:290-301 doi:10.1016/j.biocontrol.2005.06.002
- Lee JC, Heimpel GE, Leibe GL (2004) Comparing floral nectar and aphid honeydew diets on the longevity and nutrient levels of a parasitoid wasp *Entomol Exp Appl* 111:189-199 doi:10.1111/j.0013-8703.2004.00165.x
- Lefcheck JS et al. (2015) Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats *Nature Communications* 6:7 doi:10.1038/ncomms7936
- Lefcheck JS, Duffy JE (2015) Multitrophic functional diversity predicts ecosystem functioning in experimental assemblages of estuarine consumers *Ecology* 96:2973-2983 doi:10.1890/14-1977.1
- Lethmayer C (2000) Herbivore - Förderung von Schädlingen. In: Nentwig W (ed) *Streifenförmige ökologische Ausgleichsflächen in der Kulturlandschaft: Ackerunkrautstreifen, Buntbrache, Feldränder*. Verlag Agrarökologie, Bern – Hannover, pp 127-136
- Lethmayer C, Nentwig W, Frank T (1997) Effects of weed strips on the occurrence of noxious coleopteran species (Nitidulidae, Chrysomelidae, Curculionidae) *Z Pflanzenk Pflanzens-J Plant Dis Prot* 104:75-92
- Letourneau DK, Allen SGB, Stireman JO (2012) Perennial habitat fragments, parasitoid diversity and parasitism in ephemeral crops *J Appl Ecol* 49:1405-1416 doi:10.1111/1365-2664.12001
- Letourneau DK et al. (2011) Does plant diversity benefit agroecosystems? A synthetic review *Ecological Applications* 21:9-21 doi:10.1890/09-2026.1
- Letourneau DK, Jedlicka JA, Bothwell SG, Moreno CR (2009) Effects of natural enemy biodiversity on the suppression of arthropod herbivores in terrestrial ecosystems. In: *Annual Review of Ecology Evolution and Systematics*, vol 40. Annual Review of Ecology Evolution and Systematics. Annual Reviews, Palo Alto, pp 573-592. doi:10.1146/annurev.ecolsys.110308.120320
- Lichtenberg EM et al. (2017) A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes *Global Change Biol* 23:4946-4957 doi:10.1111/gcb.13714
- Liere H, Kim TN, Werling BP, Meehan TD, Landis DA, Gratton C (2015) Trophic cascades in agricultural landscapes: indirect effects of landscape composition on crop yield *Ecological Applications* 25:652-661 doi:10.1890/14-0570.1
- Liere H, Larsen A (2010) Cascading trait-mediation: disruption of a trait-mediated mutualism by parasite-induced behavioral modification *Oikos* 119:1394-1400 doi:10.1111/j.1600-0706.2010.17985.x
- Liman A-S, Dalin P, Björkman C (2016a) Enhanced leaf nitrogen status stabilizes omnivore population density *Oecologia* 1-9 doi:10.1007/s00442-016-3742-y
- Liman AS, Eklund K, Björkman C (2016b) Predator refuges for conservation biological control in an intermediately disturbed system: the rise and fall of a simple solution *J Appl Ecol* 53:1823-1830 doi:10.1111/1365-2664.12709
- Lindborg R (2007) Evaluating the distribution of plant life-history traits in relation to current and historical landscape configurations *J Ecol* 95:555-564
- Lindström SAM, Herbertsson L, Rundlöf M, Bommarco R, Smith HG (2016) Experimental evidence that honeybees depress wild insect densities in a flowering crop *Proceedings of the Royal Society B-Biological Sciences* 283:8 doi:10.1098/rspb.2016.1641
- Loeuille N, Barot S, Georgelin E, Kylafis G, Lavigne C, Guy W, David AB (2013) Eco-evolutionary dynamics of agricultural networks: implications for sustainable management. In: *Advances in Ecological Research*, vol Volume 49. Academic Press, pp 339-435. doi:<http://dx.doi.org/10.1016/B978-0-12-420002-9.00006-8>
- Long EY, Finke DL (2014) Contribution of predator identity to the suppression of herbivores by a diverse predator assemblage *Environ Entomol* 43:569-576 doi:10.1603/en13179
- Long EY, Finke DL (2015) Predators indirectly reduce the prevalence of an insect-vectored plant pathogen independent of predator diversity *Oecologia* 177:1067-1074 doi:10.1007/s00442-014-3194-1
- Loranger J et al. (2013) Predicting invertebrate herbivory from plant traits: Polycultures show strong nonadditive effects *Ecology* 94:1499-1509 doi:10.1890/12-2063.1

- Loranger J et al. (2016) Recasting the dynamic equilibrium model through a functional lens: the interplay of trait-based community assembly and climate J Ecol:n/a-n/a doi:10.1111/1365-2745.12536
- Losey JE, Denno RF (1998) Positive predator-predator interactions: enhanced predation rates and synergistic suppression of aphid populations Ecology 79:2143-2152 doi:10.1890/0012-9658(1998)079[2143:ppiep]2.0.co;2
- Lu Y, Wu K, Jiang Y, Guo Y, Desneux N (2012) Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services Nature 487:362-365 doi:<http://www.nature.com/nature/journal/v487/n7407/abs/nature11153.html> - supplementary-information
- Luka H, Lutz M, Blick T, Pfiffner L (2001) Einfluss von eingesäten Wildblumenstreifen auf die epigäischen Laufkäfer und Spinnen (Carabidae und Araneae) in der intensiv genutzten Agrarlandschaft "Grosses Moos", Schweiz Peckiana:45-60
- Lundgren JG, Fausti SW (2015) Trading biodiversity for pest problems Science Advances 1 doi:10.1126/sciadv.1500558
- Lundgren JG, Fergen JK (2014) Predator community structure and trophic linkage strength to a focal prey Mol Ecol 23:3790-3798 doi:10.1111/mec.12700
- Lys JA, Nentwig W (1992a) Augmentation of beneficial arthropods by strip-management. 4. Surface-activity, movements and activity-density of abundant carabid beetles in a cereal field Oecologia 92:373-382 doi:10.1007/bf00317463
- Lys JA, Nentwig W (1992b) Förderung von Laufkäfern (Coleoptera, Carabidae) in einem Getreidefeld durch Künstlich Angesäte Krautstreifen Mitteilungen der Deutschen Gesellschaft für Allgemeine und Angewandte Entomologie 8:128-132
- Lys JA, Nentwig W (1994) Improvement of the overwintering sites for Carabidae, Staphylinidae and Araneae by strip-management in a cereal field Pedobiologia 38:238-242
- Mace KC, Mills NJ (2017) Connecting natural enemy metrics to biological control activity for aphids in California walnuts Biol Control 106:16-26 doi:10.1016/j.biocontrol.2016.11.009
- Macfadyen S, Craze PG, Polaszek A, van Achterberg K, Memmott J (2011) Parasitoid diversity reduces the variability in pest control services across time on farms Proceedings of the Royal Society B-Biological Sciences 278:3387-3394 doi:10.1098/rspb.2010.2673
- Macfadyen S, Gibson R, Raso L, Sint D, Traugott M, Memmott J (2009) Parasitoid control of aphids in organic and conventional farming systems Agr Ecosyst Environ 133:14-18 doi:10.1016/j.agee.2009.04.012
- MacLeod A (1999) Attraction and retention of *Episyrphus balteatus* DeGeer (Diptera : Syrphidae) at an arable field margin with rich and poor floral resources Agr Ecosyst Environ 73:237-244 doi:10.1016/s0167-8809(99)00051-1
- MacLeod A, Wratten SD, Sotherton NW, Thomas MB (2004) 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat Agric For Entomol 6:147-154 doi:10.1111/j.1461-9563.2004.00215.x
- Mair J, Port GR (2001) Predation on the slug *Deroceras reticulatum* by the carabid beetles *Pterostichus madidus* and *Nebria brevicollis* in the presence of alternative prey Agric For Entomol 3:169-174 doi:10.1046/j.1461-9555.2001.00102.x
- Malézieux E et al. (2009) Mixing plant species in cropping systems: concepts, tools and models. A review Agronomy for Sustainable Development 29:43-62 doi:10.1051/agro:2007057
- Mansion-Vaquie A, Ferrante M, Cook SM, Pell JK, Lövei GL (2017) Manipulating field margins to increase predation intensity in fields of winter wheat (*Triticum aestivum*) J Appl Entomol 141:600-611 doi:10.1111/jen.12385
- Marc P, Canard A, Ysnel F (1999) Spiders (Araneae) useful for pest limitation and bioindication Agr Ecosyst Environ 74:229-273 doi:10.1016/s0167-8809(99)00038-9
- Marko V, Jenser G, Kondorosy E, Abraham L, Balazs K (2013) Flowers for better pest control? The effects of apple orchard ground cover management on green apple aphids (*Aphis* spp.) (Hemiptera: Aphididae), their predators and the canopy insect community Biocontrol Sci Technol 23:126-145 doi:10.1080/09583157.2012.743972
- Marshall EJP, Brown VK, Boatman ND, Lutman PJW, Squire GR, Ward LK (2003) The role of weeds in supporting biological diversity within crop fields Weed Res 43:77-89
- Martin AR, Rapidel B, Rounsard O, Van den Meersche K, Virginio ED, Barrios M, Isaac ME (2017) Intraspecific trait variation across multiple scales: the leaf economics spectrum in coffee Funct Ecol 31:604-612 doi:10.1111/1365-2435.12790
- Massey FP, Ennos AR, Hartley SE (2006) Silica in grasses as a defence against insect herbivores: contrasting effects on folivores and a phloem feeder J Anim Ecol 75:595-603 doi:10.1111/j.1365-2656.2006.01082.x
- Mayhew PJ (2016) Comparing parasitoid life histories Entomol Exp Appl 159:147-162 doi:10.1111/eea.12411
- Medeiros MA, Sujii ER, Morais HC (2009) Effect of plant diversification on abundance of South American tomato

- pinworm and predators in two cropping systems *Horticultura Brasileira* 27:300-306
- Meek B, Loxton D, Sparks T, Pywell R, Pickett H, Nowakowski M (2002) The effect of arable field margin composition on invertebrate biodiversity *Biol Conserv* 106:259-271 doi:10.1016/s0006-3207(01)00252-x
- Messelink GJ, Van Maanen R, Van Holstein-Saj R, Sabelis MW, Janssen A (2010) Pest species diversity enhances control of spider mites and whiteflies by a generalist phytoseiid predator *Biocontrol* 55:387-398 doi:10.1007/s10526-009-9258-1
- Meyer B, Jauker F, Steffan-Dewenter I (2009) Contrasting resource-dependent responses of hoverfly richness and density to landscape structure *Basic and Applied Ecology* 10:178-186 doi:10.1016/j.baae.2008.01.001
- Mitchell C, Brennan RM, Graham J, Karley AJ (2016) Plant defense against herbivorous pests: exploiting resistance and tolerance traits for sustainable crop protection *Frontiers in Plant Science* 7:8 doi:10.3389/fpls.2016.01132
- Montoya JM, Woodward G, Emmerson MC, Sole RV (2009) Press perturbations and indirect effects in real food webs *Ecology* 90:2426-2433 doi:10.1890/08-0657.1
- Mooney KA, Singer MS (2012) Plant effects on herbivore-enemy interactions in natural systems. In: Ohgushi T, Schmitz O, Holt RD (eds) *Trait-Mediated Indirect Interactions. Ecological and Evolutionary Perspectives*. Cambridge University Press, Cambridge pp pp. 107-130
- Morandin LA, Long RF, Kremen C (2016) Pest control and pollination cost-benefit analysis of hedgerow restoration in a simplified agricultural landscape *J Econ Entomol* 109:1020-1027 doi:10.1093/jee/tow086
- Moretti M et al. (2013) Linking traits between plants and invertebrate herbivores to track functional effects of land-use changes *J Veg Sci* 24:949-962 doi:10.1111/jvs.12022
- Moretti M et al. (2017) Handbook of protocols for standardized measurement of terrestrial invertebrate functional traits *Funct Ecol* 31:558-567 doi:10.1111/1365-2435.12776
- Moretti M, Legg C (2009) Combining plant and animal traits to assess community functional responses to disturbance *Ecography* 32:299-309 doi:10.1111/j.1600-0587.2008.05524.x
- Mouillot D et al. (2013) Rare species support vulnerable functions in high-diversity ecosystems *PLoS Biol* 11:11 doi:10.1371/journal.pbio.1001569
- Mouillot D, Villéger S, Scherer-Lorenzen M, Mason NWH (2011) Functional structure of biological communities predicts ecosystem multifunctionality *Plos One* 6:9 doi:10.1371/journal.pone.0017476
- Nentwig W (1992) Die nützlingsfördernde Wirkung von Unkräutern in angesäten Unkraustreifen *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 13:33-40
- Nentwig W (1993) Nützlingsförderung in Agrarökosystemen *Verhandlungen der Gesellschaft für Ökologie Band* 22:9-14
- Nentwig W (2002) Weedy plant species and their beneficial arthropods: potential for manipulation in field crops. In: Pickett CH, Bugg RL (eds) *Enhancing biological control*. University of California Press, Berkeley, Los Angeles, London, pp 49-71
- Nesbit CM, Menendez R, Roberts MR, Wilby A (2016) Associational resistance or susceptibility: the indirect interaction between chemically-defended and non-defended herbivore prey via a shared predator *Oikos* 125:1802-1811 doi:10.1111/oik.03157
- Nesbit CM, Wilby A, Roberts MR, Menéndez R (2015) Selection of aphid prey by a generalist predator: do prey chemical defences matter? *Ecol Entomol* 40:767-775 doi:10.1111/een.12253
- Nofemela RS (2013) The effect of obligate hyperparasitoids on biological control: Differential vulnerability of primary parasitoids to hyperparasitism can mitigate trophic cascades *Biol Control* 65:218-224 doi:10.1016/j.biocontrol.2013.02.003
- Noordijk J, Musters CJM, van Dijk J, de Snoo GR (2010) Invertebrates in field margins: taxonomic group diversity and functional group abundance in relation to age *Biodivers Conserv* 19:3255-3268 doi:10.1007/s10531-010-9890-1
- Norris RF, Kogan M (2000) Interactions between weeds, arthropod pests, and their natural enemies in managed ecosystems *Weed Sci* 48:94-158 doi:10.1614/0043-1745(2000)048[0094:ibwapa]2.0.co;2
- Norris RF, Kogan M (2005) Ecology of interactions between weeds and arthropods. In: *Annual Review of Entomology*, vol 50. Annual Review of Entomology. Annual Reviews, Palo Alto, pp 479-503. doi:10.1146/annurev.ento.49.061802.123218
- Northfield TD, Crowder DW, Takizawa T, Snyder WE (2014) Pairwise interactions between functional groups improve biological control *Biol Control* 78:49-54 doi:10.1016/j.biocontrol.2014.07.008
- Northfield TD, Snyder GB, Ives AR, Snyder WE (2010) Niche saturation reveals resource partitioning among consumers *Ecology Letters* 13:338-348 doi:10.1111/j.1461-0248.2009.01428.x
- Nyffeler M, Breene RG, Dean DA, Sterling WL (1990) Spiders as predators of arthropod eggs *J Appl Entomol* 109:490-501
- Nyffeler M, Sunderland KD (2003) Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies *Agr Ecosyst Environ* 95:579-612 doi:10.1016/s0167-8809(02)00181-0

- O'Neal ME, Zontek EL, Szendrei Z, Landis DA, Isaacs R (2005) Ground predator abundance affects prey removal in highbush blueberry (*Vaccinium corymbosum*) fields and can be altered by aisle ground covers *Biocontrol* 50:205-222 doi:10.1007/s10526-004-0676-9
- Olson DM, Wäckers FL (2007) Management of field margins to maximize multiple ecological services *J Appl Ecol* 44:13-21 doi:10.1111/j.1365-2664.2006.01241.x
- Orford KA, Murray PJ, Vaughan IP, Memmott J (2016) Modest enhancements to conventional grassland diversity improve the provision of pollination services *J Appl Ecol* 53:906-915 doi:10.1111/1365-2664.12608
- Osborne P (1960) Observations on the natural enemies of *Meligethes aeneus* (F.) and *M. viridescens* (F.) [Coleoptera: Nitidulidae] *Parasitology* 50:91-110
- Östman Ö, Ekbom B, Bengtsson J (2003) Yield increase attributable to aphid predation by ground-living polyphagous natural enemies in spring barley in Sweden *Ecol Econ* 45:149-158 doi:10.1016/s0921-8009(03)00007-7
- Otto SB, Berlow EL, Rank NE, Smiley J, Brose U (2008) Predator diversity and identity drive interaction strength and trophic cascades in a food web *Ecology* 89:134-144 doi:10.1890/07-0066.1
- Pannwitt H, Westerman PR, de Mol F, Selig C, Gerowitt B (2017) Biological control of weed patches by seed predators; responses to seed density and exposure time *Biol Control* 108:1-8 doi:10.1016/j.biocontrol.2017.01.016
- Parolin P, Bresch C, Poncet C, Desneux N (2012) Functional characteristics of secondary plants for increased pest management *Int J Pest Manage* 58:368-376 doi:10.1080/09670874.2012.734869
- Patt JM, Hamilton GC, Lashomb JH (1997) Foraging success of parasitoid wasps on flowers: Interplay of insect morphology, floral architecture and searching behavior *Entomol Exp Appl* 83:21-30 doi:10.1046/j.1570-7458.1997.00153.x
- Pearson CV, Massad TJ, Dyer LA (2008) Diversity cascades in alfalfa fields: From plant quality to agroecosystem diversity *Environ Entomol* 37:947-955 doi:10.1603/0046-225x(2008)37[947:dciaff]2.0.co;2
- Pearson DE (2010) Trait- and density-mediated indirect interactions initiated by an exotic invasive plant Autogenic ecosystem engineer *Am Nat* 176:394-403 doi:10.1086/656274
- Peeters PJ, Sanson G, Read J (2007) Leaf biomechanical properties and the densities of herbivorous insect guilds *Funct Ecol* 21:246-255 doi:10.1111/j.1365-2435.2006.01223.x
- Pekár S, Michalko R, Loverre P, Líznavá E, Černecká Ľ (2015) Biological control in winter: novel evidence for the importance of generalist predators *J Appl Ecol*:n/a-n/a doi:10.1111/1365-2664.12363
- Pell JK, Baverstock J, Roy HE, Ware RL, Majerus MEN (2008) Intraguild predation involving *Harmonia axyridis*: a review of current knowledge and future perspectives *Biocontrol* 53:147-168 doi:10.1007/s10526-007-9125-x
- Peralta G, Frost CM, Rand TA, Didham RK, Tylianakis JM (2014) Complementarity and redundancy of interactions enhance attack rates and spatial stability in host-parasitoid food webs *Ecology* 95:1888-1896
- Pérez-Harguindeguy N, Díaz S, Vendramini F, Cornelissen JHC, Gurvich DE, Cabido M (2003) Leaf traits and herbivore selection in the field and in cafeteria experiments *Austral Ecol* 28:642-650 doi:10.1046/j.1442-9993.2003.01321.x
- Petermann JS, Muller CB, Weigelt A, Weisser WW, Schmid B (2010) Effect of plant species loss on aphid-parasitoid communities *J Anim Ecol* 79:709-720 doi:10.1111/j.1365-2656.2010.01674.x
- Petersen LF, Woltz JM (2015) Diel variation in the abundance and composition of the predator assemblages feeding on aphid-infested soybean *Biocontrol* 60:209-219 doi:10.1007/s10526-014-9631-6
- Peterson JA, Ode PJ, Oliveira-Hofman C, Harwood JD (2016) Integration of plant defense traits with biological control of arthropod pests: challenges and opportunities *Frontiers in Plant Science* 7:23 doi:10.3389/fpls.2016.01794
- Pey B et al. (2014) Current use of and future needs for soil invertebrate functional traits in community ecology *Basic and Applied Ecology* 15:194-206 doi:10.1016/j.baae.2014.03.007
- Pfannenstiel RS, Patt JM (2012) Feeding on nectar and honeydew sugars improves survivorship of two nocturnal cursorial spiders *Biol Control* 63:231-236 doi:10.1016/j.biocontrol.2012.07.013
- Pfiffner L, Luka H, Schlatter C, Juen A, Traugott M (2009) Impact of wildflower strips on biological control of cabbage lepidopterans *Agr Ecosyst Environ* 129:310-314 doi:10.1016/j.agee.2008.10.003
- Pfiffner L, Wyss E (2004) Use of sown wildflower strips to enhance natural enemies of agricultural pests. In: *Ecological engineering for pest management: advances in habitat manipulation for arthropods*. CABI Publishing, Wallingford, UK, pp 165-186
- Philips CR (2013) Food webs and phenology models: evaluating the efficacy of ecologically-based insect pest management in different agroecosystems. Virginia Polytechnic Institute and State University
- Phillips BW, Gardiner MM (2016) Does local habitat management or large-scale landscape composition alter the biocontrol services provided to pumpkin agroecosystems? *Biol Control* 92:181-194 doi:10.1016/j.biocontrol.2015.10.001
- Podgaiski LR, Joner F, Lavorel S, Moretti M, Ibanez S, Mendonca MD, Pillar VD (2013) Spider trait assembly

- patterns and resilience under fire-induced vegetation change in South Brazilian grasslands PLoS One 8:11 doi:10.1371/journal.pone.0060207
- Poelman EH, van Loon JJA, Dicke M (2008) Consequences of variation in plant defense for biodiversity at higher trophic levels Trends Plant Sci 13:534-541 doi:10.1016/j.tplants.2008.08.003
- Poeydebat C, Tixier P, Chabrier C, de Bellaire LdL, Vargas R, Daribo M-O, Carval D (2017a) Does plant richness alter multitrophic soil food web and promote plant-parasitic nematode regulation in banana agroecosystems? Applied Soil Ecology 117-118:137-146 doi:<https://doi.org/10.1016/j.apsoil.2017.04.017>
- Poeydebat C, Tixier P, De Bellaire LD, Carval D (2017b) Plant richness enhances banana weevil regulation in a tropical agroecosystem by affecting a multitrophic food web Biol Control 114:125-132 doi:10.1016/j.biocontrol.2017.08.009
- Pontin DR, Wade MR, Kehrli P, Wratten SD (2006) Attractiveness of single and multiple species flower patches to beneficial insects in agroecosystems Ann Appl Biol 148:39-47 doi:10.1111/j.1744-7348.2005.00037.x
- Porcel M, Ruano F, Cotes B, Pena A, Campos M (2013) Agricultural Management Systems Affect the Green Lacewing Community (Neuroptera: Chrysopidae) in Olive Orchards in Southern Spain Environ Entomol 42:97-106 doi:10.1603/en11338
- Potts SG, Vulliamy B, Roberts S, O'Toole C, Dafni A, Ne'eman G, Willmer PG (2004) Nectar resource diversity organises flower-visitor community structure Entomol Exp Appl 113:103-107 doi:10.1111/j.0013-8703.2004.00212.x
- Powell W, Pickett JA (2003) Manipulation of parasitoids for aphid pest management: progress and prospects Pest Manage Sci 59:149-155 doi:10.1002/ps.550
- Pozzebon A, Loeb GM, Duso C (2015) Role of supplemental foods and habitat structural complexity in persistence and coexistence of generalist predatory mites Scientific Reports 5 doi:10.1038/srep14997
- Prasad RP, Snyder WE (2006) Diverse trait-mediated interactions in a multi-predator, multi-prey community Ecology 87:1131-1137 doi:10.1890/0012-9658(2006)87[1131:dtiam]2.0.co;2
- Prasad RP, Snyder WE (2010) A non-trophic interaction chain links predators in different spatial niches Oecologia 162:747-753 doi:10.1007/s00442-009-1486-7
- Prasifka JR, Schmidt NP, Kohler KA, O'Neal ME, Hellmich RL, Singer JW (2006) Effects of living mulches on predator abundance and sentinel prey in a corn-soybean-forage rotation Environ Entomol 35:1423-1431 doi:10.1603/0046-225x(2006)35[1423:eolmop]2.0.co;2
- Price PW (2002) Resource-driven terrestrial interaction webs Ecological Research 17:241-247 doi:10.1046/j.1440-1703.2002.00483.x
- Pywell RF, James KL, Herbert I, Meek WR, Carvell C, Bell D, Sparks TH (2005) Determinants of overwintering habitat quality for beetles and spiders on arable farmland Biol Conserv 123:79-90 doi:10.1016/j.biocon.2004.10.010
- Pywell RF et al. (2006) Effectiveness of new agri-environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes Biol Conserv 129:192-206 doi:10.1016/j.biocon.2005.10.034
- Quijas S, Schmid B, Balvanera P (2010) Plant diversity enhances provision of ecosystem services: A new synthesis Basic and Applied Ecology 11:582-593 doi:10.1016/j.baae.2010.06.009
- Ramsden M, Menendez R, Leather S, Wäckers F (2016) Do natural enemies really make a difference? Field scale impacts of parasitoid wasps and hoverfly larvae on cereal aphid populations Agric For Entomol:n/a-n/a doi:10.1111/afe.12191
- Ramsden MW, Menéndez R, Leather SR, Wäckers F (2015) Optimizing field margins for biocontrol services: The relative role of aphid abundance, annual floral resources, and overwinter habitat in enhancing aphid natural enemies Agr Ecosyst Environ 199:94-104 doi:10.1016/j.agee.2014.08.024
- Rand TA, Tylianakis JM, Tscharntke T (2006) Spillover edge effects: the dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats Ecology Letters 9:603-614 doi:10.1111/j.1461-0248.2006.00911.x
- Ratnadass A, Fernandes P, Avelino J, Habib R (2012) Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review Agronomy for Sustainable Development 32:273-303 doi:10.1007/s13593-011-0022-4
- Raymond L, Plantegenest M, Gagic V, Navasse Y, Lavandero B (2016) Aphid parasitoid generalism: development, assessment, and implications for biocontrol J Pest Sci 89:7-20 doi:10.1007/s10340-015-0687-6
- Raymond L, Sarthou JP, Plantegenest M, Gauffre B, Ladet S, Vialatte A (2014) Immature hoverflies overwinter in cultivated fields and may significantly control aphid populations in autumn Agr Ecosyst Environ 185:99-105 doi:10.1016/j.agee.2013.12.019
- Rebek EJ, Sadof CS, Hanks LM (2005) Manipulating the abundance of natural enemies in ornamental landscapes with floral resource plants Biol Control 33:203-216 doi:10.1016/j.biocontrol.2005.02.011
- Requier F, Odoux JF, Tamic T, Moreau N, Henry M, Decourtye A, Bretagnolle V (2015) Honey bee diet in intensive farmland habitats reveals an unexpectedly high flower richness and a major role of weeds Ecological Applications 25:881-890 doi:10.1890/14-1011.1

- Ribera I, Dolédec S, Downie IS, Foster GN (2001) Effect of land disturbance and stress on species traits of ground beetles assemblages Ecology 82:1112-1129 doi:10.1890/0012-9658(2001)082[1112:EOLDAS]2.0.CO;2
- Ricou C, Schneller C, Amiaud B, Plantureux S, Bockstaller C (2014) A vegetation-based indicator to assess the pollination value of field margin flora Ecol Indicators 45:320-331 doi:<http://dx.doi.org/10.1016/j.ecolind.2014.03.022>
- Riggi LG, Gagic V, Rusch A, Malsher G, Ekbom B, Bommarco R (2017) Pollen beetle mortality is increased by ground-dwelling generalist predators but not landscape complexity Agr Ecosyst Environ 250:133-142 doi:10.1016/j.agee.2017.06.039
- Robinson JV (1981) The effect of architectural variation in habitat on a spider community - An experimental field study Ecology 62:73-80 doi:10.2307/1936670
- Rodríguez MÁ, Hawkins BA (2000) Diversity, function and stability in parasitoid communities Ecology Letters 3:35-40 doi:10.1046/j.1461-0248.2000.00115.x
- Rohr JR et al. (2015) Predator diversity, intraguild predation, and indirect effects drive parasite transmission Proc Natl Acad Sci U S A 112:3008-3013 doi:10.1073/pnas.1415971112
- Roland J, Taylor PD (1997) Insect parasitoid species respond to forest structure at different spatial scales Nature 386:710-713 doi:10.1038/386710a0
- Rollin O, Benelli G, Benvenuti S, Decourtye A, Wratten SD, Canale A, Desneux N (2016) Weed-insect pollinator networks as bio-indicators of ecological sustainability in agriculture. A review Agronomy for Sustainable Development 36:22 doi:10.1007/s13593-015-0342-x
- Rollin O, Bretagnolle V, Decourtye A, Aptel J, Michel N, Vaissière BE, Henry M (2013) Differences of floral resource use between honey bees and wild bees in an intensive farming system Agr Ecosyst Environ 179:78-86 doi:10.1016/j.agee.2013.07.007
- Roschewitz I, Hucker M, Tschamtk T, Thies C (2005) The influence of landscape context and farming practices on parasitism of cereal aphids Agr Ecosyst Environ 108:218-227 doi:10.1016/j.agee.2005.02.005
- Rosenheim JA (1998) Higher-order predators and the regulation of insect herbivore populations Annu Rev Entomol 43:421-447 doi:10.1146/annurev.ento.43.1.421
- Rouabah A, Lasserre-Joulin F, Amiaud B, Plantureux S (2014) Emergent effects of ground beetles size diversity on the strength of prey suppression Ecol Entomol 39:47-57 doi:10.1111/een.12064
- Rouabah A, Villerd J, Amiaud B, Plantureux S, Lasserre-Joulin F (2015) Response of carabid beetles diversity and size distribution to the vegetation structure within differently managed field margins Agr Ecosyst Environ 200:21-32 doi:<http://dx.doi.org/10.1016/j.agee.2014.10.011>
- Roubinet E, Birkhofer K, Malsher G, Staudacher K, Ekbom B, Traugott M, Jonsson M (2017) Diet of generalist predators reflects effects of cropping period and farming system on extra- and intraguild prey Ecological Applications 27:1167-1177 doi:10.1002/eap.1510
- Roumegous S (2012) Impact of natural infrastructures surrounding arable fields on two arthropods guilds : *Carabidae* and *Syrphidae*. Msc Thesis Report, WU BFS Group & ISARA Lyon, Chambre régionale d'agriculture de Charente-Maritime
- Ruppert V (1992) Einfluss blütenreicher Feldrandstrukturen auf die Dichte blütenbesuchender Nutzinsekten insbesondere der Syrphidae. vol PhD thesis. Agrarökologie; Bd. 8. Bern: Haupt, 1992,
- Rusch A, Binet D, Delbac L, Thiéry D (2016a) Local and landscape effects of agricultural intensification on Carabid community structure and weed seed predation in a perennial cropping system Landsc Ecol 31:2163-2174 doi:10.1007/s10980-016-0390-x
- Rusch A, Birkhofer K, Bommarco R, Smith HG, Ekbom B (2015) Predator body sizes and habitat preferences predict predation rates in an agroecosystem Basic and Applied Ecology 16:250-259 doi:10.1016/j.baae.2015.02.003
- Rusch A et al. (2016b) Agricultural landscape simplification reduces natural pest control: a quantitative synthesis Agr Ecosyst Environ 221:198-204 doi:<http://dx.doi.org/10.1016/j.agee.2016.01.039>
- Rusch A, Valantin-Morison M, Roger-Estrade J, Sarthou JP (2012) Local and landscape determinants of pollen beetle abundance in overwintering habitats Agric For Entomol 14:37-47 doi:10.1111/j.1461-9563.2011.00547.x
- Rusch A, Valantin-Morison M, Sarthou JP, Roger-Estrade J (2011) Multi-scale effects of landscape complexity and crop management on pollen beetle parasitism rate Landsc Ecol 26:473-486 doi:10.1007/s10980-011-9573-7
- Salisbury A, Armitage J, Bostock H, Perry J, Tatchell M, Thompson K (2015) Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? J Appl Ecol 52:1156-1164 doi:10.1111/1365-2664.12499
- Salveter R (1998) The influence of sown herb strips and spontaneous weeds on the larval stages of aphidophagous hoverflies (Dipt., Syrphidae) Journal of Applied Entomology-Zeitschrift Fur Angewandte Entomologie 122:103-114
- Samu F, Beleznaï O, Tholt G (2013) A potential spider natural enemy against virus vector leafhoppers in agricultural mosaic landscapes - Corroborating ecological and behavioral evidence Biol Control 67:390-396

- doi:10.1016/j.biocontrol.2013.08.016
- Samu F, Németh J, Kiss B (1997) Assessment of the efficiency of a hand-held suction device for sampling spiders: improved density estimation or oversampling? *Ann Appl Biol* 130:371-378 doi:10.1111/j.1744-7348.1997.tb06840.x
- Sauve AMC, Thebault E, Pocock MJO, Fontaine C (2016) How plants connect pollination and herbivory networks and their contribution to community stability *Ecology* 97:908-917 doi:10.1890/15-0132.1
- Schädler M, Jung G, Auge H, Brandl R (2003) Palatability, decomposition and insect herbivory: patterns in a successional old-field plant community *Oikos* 103:121-132 doi:10.1034/j.1600-0706.2003.12659.x
- Schaffers AP, Raemakers IP, Sykora KV, Ter Braak CJF (2008) Arthropod assemblages are best predicted by plant species composition *Ecology* 89:782-794 doi:10.1890/07-0361.1
- Scheid BE, Thies C, Tschardt T (2011) Enhancing rape pollen beetle parasitism within sown flower fields along a landscape complexity gradient *Agric For Entomol* 13:173-179 doi:10.1111/j.1461-9563.2010.00516.x
- Schellhorn NA, Bellati J, Paull CA, Maratos L (2008) Parasitoid and moth movement from refuge to crop *Basic and Applied Ecology* 9:691-700 doi:10.1016/j.baae.2007.12.010
- Scheper J et al. (2015) Local and landscape-level floral resources explain effects of wildflower strips on wild bees across four European countries *J Appl Ecol* 52:1165-1175 doi:10.1111/1365-2664.12479
- Schleuning M, Fründ J, García D (2015) Predicting ecosystem functions from biodiversity and mutualistic networks: an extension of trait-based concepts to plant-animal interactions *Ecography* 38:380-392 doi:10.1111/ecog.00983
- Schmidt JM, Barney SK, Williams MA, Bessin RT, Coolong TW, Harwood JD (2014) Predator-prey trophic relationships in response to organic management practices *Mol Ecol* 23:3777-3789 doi:10.1111/mec.12734
- Schmidt MH, Tschardt T (2005a) Landscape context of sheetweb spider (*Araneae* : *Linyphiidae*) abundance in cereal fields *J Biogeogr* 32:467-473 doi:10.1111/j.1365-2699.2004.01244.x
- Schmidt MH, Tschardt T (2005b) The role of perennial habitats for Central European farmland spiders *Agr Ecosyst Environ* 105:235-242 doi:10.1016/j.agee.2004.03.009
- Schmidt-Entling MH, Döbeli J (2009) Sown wildflower areas to enhance spiders in arable fields *Agr Ecosyst Environ* 133:19-22 doi:10.1016/j.agee.2009.04.015
- Schmitz OJ, Buchkowski RW, Burghardt KT, Donihue CM (2015) Functional traits and trait-mediated interactions: connecting community-level interactions with ecosystem functioning. In: Samraat Pawar GW, Anthony ID (eds) *Advances in Ecological Research*, vol Volume 52. Academic Press, pp 319-343. doi:<http://dx.doi.org/10.1016/bs.aecr.2015.01.003>
- Schneider G, Krauss J, Boetzi FA, Fritze MA, Steffan-Dewenter I (2016) Spillover from adjacent crop and forest habitats shapes carabid beetle assemblages in fragmented semi-natural grasslands *Oecologia* 182:1141-1150 doi:10.1007/s00442-016-3710-6
- Settle WH et al. (1996) Managing tropical rice pests through conservation of generalist natural enemies and alternative prey *Ecology* 77:1975-1988 doi:10.2307/2265694
- Shackelford G, Steward PR, Benton TG, Kunin WE, Potts SG, Biesmeijer JC, Sait SM (2013) Comparison of pollinators and natural enemies: a meta-analysis of landscape and local effects on abundance and richness in crops *Biological Reviews* 88:1002-1021 doi:10.1111/brv.12040
- Shennan C (2008) Biotic interactions, ecological knowledge and agriculture *Philosophical Transactions of the Royal Society B-Biological Sciences* 363:717-739 doi:10.1098/rstb.2007.2180
- Sih A, Englund G, Wooster D (1998) Emergent impacts of multiple predators on prey *Trends in Ecology & Evolution* 13:350-355 doi:10.1016/s0169-5347(98)01437-2
- Silva EB, Franco JC, Vasconcelos T, Branco M (2010) Effect of ground cover vegetation on the abundance and diversity of beneficial arthropods in citrus orchards *Bull Entomol Res* 100:489-499 doi:10.1017/s0007485309990526
- Simpson M et al. (2011) Attract and reward: combining chemical ecology and habitat manipulation to enhance biological control in field crops *J Appl Ecol* 48:580-590 doi:10.1111/j.1365-2664.2010.01946.x
- Singer MS, Clark RE, Lichter-Marck IH, Johnson ER, Mooney KA (2017) Predatory birds and ants partition caterpillar prey by body size and diet breadth *J Anim Ecol* 86:1363-1371 doi:10.1111/1365-2656.12727
- Sivinski J, Wahl D, Holler T, Al Dobai S, Sivinski R (2011) Conserving natural enemies with flowering plants: Estimating floral attractiveness to parasitic Hymenoptera and attraction's relationship to flower and plant morphology *Biol Control* 58:208-214 doi:10.1016/j.biocontrol.2011.05.002
- Snyder WE, Snyder GB, Finke DL, Straub CS (2006) Predator biodiversity strengthens herbivore suppression *Ecology Letters* 9:789-796 doi:10.1111/j.1461-0248.2006.00922.x
- Snyder WE, Wise DH (1999) Predator interference and the establishment of generalist predator populations for biocontrol *Biol Control* 15:283-292 doi:10.1006/bcon.1999.0723
- Sorribas J, González S, Domínguez-Gento A, Vercher R (2016) Abundance, movements and biodiversity of flying predatory insects in crop and non-crop agroecosystems *Agronomy for Sustainable Development* 36:9 doi:10.1007/s13593-016-0360-3

- Southwood TRE (1977) Habitat, the templet for ecological strategies? *J Anim Ecol* 46:337-365
- Speight MR, Lawton JH (1976) Influence of weed-cover on mortality imposed on artificial prey by predatory ground beetles in cereal fields *Oecologia* 23:211-223 doi:10.1007/bf00361237
- Stang M, Klinkhamer PGL, van der Meijden E (2006) Size constraints and flower abundance determine the number of interactions in a plant-flower visitor web *Oikos* 112:111-121 doi:10.1111/j.0030-1299.2006.14199.x
- Stang M, Klinkhamer PGL, Waser NM, Stang I, van der Meijden E (2009) Size-specific interaction patterns and size matching in a plant-pollinator interaction web *Ann Bot* 103:1459-1469 doi:10.1093/aob/mcp027
- Steffan SA, Snyder WE (2010) Cascading diversity effects transmitted exclusively by behavioral interactions *Ecology* 91:2242-2252 doi:10.1890/09-0787.1
- Stephens CJ, Schellhorn NA, Wood GM, Austin AD (2006) Parasitic wasp assemblages associated with native and weedy plant species in an agricultural landscape *Aust J Entomol* 45:176-184 doi:10.1111/j.1440-6055.2006.00519.x
- Stiling P, Cornelissen T (2005) What makes a successful biocontrol agent? A meta-analysis of biological control agent performance *Biol Control* 34:236-246 doi:10.1016/j.biocontrol.2005.02.017
- Storkey J, Brooks D, Haughton A, Hawes C, Smith BM, Holland JM (2013) Using functional traits to quantify the value of plant communities to invertebrate ecosystem service providers in arable landscapes *J Ecol* 101:38-46 doi:10.1111/1365-2745.12020
- Storkey J, Döring T, Baddeley J, Collins R, Roderick S, Jones H, Watson C (2015) Engineering a plant community to deliver multiple ecosystem services *Ecological Applications* 25:1034-1043 doi:10.1890/14-1605.1.sm
- Straub CS, Finke DL, Snyder WE (2008) Are the conservation of natural enemy biodiversity and biological control compatible goals? *Biol Control* 45:225-237 doi:<http://dx.doi.org/10.1016/j.biocontrol.2007.05.013>
- Sutter L, Albrecht M (2016) Synergistic interactions of ecosystem services: florivorous pest control boosts crop yield increase through insect pollination *Proceedings of the Royal Society B-Biological Sciences* 283:8 doi:10.1098/rspb.2015.2529
- Symondson WOC et al. (2006) Biodiversity vs. biocontrol: positive and negative effects of alternative prey on control of slugs by carabid beetles *Bull Entomol Res* 96:637-645 doi:10.1079/ber2006467
- Symondson WOC, Glen DM, Ives AR, Langdon CJ, Wiltshire CW (2002a) Dynamics of the relationship between a generalist predator and slugs over five years *Ecology* 83:137-147 doi:10.2307/2680127
- Symondson WOC, Sunderland KD, Greenstone MH (2002b) Can generalist predators be effective biocontrol agents? *Annu Rev Entomol* 47:561-594 doi:10.1146/annurev.ento.47.091201.145240
- Szigeti V, Kőrösi Á, Harnos A, Nagy J, Kis J (2016) Measuring floral resource availability for insect pollinators in temperate grasslands – a review *Ecol Entomol* 41:231-240 doi:10.1111/een.12298
- Thies C, Roschewitz I, Tschantke T (2005) The landscape context of cereal aphid-parasitoid interactions *Proceedings of the Royal Society B-Biological Sciences* 272:203-210 doi:10.1098/rspb.2004.2902
- Thies C, Tschantke T (1999) Landscape structure and biological control in agroecosystems *Science* 285:893-895 doi:10.1126/science.285.5429.893
- Thomas CFG, Holland JM, Brown NJ (2002) The spatial distribution of carabid beetles in agricultural landscapes. In: Holland JM (ed) *The agroecology of carabid beetles*. Intercept Limited, Andover, Hampshire, UK,
- Thomas CFG, Marshall EJP (1999) Arthropod abundance and diversity in differently vegetated margins of arable fields *Agr Ecosyst Environ* 72:131-144 doi:10.1016/s0167-8809(98)00169-8
- Thompson PL, Davies TJ, Gonzalez A (2015) Ecosystem functions across trophic levels are linked to functional and phylogenetic diversity *Plos One* 10:19 doi:10.1371/journal.pone.0117595
- Tilman D, Reich PB, Knops J, Wedin D, Mielke T, Lehman C (2001) Diversity and productivity in a long-term grassland experiment *Science* 294:843-845 doi:10.1126/science.1060391
- Tixier P, Dagneaux D, Mollot G, Vinatier F, Duyck PF (2013) Weeds mediate the level of intraguild predation in arthropod food webs *J Appl Entomol* 137:702-710 doi:10.1111/jen.12060
- Toft S, Wise DH (1999) Growth, development, and survival of a generalist predator fed single- and mixed-species diets of different quality *Oecologia* 119:191-197 doi:10.1007/s004420050776
- Topping CJ (1993) Behavioural responses of three linyphiid spiders to pitfall traps *Entomol Exp Appl* 68:287-293
- Topping CJ, Sunderland KD (1992) Limitations to the use of pitfall traps in ecological-studies exemplified by a study of species in a field of winter-wheat *J Appl Ecol* 29:485-491 doi:10.2307/2404516
- Traugott M, Bell JR, Raso L, Sint D, Symondson WOC (2014) Generalist predators disrupt parasitoid aphid control by direct and coincidental intraguild predation *Bull Entomol Res* 102:239-247 doi:10.1017/s0007485311000551
- Trichard A, Alignier A, Biju-Duval L, Petit S (2013a) The relative effects of local management and landscape context on weed seed predation and carabid functional groups *Basic and Applied Ecology* 14:235-245 doi:10.1016/j.baae.2013.02.002
- Trichard A, Alignier A, Chauvel B, Petit S (2013b) Identification of weed community traits response to conservation agriculture *Agr Ecosyst Environ* 179:179-186 doi:10.1016/j.agee.2013.08.012
- Trichard A, Ricci B, Ducourtieux C, Petit S (2014) The spatio-temporal distribution of weed seed predation differs

- between conservation agriculture and conventional tillage *Agr Ecosyst Environ* 188:40-47 doi:10.1016/j.agee.2014.01.031
- Tscharntke T et al. (2007) Conservation biological control and enemy diversity on a landscape scale *Biol Control* 43:294-309 doi:10.1016/j.biocontrol.2007.08.006
- Tscharntke T et al. (2016) When natural habitat fails to enhance biological pest control - Five hypotheses *Biol Conserv* 204:449-458 doi:10.1016/j.biocon.2016.10.001
- Tscharntke T, Rand TA, Bianchi FJJA (2005) The landscape context of trophic interactions: insect spillover across the crop-noncrop interface *Ann Zool Fenn* 42:421-432
- Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C (2002) Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes *Ecological Applications* 12:354-363 doi:10.2307/3060947
- Tschumi M, Albrecht M, Bärtschi C, Collatz J, Entling MH, Jacot K (2016) Perennial, species-rich wildflower strips enhance pest control and crop yield *Agr Ecosyst Environ* 220:97-103 doi:<http://dx.doi.org/10.1016/j.agee.2016.01.001>
- Tschumi M, Albrecht M, Entling MH, Jacot K (2015) High effectiveness of tailored flower strips in reducing pests and crop plant damage *Proceedings of the Royal Society B-Biological Sciences* 282:189-196 doi:10.1098/rspb.2015.1369
- Tylianakis JM, Tscharntke T, Lewis OT (2007) Habitat modification alters the structure of tropical host-parasitoid food webs *Nature* 445:202-205 doi:10.1038/nature05429
- Uyttenbroeck R et al. (2016) Pros and cons of flower strips for farmers. A review *Biotechnologie, agronomie, société et environnement* 20:1-9
- Uyttenbroeck R, Hatt S, Piqueray J, Paul A, Bodson B, Francis F, Monty A (2015) Creating perennial flower strips: think functional! In: Cimpeanu SM, Fintineru G, Beciu S (eds) *Conference Agriculture for Life, Life for Agriculture*, vol 6. Agriculture and Agricultural Science Procedia. Elsevier Science Bv, Amsterdam, pp 95-101. doi:10.1016/j.aaspro.2015.08.044
- Uyttenbroeck R, Piqueray J, Hatt S, Mahy G, Monty A (2017) Increasing plant functional diversity is not the key for supporting pollinators in wildflower strips *Agr Ecosyst Environ* 249:144-155 doi:10.1016/j.agee.2017.08.014
- Valantin-Morison M, Meynard J-M, Doré T (2007) Crop management and environment effects on insects in organic winter oil seed rape in France *Crop Prot* 26:1108-1120
- Van Maanen R, Messelink GJ, Van Holstein-Saj R, Sabelis MW, Janssen A (2012) Prey temporarily escape from predation in the presence of a second prey species *Ecol Entomol* 37:529-535 doi:10.1111/j.1365-2311.2012.01395.x
- van Rijn PCJ, Wäckers FL (2010) The suitability of field margin flowers as food sources for zoophagous hoverflies *Landscape management for functional biodiversity* 56:125-128
- van Rijn PCJ, Wäckers FL (2016) Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control *J Appl Ecol*:n/a-n/a doi:10.1111/1365-2664.12605
- van Veen FJF, Brandon CE, Godfray HCJ (2009) A positive trait-mediated indirect effect involving the natural enemies of competing herbivores *Oecologia* 160:195-205 doi:10.1007/s00442-009-1288-y
- van Veen FJF, Morris RJ, Godfray HCJ (2006) Apparent competition, quantitative food webs, and the structure of phytophagous insect communities. In: *Annual Review of Entomology*, vol 51. Annual Review of Entomology. pp 187-208. doi:10.1146/annurev.ento.51.110104.151120
- Vanbergen AJ et al. (2010) Trophic level modulates carabid beetle responses to habitat and landscape structure: a pan-European study *Ecol Entomol* 35:226-235 doi:10.1111/j.1365-2311.2010.01175.x
- Varennes YD, Boyer S, Wratten SD (2016) Nectar from oilseed rape and floral subsidies enhances longevity of an aphid parasitoid more than does host honeydew *Biocontrol* 61:631-638 doi:10.1007/s10526-016-9750-3
- Vattala HD, Wratten SD, Phillips CB, Wäckers FL (2006) The influence of flower morphology and nectar quality on the longevity of a parasitoid biological control agent *Biol Control* 39:179-185 doi:10.1016/j.biocontrol.2006.06.003
- Veddeler D, Tylianakis J, Tscharntke T, Klein AM (2010) Natural enemy diversity reduces temporal variability in wasp but not bee parasitism *Oecologia* 162:755-762 doi:10.1007/s00442-009-1491-x
- Venjakob C, Klein AM, Ebeling A, Tscharntke T, Scherber C (2016) Plant diversity increases spatio-temporal niche complementarity in plant-pollinator interactions *Ecology and Evolution* 6:2249-2261 doi:10.1002/ece3.2026
- Venturini EM, Drummond FA, Hoshida AK, Dibble AC, Stack LB (2017) Pollination reservoirs for wild bee habitat enhancement in cropping systems: a review *Agroecology and Sustainable Food Systems* 41:101-142 doi:10.1080/21683565.2016.1258377
- Veres A, Petit S, Conord C, Lavigne C (2013) Does landscape composition affect pest abundance and their control by natural enemies? A review *Agr Ecosyst Environ* 166:110-117 doi:10.1016/j.agee.2011.05.027
- Vialatte A, Plantegenest M, Simon JC, Dedryver CA (2007) Farm-scale assessment of movement patterns and

- colonization dynamics of the grain aphid in arable crops and hedgerows *Agric For Entomol* 9:337-346 doi:10.1111/j.1461-9563.2007.00347.x
- Vialatte A et al. (2017) Landscape potential for pollen provisioning for beneficial insects favours biological control in crop fields *Landsc Ecol* 32:465-480 doi:10.1007/s10980-016-0481-8
- Vickery J, Carter N, Fuller RJ (2002) The potential value of managed cereal field margins as foraging habitats for farmland birds in the UK *Agr Ecosyst Environ* 89:41-52 doi:10.1016/s0167-8809(01)00317-6
- Violle C, Navas ML, Vile D, Kazakou E, Fortunel C, Hummel I, Garnier E (2007) Let the concept of trait be functional! *Oikos* 116:882-892
- Violle C, Reich PB, Pacala SW, Enquist BJ, Kattge J (2014) The emergence and promise of functional biogeography *Proceedings of the national academy of sciences* 111:13690-13696 doi:10.1073/pnas.1415442111
- Wäckers F, Bonifay C, Vet L, Lewis J (2006) Gustatory response and appetitive learning in *Microplitis croceipes* in relation to sugar type and concentration *Anim Biol* 56:193-203 doi:10.1163/157075606777304230
- Wäckers FL (1999) Gustatory response by the hymenopteran parasitoid *Cotesia glomerata* to a range of nectar and honeydew sugars *J Chem Ecol* 25:2863-2877 doi:10.1023/a:1020868027970
- Wäckers FL (2004) Assessing the suitability of flowering herbs as parasitoid food sources: flower attractiveness and nectar accessibility *Biol Control* 29:307-314 doi:10.1016/j.biocontrol.2003.08.005
- Wäckers FL, Romeis J, van Rijn P (2007) Nectar and pollen feeding by insect herbivores and implications for multitrophic interactions. In: *Annual Review of Entomology*, vol 52. *Annual Review of Entomology*. Annual Reviews, Palo Alto, pp 301-323. doi:10.1146/annurev.ento.52.110405.091352
- Wäckers FL, van Rijn PCJ (2012) Pick and mix: selecting flowering plants to meet the requirements of target biological control insects. In: *Biodiversity and Insect Pests*. John Wiley & Sons, Ltd, pp 139-165. doi:10.1002/9781118231838.ch9
- Wäckers FL, van Rijn PCJ, Bruin J (2005) *Plant-provided food for carnivorous insects*. Cambridge University Press, Cambridge, UK,
- Wanner H, Gu HN, Gunther D, Hein S, Dorn S (2006) Tracing spatial distribution of parasitism in fields with flowering plant strips using stable isotope marking *Biol Control* 39:240-247 doi:10.1016/j.biocontrol.2006.06.001
- War AR, Paulraj MG, Ahmad T, Buhroo AA, Hussain B, Ignacimuthu S, Sharma HC (2012) Mechanisms of plant defense against insect herbivores *Plant signaling & behavior* 7:1306-1320 doi:10.4161/psb.21663
- Warner DJ, Allen-Williams LJ, Ferguson AW, Williams IH (2000) Pest-predator spatial relationships in winter rape: implications for integrated crop management *Pest Manage Sci* 56:977-982 doi:10.1002/1526-4998(200011)56:11<977::aid-ps224>3.0.co;2-u
- Webb CT, Hoeting JA, Ames GM, Pyne MI, Poff NL (2010) A structured and dynamic framework to advance traits-based theory and prediction in ecology *Ecology Letters* 13:267-283 doi:10.1111/j.1461-0248.2010.01444.x
- Weiss E, Stettmer C (1991) *Unkräuter in der Agrarlandschaft locken blütenbesuchende Nutzinsekten an*. vol Agrarökologie ; Bd. 1 Haupt, Bern,
- Welch KD, Harwood JD (2014) Temporal dynamics of natural enemy-pest interactions in a changing environment *Biol Control* 75:18-27 doi:10.1016/j.biocontrol.2014.01.004
- Wheater CP, Evans MEG (1989) The mandibular forces and pressures of some predacious coleoptera *J Insect Physiol* 35:815-820 doi:10.1016/0022-1910(89)90096-6
- Wielgoss A, Tscharnkte T, Rumedé A, Fiala B, Seidel H, Shahabuddin S, Clough Y (2014) Interaction complexity matters: disentangling services and disservices of ant communities driving yield in tropical agroecosystems *Proceedings of the Royal Society B-Biological Sciences* 281 doi:10.1098/rspb.2013.2144
- Wilby A, Anglin LA, Nesbit CM (2013) Plant species composition alters the sign and strength of an emergent multi-predator effect by modifying predator foraging behaviour *PLoS One* 8:7 doi:10.1371/journal.pone.0070258
- Wilby A, Orwin KH (2013) Herbivore species richness, composition and community structure mediate predator richness effects and top-down control of herbivore biomass *Oecologia* 172:1167-1177 doi:10.1007/s00442-012-2573-8
- Wilby A, Thomas MB (2002a) Are the ecological concepts of assembly and function of biodiversity useful frameworks for understanding natural pest control? *Agric For Entomol* 4:237-243 doi:10.1046/j.1461-9563.2002.00165.x
- Wilby A, Thomas MB (2002b) Natural enemy diversity and pest control: patterns of pest emergence with agricultural intensification *Ecology Letters* 5:353-360 doi:10.1046/j.1461-0248.2002.00331.x
- Wilby A, Villareal SC, Lan LP, Heong KL, Thomas MB (2005) Functional benefits of predator species diversity depend on prey identity *Ecol Entomol* 30:497-501 doi:10.1111/j.0307-6946.2005.00717.x
- Williams IH (2006) Integrating parasitoids into management of pollen beetle oilseed rape *Agron Res* 4:465-470
- Winder L, Alexander CJ, Holland JM, Symondson WOC, Perry JN, Woolley C (2005) Predatory activity and spatial pattern: the response of generalist carabids to their aphid prey *J Anim Ecol* 74:443-454 doi:10.1111/j.1365-2656.2005.00939.x
- Winkler K, Wäckers FL, Kaufman LV, Larráz V, van Lenteren JC (2009) Nectar exploitation by herbivores and their

- parasitoids is a function of flower species and relative humidity Biol Control 50:299-306 doi:10.1016/j.biocontrol.2009.04.009
- Winkler K, Wackers FL, Termorshuizen AJ, van Lenteren JC (2010) Assessing risks and benefits of floral supplements in conservation biological control Biocontrol 55:719-727 doi:10.1007/s10526-010-9296-8
- Winqvist C et al. (2014) Species' traits influence ground beetle responses to farm and landscape level agricultural intensification in Europe J Insect Conserv 18:837-846 doi:10.1007/s10841-014-9690-0
- Wood SA, Karp DS, DeClerck F, Kremen C, Naeem S, Palm CA (2015) Functional traits in agriculture: agrobiodiversity and ecosystem services Trends in Ecology & Evolution 30:531-539 doi:10.1016/j.tree.2015.06.013
- Wood TJ, Holland JM, Goulson D (2017) Providing foraging resources for solitary bees on farmland: current schemes for pollinators benefit a limited suite of species J Appl Ecol 54:323-333 doi:10.1111/1365-2664.12718
- Woodcock BA et al. (2009) Responses of invertebrate trophic level, feeding guild and body size to the management of improved grassland field margins J Appl Ecol 46:920-929 doi:10.1111/j.1365-2664.2009.01675.x
- Woodcock BA, Potts SG, Westbury DB, Ramsay AJ, Lambert M, Harris SJ, Brown VK (2007) The importance of sward architectural complexity in structuring predatory and phytophagous invertebrate assemblages Ecol Entomol 32:302-311 doi:10.1111/j.1365-2311.2007.00869.x
- Woodcock BA et al. (2010) Impact of habitat type and landscape structure on biomass, species richness and functional diversity of ground beetles Agr Ecosyst Environ 139:181-186 doi:10.1016/j.agee.2010.07.018
- Woodcock BA, Westbury DB, Potts SG, Harris SJ, Brown VK (2005) Establishing field margins to promote beetle conservation in arable farms Agr Ecosyst Environ 107:255-266 doi:10.1016/j.agee.2004.10.029
- Woodcock BA et al. (2008) Effects of seed mixture and management on beetle assemblages of arable field margins Agr Ecosyst Environ 125:246-254 doi:10.1016/j.agee.2008.01.004
- Wratten SD, Gillespie M, Decourtye A, Mader E, Desneux N (2012) Pollinator habitat enhancement: benefits to other ecosystem services Agr Ecosyst Environ 159:112-122 doi:10.1016/j.agee.2012.06.020
- Yoo HJS, O'Neil RJ (2009) Temporal relationships between the generalist predator, *Orius insidiosus*, and its two major prey in soybean Biol Control 48:168-180 doi:10.1016/j.biocontrol.2008.10.007
- Zaller J, Moser D, Drapela T, Frank T (2009a) Ground-dwelling predators can affect within-field pest insect emergence in winter oilseed rape fields Biocontrol 54:247-253 doi:10.1007/s10526-008-9167-8
- Zaller JG, Moser D, Drapela T, Schmöger C, Frank T (2008) Effect of within-field and landscape factors on insect damage in winter oilseed rape Agr Ecosyst Environ 123:233-238 doi:10.1016/j.agee.2007.07.002
- Zaller JG, Moser D, Drapela T, Schmöger C, Frank T (2009b) Parasitism of stem weevils and pollen beetles in winter oilseed rape is differentially affected by crop management and landscape characteristics Biocontrol 54:505-514 doi:10.1007/s10526-009-9212-2
- Zhao ZH, Hui C, He DH, Li BL (2015) Effects of agricultural intensification on ability of natural enemies to control aphids Scientific Reports 5:7 doi:10.1038/srep08024