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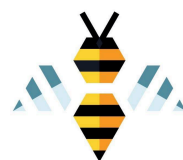


Bachelor thesis

Pollination and pest control in agricultural landscapes

The implementation of landscape elements for optimising natural pollination and pest control in the farmer collective the Waadrâne (Northern Friesland)

Anouk Boersma
May, 2020



Interreg
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Wildlife Management

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Preface

This study is conducted within the context of my bachelor thesis for the study Animal Management, with the specialisation Wildlife Management, at UAS Van Hall Larenstein. It will mark the end of my time as a student and a very exciting beginning of working life. I hope it will make a small contribution to reversing the alarming decline of insects and recreating a beautiful, biodiverse landscape, as the generations before me have known.

First of all, I would like to thank Marcel Rekers, who was either involved in or supervised me throughout all projects I worked on during my Wildlife major. He has always compassionately guided me through the processes and inspired me to change my study direction from fauna to flora by focussing on botany-related projects. Also, I could not have done this without Jozanneke Bijkerk, who not only taught me so much by always enthusiastically answering my endless list of plant-related questions, but also introduced me to the incredible world of wildflowers, where I will stay after my study is completed. I would also like to thank Arjen Strijkstra for giving me the opportunity to work on this project and sharing his passion about bees during my major. His enthusiasm for the subject is contagious.

Anouk

Leeuwarden, 2020

Summary

This thesis is a part of BEESPOKE, an international initiative to reverse the decline of wild pollinators and create more resilient agroecosystems by providing expertise, tools and financial knowledge to land managers and policy makers.

The severe decline of pollinators and other beneficial insects is a major concern in agricultural systems, leading to economic losses of billions of dollars annually. The leading factor of this decline is the deterioration of the landscape, resulting from intensification of agricultural processes. Small landscape elements used to fulfil important functions in agricultural pastures for both farmer and nature, leading to heterogenous landscapes where beneficial insect populations were able to sustain themselves. Today, landscape elements are often removed as a result of costly maintenance or loss of productive agricultural surface. Development of policy frameworks and management solutions that recreate heterogeneity by the implementation of landscape elements in agroecosystems might reinstate the ecosystem services of pollination and natural pest control. This thesis brings insight in the relationships between the target crops of BEESPOKE [squash, rape seed, potato, field beans and wheat], insects that are beneficial for their pollination or natural pest control and the landscape elements they need to survive in and around the crop in an extensive literature review:

[1] Squash, rape seed and field beans generally rely on insect pollination, although rape seed and field beans are also capable of self-pollination. Wild pollinators of these crops are bees and hoverflies.

[2] The floral structure of field beans generally requires bigger pollinating species with long tongues, whereas the shallow flowers of the other crops rely on species with short-tongues and small bodies.

[3] Wheat is completely self-pollinating and potato also does not rely on pollination for commercial cultivation, as the plant is vegetatively cloned from the tuber. However, potato plants have a rich bee community and pollination can have a beneficial influence on fighting diseases.

[4] Aphids are the most abundant transmitters of diseases of squash, potato and wheat, attracting mostly parasitoids as natural enemy. Rape seed seem to be mostly infested by beetles, which can be controlled by attracting bigger coleopterans. Weevils are predominantly associated with field beans, which are mostly controlled by coccinellids.

[5] Optimizing pollination and natural pest control of squash or rape seed requires most habitat alterations, whereas wheat seems to be least demanding.

[6] Natural enemies of all crops show preference for habitats with hedgerows, whereas pollinators can be most effectively attracted by the presence of flower strips.

The importance of planning and management of flower strips is emphasized in this study. Flower mixes of BEESPOKE have therefore been evaluated. Alterations are recommended for floral composition in squash, rape seed and field bean mixes as they contain species that attract crop-specific pests or act as reservoir for diseases or lack important species that might increase attractiveness to beneficial insects.

The findings highlight the importance of a case-specific assessment and decision-making requires species, crop- and location-specific knowledge. Findings of the literature review are therefore projected on two demonstration farms of BEESPOKE by mapping the presence, location and connectivity of beneficial landscape elements connected to the crops that will be cultivated; field beans, squash, rape seed and wheat. These maps highlight the value of the landscape for several beneficial insects, based on their habitat requirements and home range, and reveal gaps of missing landscape elements that should be implemented to optimize pollination or natural pest control.

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Glossary

- **Demo farm:** a handful of farms that will function as demonstration sites within the project of BEESPOKE. The owners of these farms are voluntarily going to produce crops that are designated to the Netherlands by the international BEESPOKE board in order to measure before- and after situations on pollinator population viability and overall biodiversity. All demo farms are located within the farmer's collective Waadrâne, which all have diverse farming strategies. Some of them are not particularly biodiverse. Others are already working on creating biodiversity for a longer period of time, most of those are focused on meadow bird conservation.
- **FAB:** abbreviation for 'functional agro-biodiversity'. Usually FAB-borders are perennial strips of a specific set of flowers along arable land that are supposed to attract valuable species (i.e. bees, worms, flies or beetles) in order to generate ecosystem services, such as pollination, good soil quality and natural pest control. The FAB-borders are usually sown on strips of land that are either less productive or difficult to farm. Due to the fact that they are located right next to the target crop field, it is believed that their agricultural functionality is higher than other landscape elements, which are usually located further away from the field (Van Rijn, et al., 2011).
- **Landscape element (LE):** elements within a landscape that provide natural, cultural or historical significance to the landscape. Natural landscape elements include 'green elements' (vegetations or solitary plant species) and 'blue elements' (bodies of water) and have a regional character (Mobach, 1987). They provide a variety of habitats and thus promote ecological balance. Examples are hedgerows, tree lines, shrubs, ponds, ditches and wildflower strips.
- **Natural pest management:** a way of sustainable farming, which strives to a minimal dependency on chemical plant protection products against pests and diseases. In this thesis, the term 'natural pest management' refers to biological control in which natural enemies of bacteria, fungi and pest insects are used. In a resilient cultivation system, useful micro- and macro-organisms are present from the start of cultivation. These organisms can therefore do their work as soon as pests or diseases break out. Such a system can be designed if there is thorough understanding of different facets of the system: pests and diseases, natural enemies, the plant its response to these organisms and all interactions between organisms (De Kogel, 2018).
- **Small-scale approach:** in spatial ecology, scale refers to the extent of ecological processes and the interpretation of data. In this thesis, the term 'small-scale' refers to the ecology of pollinators and natural pest control insects and their interacting organisms in their physical environment, the agricultural landscape. Activity of successful individuals of such species are usually limited to a radius of ten to hundreds of meters (Gathmann & Tschardt, 2002).

- **IGP**: abbreviation for ‘intraguild predation’. A predation event where a member of the guild preys upon another member of the same guild. A **guild** is defined as all species exploiting a similar resource, regardless of their nutrition mode, ecology, or taxonomic position (Root, 1967). The predator of an IGP system is defined as the intraguild predator, the prey as the intraguild prey and their common resource as the extraguild prey (Lucas, 2005).

1. Introduction

1.1 Problem statement

Anthropogenic changes in habitats and climates have resulted in substantial reductions in biodiversity of many taxa, among which insect biodiversity. A recent study from Germany shows a decrease of 76% of total insect biomass over the last 27 years (Hallmann, et al., 2017). The main driver of the current decline of pollinators and beneficial insects is the intensification of agriculture (Thomann, et al., 2013). The results are habitat fragmentation, expansion of monocultures, lack of diversity and the spraying of herbicides, fungicides and pesticides, which are major threats.

Loss of pollinating- and other beneficial insects is a matter of public concern because agricultural crops and natural plant populations are highly dependent on pollination and natural pest control (Biesmeijer, et al., 2006). Crop pollination is a clear example of an ecosystem service. Data from 200 countries show that fruit, vegetable and seed production of 87 of the leading global food crops is directly dependent on natural, insect-mediated pollination (Klein, et al., 2007). Pollinating insects also supply a valuable input to agricultural production that can increase both the size and the quality of harvests (Allen-Wardell, et al., 1998). The economic benefit of pollination has been estimated around €265 billion annually worldwide and €1 billion in the Netherlands alone (Tirado, et al., 2013).

Another key ecosystem service is the control of pests by their natural enemies. Natural pest control helps maintain long-term stability of crop ecosystems and is crucial for food security. The economic value of insect natural enemies attacking native pests of crops in the US alone is estimated around €4.9 billion annually (Naranjo, et al., 2014). Natural pest control practices involve changes to the crop environment, including the landscape in which the crop is embedded, to favour the abundance and pest-suppression activity of native natural enemies (Barbosa, 1998). Although the importance of natural pest management is being gradually more recognized in many agricultural regions, the application of synthetic pesticides remains the dominant form of pest control, which is further reducing the viability of natural pest control insect populations (López, et al., 2005). The use of broad-spectrum insecticides, for example, can damage populations of natural enemies, reducing not only beneficial insect biodiversity in the agricultural landscape, but also the cost-effectiveness of insecticide investment in the first place (Zhang & Swinton, 2009).

1.2 Objective

Almost a century ago, agricultural pastures used to be an oasis of wildflowers and insects because the needs of the farmer were aligned with the needs of nature. Food was grown on a small scale and instead of farming one crop, the farmer used to have a wide array of crops, resulting in a more heterogenous agricultural landscape with a much higher biodiversity than is the case nowadays (Flower, 2008). Until the 20th century, fields of clover were used to build up sufficient levels of nitrogen in the soil (Kjærgaard, 2003). With the emerge of inorganic fertilizer roughly halfway the 20th century, this practice was eventually abandoned. Inorganic fertilizer was in major supply after the second world war. The human population was growing and inorganic fertilizer increased the yield of the crops substantially, which was therefore preferred by farmers. Additionally, certain landscape elements used to fulfil important functions in agriculture. For example, ponds used to function as drinking places for cattle but are now replaced by drinking troughs and hedgerows used to border patches of grassland, but have now been replaced by simple fences. From an ecological perspective, these elements were

also essential to pollinator biodiversity on the farms, due to the small-scale mosaic of food sources and nesting facilities they provide (EIS, 2019). However, nowadays these small landscape elements are often removed because they are considered a nuisance to the farmer, since maintenance is costly and the space of land it takes up is not suitable for direct farming purposes (Mobach, 1987). The consequence is deterioration of ecological heterogeneity at multiple spatial and temporal scales (Benton, et al., 2003). An additional issue that has to be kept in mind is the small-scale connectivity that the densely distributed landscape elements used to provide for pollinators. Maintaining functional connectivity in the modern agricultural landscape will likely be critical for persistence of pollinator populations as these habitats are increasingly fragmented (Williams & Kremen, 2007). Monoculture grasslands only sporadically provide small ‘habitat islands’ of food sources and nesting opportunities (Steffan-Dewenter & Tscharntke, 1999). The connectivity of these islands is often too poor for pollinators to bridge, since the maximum flight distance of most pollinators is simply not long enough. This suggests that careful consideration of small-scale landscape design might be extremely important for those who are less mobile (Rands & Whitney, 2010). Bumblebees, however, are usually strong flyers and would in fact be able to cover long distances (Heinrich, 2004). This would imply that they would not experience problems when they have to continue flying in order to collect pollen from an area where food sources are sparsely distributed. However, in practice these long foraging distances hinder them in their natural activity pattern. A bumblebee colony has an energy cycle in which nectar is the source. When bumblebees are foraging, they will minimize their flight time and distance to keep their individual energy balance positive (Heinrich, 2004).

Development of policy frameworks and management solutions that can recreate a similar heterogeneity as the agricultural landscape previously described, are required in order to restore and sustain biodiversity in agroecosystems. The most practical and straightforward management solution to restore and sustain beneficial insect biodiversity is to manually reintroduce ecologically valuable elements to a deteriorated landscape in order to recreate attractive habitat. Elements of this strategy include an increased understanding of the biology and ecology of pollinators and natural enemies, as well as providing appropriate nesting habitat and ensuring the availability of alternative sources of suitable food plants in order to sustain viable populations when target crops are not in bloom (Kevan, et al., 1990). The aim of this study is therefore to provide valuable information about the ecological perspective as well as the implementation of landscape elements in order to restore attractive habitat for the conservation of pollinators and insects which are natural enemies of pests.

1.3 BEESPOKE

This thesis is part of BEESPOKE, an initiative taken by the Game & Wildlife Conservation Trust in order to reverse the decline of wild pollinators at landscape level over a period of three and a half years. The project is carried out in the framework of the Interreg North Sea Region Programme (Interreg North Sea Region, 2015). The aim of BEESPOKE is to provide land managers and policy makers with the expertise, tools and financial knowledge to create a more sustainable and resilient agroecosystem (Game & Wildlife Conservation Trust, 2019). The transnational project will develop habitat management guidelines to support the suite of pollinators required for 14 crop species on 72 demonstration sites, across 6 North Sea Region [NSR] countries: Great Britain, Belgium, Germany, the Netherlands, Denmark and Sweden. Designated crop species in the Netherlands are Squash (*Cucurbita pepo*), Rape seed (*Brassica napus*), Potato (*Solanum tuberosum*), Field bean (*Vicia faba*), herb-rich grassland and Wheat (*Triticum aestivum*). These crops will be cultivated on demonstration sites, which are located within the farmer’s collective Waadrâne, Northern-Friesland. An added factor to this thesis is

natural pest control, since natural pest control is of great interest to the executing party, in this case the farmers. Additionally, pollinators and natural pest control insects share a large overlap in habitat requirements (Shackelford, et al., 2013). This bachelor thesis will be a first step towards the greater end goal of developing an application in which members of the executing party can give up the crop they will cultivate, together with their location. They will then receive information on which local pollinators and natural enemies will be beneficial for their crop and how to attract those.

1.4 Goals and objectives

The research goal of this thesis is to obtain insight in knowledge about the relationships between target crops, beneficial insects and landscape elements through reviewing literature, together with the evaluation of possible practical measures, in this case the implementation of landscape elements, in order to recreate attractive habitat to target insect species. The second step, the management goal in this study, is to translate this knowledge into action by creating a location specific advice for two demonstration sites in the Waadrâne. The products that will be made are a literature report, including an overview table of available literature on the subject, a decision schedule and information materials, including maps of each demonstration site with a ‘before’ and proposed ‘after’ situation. This study will be divided into a literature studies and a case study involving a landscape analyses. The literature study will provide knowledge that will be more practically applied to the specific North-Frisian region of the farmer’s collective Waadrâne in the case study. The main objective in both parts is the following question:

How can landscape elements be implemented in order to optimize crop-specific pollination and natural pest control, and improve general biodiversity of pollinators in the Waadrâne area?

The literature review of this study will be focused on obtaining more general knowledge about pollination, natural pest control and the role of landscape features in these matters, answering the following sub questions:

- What is the relationship between BEESPOKE’s target crops and their wild pollinators and natural pest control insects?
- What is the impact of the implementation of landscape elements on these wild pollinators and natural pest control insects?

The case study will involve a small-scale landscape analysis for each of the designated demonstration sites within the project of BEESPOKE. This part will be focused on obtaining more location-specific advice about the implementation of landscape elements, answering the following sub question:

- What is the current situation with respect to landscape elements on BEESPOKE’s demonstration sites and which changes can be made in order to create an optimal environment for wild pollinators and natural pest control insects?

2. Methods

2.1 Study area

De Waadrâne is an area along the northern coastal strip in the province of Friesland, the Netherlands, shown in figure 1. The farmer collective has more than 145 farming and managing members and includes the municipalities of Noardeast-Fryslân, Waadhoeke and Leeuwarden, (Agrarisch Collectief Waadrâne, 2019). The focal area of this farmer collective is the protection of meadow birds, but other interests encompass overall nature conservation. The predominant landscape types in the area are terp-landscapes, salt marshes and flood plains (Provinsje Fryslân, 2019). The region is founded on both clay and sandy clay soil, which are both characterised by their nutrient-rich properties and high water-storage capacity (Londo, 2010). These properties create a very attractive landscape for agricultural purposes and historically these practices created a very open structure (Provinsje Fryslân, 2019). To represent this area, five farms voluntarily gave up either one or more of their parcels to function as BEESPOKE's demonstration sites.

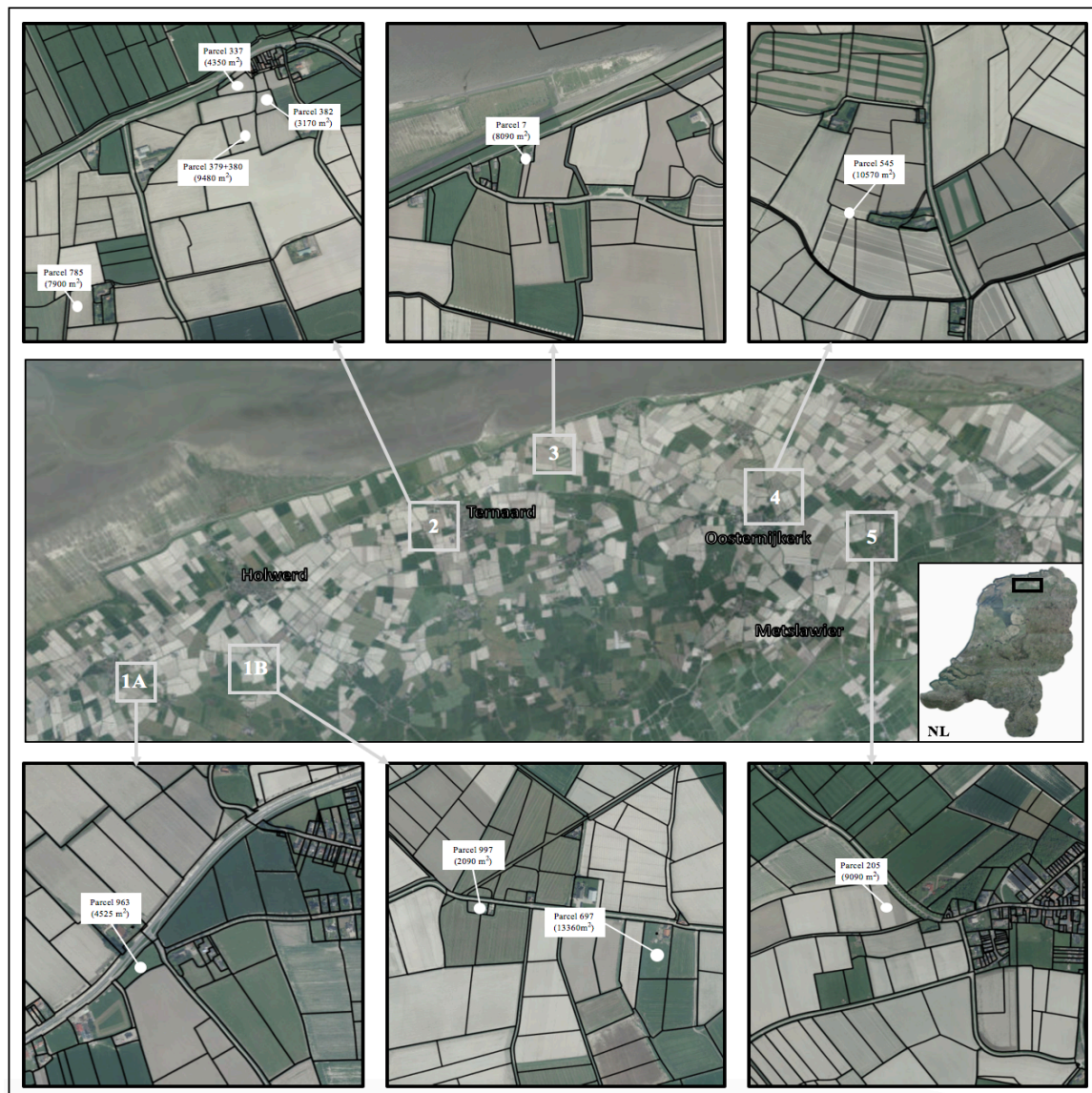


Figure 1. A map of the Waadrâne in the North of Friesland. The location of all demonstration sites for BEESPOKE is shown with parcel number and surface in square meters (Kadaster, 2019).

2.2 Research design

This research will be divided into two sections: a literature study and a case study (landscape analysis). The literature section will gather knowledge in order to answer first two research questions in this study and form a base for doing the landscape analysis. The case study will consist of mapping and analysing the current landscape situation. The case study is area-specific. It will determine the current and desired situation of the landscape on demo farms within the farmer's collective and make clear which limitations the implementation of possible landscape elements will bring about. The mapping section will answer the third research question. In this section, a design will be created in which the current situation is shown and the location and selection of landscape elements that can be implemented in order to optimize pollination, natural pest control and overall insect biodiversity.

2.2.1 Literature study

To understand the methodological approach of this study, figure 2 shows a flowchart in which the methodology for a literature search and a literature review is visually explained. The literature search methodology shows a step-wise approach to the inclusion of relevant literature. The literature review mainly shows the analysis' focus criteria, discussion and conclusion.

The focus point of this literature study will be the effect of implementing landscape elements on attracting insects that are improving ecosystem services, such as the pollination of crops and acting as natural pest control. Literature will be used to substantiate, elaborate or contradict this relatively new idea. The literature section will be divided over the two main questions in this study [paragraph 1.3]:

- [1] The relationship between insects and target crops
- [2] Creating attractive habitat for target species through implementing landscape elements

Therefore, it is important to first determine the target species within the scope of BEESPOKE. The book series of the 'Natuur van Nederland' (EIS, 1999-2012) will be used for determining the more general insect species composition in the area as a starting point for selecting target species. Depending on the geographical location, current plant composition and the target crops of the Dutch BEESPOKE department, a more specific selection can be made. Suitable literature supporting these questions will be summarized in a table, divided by landscape element. This table will give information about the author, year, target species, methodology, and results. An example of such a table is given in figure 3. Once target species are known and the relationship between them and target crops are better understood, the study will focus on finding suitable landscape elements that can be implemented in the study area to improve habitat quality for target species.

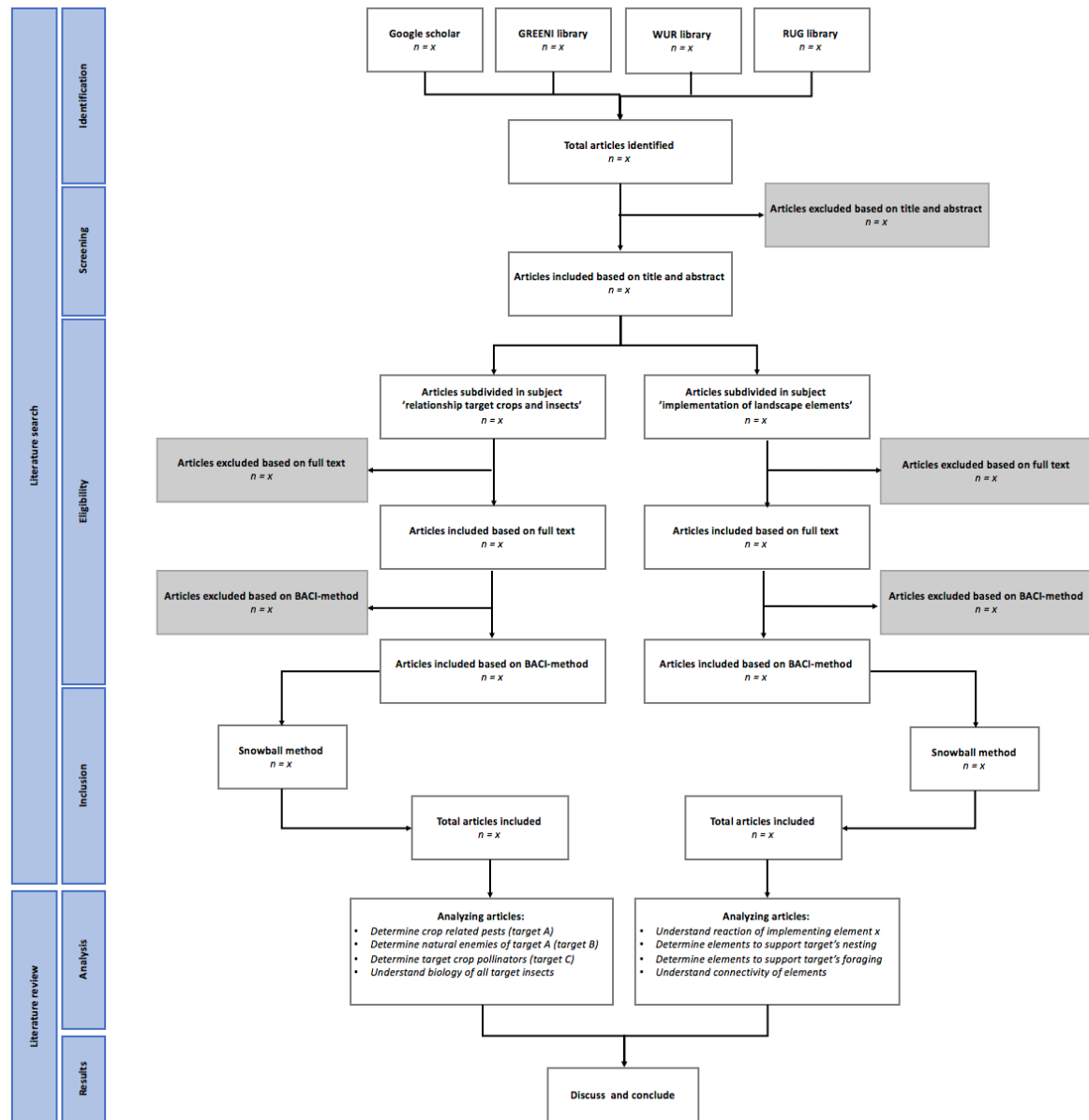


Figure 2. Schematic overview of the proposed methodology for the literature review, showing a step-wise approach to the inclusion and analysis of relevant literature.

In order to determine the suitability of certain element options, the biology of the target species has to be understood. The main criteria of suitable landscape elements are foraging facilities, nesting facilities and connectivity. Connectivity will be based on dispersal distances of each target insect. For some species, little is known about the dispersal. Where dispersal information about a bee is absent, a rough estimation will be made based on the findings of Greenleaf, et al. (2007), who found that body size and dispersal abilities are strongly correlated in stingless bees. For other species, dispersal of related species will be evaluated and used as reference. References that are used for this part of the literature study will be summarized in a separate table.

Author	Species	Methodology	Results
<i>Ditches</i>			
(Van Geert, et al., 2010)	<i>Bombus hypnorum</i> , <i>B. pascuorum</i> , <i>B. pratorum</i> , <i>B. terrestris</i>	Testing the dispersal of pollen by using fluorescent dye particles as pollen analogues in 20 patches of <i>Primula vulgaris</i> , where 13 were connected by a ditch and the others were not (<i>control-impact</i>)	Dispersal of pollen was significantly higher when crops were connected by a ditch
"	"	"	"
"	"	"	"
<i>Hedgerows</i>			
(Mondarin & Kremen, 2013)	<i>Apoidea</i> and <i>Syrphidae</i>	Pollinators were assessed in fields of tomato crops with hedgerow borders and compared to fields of tomato crops bordered with weedy, unmanaged strips of vegetation, using visual observations and pan- and net traps, 4 times per summer, 2 years in a row (<i>control-impact</i>)	Native bees and syrphid flies were more abundant, species-rich and diverse in hedgerow plots than in weedy, unmanaged areas, of which 40% of the species were exclusive to hedgerow sites
"	"	"	"
"	"	"	"

Figure 3. Example of an overview table summarizing all relevant literature per research question, in which the table for the second research question sections are made of each landscape element.

2.2.2 Landscape elements

An overview of the landscape elements used in this thesis is given in table 1, and the value of them will be briefly described afterwards.

Table 1. Overview of the landscape elements in this thesis.

Category	Biotic	Abiotic	Artificial	Linear	Organic matter
LE's	Trees	Slopes	Beetle banks	Flower strips	Leaf litter
	Forests	Bare ground	Bee hotels	Hedgerows	Compost
	Fallows	Water	Buildings	Forest edges	Manure
	Tussocks	Rocks		Fences	
				Road verges	

Solitary trees are, unlike trees in a forest, able to freely develop a natural shaped crown and are therefore characteristic elements in a landscape. This characteristic architecture provides many different opportunities, offers a variety of micro-climates. Depending on the species, the permanent aboveground parts offer food security or favourable opportunities for shelter or even nesting (Moraal, 2001). In **forests**, mainly the lower three layers (litter, herbs and shrubs) are interesting for insects. Many species use the bare ground or cavities in dead wood for nesting. Leaf litter covering the forest floor provides excellent sites for hibernation or overwintering. The herb layer of forests can also provide alternative food sources. For example, *Aegopodium podagraria* is visited by many *Andrena spp.* and *Lassioglossum spp.* and *Anemona nemorosa* is important for *Andrena bicolor* and *A. fulva*, whereas several *Bombus spp.* and *Anthophora plumipes* are often observed on *Ajuga reptans*. In the shrub layer, *Prunus spp.*, *Crataegus spp.* and *Rubus spp.* are important food sources for insects. Furthermore, **fallow vegetation** can act as reservoir for above- and belowground biodiversity. Valuable plants such as *Cirsium arvense*

and *Urtica dioica* thrive in these environments. Not only have many studies proven that the abundance of natural enemies is higher in cropping systems surrounded by fallow field margins, they also provide a stable habitat for overwintering, nesting or foraging when the arable land is inactive. **Tussock vegetation** (most often bunch-grasses) act as a similar type of reservoir to ground-dwelling insects, such as beetles and spiders. The attraction of tussock-forming vegetation compared to mat-forming vegetation is not yet fully understood, although several ecologists expect that it provides a favourable microclimate with higher temperatures and humidity, which may act as a shelter from cold (Luff, 1996).

Bare ground is used by ground-nesting bees to dig burrows and nest in it. Several studies support that nest density of ground nesting bees increased when removing plant cover (Wesserling & Tschardtke, 1995) (Edwards, 1996). The **slope** and sunlight is an important factor for ground-nesting bees. *Andrena fulva*, for example, seems to prefer nesting on flat, shaded places, whereas *Colletes hederæ* prefers sloped, sunny places. **Water bodies**, such as ponds usually have banks with a gradual transition from water to land, which means there is variation in water depths. This gives a variation of growing conditions and accommodates a diversity of plants that are providing pollinators with nectar and pollen. Purple loosestrife (*Lythrum salicaria*), for example, is a typical plant that grows along the banks of a pond or a ditch, which attracts many pollinators. Marsh woundwort (*Stachys palustris*) is favoured by the European wool carder bee (*Anthidium manicatum*) and *Angelica* species attract many hoverflies (Ottburg, 2018). The shallow water of a riparian zone also facilitates nesting of certain insect species, such as dragonflies. Ditches rather have a steep slope, which provides suitable nesting places for many bee species. Reed (*Phragmites spp.*) is a characteristic plant species along ditches in the Dutch agricultural landscape. Bee species, such as Leafcutter bees (*Megachile spp.*) and Mason bees (*Osmia spp.*), use the hollow stems of reed sections as nesting sites (Kiviat, 2013).

A **beetle bank** is an artificial ridge of approximately 0,4 m high and 2 m wide (Game & Wildlife Conservation Trust, 2020), covered with a combination of tussock and mat-forming grasses (figure 4). These banks act as refuge for many arthropod species and provide overwintering shelter for predator Coleopterans (Macleod, et al., 2004). **Bee hotels** are artificial nesting places for solitary bees, which often compose of hollow reed stems and wood with pre-drilled cavities. The visitors of these hotels depend on the composition, location and small details, such as the length of reed stems. For example, *Osmia bicornis* uses larger tubes up to 12 mm width, whereas *Megachile rotundata* mostly uses 5.5 mm tubes (MacIvor & Packer, 2015). Some species, mainly pollinators, are well adapted to anthropogenic changes and thrive in towns and cities. Cavity-nesting bees can use stone walls of **buildings** to build their nest, whereas gardens may provide suitable nesting sites for ground-nesting bees. Alternatively, **gardens** provide many flying insects, among which bees and hoverflies, with food sources. Plant selection of gardens is a major determinant whether it is attractive to pollinators, as not all exotic cultivars are suitable food plants. According to Immerzeel (2008), native plant species are more commonly used by a wide range of insects than exotic species.

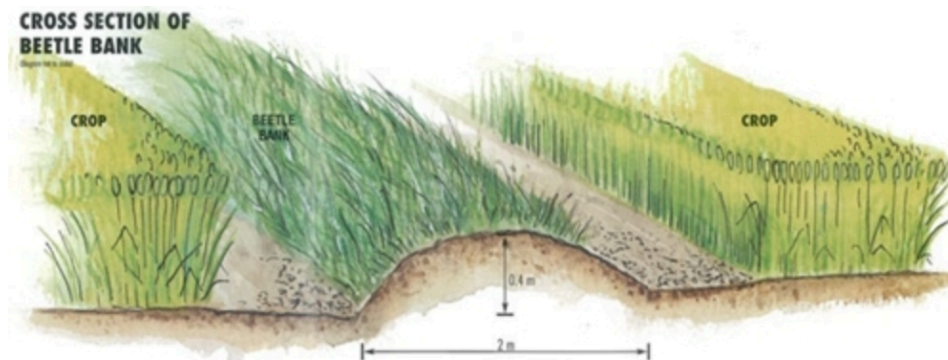


Figure 4. Cross-section of a beetle bank (Game & Wildlife Conservation Trust, 2020).

Many studies have already shown that **linear landscape elements** [LLE] can act as corridors enhancing pollen dispersal (Beier & Noss, 1998); (Haddad, et al., 2003); (Gilbert-Norton, et al., 2010). Hedgerows are an important LLE for both pollinators and natural enemies. Hollow stems of bramble, bare ground, tussocky grass and rocks provide valuable nesting opportunities for a wide array of insect species, whereas a diversity of shrub species (for example, *Craetagus monogyna*, *Rubus fruticosus*, or *Rosa canina*) provide pollen, nectar and other food sources, such as alternative aphids, throughout the season. Linear **fences** also seem to attract pollinators, as the wooden posts may provide nesting opportunity and vegetation around the posts are usually left uncut, providing a small patch of stable food sources and diversity in vegetation structure. **Field margins** are linear features thought to act as corridors for movement of fauna. They also act as overwintering and foraging habitat for many insects and act as a buffer between crop and surrounding landscape. Examples of field margins are **grassy strips**, **weedy strips**, wildflower strips, hedges or even beetle banks and fallows. Furthermore, study shows that **road verges** in the Netherlands house a large variety of both eurytopic and stenotopic and endangered insect species (Reamakers, et al., 2001). Mowing is usually done in phases, once or twice a year, resulting in a species-rich road verge (Rijkswaterstaat, 2006). There is a high degree of pollution in the verges, traffic causes disruption and because of their shape, verges are sensitive to an "edge effect" (Forman & Alexander, 1998). These circumstances create a unique microclimate that offers many ecological benefits within our intensively managed agricultural landscape (Noordijk, et al., 2006). Furthermore, in the Netherlands, management of **dikes** is usually focused on maintaining a closed mat of grasses and herbs, which protects the structure against erosion. A twice-a-year mowing regime, removing the cuttings and rotational grazing by sheep resulted in a vegetation rich in flowers. This provides many flying insects, among which bees, hoverflies, beetles and butterflies with valuable food sources. Additionally, the slope (especially if facing South) and cavities between rocks are valuable nesting sites for bees. **Flower strips** are the main focus of BEESPOKE. Wildflowers are the main food source for pollinators and in cooperation with wildflower seed distributor Cruydt-Hoeck, mixes of native flower species will be made for farmers of the Waadrâne to implement in their business strategy [paragraph 2.2.3 and table 1]. For this landscape element, the literature study will focus on the results of different implementation strategies of wildflower strips and species composition and interactions.

2.2.3 Literature search

A literature search will be conducted on Google Scholar, the Greeni catalog, the online library of the Rijksuniversiteit Groningen and the online library of the University Wageningen. Additionally, useful references used in the found studies will also be selected to complement this literature search by the means of snowballing methodology (Rijksuniversiteit Groningen, 2019). Because most of the studies are expected to differ both in aim and methodology, quantitative comparisons will be difficult to make. However, these studies are going to be used to give a qualitative idea about the relationship between target crop species and their pollinators and natural pest control insect, as well as the effect of implementing different landscape elements. Various keywords have been used in order to obtain the most complete reading list possible. The following keywords were used: 'landscape(-s)', 'landscape elements', 'pollination', 'pollinators', 'natural pest control', 'insect', 'natural enemies', 'agriculture', 'food crops', 'biodiversity', 'functional agrobiodiversity' (+FAB), 'wild bees', 'bumblebees', 'butterflies', 'moths', 'Hymenoptera', 'hoverflies', 'Apidae', 'gall midges', 'robber flies', 'Diptera', 'mites', 'parasitoid wasps', 'lacewings', 'lady bugs', 'Coleoptera', 'land cover', 'vegetation', 'water bodies', 'elevation', 'structures', 'connectivity', 'habitat fragmentation', 'linear landscape elements', 'wooded strip', 'solitary tree', 'pollard tree', 'water body', 'ponds', 'ditches', 'reed', 'riparian zone', 'water bank' and 'road verge'. All keywords were used in both Dutch and English, and of all crop and insect species the Dutch, English and scientific name were used as keywords. Also, after determination of suitable landscape elements, these will be added to the list of keywords. Every study found will be considered and determined whether suitable for this literature study, although experiments in the Netherlands or closely surrounded countries will be given priority.

The methodology focuses on a step-wise approach to exclusion of irrelevant literature, based on the title, the abstract or the full text. Ideally, round about 40 sources will be included, which is based on the length of the paper, novelty of used citations and general requirements of academic journals in the field of ecology (Milojevic, 2012). Meaning, round about 5 sources per landscape element. Furthermore, references used in this study will be assessed for usability and reliability by evaluating whether the study is constructed as a BACI-design (Smith, 2002): impact is either evaluated by measuring a before- and after situation (before-after) and/or comparing an experimental group with a control group (control-impact). Results of this assessment will be given in a table.

2.2.4 Case study

As a result of the literature review, a location-specific advice will be made. This advice will explain which landscape elements can be implemented at which locations in order to attract the right pollinators and natural pest control insects and to facilitate them with the right habitat conditions. Within the project of BEESPOKE two demo farms will be designated in the study area. These demo farms are chosen due to the fact that these are the only two that finished their cropping plan for the duration of BEESPOKE at the time of this bachelor thesis and are an excellent fit for a practical case study, due to the variety of target crops they are farming. Figure 5 (page 15) shows a flowchart explaining the proposed methodology for the case study, which shows the input and output data, processing tools, analysis and the decision-making process of currently present and absent landscape elements. The current situation regarding landscape elements will be mapped for demo farms with the use of ArcGIS (Esri, 2019). The landscape elements (paragraph 2.2.2) will be identified on each demo farm. The boundaries of target parcels will be derived from the 'Digitale Kadastrale Kaart' [DKK] (Kadaster, 2019), in order to select the landscape elements in and around the target parcels only. Information on most features will be derived from Top10NL (Kadaster, 2019), from which the layers 'terrain',

‘layout feature (line)’, layout feature (point), ‘water part (line)’ and ‘water part (area)’, buildings (area) will be used. A description of the used datasets is given in table 1. Before maps are finalized, the rough sketch of the current situation will be validated by conducting a field visit. Preparation of field visits included looking at aerial photos of Google Earth were to get an idea of landscape elements in the (broader) surrounding, which were then validated by an actual visit. During the visit, every road within the home range of the target insect was driven and two people scanned the landscape for the presence of the landscape element that had to be verified. The location of landscape elements which could not be mapped by the use of ArcGIS, such as specific tree species, rocks or bare ground or a south facing slope were also verified in the same way. An overview of the landscape elements per crop and the source it will be derived from is given in table 2.

Table 1. Metadata overview of the datasets used for the case study.

Name	Description	Format	Year	Scale	Owner
Top10NL	TOP10NL is the digital topographic basic file of the Land Registry. This is the most detailed product within the Basic Registration Topography (BRT). The file is uniform and consistent. TOP10NL is also nationwide, which means that you can use it as a basis for the entire Netherlands.	Vector	2019	1:10.000	Kadaster
DKK	The Digitale Kadastrale Kaart (DKK) dataset shows the location of cadastral parcels in relation to the surroundings. The Digital Cadastral Map contains cadastral parcel boundaries and / or planes; lot numbers; the most important buildings and street names and house numbers.	Vector	2019	1:6.000	Kadaster

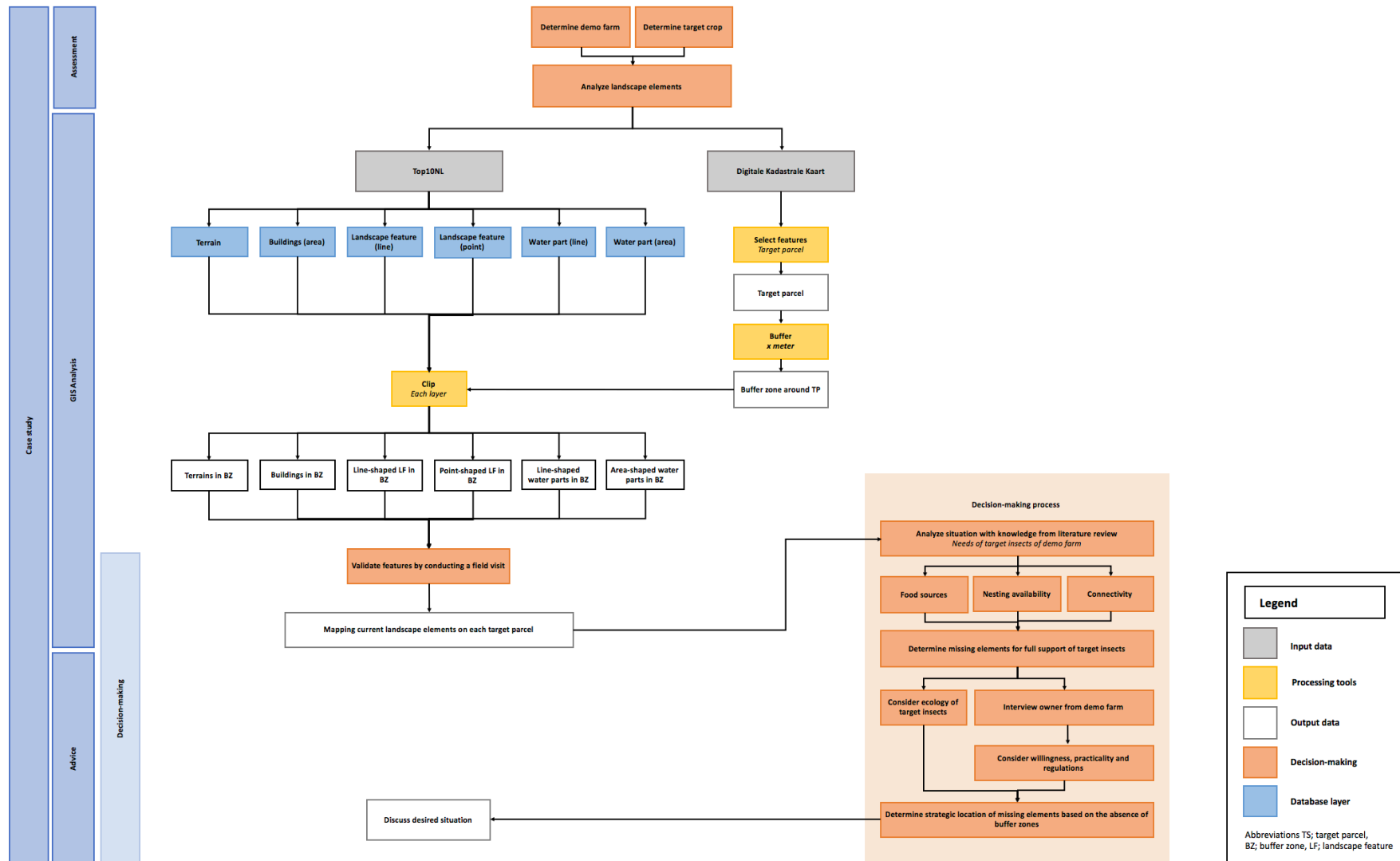


Figure 5. Schematic overview of the methodology for the case study, showing the ArcGIS-analysis and decision-making process. *Abbreviations: TP; target parcel, BZ; buffer zone, LF; landscape feature*

Table 2. Overview of landscape elements used in this case study and the source it was derived from. All layers mentioned are part of the dataset Top10NL. For some landscape elements assumptions are made in which they occur, these are marked in grey.

Landscape element	Source	Feature	Layer	Analysis
C. pepo				
Flower strip	Present, but not visible on map			
Slope facing south	<i>Field visit</i>			Discussed
Pond	ArcGIS data	Lake, puddle or pond	Water part (area)	Mapped
Hedgerow	ArcGIS data	Hedgerow	Layout feature (line)	Mapped
Fence	ArcGIS data	Fence	Layout feature (line)	Mapped
Grassy strip	ArcGIS data	Grassland	Terrain	Mapped
Weedy strip	Assumption: flower strip			Discussed
Fallow	ArcGIS data	Fallow	Terrain	Mapped
Grass tussock	<i>Field visit</i>			Discussed
Forest edge	ArcGIS data	Forest: all	Terrain	Mapped
Coniferous tree	<i>Field visit</i>	Tree	Layout feature (point)	Mapped
B. napus				
Flower strip	Present, but not visible on map			
Bare ground	<i>Field visit</i>			Discussed
<i>Salix spp.</i>	<i>Field visit</i>			Discussed
Buildings	ArcGIS data	Buildings	Terrain	Mapped
<i>Quercus spp.</i>	<i>Field visit</i>	Tree		Discussed
Decaying wood	ArcGIS data	Assumption: forest	Terrain	Mapped
Fence	ArcGIS data	Fence	Layout feature (line)	Mapped
Linear elements	ArcGIS data	All	Layout feature (line)	Mapped
Hedgerow	ArcGIS data	Hedgerow	Layout feature (line)	Mapped
Forest edge	ArcGIS data	Forest: all	Terrain	Mapped
Water	ArcGIS data	Ditch, pond	Water part (area/line)	Mapped
Grassy strip	ArcGIS data	Grassland	Terrain	Mapped
Weedy strip	Assumption: flower strip			
Fallow	ArcGIS data	Fallow	Terrain	Mapped
Coniferous tree	<i>Field visit</i>	Tree	Layout feature (point)	Mapped

S. tuberosum				
Flower strip	Present, but not visible on map			
Hedgerow	ArcGIS data	Hedgerow	Layout feature (line)	Mapped
<i>Salix spp.</i>	<i>Field visit</i>			Discussed
Grass tussock	<i>Field visit</i>			Discussed
Forest edge	ArcGIS data	Forest: all	Terrain	Mapped
Bare ground	<i>Field visit</i>			Discussed
Field margins	Assumption: flower strip			Discussed
Roadside verge	ArcGIS data	Assumption: grassland	Terrain	Mapped
Fallow	ArcGIS data	Fallow	Terrain	Mapped
Grassland	ArcGIS data	Grassland	Terrain	Mapped
Decaying wood	ArcGIS data	Assumption: forest	Terrain	Mapped
Buildings	ArcGIS data	Buildings	Buildings (area)	Mapped
Fence	ArcGIS data	Fence	Layout feature (line)	Mapped
Garden	ArcGIS data	Buildings	Terrain	Mapped
V. faba				
Flower strip	Present, but not visible on map			
Dikes	ArcGIS data	Basalt blocks	Terrain	Mapped
Grass tussock	<i>Field visit</i>			Discussed
Beetle bank	<i>Field visit</i>			Discussed
Hedgerow	ArcGIS data	Hedgerow	Layout feature (line)	Mapped
Forest edge	ArcGIS data	Forest: all	Terrain	Mapped
<i>Tilia, Salix, Populus</i> or <i>Platanus</i>	<i>Field visit</i>	Tree	Layout feature (point)	Discussed
<i>Quercus spp.</i>	<i>Field visit</i>	Tree	Layout feature (point)	Discussed
T. aestevium				
Hedgerow	ArcGIS data	Hedgerow	Layout feature (line)	Mapped
Forest	ArcGIS data	Forest: all	Terrain	Mapped
Buildings	ArcGIS data	Buildings	Buildings (area)	Mapped
Leaf litter	ArcGIS data	Assumption: forest	Terrain	Mapped

Once current landscape elements are mapped, it is important to determine whether all important habitat requirements of target insects are present within their dispersal ranges and which should be added. For this evaluation, landscape elements are divided into [1] critical LE's, on which one or more species directly depend, [2] beneficial LE's, which are likely to attract greater abundance of target species, [3] easy to add LE's (which is usually small, mobile and not distinguishable on maps) and [4] LE's used by more than 3 target species. Decision-making is based on this division. Connectivity is another important factor of decision-making, which will be determined by adding buffer zones around the target parcel. The radius of the buffer zone is representative for the mobility of the five most representative target species, so that the habitat quality can be evaluated from their perspective by comparing their requirements to the current landscape situation. Additional information will be derived by measuring the distance to the nearest landscape element with the measuring tool in ArcGIS. This distance will be compared to the mobility of the least mobile target species making use of the element. Information on mobility of target species is extracted from literature, if available. In case the mobility of a target species is not yet studied, this information is derived from an assumption that it is similar to the mobility of a closely related species, or, in case of solitary bees, body size (Greenleaf, et al., 2007). The goal is to determine per location and crop, which landscape elements are present and accessible and which are still missing or out of reach. A location-specific advice will be formed for the two demonstration farms, based on this information.

Specific landscape features that need a different approach are wildflower strips. A general seed mixture will be developed for BEESPOKE crops in the Netherlands. This seed mixture will be highly location specific and data on native vegetation in the study area will be derived from the biological classification system SynBioSys (Wageningen University & Research, 2019). The proposed step-wise inclusion of species is shown in figure 6. Once a list of all vegetation in the area is derived, a rough selection will be made, excluding grasses, shrubs and other unsuitable plant species. Grasses are generally growing quickly and outcompete wildflowers, giving them no room to develop after sprouting. Shrubs are considered unsuitable for flower mixes because it is not only a different type of vegetation, it is also impractical with mandatory maintenance practices, such as mowing. Other unsuitable plant species are for example plants that are simply not available or don't fit into certain vegetation types. Vegetation from the following associations are commonly used in the process of designing flower mixes: *Koelerio-Coryneporetea*, *Festuco-Brometea*, *Molinio-Arrhenatheretea*, *Melampyro-Holcetea mollis* and *Artemisietea vulgaris*. These associations are preferred due to their grassland-associated nature (Schaminee & Haveman, 2019). The second step is to assess a set of criteria for each individual plant species in the list (table 3).

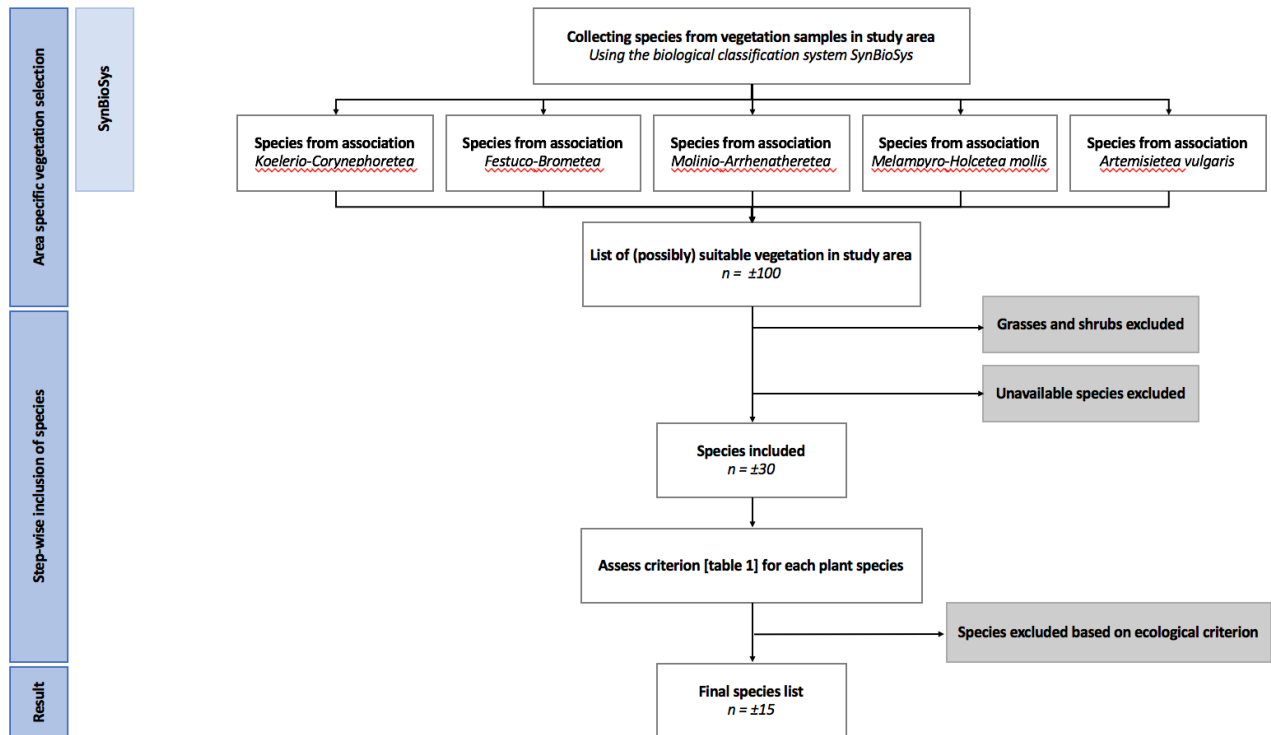


Figure 6. Schematic overview of the proposed methodology for the case study, showing the GIS-analysis and decision-making process.

Table 3. the set of criteria for each individual wildflower species considered for the seed mixture.

Criteria	Specifics	Category
Aesthetics	<i>'Is the plant considered visually pleasing?'</i>	
Price	<i>'What price category is the seed of this plant in if purchased?'</i>	
Availability	<i>'Are seeds of this species in stock or available elsewhere?'</i>	
Natural enemies	<i>'For which natural enemies is this plant attractive?'</i>	Gall midgets Hover flies Lady bugs Lace wings Parasitoid wasps Other
Development	<i>'What is the lifespan of the plant?'</i>	Annual Biennial Perennial
Poisonous	<i>'Is this plant suitable for livestock feed?'</i>	
Taproot	<i>'Does this plant have a taproot? [soil structure]'</i>	
Nitrogen-fixing	<i>'Does this plant fix nitrogen in its roots?'</i>	
Flowering time	<i>'When is this plant in bloom?'</i>	Early spring Spring Summer Late summer
Flower depth	<i>'How deep is this flower? [pollinator accessibility]'</i>	Deep Shallow
Specialist	<i>'Does this plant have a depending pollinator specialist?'</i>	
Foraging	<i>'Does this plant offer nectar, pollen, or both?'</i>	Nectar Pollen

All selection criteria for natural enemies and pollinators are target crop specific. For example, pumpkins are sensitive to infestations by the green peach aphid (*Myzus persicae*), so plant selection for a wildflower mixture surrounding this crop should show preference for plants that host or support natural enemies of this specific aphid. Knowledge on floral preference of beneficial insects or plant species that act as natural reservoir of pests or diseases of the crop will be derived from the literature review and implemented in the design. For the selection criteria development time, the preference will always be given to perennial plants because they provide more stable habitat conditions and are therefore more suitable in supporting viable insect populations. Additionally, a selection of plants with a wide variety of flowering time will be made in order to provide a stable food source and support the formation of social insect colonies, such as bumblebees (*Bombus spp.*). Whether a plant is able to fix nitrogen in the soil, is of great interest for agriculture, since nitrogen is a primary nutrient which is essential for building strong plants with healthy growth. Nitrogen-fixing plants convert nitrogen from the air into a form that is useable for plant roots (Sprent & Sprent, 1990). The most important nitrogen-fixing symbiotic association is the relationship between the economically important legume family (*Fabaceae*) and *Rhizobium* or *Bradyrhizobium* bacteria (Phillips, 1980). Furthermore, flower depth is highly related to tongue length of pollinators, affecting their nectar foraging efficiency (Nilsson, 1998). When a plant species is host to a specialised target insect, and its presence is thus crucial to that insect's survival, this species is given priority in a seed mixture. Accountability of the decision-making process is mainly based on ecology, but within this project it is important not to disregard practicality. Examples of the more practical criterion are aesthetics, price and availability. The results of these flower mixes are given in appendix I.

3. Review

3.1 Pollination needs

Target crops in this study are Squash (*Cucurbita pepo*), Rape seed (*Brassica napus*), Potato (*Solanum tuberosum*), Field bean (*Vicia faba*), Wheat (*Triticum aestivum*) and herb-rich grassland. Each target crop is carefully considered to determine pollinating insects and natural enemies valuable to these crops. Efficiency of pollinators can be measured in parameters such as visitation frequency, pollen harvest and deposition and fruit and seed set due to their visits (Ne'eman, et al., 2010). These parameters help in measuring overall performance of a pollinator and the reproductive success of the plant. The potential wild pollinators of each target crop are given in appendix II, and further elaborated in this paragraph. An overview of the used literature per crop species is given in appendix III, in which target species, methods and results are briefly described.

3.1.1 *Cucurbita pepo*

Cucurbita pepo is monoecious, meaning that one plant has both male and female flowers. Natural fertilization of this species is generally carried out by insects. Niche complementarity, both spatial and temporal, is an important factor in the pollination of *Cucurbita* species. Hoehn, et al. (2008) have found that pollinator diversity, rather than abundance, was positively related to the seed set of pumpkins. Their study measured flower visiting height, flower visiting time of the day and body size of the pollinator. Species differed in their visitation height, with some species showing clear preference for the low-laying flowers and others for the higher ones. Temporal species turnover showed even stronger differences. Flowers of *C. pepo* open before daylight and close around 11 a.m. (Amaral & Mitidier, 1966). To increase pollinating effectivity, bee activity needs to be in synchronization with the opening of flowers (van Wijk, et al., 2008). The same study also shows that body size was closely related to pollinator behaviour. Pollinators with a larger body size visited more flowers, but only distributed pollen on the surface of the flower, whereas smaller pollinators could reach the deeper parts of the flower (Hoehn, et al., 2008). Although many insects, including cucumber-, scarab-, and meloid beetles, flies and moths are also involved, bees are the major pollinators (Michelbacher, et al., 1964). Many authorities give primary credit to the honey bee (*Apis mellifera*) for the pollination of *C. pepo*. Walters & Taylor (2006), for example, have found increased fruit set, size, weight and number of seeds per fruit where honey bees were managed for pollination. Other studies, however, suggest that *A. mellifera* is less effective in pollinating *C. pepo*, due to uncertain visitation patterns when competing crops are nearby (Westerkamp, 1991). Linsley (1961) also showed their inefficacy in harvesting pollen from the anthers. Mudssar, et al. (2014) draws attention to the importance of native insect pollinators in Pakistan and have found that *Lassioglossum* spp., *Halictus* spp., and *Eristalinus aeneus* (among other species foreign to the Netherlands) pollinated *C. pepo* effectively in areas where honeybees were less abundant, with emphasis on the greatest pollination effectivity of *Halictus* spp. (table 7).

Table 7. Pollination effectiveness of three pollinators of *Cucurbita pepo* in terms of pollen harvest and deposition along with fruit set per single visit (Mudssar, et al., 2014)

Pollinator species	Pollen harvesting (n=50)	Pollen grains deposited /stigma/visit (n=30)	Single visit fruit set (%) (n=30)
<i>Lasioglossum</i> spp.	582.80 ± 80.22	138.45 ± 13.05	13.33
<i>Halictus</i> spp.	798.45 ± 109.39	177.85 ± 16.31	20.0
<i>Eristalinus aeneus</i>	106.65 ± 12.56	70.95 ± 07.64	6.66

Furthermore, the Food and Agriculture Organization (FAO) names *Ceratina* spp. as a bee genus that is positively linked to the pollination of *C. pepo*, of which the only species occurring in the Netherlands is *Ceratina cyanea* (EIS , 1999-2012).

3.1.2 Brassica napus

Brassica napus is entomophilous. This means that the plant is cross-pollinated through insects, although it is also capable of self-pollination. Faegri and van der Pijl (1971) explain that the flower of *B. napus* has an open structure, which almost all groups of pollinating insects can feed from. Many studies show that insect pollination is favourable in terms of both qualitative as quantitative yields, as pollination can not only enhance the yield of the crop, but also contributes to uniform and early pod setting. (Sabbahi, et al., 2005) (Kevan & Eisikowitch, 1990) (Williams, et al., 1987). It is widely believed that honey bees are responsible for most of *B. napus* pollination, however, Button & Elle (2014) point out that pollination deficit levels are never significantly reduced by honey bees alone and that wild pollinators are much needed to maximize yields in pollinator-dependent agricultural systems.

Jauker, et al. (2012) studied the pollination efficiency of *Osmia bicornis* and two species of hoverflies (*Eristalis tenax* and *Episyrphus balteatus*) provided to *B. napus* in Germany and compared them to the efficiency of honey bees (figure 7). The yield of *B. napus* pollinated by wild pollinators in high densities was comparable to the yield of *B. napus* pollinated by a small colony of honey bees. The hoverflies, however, required a five times higher population density than *O. bicornis* in order to get the same yield and therefore seemed less efficient. Another study from Germany contradicts the inefficiency of hoverflies as pollinators, which found a significant increase in both seed set and yield when *B. napus* was pollinated by *Episyrphus balteatus* (Jauker & Wolters, 2008). They point out that, in contrast to bee pollination, the effect of *E. balteatus* was lower at high pollinator densities than at low pollinator densities, suggesting adverse effects of density-dependent factors on pollination efficiency at high density. Another study, conducted in Ireland, compared the relevance of 25 wild pollinators and honey bees in terms of visitation, abundance and amount of pollen carried (Stanley, et al., 2013). They found that *Eristalis* hoverflies and bumblebees (specifically *Bombus sensu stricto* (a.k.a *Bombus terrestris* complex) and *Bombus lapidarius*) were the best wild pollinators of *B. napus*. Both bumblebee species had the highest visitation rate per *B. napus* flower, also compared to honeybees, but *Eristalis* hoverflies were the most abundant flower visitor. Additionally, Mudssar, et al. (2009) tested the efficiency of 17 species in pollinating *B. napus* in Pakistan, among which 9 species naturally occur in the Netherlands. Five of these species showed a significantly higher number of either harvested or deposited pollen grains than the others, shown in table 8. *Andrena* spp. had the highest visitation rate and collected most pollen, whereas

Halictus spp. deposited more pollen grains in a single visit. Pollination by *Halictus spp.* also resulted in a higher seed set.

Figure 7. Pollination effectivity of *Osmia bicornis*, *Eristalis tenax* and *Episyrphus balteatus* compared to honey bees in terms of fruit set, seeds per pod and yield (Jauker, et al., 2012).

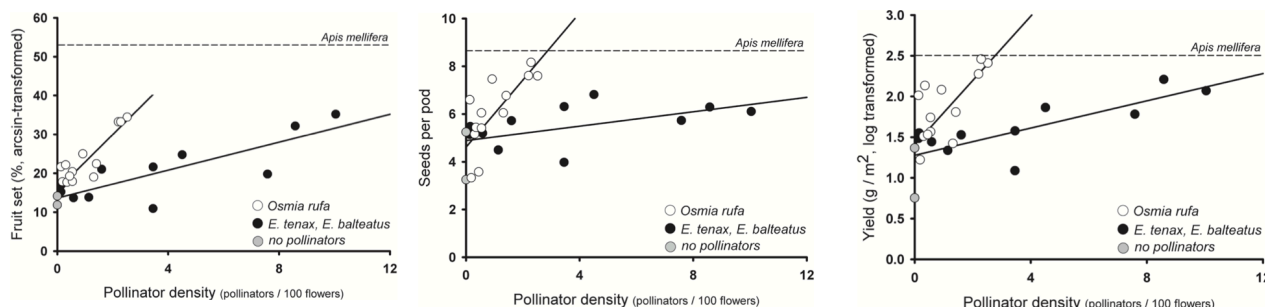


Table 8. Pollination effectivity of five pollinators of *Brassica napus* in terms of pollen harvest and deposition along with visitation rate per minute (Mudssar , et al., 2011).

Pollinator species	Pollen harvesting (n=10)	Pollen grains deposited /stigma/visit (n=50)	Visitation rate of flowers visited/min (n=100)
<i>Halictus spp.</i>	148.46 ± 17.23	293.86 ± 48.34	3.00 ± 0.31
<i>Andrena spp.</i>	635.30 ± 113.14	175.20 ± 24.38	15.44 ± 0.57
<i>Episyrphus balteatus</i>	104.20 ± 27.13	64.26 ± 13.82	2.17 ± 0.31
<i>Eupeodes corollae</i>	96.30 ± 12.22	50.26 ± 16.82	2.00 ± 0.53
<i>Eristalinus aeneus</i>	127.10 ± 13.67	116.20 ± 27.86	4.45 ± 0.67

3.1.3 Solanum tuberosum

Solanum tuberosum is also a monoecious plant, containing male and female flowers on one plant. For commercial production, pollination does not have to occur for propagation, as the plant is vegetatively cloned from the tuber. The flowers of commonly used *S. tuberosum* provide only pollen and are very attractive to many pollen collecting insect species and therefore still add to the biodiversity potential of an agroecosystem. Cross-pollination, which is mostly carried out by insects, might still be valuable for *S. tuberosum* in cultivars that provide nectar. Corporaal & Stortelder (2013) found that the pollination of bumblebees can protect potatoes from *Phytophthora infestans* (Kleis, 2013). This plant damaging water mold causes potato blight, which is capable of causing enormous economic losses (Erwin & Ribeiro, 1996). This study compared two plots of *S. tuberosum*, of which both were isolated in a cage. One cage housed bumblebees and the other did not. The underground parts of only two plants in the bumblebee plot were affected by *Phytophthora*, whereas the underground parts of twenty plants were affected under the normal circumstances. Generally, there is major lack of information about the insect species that can be found in potato fields, with the exception of Buchanan, et al. (2017), who maps out the bee community of commercial potato fields in Michigan. Four of these findings were also native to the Netherlands, i.e. *Halictus rubicundus*, *H. confusus* and *Lassioglossum leucozonium* and *L. zonulum*.

3.1.4 *Vicia faba*

Although *Vicia faba* is a self-fertile crop, the floral biology tends to cause weak self-incompatibility (Stoddard & Bond, 1987). Cross-pollination through flower visitors results in more outcrossed individual, which are more vigorous and produce higher yields than inbred individuals (Fyfe, 1954). Several studies showed that the yield increased between 40% to 185% when *V. faba* were pollinated by insects (Bartomeus, et al., 2014) (Nayak, et al., 2015). Other benefits of insect pollination of *V. faba* is a more synchronous pod set, resulting in more even ripening of the pods (Kendall & Smith, 1975). In temperate regions honey bees and bumblebees are the primary pollinators, occasionally together with solitary bees (Bond & Poulsen, 1983) (Garratt, et al., 2014) (Nayak, et al., 2015).

Stoddard & Bond (1987) report that *Bombus ruderatus*, *Bombus pascuorum* and *Bombus hortorum* are reliable pollinators of *V. faba*, due to their long tongues being compatible with the long corollas of *V. faba* flowers. *Bombus terrestris* and *Bombus lucorum*, however, are more likely to rob the flower of nectar and therefore play a less important role in pollen displacement (Kendall & Smith, 1975). Marzinzig, et al. (2018) further eliminates this result, finding that the two locally most dominant pollinators in Germany, the honey bee and *B. terrestris* agg., did not provide efficient pollination service due to robbing behaviour. In contrast, they found that the less frequent and more specialised species, *B. hortorum*, was the most efficient pollinator of *V. faba*, followed by *Bombus lapidarius* (table 9). Another study conducted in Denmark, found bumblebees to be less numerous than honey bees, but –specifically *B. hortorum*- seemed to be much more efficient (Poulsen, 1973). Bond & Kirby (1999) studied the effectivity of *Anthophora plumipes* as pollinator of *V. faba*, and compared them to honeybees, *Bombus hortorum* and *Bombus pascuorum*. Not only was *A. plumipes* observed in greater numbers than the other species, they also visited more flowers per minute (13,8) compared to *B. pascuorum* (9,2).

Table 9. Pollination effectiveness of five pollinators of *Vicia faba* in terms of species abundance and foraging behaviour. Abbrev. EFN – nectar collection on extrafloral nectaries (unsuccessful pollination) (Marzinzig, et al., 2018).

Pollinator species	Observations	Foraging behaviour (% of all observations)		
		Pollination	Nectar robbing	EFN
<i>Apis mellifera</i>	4176	20.7	39.7	39.5
<i>Bombus terrestris</i>	2727	31.1	67.4	1.5
<i>Bombus hortorum</i>	320	97.2	2.8	0.0
<i>Bombus lapidarius</i>	130	87.5	12.5	0.0
<i>Bombus pascuorum</i>	95	78.3	13.0	8.7

3.1.5 *Triticum aestivum*

Triticum aestivum is chasmogamous, meaning that they open their flowers after self-pollination is completed. Cross-pollination is required to produce hybrid seeds, but this rarely happens in nature (Okada, et al., 2017). Therefore, this crop species is not interesting for further research on pollinators.

3.1.6 Herb-rich grassland

Herb-rich grassland is one of several agricultural nature types that is recommended and subsidised by the Dutch government (BIJ12, 2019). Study shows that both abundance and diversity of insects is higher in herb-rich grassland than in sown grass margins and natural regeneration (Sheridan, et al., 2008). Herb-rich grassland is often used as part of a FAB-based practice to provide alternative food sources and overwintering sites for pollinators and natural pest enemies (ELN-FAB, 2012). This crop is different from the other BEESPOKE crops, since it contains many (wild) plant species, which all have different pollination needs.

In practice, the species composition of herb-rich grassland depends on management of the grassland and/or the choice of seed mixture, which in turn depends on location, soil type, management type, personal preference, financial possibilities, etc. The right choice of species and sustainable, goal-oriented management contribute vastly to a biodiverse end result. Nowadays, the Dutch market offers many seed mixes with a large proportion of exotic plants. These colourful, exotic mixes are also known as carnival mixes. Immerzeel (2018) studied the biodiversity potential of carnival mixes and compared them to locally native mixes. He found that native plants made a higher contribution to biodiversity and were used by many more insects than carnival mixes. Furthermore, in the choice of species composition, annual plants are often preferred, in order to have a faster and more colourful result. A high proportion of annuals in a seed mixture inhibits the development of the perennials by growing rapidly and taking away light and nutrients from the soil. However, study shows that many ecosystem services, such as methane consumption, pest suppression, conservation of grassland birds and pollination is higher in grasslands rich in perennial plants (Werling, et al., 2014). Additionally, in many cases the management measures are not properly adjusted to have a positive influence on biodiversity. A Dutch study evaluated the effectivity of management of botanical grassland. They found that biodiversity rapidly decreased when management was less intensive or even absent and pernicious weeds and vigorous grasses were more suppressed as management got more intensive (Melman, et al., 2010). Regular and well-timed mowing is important to interfere with the natural succession of the grassland and therefore maintain the current vegetation (Hamelink & Kristalijn, 2009). Removing the cuttings after mowing is essential for developing and maintaining a grassland low in nutrients. A nutrient-low soil generally promotes a more flower-rich vegetation to develop and works to the disadvantage of fast growing plant species.

Many species in an herb-rich grassland are not as well studied as commercial crop species. However, estimating the biodiversity of this type of grassland can be very valuable, as it has both a high ecologic and economic potential (Krautzer, 2014). Also, herb-rich grassland gained a lot of popularity recently. The sales figures of Limagrain, a prominent Dutch supplier of agricultural seeds, show that the sale of herb-rich grassland mixes in the Netherlands increases with 30%, every year (Limagrain, 2018).

In order to determine the biodiversity value of herb-rich grassland, representative plant associations are used in this review. In practice, *Plantagini-Lolietum perennis* is a realistic starting situation for many nutrient-rich grasslands. This association is very common in the Netherlands, because it thrives on compacted soil, which is a characteristic result of agricultural management practices. Another realistic starting situation in the Netherlands would be *Ranunculo-Alopecuretum geniculati*, which is more widely represented in moister environments (Cruydt-Hoeck, 2019). Both associations are relatively low in presence and number of herb species, whereas they are high in abundance of grasses. The ambition is to transform these vegetations into a more species-rich grassland, which, depending on the location, would ideally be represented by *Lychnido-Hypericetum tetrapteris* on moist, non-

fertilized soil, *Ranunculo-Senecionetum aquatici* on non-calcareous, moist (clay) soil, *Fritillario-Alopecuretum pratensis* on seasonally flooded, sandy clay or clay soil which is not fertilized or grazed on, or *Arrhenatherum elatioris* on calcareous, moist clay, sandy clay or silty soil (Schaminée, et al., 2010). An additional vegetation class used as reference is *Nardetea*, which grows on slightly acidic, dryer sandy or loamy soil. In the Netherlands, *Nardetea* associations are rare due to their sensitivity to human supply of Sulphur and Nitrogen, which seriously affects its acid buffering ability (Van der Zee, et al., 2017). Therefore, the most common, or least sensitive species from several *Nardetea* associations are combined into one vegetation composition in cooperation with the Cruydt-Hoeck, in order to increase the likeliness that it will successfully develop. The gradual transformation of the starting situation into the ideal situation takes time and highly depends on location and management. The situation will most likely not result in the full potential of the associations. Realistically, a combination of plant species from the starting association and the desired association will establish over time (Cruydt-Hoeck, 2019). Therefore, a selection is made of the most realistic set of plant species for each situation described above, in which grasses, mosses, wind-pollinated plants, poisonous or unwanted plants for fodder crops and rare plants are excluded (Appendix II). An overview of the associated bee species of these plant compositions are given in a separate Excel document: 'BT BEESPOKE Herb-rich grassland'.

3.2 Pests and their natural enemies

Some predators, for example *Aphidoletes aphidimyza*, are specialized on aphids. However, most predators have polyphagous habits and are rather generalist predators, such as lacewings or lady beetles, which also include spider mites, thrips, whiteflies, coleopteran/lepidopteran eggs and larvae in their diet (Hodek, 1996). Generalist predators may be able to inhibit aphid populations growth sufficiently to prevent an outbreak. However, aphids are low quality food compared to alternative prey types (e.g. *Collembola* or *Diptera*) for many generalist predators. The generalist predators rely on alternative prey for maintenance and reproduction and therefore, the presence of alternative (higher quality) prey can largely influence the impact of generalist predators on aphid natural control (Toft, 2005). Within intra guild predation systems (IGP; glossary), aphids usually constitute the extraguild prey (figure 8). Generalist predators within such a system might compete for prey, in which case biological control of aphids is impaired or even adversed (Lucas, 2005). For example, in alfalfa fields, the generalist predator *Pterostichus melanarius* disrupted biological control of the aphid *Acyrtosiphon pisum* by preying on another aphidophagous predator *Aphidius ervi* (Snyder & Ives, 2003). However, several other studies suggest synergistic effects of predators, leading to more effective control of extraguild prey. For example, the effect of biological control of pea aphids, *Acyrtosiphon pisum*, is optimised when both generalist predator *Coccinella septempunctata*, and parasitoid wasp *Aphidius ervi* are present, despite intraguild predation of *C. septempunctata* on *A. ervi* (Weisser, 2003).

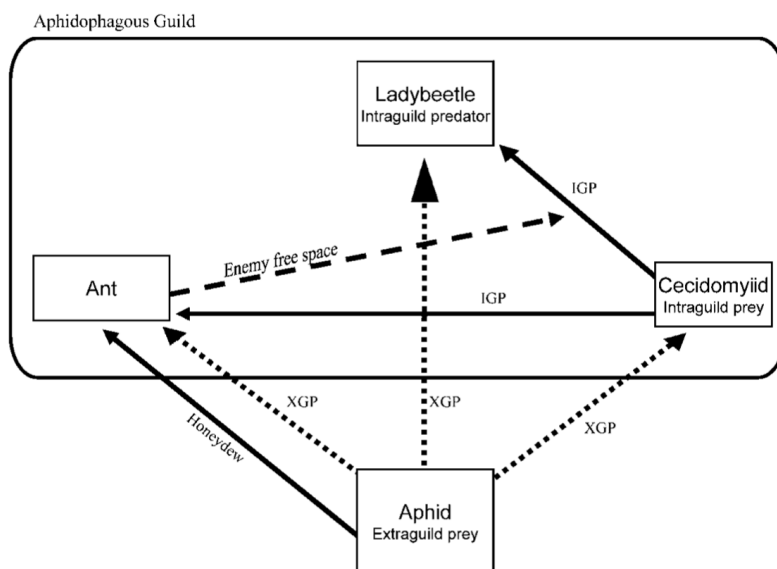


Figure 8. An example of an aphidophagous IGP system in which arrows indicate the direction of the interaction, pointing towards the predator. Abbr. XGP – extraguild predation.

The literature that is used to describe and understand the relationship between the target crop species, their pests and natural enemies is summarized in Appendix IV, in which methods and results are briefly described. Herb-rich grassland is excluded from the literature review on pests and natural enemies, because it is not, unlike the other crops, used for commercial harvesting. Therefore, it is not necessarily negatively affected by pests and the species composition is too complex and variable to get relevant results. However, the primary host plants of certain pests of the other target crops are given when found in the literature. This gives the possibility to include this information in the decision-making process of designing seed mixes for herb-rich grassland.

3.2.1 Cucurbita pepo

The leaves and stems of *C. pepo* contains spiky hairs, which generally protects them against damage caused by insects. The two most well-known diseases in the cultivation of *C. pepo* are powdery mildew (*Sphaerotheca fuliginea*) and the **Zucchini yellow mosaic virus** (ZYMV). In the Netherlands, *S. fuliginea* is not a major threat to *C. pepo*, as it develops late in the growing season and usually does not have any negative effects on the harvest anymore (Minderhoud & Troost, 2008). The ZYMV, however, can severely inhibit growth and cause fruit deformation, and therefore dramatically reduce yields in many members of the *Cucurbitaceae* family (Gallon, 2007). The virus overwinters in weeds and is then efficiently transmitted by aphids. Svoboda & Polák (2002) studied the distribution, variability and overwintering of the ZYMV in the Czech Republic. They found that *Tripleurospermum maritimum*, *Stellaria media* and *Trifolium repens* were common overwintering hosts. Other studies also found *Ranunculus sardous* (Perring, et al., 1992), *Senecio vulgaris* (Desbiez & Lecoq, 1997), *Matricaria discoidea* and *Trifolium repens* (Fletcher, et al., 1999) to be natural reservoirs of the ZYMV.

Transmission of the ZYMV is primarily carried out by *Aphis gossypii* and *Myzus persicae*, although *M. persicae* is more efficient in lower temperatures and humidities than *A. gossypii* (Ferreles, et al., 1992). De Backer, et al. (2015) studied the predation effectivity of the mirid predator *Macrolophus pygmaeus* on *M. persicae* and found that *M. pygmaeus* managed to reduce numbers of *M. persicae*, but was not able to fully eradicate the aphid population (figure 9).

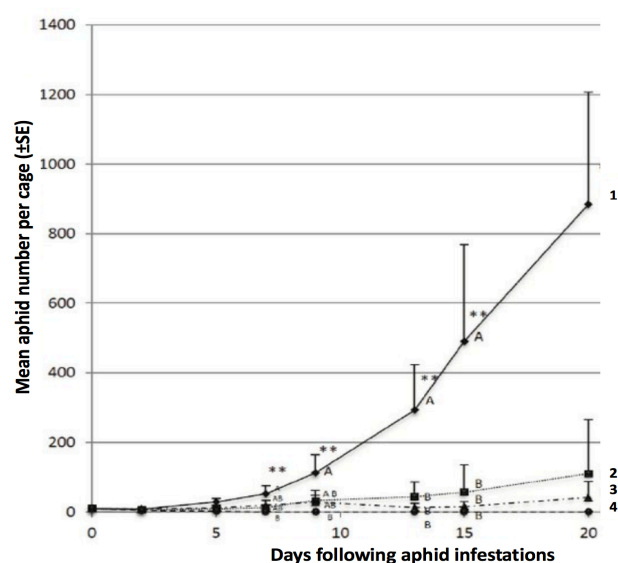


Figure 9. The evolution of mean number *M. persicae* in cages (n=4), in presence of either [1] 0 *M. pygmaeus*, [2] 16 *M. pygmaeus*, [3] 32 *M. pygmaeus* or [4] 48 *M. pygmaeus* (De Backer, et al., 2015).

In Keles, et al. (2016), *Coccinella septempunctata* was the most common natural enemy of *M. persicae* and Cabral, et al. (2009) studied the effectivity of another coccinellid preying on *M. persicae*: *Coccinella undecimpunctata*. Under controlled conditions, they found that larvae of *C. undecimpunctata* were satiated when 130 aphids were provided, whereas adults were satiated when 90 aphids were provided, meaning that the larvae displayed a lower handling time and were therefore more effective. A study conducted in Greece found that other, naturally in the Netherlands occurring, enemies of *M. persicae* are the parasitoids *Aphidius ervi*, *Aphidius matricariae* and *Praon volucre* (Kavallieratos, et al., 2004).

Another pest associated with *C. pepo* is the **greenhouse whitefly** (*Trialeurodes vaporariorum*) (Wolthoorn, 2016). *T. vaporariorum* causes damage to the plant in various ways: by extracting sap from the phloem, excreting honey dew on the plant and transmitting plant viruses (Cranshaw, 2013). Peric, et al. (2009) studied natural enemies of *T. vaporariorum* in Serbia and found that *Encarsia tricolor* and *Dichyphus errans* fed on *T. vaporariorum*.

3.2.2 Brassica napus

The main insects that cause damage to *B. napus* are the **cabbage stem flea beetle** (CSFB) *Psylliodes chrysocephala*, the **pollen beetle** *Meligethes aeneus*, the **cabbage seed weevil** *Ceutorhynchus assimilis*, the **cabbage stem weevil** *Ceutorhynchus pallidactylus*, the **rape stem weevil** *Ceutorhynchus napi* (Williams, 2010) and the **cabbage aphid** *Brevicoryne brassicae* (Pontoppidan, et al., 2003).

Veromann, et al. (2006) found that *M. aeneus* was by far the most numerous pest insect in spring oilseed rape and accounted for 98,6% of the crucifer-specialists caught in an Estonian field survey. *M. aeneus* lays its eggs on spring oilseed rape. The larvae feed on leaf tissue, which makes the plant more vulnerable to certain weather conditions (Stara & Kocourek, 2019) whereas adults feed heavily on young seedlings, inhibiting plant growth (Højland, et al., 2015). *Diospilus capito* is identified as parasitoid of *M. aeneus* (Veromann, et al., 2006). *P. chrysocephala* damages *B. napus* in the same way as *M. aeneus*, but uses winter oilseed rape for oviposition. The immature stages of both *P. chrysocephala* as *M. aeneus* are vulnerable to carabid predation. For instance, field survey shows that *Trechus quadristiatus* and *Pterostichus madidus* feed on the eggs of *P. chrysocephala* and *Amara similata*, *Nebria brevicollis* and *Asaphidion spp.* on the larvae of *M. aeneus* (Williams, et al., 2010). Another study shows that the presence of carabid beetles *Anchomenus dorsalis* and *Poecilus cupreus* significantly reduced *M. aeneus* emergence (Zaller, et al., 2009). *C. assimilis* lays its eggs in the pods of *B. napus*. Larvae feed within the pods, destroying developing seeds and often shattering premature pods (Buntin, et al., 1995). Research on natural enemies of *Ceutorhynchus spp.* is mostly focused on parasitoids. An Estonian study, for example, found that *Trichomalus perfectus*, *Mesopolobus morys* and *Stenomalina gracilis* were naturally-occurring ectoparasitoids of *C. assimilis* and have good potential to contribute to its biological control (Veromann, et al., 2011). Another study even found that *Trichomalus perfectus*, which parasitizes on the larvae of *C. assimilis* and has parasitism rates exceeding 70% (Alford, et al., 1995). *C. pallidactylus* and *C. napi* are both stem-mining weevils that lay eggs into a hole in the stem of *B. napus*. Larvae feed on plant tissue inside the stems and move upwards or downwards during the winter months, severely damaging the crop (Juran, et al., 2011). Zaller, et al. (2009) found that fields in which predatory carabids *Anchomenus dorsalis* and *Poecilus cupreus* were present, 2 to 10 times less stem-mining weevils emerged, emphasizing that 50 individuals of *A. dorsalis* reduces the emergence of *C. pallidactylus* with more than 50%. Additionally, a Polish study found that *Stenomalina gracilis* (previously only reported to parasitize on *C. assimilis*) also develops in *C. napi* (Klukowski & Kelm, 2000). *B. brassicae* is an aphid feeding on young leaflets, weakening the plants and decreasing both the amount and quality of seeds. Another, indirect, effect is the production of a large quantity of honeydew, resulting in black mold on the leaflets, which decreases photosynthesis (Costello & Altieri, 1995). The parasitoid *Diaeretiella rapae* has shown to be able to control *B. brassicae* populations by parasitizing on all its stages, severely decreasing their fertility (Zhang & Hassan, 2003). A Lithuanian study confirmed these results, explaining that *D. rapae* could reduce populations of *B. brassicae* up to 28.5% (Duchovskiene, et al., 2012). The same study found that *Aphidoletes aphidimyza* and *Coccinella septempunctata* were other observed predators of *B. brassicae*.

Beet mild yellows virus (BMV) and **Turnip yellows virus (TuYV)**, previously beet western yellows virus) are common aphid-borne viruses in *B. napus*, causing a decrease in both seed yield and oil content. Smith & Hinckes (1985) found that plots of 100% TuYV-infected *B. napus* yielded 13.4% less oil than plots with 18% infected *B. napus*. Another study found that plots with 96% and 100% TuYV-infected *B. napus* had decreased seed yields by up to 46% and 37% respectively (Jones, et al., 2007). *Myzus persicae* seems to be the principal vector for both viruses. A German study found that the transmission rates of BMV by *M. persicae* were 28.6%, whereas transmission rates of TuYV were 96.4% (Schliephake, et al., 2000). Additionally, they found *Cavariella aegopodii*, *Macrosiphum albifrons*, *Nasonovia ribisnigri*, *Rhopalosiphum maidis* and *Sitobion avenae* to be alternative vectors of TuYV. BMV seemed to have only alternative vector, which is *Aphis fabae*. Host plants of both TuYV and BMV include *Capsella bursa-pastoris* and *Senecio vulgaris* (Duffus & Russel, 1970) and also *B. napus* itself is proven to be an important host for TuYV (Smith & Hinckes, 1985).

3.2.3. *Solanum tuberosum*

The **Colorado potato beetle** (*Leptinotarsa decemlineata*) is considered to be one of the most important insect defoliator of potatoes (Alyokhin, 2009). One individual consumes approximately 40 cm² of leaf tissue throughout their larval stage, whereas an adult consumes about 10 cm² in one day (Ferro, et al., 1985). Nowadays, crop rotation is the most frequently used cultural control against *L. decemlineata* (Alyokhin, 2009). However, several arthropod species have also proven to be effective biological control agents. For example, a survey of arthropods in Delaware potato fields found *Chrysoperla carnea* and *Phalangium opilio* to be a potentially important predator of *L. decemlineata* (Heimpel & Hough-Goldstein, 1992).

Another common pest insect to *S. tuberosum* are the **wireworms** of *Agriotes lineatus* and *Agriotes obscurus*, which cause damage to the tubers and reduce crop quality, rather than yield (Parker & Howard, 2001). Currently, the use of insecticides is the most common control measure (Vernon & Van Herk, 2013). Since their subterranean habitat conceals them from observation, not much information about natural predators of wireworms is available (Van Herk, et al., 2015). However, an older report claims that predacious insects prey on all stages of elaterids, with Coleopterans in particular (Rawlins, 1940). Fox & MacLellan (1956) support this theory, elaborating that in their study, 29.8% of the carabid *Amara familiaris* and 54% of *Harpalus affinis* were shown to have fed on the closely related *Agriotes sputator*. A more recent study found that also the larvae of *Thereva nobilitata* feed on various sized of *A. obscurus* wireworms (Van Herk, et al., 2015).

The **common green capsid** (*Lygocoris pabulinus*) causes damage to potatoes by stinging shoot tips, flower buds and fruits to suck sap from the phloem, which impair shoot growth (Wheeler, 2001). Herbaceous hosts of *L. pabulinus* are *Leucenanthemum vulgare*, *Taraxacum officinale* and *Urtica dioica*, *Rumex spp.* and *Senecio spp.*, whereas woody hosts are *Prunus spp.*, *Crataegus spp.* and *Ribes spp.* (Blommers, et al., 1997). Capsid bugs generally have few natural enemies (Crook, et al., 2001). However, a factsheet of the Agriculture and Horticulture Development Board (AHDB) mentions that previous feeding tests with field collected predators indicate that potentially effective predators include species from the orders *Araneae*, *Dermaptera*, *Nabidae* and *Opiliones* (Collier & Norman, 2018).

The **potato virus Y (PVY)** is an aphid-borne virus, which causes substantial losses of commercial potato production by decreasing yield, as well as affecting the quality of the tubers (Karasev, et al., 2008). PVY can be transmitted by many aphid species, but not all are equally efficient. The relative efficiency factor (REF) of transmission by aphids is commonly used in

Dutch management systems for PVY (Verbeek, et al., 2009). Van Harten (1983) established these numbers in the 80's. More recently, Verbeek, et al. (2009) revised the REF for a few aphid species and found that not all were the same. Both REF-values are given in table 11 for a few common aphid species. Research in this field both concedes with or contradicts these results. Boquel, et al. (2011) re-examined the REF-values with alternative methods. They measured higher transmission rates of 83.3% in *Myzus persicae*. *Macrosiphum euphorbiae* seemed to have higher transmission rates than previously proven as well and *Sitibion avenae* was a new efficient transmitter. Also, unlike the results of Van Harten, *Rhopalosiphum padi* and *Aphis fabae* did not transmit PVY at all (Boquel, et al., 2011). Aphidophagous and generalist predation is described in the introduction of this chapter and natural predators of *M. persicae* are given in paragraph 3.2.1.

Table 11. REF-values for common aphid vectors of PVY, in which *Myzus persicae* is the most efficient transmitter and used as reference value (Van Harten, 1983). The revised REF-values of a few aphid species is given in the third and sixth column (Verbeek, et al., 2009).

REF-value for common aphid vectors of PVY					
Aphid species	REF 80's	REF	Aphid species	REF 80's	REF
<i>Myzus persicae</i>	1.00	1.00	<i>Macrosiphum euphorbiae</i>	0.10	
<i>Myzus centus</i>	0.44		<i>Acyrtosiphon pisum</i>	0.05	0.08
<i>Aphis nasturtii</i>	0.42	0.46	<i>Rhopalosiphum padi</i>	0.02	0.00
<i>Aphis frangulae</i>	0.42		<i>Brachycaudus helichrysi</i>	0.01	
<i>Phorodon humili</i>	0.15	0.22	<i>Metopolophium dirhodum</i>	0.01	
<i>Aphis fabae</i>	0.10	0.03			

The **greenhouse whitefly** (*Trialeurodes vaporariorum*) is another well-known pest associated with *S. tuberosum*. This pest and its natural enemies are described in paragraph 3.2.1.

3.2.4 Vicia faba

The **pea leaf weevil**, *Sitona lineatus*, lays eggs in the soil near *V. faba* seedlings. The larvae develop in the nitrogen-fixing nodules of the roots, which inhibits nitrogen-fixation and results in growth reduction, low seed yields and sensitivity to drought stress (Vankosky, et al., 2009). A German study measured the impact of *S. lineatus* on *V. faba* and found a decrease in yield up to 28% (Nielsen, 1990). A Canadian study experimented with potential natural predators and found that *Bembidion quadrimaculatum* was the most successful predator of *S. lineatus*, ingesting 94.6% of its eggs (Vankosky, et al., 2010). Furthermore, Hamon, et al. (1990) found that generalist carabid predation played a significant role in the population dynamics of *S. lineatus*.

The **broad bean weevil**, *Bruchus rufimanus*, uses the pods of *V. faba* for oviposition. When hatched, larvae bore into the pod wall and develop within the seed, causing yield losses up to 70% (Epperlein, 1992). *Dinarmus acutus* is found to parasitize on *B. rufimanus*, but no data is available on their potential to control the population numbers (Roubinet, 2016).

The **black bean aphid**, *Aphis fabae*, is generally considered a serious pest of *V. faba*. *A. fabae* feeds on the plant, which reduces plant productivity and causing yield losses that can exceed 50% (Hinz & Daebeler, 1981). Natural enemies of *A. fabae* are mainly coccinellids. For example, a recent study found that release of newly hatched *Coccinella septempunctata* larva significantly reduced *A. fabae* density to 32.8%-57.2% (Shannag & Obeidat, 2008). Other

coccinellid predators of *A. fabae* are *Propylea quatuordecimpunctata* (Hodek, 1996) and *Hippodamia variegata* (Farhadi, et al., 2010)

The **pea aphid**, *Acyrtosiphon pisum*, can cause yield losses as high as 37% by feeding damage (Gebremedhin, 1990). It is also the vector of more than 35 plant viruses (Kennedy, et al., 1962). One of the most abundant viruses transmitted by *A. pisum* is the **Turnip Yellow Virus** (TuYV) (Makkouk, et al., 2001). A description of this virus is given in paragraph 3.2.2, together with its potential vectors and their natural enemies. A recent study found that coccinellids were the most abundant predators of *A. pisum*, representing 51% of the total observations (Ximenez-Embun, et al., 2014). Additionally, they found that *Hippodamia variegata* was the most abundant predator of *A. pisum* in spring. This result is supported by Giles, et al. (1994), who additionally found that the populations of *Hippodamia tredecimpunctata*, *Coccinella septempunctata* and *Adalia bipunctata* were highly correlated with the population of *A. pisum*. Other natural enemies include the parasitoid wasp *Aphidius ervi* (Takemoto, et al., 2009), *Orius spp.* (Nakashima & Akashi, 2005) and *Nabis spp.* (Straub, et al., 2013). Another aphid-borne virus in *V. faba* is **Bean Yellow Mosaic Virus** (BYMV). A survey in Iraq identified virus diseases affecting *V. faba* and found that BYMV was the most abundant virus, identified in 68% of their samples (Makkouk, et al., 2001). Yield losses of up to 96.3% have been observed as a result of early infections with BYMV (Frowd & Bernier, 1977). Transmission is primarily carried out by *A. pisum*, although some studies also suggest that *Myzus persicae* is able to transmit the virus as well (Swenson, 1960). Host plants of BYMV include *Trifolium spp.* and *Vicia spp.* (Gadh & Bernier, 1984).

3.2.5 Triticum aestivum

The three most common pests of *T. aestivum* are the **bird cherry-oat aphid**, *Rhopalosiphum padi*, the **rose grain aphid** *Metopolophium dirhodum*, and the **English grain aphid** *Sitobion avenae* (Plantegenest, et al., 2001). All aphids are causing damage to the plant through sap sucking. Additionally, *R. padi* and *S. avenae* are vectors for **Barley Yellow Dwarf Virus** (BYDV), although transmission rates of *R. padi* are much higher (Gray, et al., 1991). The virus in combination with *R. padi* infestation have shown to reduce wheat yields by 30-40% (Gaunce & Bockus, 2015).

Smyrnioudis, et al. (2001) studied the effect of natural enemies of *R. padi* on the spread of BYDV and found that the presence of *Aphidius rhopalosiphi* resulted lower infection rates. Additionally, an Italian study suggests *Chrysoperla carnea* as common predator of *R. padi* (Lozzia, et al., 1998). The main natural enemy of *S. avenae* is fungal disease, accounting for 75% of the reduction in aphid density (Plantegenest, et al., 2001). However, observations of a British study strongly suggest that predation by hymenopterous parasitoids also controls aphid population growth (Chambers, et al., 1986). For example, a Belgian study shows that the population of *S. avenae* decreased markedly during winter in the presence of parasitoid *Aphidius rhopalosiphi*, and remained low in the beginning of spring (Legrand, et al., 2005). A Serbian survey found that *Dendrocerus carpentri* and *Asaphes suspensus* were the most abundant mummy parasitoids of *R. padi* and *S. avenae*, whereas *Alloxysta victrix* and *Asaphes vulgaris* were the most abundant parasitoids of *M. dirhodum* (Tomanovic, et al., 2008). Another common parasite of *M. dirhodum* is *Aphidius uzbekistanicus* (Dean, et al., 1981).

3.3 Target species and their associated landscape elements

An overview of the connections between the target crops and their associated pollinators and natural enemies is given in appendix V. Habitat requirements will be evaluated by nesting opportunities, foraging plants and connectivity.

3.3.1 C. pepo

Pollinators of *C. pepo* are *Halictus spp.*, *Lasioglossum spp.*, *Ceratina cyanea* and *Eristalinus aeneus*. Both *Halictus spp.* and *Lasioglossum spp.* are typically ground-nesting bees. Although the nesting preferences of ground-nesting bees are not yet fully understood, Cane (2015) recently found that females of *Halictus rubicundus* consistently preferred to nest amid flat landscaping **pebbles** than adjacent bare dirt. Potts & Willmer (2003) also studied the nest-site selection by *H. rubicundus* and found that they showed preference for **softer soils** with the thermal advantages of a southern aspect. Westrich (1996) further elaborates that *H. quadricinctus* nests in a **marginal vertical face**. In contrast, a Mediterranean study found that *Lasioglossum malachurum* nests in areas with high soil hardness and low acidity (Polidori, et al., 2010). The same study shows that *L. malachurum* showed a strong preference for foraging from the **Compositae family**, which represented 80.3% of their pollen loads in agricultural habitats. Field observation show that newly emerged queens of *Halictus confusus* used *Taraxacum officinale* as main food source and shifted to *Barbarea vulgaris* in May (Dolphin, 1971). During summer, female workers favoured ***Trifolium repens* and *T. pratense***, whereas *H. ligatus* was more commonly observed on ***Achillea millefolium*, *Erigeron annuus* and *Leucanthemum vulgare***. However, both *Halictus spp.* and *Lasioglossum spp.* are quite generalistic, with many of them foraging on dozens of different plant species (Peeters, 2012). Wright, et al. (2015) studied the forage distance limitations of small bees. He used both *Lasioglossum* and *Halictus spp.* and found that the small bee abundance was reduced to 10% at a distance of 250-370 m away from the nesting habitat (Wright, et al., 2015).

Ceratina cyanea uses **marrow-containing stems** for nesting, in which they form a simple linear cavity. An Iranian study explains that *Ceratina spp.* restrict their nesting distribution to habitats rich in ***Rubus spp.*** or in similar plants, such as *Verbascum spp.* (Salarian, et al., 2016). Due to their long tongue, they are able to forage from flowers with a relatively deep corolla. In the Netherlands, observations show that *Hieracium pilosella*, *Echium vulgare* and *Jasione montana* are preferred food plants (Peeters, 2012). Little information about the dispersal of *C. cyanea* is available, however body size and foraging range is strongly related (Greenleaf, et al., 2007). According to Peeters, et al. (2012), *C. cyanea* has a body size of 5-7 mm. A rough estimation on their foraging range would then be 200-500 m.

According to the Natuur van Nederland, the larvae of *E. aeneus* live in both stagnant and weakly flowing **water** and need **rotting materials**. In the Netherlands, it is known that they develop in salt water pools (Reemer, et al., 2009). However, Pérez-Bañón, et al. (2003) found that *E. aeneus* larvae can develop in **fresh water ponds** and manure as well. According to De Buck (1990), *E. aeneus* feeds mostly on **yellow composites** and **white umbellifers**. However, Sajjad & Saeed (2010) studied the floral host range of syrphid flies in Pakistan, in which *E. aeneus* was by far the most abundant syrphid fly and they found that *Daucus carota* and *Cirsium arvense* were the most preferred plant species (Sajjad & Saeed, 2010). Bortolotto, et al. (2016) studied the dispersal of syrphid flies and found that the abundance of most species severely reduced at a distance higher than 25 m.

Natural enemies that can lower population numbers of *C. pepo* pests are the mirid beetles *Dicyphus errans* and *Macrolophus pygmaeus*, the Coccinellids *Coccinella septempunctata* and *Coccinella undecimpunctata*, the Braconidae *Aphidius ervi*, *Aphidius matricariae* and *Praon volucre* and the parasitoid wasp *Encarsia tricolor*.

Aviron, et al. (2016) studied the effects of landscape heterogeneity on mirid bugs and found that abundance of *Macrolophus spp.* can be explained by the presence and connectivity of

fallow vegetation, whereas *Dicyphus* spp. abundance can be explained by the presence of **hedges/woodlots** and **grassland**. Additionally, they responded to landscape factors on different spatial scales (200-300 m and 100 m, respectively), suggesting different dispersal abilities (Aviron, et al., 2016). *D. errans* and *M. pygmaeus* are both omnivorous feeders. **Perennial flower strips** act as winter shelter for mirid bugs, providing them with food when their prey is rare (Lambion, 2014). Both species show floral preference for *Calendula officinalis*, *Geraniaceae* spp. and *Lamiaceae* spp. (Lambion, 2011). According to a preference test, in which they were given the option between 9 plant species, both species preferred *Verbascum thapsus* (Messelink, et al., 2019). Additionally, according to Voight (2019), *D. errans* shows preference for pubescent plant species, which gives them a stronger physical attachment to the plant. The fecundity, hatching rate and juvenile development significantly increase as the attachment is stronger (Voight, 2019).

In a British study, insects on flowering plant species were sampled and the highest total amount of coccinellids were obtained from *Anthemis arvensis*, *Centaurea cyanus* and *Glebionis segetum* (Solomon, et al., 1999). Whereas Ricci, et al. (2005) found that *Compositae*, *Umbelliferae* and *Gentianaceae* were preferred plant families. However, *Gentianaceae* are not common in the Netherlands. Coccinellids have been observed dispersing over distances up to 4 km (Hodek, et al., 1993). The habitat preferences of *C. undecimpunctata* are not yet extensively studied on species-level. The habitat preferences of *C. septempunctata*, however, is. Bianchi & van der Werf (2003) found that *C. septempunctata* depends on non-crop elements for hibernation. In their study, landscapes with 9-16% of non-crop habitat contained populations enough to control aphid infestations, whereas landscapes with 1-4% of non-crop habitat did not provide enough potential for effective aphid control. They also found that **linear hedgerows** attracted bigger *C. septempunctata* populations and aphid control was optimized when several small hedgerows were evenly distributed in the landscape (Bianchi & Van der Werf, 2003). A later study by Van der Werf & Bianchi (2007) further elaborates these results by simulating the influence of non-crop habitat size and distribution on the natural control of aphids by *C. septempunctata* with computer modelling (figure 10). Additionally, Honek, et al. (2007) studied the aggregation of coccinellids at different hibernation sites and found that *C. septempunctata* showed a significant preference for hibernating in **grass tussocks** or **under rocks**. However, according to Hemptinne (1988), *C. septempunctata* prefers to hibernate in leaf litter in **forest edges** orientated to the South and West. Honek (1985) studied habitat preferences of coccinellids and found most *C. septempunctata* individuals on herbaceous plants in **sunny places**, specifically *Tripleurospermum* spp. and *Anthriscus* spp.

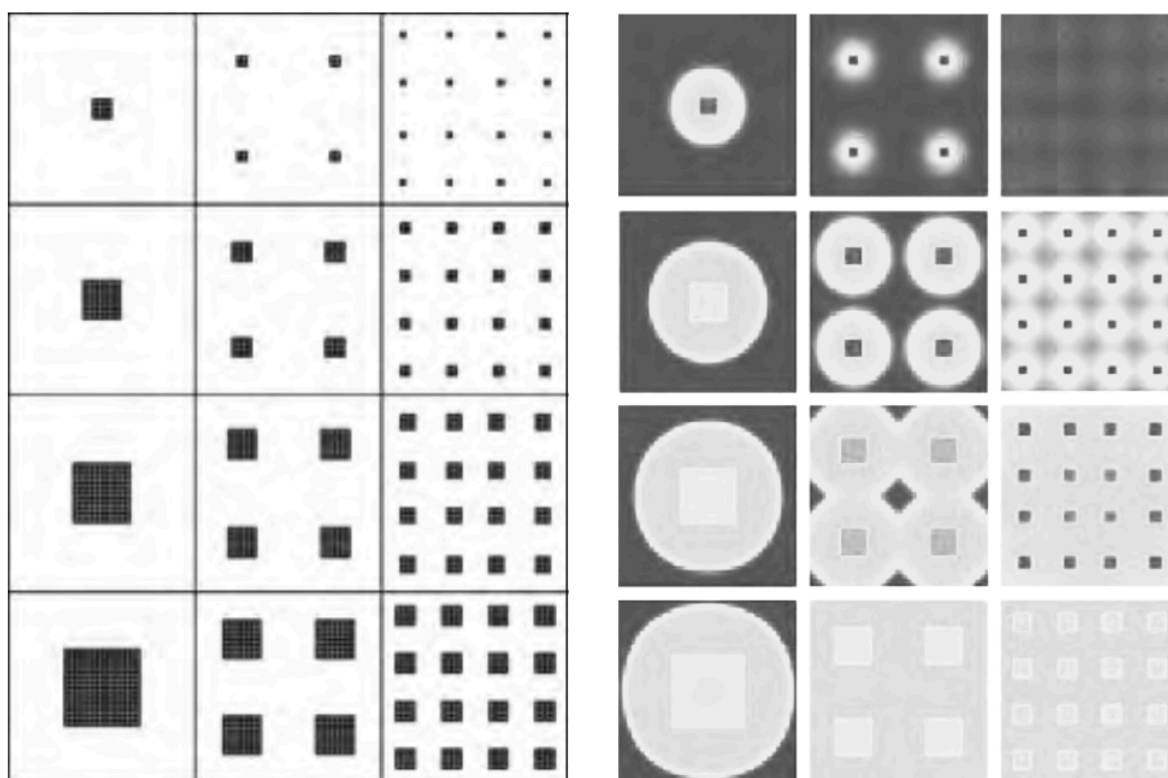


Figure 10. On the left: 12 model habitats of 400 x 400 m agricultural landscape (white) with different sizes and distributions of non-crop habitat (green). On the right: density of aphids in number per m² (dark – high population numbers, light – low population numbers) (Van der Werf & Bianchi, 2007).

The habitat preferences of *A. matricariae* is not as well studied as its commercially used family member, *A. ervi*. However, it is unclear whether *A. matricariae* is actually a cryptic species or a part of a species complex, including *A. ervi* (Derocles, et al., 2015). Due to their close kinship (Stilmant, et al., 2008) and the fact that *A. matricariae* is a true habitat generalist, it is likely that it either has similar preferences as *A. ervi*, or no strong habitat preferences at all. Vollhardt, et al. (2008) studied the effect of landscape complexity for parasitoids of cereal aphids, among which *A. ervi*, and found that arable fields in high-intensity agricultural landscapes with little non-crop areas supported a similar diversity of parasitoids as highly complex landscapes. These findings suggest that *A. ervi* is adaptable and does not have specific habitat needs. Derocles, et al. (2015) support this, explaining that both *A. matricariae* and *A. ervi* are habitat generalists. However, non-prey feeding has a strong impact on the survival and fecundity of parasitoids (Wäckers, et al., 2008). To elaborate, Araj, et al. (2006) compared the longevity of *A. ervi* exposed to different floral resources. They found that individuals fed on *Fagopyrum esculentum* survived 45 times longer than control plots (no floral resource) and individuals fed on *Phacelia tanacetifolia* survived 34 times longer (Araj, et al., 2006). Wäckers (2004) studied flower attractiveness and nectar accessibility of eleven insect-pollinated plants for *Cotesia glomerata* and *Heterospilus prosopidis*, two parasitoid wasps from the same family as *A. ervi*. He found that *Aegopodium podagraria* and *Origanum vulgare* were optimal food sources, whereas *Achillea millefolium*, *Trifolium pratense* and *Vicia sepium* rather acted as a repellent (Wäckers, 2004). Additionally, hedgerows are associated with parasitoids in general, since they provide alternative prey and nectar sources (Bianchi, et al., 2006)

Although *E. tricolor* is commercially used on many crops, very little information about its ecology or population dynamics under natural conditions is available (Hoddle, et al., 1998) (Laurenz & Meyhöfer, 2016).

3.3.2 *B. napus*

Pollinators of *B. napus* are the solitary bees *Andrena spp.*, *Halictus spp.* and *Osmia bicornis*, the bumblebees *Bombus lapidarius*, *Bombus sensu stricto* (here evaluated as *B. terrestris*) and the syrphid flies *Episyrphus balteatus*, *Eristalis spp.* and *Eupeodes corollae*. *Halictus spp.* is previously discussed as pollinator of *C. pepo*, so this paragraph will focus on the other pollinating species.

Approximately 74 species of *Andrena* are known to occur in the Netherlands, of which 43 are polylectic and 31 are oligolectic, meaning they forage from one plant family or genus (Peeters, 2012). For example, Westrich (1996) collected the pollen carried by different *Andrena spp.* and identified the plant family or genus they were derived from. Results are given in table 12.

Table 12. Examples of oligolectic *Andrena spp.* and their pollen sources (Westrich, 1996)

<i>Andrena spp.</i>	Plant family or genus
<i>A. denticulata</i>	<i>Asteraceae</i>
<i>A. proxima</i>	<i>Apiaceae</i>
<i>A. agilissima</i>	<i>Brassicaceae</i>
<i>A. curvungula</i>	<i>Campanula spp.</i>
<i>A. florea</i>	<i>Bryonia</i>
<i>A. hattorfiana</i>	<i>Dipsaceae</i>
<i>A. lapponica</i>	<i>Ericaceae</i>
<i>A. lathyri</i>	<i>Vicia/Lathyrus spp.</i>
<i>A. vaga</i>	<i>Salix spp.</i>

Some of these species, such as *A. agilissima* and *A. curvungula*, are not very common in the Netherlands. These species should still be considered for wild bee conservation but are therefore less relevant for optimising pollination. In general, dietary specialisation of solitary bees results in rarity (Wood, et al., 2016). That is reflected in the fact that polylectic *Andrena spp.* are more common in the Netherlands. For example, *A. flavipes* is a common species, known to forage on a wide variety of trees and herbs. However, *Brassicaceae* (Güler & Sorkun, 2010) and *Asteraceae* (Dylewska, 1987) seem to be preferred food plant families, whereas *A. carantonica* prefers to forage from the *Rosaceae* family (Westrich, 1989) and *A. haemorrhoea* from *Salix spp.* (Peeters, 2012). All *Andrena spp.* are ground-nesting bees. According to Peeters, et al. (2012) the presence of **bare soil** is the most crucial factor for the occurrence of *Andrena spp.*, elaborating that most nests are found on horizontal, sunny places which are protected from the wind. Foraging ranges of different *Andrena* species differ and is only studied for some species. Beil, et al. (2008), for example, found a foraging distance of up to 650 m for *A. dorsata* and 1150 m for *A. flavipes*. Gathmann & Tschardtke found a foraging distance 510 m for *A. vaga* and Wesseling & Tschardtke (1995) found a foraging distance of 500 m of *A. barbilabris*.

Osmia bicornis is a very common cavity nesting bee in the Netherlands, naturally using **hollow stems** or beetle borer tunnels in **dead wood** (Peeters, 2012). However, according to Westrich (1996) *O. bicornis* is an opportunist who nests in a wide variety of places, which makes it easy to attract by artificial nesting aids, such as **bee hotels**. Everaars, et al. (2011) employed citizen science to study the drivers behind the spatial distribution of *O. bicornis* and found that location of nesting aids was the most important factor, occupancy was significantly lower in nests that

were attached to trees or shrubs than nests that were attached to balconies, carports or other anthropogenic objects. The second and third most important factors were high sun exposure and a short distance to foraging resources. Additionally, a recent study found that specifically 6-12 mm tubes in bee hotels were occupied by *O. bicornis* (Seidelmann, et al., 2016). *O. bicornis* is a polylectic bee species, foraging from many different plant families, although Hallmen & van Leeuwen (1990) suggest that populations may be monolectic. For example, Raw (1974) examined pollen from nests of *O. bicornis* and found that 90% of the pollen collected was from *Ranunculus* and *Quercus*. Additionally, a more recent study conducted in an agricultural landscape in the UK found that 83% of the pollen samples were derived from *Rosa canina*, even suggesting that planting this species should be encouraged to support their foraging requirements more specifically (Gresty, et al., 2018). Gathmann & Tschamtker (2002) used translocation experiments to study the foraging distance of solitary bees and found that the average foraging distance of *O. bicornis* significantly decreased when the number of suitable food plants increased. They estimated the flight range of *O. bicornis* to be 900 m.

Both bumblebee species are **polylectic** and very common in the Netherlands. According to Peeters, et al. (2012), *B. terrestris* queens emerge early in the season and they forage from **Willow spp.** in massive numbers, in early spring. Before many other plant species reach inflorescence, they also rely on **Glechoma hederacea** and **Taraxacum officinale**. In a survey conducted in the Wrocław Botanical Gardens, *B. terrestris* foraged on 133 plant species belonging to 32 botanical families, with *Asteraceae* being the most frequently visited, whereas *B. lapidarius* foraged on 52 plant species belonging to 22 botanical families (Sikora & Kelm, 2012). Due to their strong adaptability, the flower composition of a certain habitat does not need specific attention in this study. Kells & Goulson (2002) found that both *B. terrestris* and *B. lapidarius* showed preference for subterranean nesting in open habitats that contained banks. They also studied preference for different type of parcel boundaries and found that *B. lapidarius* nested most often along **fences** that separated fields and where no hedge-type vegetation was associated, resulting in a higher degree of warmth from the sun than, for example, hedges. According to Peeters, et al. (2012), *B. lapidarius* also nests under **rocks**, old mouse burrows and abandoned nest boxes. A study on resource alterations in the habitats of different *Bombus spp.* on multiple spatial scales implies foraging distances of 3000 m for *B. terrestris* and 2750 m for *B. lapidarius* (Westphal, 2006). In contrast, a British study estimated a flight range of 758 and 450 for *B. lapidarius* and *B. terrestris*, respectively (Knight, et al., 2005). Furthermore, Krewenka, et al. (2011) studied the effect of LLE's on solitary bees, trap-nesting bees, wasps, parasitoids and bumblebees. They found that LLE's (in this case hedges) acted as a barrier for all species, but rather as a corridor for bumblebees. For example, a Norwegian study found a significant, positive correlation between bumblebees (both density and species richness) and the presence of different **LLE's**, with the exception of roads. Specifically, in habitats with pasture or cropland verges, 41% more bumblebee individuals and 11% more species were observed (Kallioniemi, et al., 2017), meaning that **several smaller pastures**, in which the surface/edge ratio is smaller, are preferred over one big pasture.

Episyrphus balteatus is the most common syrphid fly in the Netherlands and can be found throughout the year. According to Peeters, et al. (2012), *E. balteatus* is very generalistic and does not show particular flower preference. This is supported by Sajjad & Saeed (2010), who found that *E. balteatus* visited the highest number of plant species of all studied syrphid flies, up to 37. However, Goulson and Wright (1998) found that a substantial portion of the diet of *E. balteatus* consisted of **Compositae** (74%), with *Pulicaria dysenterica*, *Eupatorium cannabinum* and *Centaurea nigra* in particular. Additionally, a French study examined the importance of landscape parameters in the distribution and abundance of *E. balteatus* and found

that the presence of **shrubs** positively affected abundance, as well as **forest edges** (Sarhou, et al., 2005). *Eupeodes corollae* is another very common, generalistic syrphid fly, which has similar habitat preferences as *E. balteatus* (Branquart & Hemptinne, 2000). Peeters, et al. (2012) explains that *E. corollae* has preference for sheltered places in open habitat. Both *E. balteatus* and *E. corollae* are strong flyers. However, MacLeod (1998) found that *E. balteatus* is able to detect a flower patch over a distance of approximately 285 m, which he suggests is an important factor in the daily foraging mechanisms of this species.

Fourteen species of *Eristalis* naturally occur in the Netherlands, of which 4 are common in agricultural landscapes (*E. tenax*, *E. abusiva*, *E. arbustorum* and *E. nemorum*) (Peeters, 2012). According to Peeters, et al. (2012) most *Eristalis* spp. are generalistic and have no strong floral preference or habitat requirements. The larvae need an **aquatic environment** with organic matter to feed on. For example, Hartley (1961) found *E. nemorum* larvae in drainage water puddles and cow manure, and *E. abusiva* larvae in muddy shores. He found *E. arbustorum* larvae in a wide variety of moist environments. All four species are strong flyers and adults are frequently observed far away from their larval habitat (Peeters, 2012). However, Wellington & Fitzpatrick (1981) found that males only disperse over long distances after emerging. Once they are settled, the males generally have stationary home base with a range of approximately 500 m², meaning that they will fly distances of max. 13 m from their station.

Natural enemies that can lower population numbers of *B. napus* pests are the carabid beetles *Amara similata*, *Anchomenus dorsalis*, *Asaphidion* spp., *Poecilus cupreus*, *Pterostichus madidus*, *Trechus quadristiatus* and *Nebria brevicollis*, the coccinellids *Coccinella septempunctata* and *Coccinella undecimpunctata*, the Braconidae *Diaeretiella rapae* and *Diospilus capito*, the Braconids *Aphidius ervi*, *Aphidius matricariae*, *Praon volucre* the Pteromalidae *Stenomalina gracilis*, *Trichomalus perfectus* and *Mesopolobus morys* and the aphid midge *Aphidoletes aphidimyza*. The habitat requirements of all coccinellids and Braconids is already discussed in paragraph 3.3.1.

Knapp & Rezác (2015) studied the importance of non-crop habitat islands and found that even the smallest islands (<100 m²) were inhabited by carabid assemblages with a higher species richness than the surrounding agricultural landscape it was in. Pywell, et al. (2005) found that abundance and richness of carabids were significantly higher in hedgerow habitats than field margins. They emphasize the importance of **hedgerows** as overwintering habitat for carabids (Pywell, et al., 2005). For example, Fournier & Lereau (1999) studied the effect of hedgerows on carabid abundance and diversity and found that *A. similata* was significantly more abundant in hedges than in crops. These findings are also supported by Asteraki, et al. (1995). However, they also found that *P. cupreus* showed a preference for **fence margins** rather than hedges and some carabid species, among which *N. brevicollis*, showed preference for hedge margins during spring and summer only, whereas they showed preference for fence margins later in the year. They explain that these species use hedges as undisturbed feeding habitat and later move to more open areas for breeding (Asteraki, et al., 1995). Holland, et al. (2004) had similar findings, in which *P. madidus* was associated with field margins early in the year, whereas emerging teners were most abundant within arable fields. Additionally, Ranjha & Irmeler (2013) studied which carabid species benefit from different types of agricultural habitat and found that *A. similata* was most abundant in **grassy strips**, *A. dorsalis* in **woody field margins**, and *T. quadristiatus* and *N. brevicollis* in the open field. Twardowski, et al. (2006) also found that **weedy strips** seem to attract carabids. *A. similata* is granivorous in its larval stage (Klimes & Saska, 2009). Although they do not seem specialistic in their choice of seeds, they show lower mortality when fed on seeds of *Capsella bursa-pastoris* (Jørgensen & Toft, 1997). Little

information about the dispersal of carabids is available. However, the dispersal of a carabid closely related to *P. madidus*, *P. melanarius* was studied by Allema (2014), in which he predicted a dispersal distance of 100-160 m.

The Braconidae *D. rapae* and *P. volucre* are considered habitat generalists (Antolin, et al., 2006) (Stilmant, et al., 2008). Geiger, et al. (2005) studied the importance of flower strips in winter for parasitoids, as they provide additional nectar and hibernation sites. However, they found that *D. rapae* was more abundant in **open landscapes** and no individuals were found in flower strips. In contrast, Büchi (2002) studied effect of conservation strips on the mortality of pollen beetles by predators and parasitoids, among which *D. capito*. He found that mortality by parasitism was significantly higher in fields with **flower strips** and decreased as distance from the strip increased (Büchi, 2002). Additionally, Kovács, et al. (2013) studied the attractiveness of wild cruciferous plants on several parasitoids and found that *D. capito* was most abundant on **Brassica napus**. Whereas *Sonchus oleraceus* acts as reservoir of *P. volucre* (Kavallieratos, et al., 2008). Little is known about the dispersal abilities and movement patterns of parasitoids. However, Langhof, et al. (2005) studied the field dispersal of the related Braconid *Aphidius colemani*, and found dispersal distances of up to 16 m.

It is suggested that *S. gracilis* is a broad generalist. However, Kruess (2003) found that *S. gracilis* was most abundant in **fallow patches**, dominated by *Cirsium arvense* and Berger, et al. (2018) found that *S. gracilis* was significantly more abundant in crops further away from forests. In contrast, the presence of **woody areas** was in this study of great importance for *T. perfectus*, which is believed to hibernate on **coniferous trees** (Von Rosén, 1964). Hatt, et al. (2018) assessed how flower traits affect the density of parasitoids in wildflower strips. *S. gracilis*, *T. perfectus* and *M. morys* were all attracted to flowers with open nectaries, but violet coloured flowers repelled *T. perfectus* and *M. morys*. According to Kovács, et al. (2016), *T. perfectus* and *M. morys* have very similar plant preferences. In this study, they were mostly found on **Brassica rapa** and **Brassica napus**. The dispersal of Pteromalidae is not yet extensively studied. However, Machtinger, et al. (2015) studied the linear dispersal of related *Spalangia cameroni* and found that they didn't parasitize further than 5 m away from their release site. Therefore, they strongly suggest that pastures where long-distance flights are needed for control are not suitable (Machtinger, et al., 2015).

According to Markkula & Tiittanen (1985), *A. aphidimyza* has a very low capacity of movement. Van Schelt & Mulder (2000) specify that they found individuals up to 45 m from their release point. Under natural conditions, *A. aphidimyza* uses **spider webs** for mating. However, Abe & Yukawa (2003) found that an **artificial hanging substrate**, such as fishing lines can also promote copulation. The larvae pupate and overwinter in the soil. Therefore, soil health is a crucial factor in the life cycle of *A. aphidimyza* (Van Schelt, 2007). It is not known whether the pupas can survive heavy tillage, but Mathews, et al. (2002) found that the use of **compost** can support the survival of *A. aphidimyza* pupas. Van Schelt (2007) also suggests that **field margins** or **hedges** with alternative aphid prey can support the population of *A. aphidimyza*.

3.3.3 *S. tuberosum*

Associated bee species of *S. tuberosum* are bumblebees and solitary bees *Halictus confusus*, *Halictus rubicundus*, *Lasioglossum leucozonium*, *Lasioglossum zonulum*. These species are not mandatory for pollination, however, for maintaining pollinator biodiversity, it might still be a good option to enrich *S. tuberosum* fields with landscape elements that attract its associated bee species.

All *Bombus* spp. in the Netherlands are polylectic. According to Peeters, et al. (2012), **Fabaceae, Lamiaceae, Orobanchaceae and Boraginaceae** are the most important plant families for bumblebees. Bumblebees need suitable food plants for a longer period of time in order to produce offspring and successfully build a colony; their social way of life makes them more susceptible to interruptions in food availability than solitary bees (Kleijn & Raemakers, 2008). Persson and Smith (2011) found that bumblebee colonies produced larger adults in more complex landscapes with smaller agricultural fields and suggested that landscapes with lower complexity negatively affected the reproductive success of colonies. This is elaborated by Walther-Hellwig & Frankl (2003), who found that **permanent foraging habitat**, such as flowering **hedgerows**, attract a higher diversity of bees, whereas crops represent temporal, but highly rewarding, foraging habitats with high abundance, but low diversity of bumblebees. They explain that low complexity patches of these highly rewarding forage crops are only visited by species with large foraging ranges, such as *B. terrestris*. Certain species of bumblebees, such as *B. terrestris*, *B. lucorum* and *B. pratorum*, emerge very early in spring. *Salix* spp. are almost the only food supply during these early weeks and are therefore of great value in the survival of these species (Svensson, 2002). Most *Bombus* spp. in the Netherlands are ground-nesting, with the exception of *B. hypnorum*, which nests in wood and other (artificial) cavities (Peeters, 2012). Kells & Goulson studied nesting preference of several *Bombus* spp. and found that *B. terrestris*, *B. lapidarius* and *B. lucorum* preferred subterraneous nesting in banks, whereas *B. pascuorum*, *B. hortorum* and *B. ruderarius* prefer nesting in **tussock-type vegetation**. A similar study found that *B. terrestris*, *B. lapidarius* and *B. sylvarum* preferred **open terrain**, whereas *B. lucorum* and *B. pascuorum* preferred **forest edges** (Svensson, et al., 2000). In general, bumblebees are strong flyers. However, Goulson & Osborne refer to *B. pascuorum*, *B. sylvarum*, *B. ruderarius* and *B. muscorum* as ‘doorstep foragers’, meaning they usually forage within a range of 500 m away from their nests. For example, Connop, et al. (2010) found an average foraging distance of 231 m for *B. sylvarum* and Knight, et al. (2005) found a foraging distance of 449 m for *B. pascuorum*. In contrast, *B. terrestris* has one of the largest flight ranges and is often observed foraging more than 2 km away from its nest (Goulson & Osborne, 2009).

Halictus confusus and *Halictus rubicundus* are ground-nesting bees. In the Netherlands, *H. confusus* exclusively occurs on **sandy soils**, whereas *H. rubicundus* is less selective in its habitat choice (Peeters, 2012). As mentioned in paragraph 3.3.1, *H. rubicundus* seems to prefer to nest in **softer soils** with the thermal advantages of a **southern aspect**, preferably amid flat landscaping **pebbles** rather than adjacent bare dirt. According to Dolphin (1978), *H. confusus* primarily nests in open fields, preferring **bare or sparsely vegetated sites**. However, more detailed information about the nesting preferences of *H. confusus* is distinctly lacking (Richards, et al., 2010). Both *Halictus* spp. are very polylectic. Although, according to Peeters, et al. (2012), *H. rubicundus* is often observed on *Tanacetum vulgare* and *Taraxacum officinale*. In Dolphin (1971), *H. confusus* utilized *Taraxacum officinale* as food source early in the season, then shifted to *Barbarea vulgaris* in May and *Trifolium repens* and *T. pratense* during summer.

L. leucozonium is very common in the Netherlands, whereas *L. zonulum* is less common and rarely, if not at all, occurs in the North of the Netherlands (Peeters, 2012). Both *L. leucozonium* and *L. zonulum* are ground-nesting bees. According to Peeters, et al. (2012), *L. leucozonium* usually nests in flat surfaced, sandy soil. *L. leucozonium* and *L. zonulum* are polylectic bees. For example, Westrich (1989) reports flower visits from 11 plant families for *L. zonulum*. However, they both show strong preference for yellow composites, such as *Hypochaeris*

radicata, *Hieracium* spp., *Crepis* spp. and *Solidago virgaurea* (Peeters, 2012). However, very little information on the ecology of these *Lasioglossum* spp. was found.

Natural enemies that can lower population numbers of *S. tuberosum* are the carabid beetles *Amara familiaris* and *Harpalus affinis*, the Braconidae *Aphidius ervi*, *Aphidius matricariae* and *Praon volucre*, the coccinellid *Coccinella undecimpunctata*, the parasitoid wasp *Encarsia tricolor*, the mirid beetle *Dichyphus errans* and *Macrolophus pygmaeus*, the Therevid fly *Thereva nobilitata*, the lacewing *Chrysoperla carnea*, *Dermaptera* spp., *Nabidae* spp., *Aranea* spp. and *Opiliones* spp., with *Phalangium opilio* in specific. The literature which evaluates the habitat requirements of *A. ervi*, *A. matricariae*, *P. volucre*, *C. undecimpunctata*, *E. tricolor*, *D. errans* and *M. pygmaeus* is discussed in paragraph 3.3.1, therefore the next part will be focused on the remaining natural enemy species.

According to Mayr, et al. (2007), *A. familiaris* was orientated towards patches with a **high pH** value and a low plant species richness. This might be explained by the fact that larvae of *A. familiaris* are known to feed on seeds of *Stellaria media* (Klimes & Saska, 2009). According to other studies by Saska (2008a/2008b), females do not reproduce without access to these seeds and therefore this species is highly associated with patches of *S. media* in the field. Additionally, Sotherton (1984) studied the distribution of arthropods in agricultural landscapes and found that densities of overwintering *A. familiaris* were highest in **field margins**. *H. affinis* is also partly granivorous, but seems less specialized than *A. familiaris*. Several studies looked into the seed diet of *H. affinis*, which found that it consumed seeds of *Stellaria media*, *Taraxacum officinale*, *Trifolium pratense*, *Digitaria sanguinalis*, *Polygonum aviculare* (Hagley, et al., 1982), *Poa annua* (Johnson & Cameron, 1969) and *Brassica* spp. (Skuhavy, 1959). However, it is likely that it consumes seeds from many other species. Furthermore, Fusser, et al. (2016) studied the effect of landscape composition on carabids and found that *H. affinis* was most abundant in **linear habitats** dominated by **herbaceous vegetation**. These findings are supported by Ranjha & Irmeler (2013), who found significantly more *H. affinis* individuals in grassy strips than in wooded margins or crop fields. Additionally, *Harpalus* spp. hibernate deep in the soil (Luff, 1980). Therefore, they may escape the effect of harmful farming practices (Holland & Luff, 2000), which could allow them to hibernate in farmland. According to Schaffers, et al. (2010) many Araneae and Caribidae, among which *H. affinis*, also use **roadside verges** as overwintering site.

According to Holston (2005), it is likely that *T. nobilitata* is associated with pioneer shrub vegetation. Additionally, Engelhardt (1916) described the ecology of *T. nobilitata* larvae and claimed they can be found in **sand, dung, rotting tree bark or decaying wood**. Besides this, little information about the habitat preferences of *T. nobilitata* is available.

Patt, et al. (2003) found that *C. carnea* developed more quickly and grew larger when additionally fed on pollen (Patt, et al., 2003). They are opportunistic feeders. In a French field survey, they fed on over 28 plant families (Villenave, et al., 2006). In this survey, they showed preference for *Asteraceae*, *Chenopodiaceae*, *Gramineae* and *Ranunculaceae*. In Perrin (1975), also the importance of *Urtica dioica* as reservoir for *C. carnea* is demonstrated. According to Szentkirályi (2001), *C. carnea* lays eggs on many different plant species, showing no preference. However, Koczor, et al. (2016) found that oviposition rates were significantly higher on spiny and black surfaces. These findings are equal to Sattar & Abro (2011), but have only been tested on synthetic materials in laboratory environments. Artificial overwintering chambers have been established to increase biological control by lacewings, but several studies found that these are not used in great numbers by *C. carnea* (Bozsik, 2006) (Thierry, et al.,

2002) (McEwen, et al., 2001). Under natural conditions, *C. carnea* overwinters in **leaf litter, ivy tufts or unheated parts of buildings** (Thierry, et al., 1994). The dispersal of larvae (which are important for natural pest control), is very low. According to Duelli (1984), the average dispersal distance is less than 1 m. However, this might be quite irrelevant if the population is abundant, since oviposition will then occur throughout the whole crop and adult dispersal abilities run up to distances 40 km (Duelli, 1980).

Dermapterans are true generalists and occur in many natural habitats. However, they are often absent in modern agroecosystems, most likely due to disruption of their nests which inhibits the growth of their population (Helsen & Winkler, 2007). Nests are often constructed in the soil, under **stones, pieces of wood or plant roots** (Lamb, 1976). Therefore, they prefer dry conditions and avoid places with regular flooding (Helsen & Simonse, 2006). Happe, et al. (2018) studied the response of Dermapterans to landscape factors and suggests that **hedgerows and forest edges** act as sink-habitats, attracting them by providing alternative prey and shelter. These findings are in accordance with Geiger, et al. (2009), who studied hibernation of arthropods in semi-natural habitats and found overwintering Dermapterans in **forest-dominated sites** only.

Debras, et al. (2008) studied the effect of hedges on an arthropod community in France and found that Heteropterans, among which *Nabidae spp.* were significantly more abundant in zones close to **mixed hedges**. They explain that the hedge shelters them during winter and provides alternative prey in early spring when pest prey populations are low. The mixed hedges contained, for example, *Sambucus nigra*, *Fraxinus excelsior* and *Coryllus avellana*. Additionally, a Swiss study found that Heteropteran abundance is positively influenced **wildflower strips** in which specifically **perennial plants** seemed to attract the most individuals (Ulrich, 1966). Dispersal abilities of *Nabidae spp.* is highly variable, as some species lack fully-developed wings or flight muscles. According to Reynolds, et al. (2013) even species that are fully capable of flying might display station-keeping behaviour. Currently, the exact home range is not studied for any *Nabidae spp.* However, it is important to keep the dispersal ability of the least mobile species in mind. Solbreck (1985) studied the migration rate of related Heteropteran *Lygaeus equestris* and found that they disperse over a few hundred meters, whereas the windborne migration distance of *Nysius vinitor* can be up to 300 km (McDonald & Farrow, 1988)

More than 650 species of *Araneae* occur in the Netherlands (Tutelaers, 2016). They generally lead a hidden existence in dark corners of basements, sheds and other anthropogenic structures. In natural conditions, they live, for example, under tree bark or stones. Popov, et al. (2000) studied the spatial pattern of *Araneae* assemblages and found that they were mainly affected by moisture, light and vegetation structure. *Pirata latitans*, *Pirata hygrophilus* and *Pardosa prativaga* were associated with humid conditions, whereas *Xysticus kochi* and *Thanatus vulgaris* were characteristic for dry sites. *Phlegra fasciata* was more abundant in sites with an open vegetation structure and *Steatoda albomaculata*, *Liocranum rupicola*, *Microneta viaria* and *Ozyptila praticola* in forested sites (Popov, et al., 2000). Other studies found that **herbaceous field margins** (Geiger, et al., 2008) and **hedgerows** (Thomas & Marshall, 1999) (Treier, et al., 2017) can support *Araneae* populations by providing overwintering habitat. However, since it is such a diverse group of species with wide variety of habitat preferences (Weeks & Holtzer, 2000) (Pearce, et al., 2004), it is questionable whether it is relevant to determine a generalised set of essential landscape elements for this order.

Treier, et al. (2017) found that *Opiliones* were more abundant in **woody linear elements** and **grassland edges** than in cover crop edges, whereas another study found that the highest number of taxa was recorded in **natural regeneration** and the lowest number in permanent crop rotation (Stasiov, et al., 2006). *P. opilio* occurs in a wide array of habitats (Allard & Yeargan, 2005). According to Edgar (1980), typical habitats of *P. opilio* are **road verges, fence rows, gardens, grassy field edges** and **foundations of buildings**, whereas it seems to avoid shrubs and other brushy vegetation. Additionally, Novak, et al. (2009) studied its preferences for different substrates and found that pinewood offered the most stable temperature and humidity conditions, providing the most suitable resting place for *P. opilio*.

3.3.4 *V. faba*

Pollinators of *V. faba* are *Anthophora plumipes*, *Bombus hortorum*, *Bombus pascuorum* and *Bombus ruderatus*. However, *B. ruderatus* was last seen in the Netherlands in 1975 (Peeters, 2012). Therefore, this paragraph will only focus on the other pollinator species.

A. plumipes is a **polylectic** bee, foraging from the plant families *Lamiaceae*, *Primulaceae*, *Fumariaceae*, *Fabaceae* and *Boraginaceae* (Batra, 1994). *A. plumipes* is found throughout the Netherlands, but is restricted by its nesting requirements. According to Van Breugel (2002), they are strongly dependent on the presence of bare ground on steep slopes, such as **dikes** or **river banks**. Their flight range is unsure, however Batra (1997) found that the closely related *Anthophora abrupta* has a flight range up to 3.2 km.

Bombus hortorum and *Bombus pascuorum* have similar habitat preferences. In the UK, nests of both species are strongly associated with **tussock-type vegetation** and specifically *B. pascuorum* seems to show preference for field boundaries with **hedges** (Kells & Goulson, 2003). Peeters, et al. (2012) also claims that *B. pascuorum* nests in old mouse burrows and barns, whereas *B. hortorum* exclusively nests underground or straight on the soil. Most *Bombus* spp. are **polylectic**, although their tongue length strongly affects their foraging preferences. *B. hortorum* and *B. pascuorum* are both long-tongued species, meaning they generally forage from flowers with a deep corolla. For example, in Scottish bee walks, the majority of observed *B. hortorum* was found on *Vicia sepium*, *Trifolium repens* and *Digitalis purpurea*, whereas *B. pascuorum* was mainly found on *Vicia sepium*, *Digitalis purpurea* and *Trifolium pratense* (Brodie, 1996). Additionally, Peeters, et al. (2012) states that both *B. hortorum* and *B. pascuorum* mainly forage on *Lamium album* in agricultural landscapes, of which *B. hortorum* has additional preference for *Symphytum officinale*. Queens of *B. hortorum* emerge early in the season and is therefore more dependent on the availability of ***Salix* spp.** for pollen. A German study tracked *B. hortorum* individuals in their daily activities with transmitters and found that they spend approximately 50% of their time resting, mainly on **trees** (Hagen, et al., 2011). Furthermore, Westphal, et al. (2006) suggests a foraging range up to approximately 1000 m for *B. pascuorum*, whereas Knight, et al (2005) estimates a range of 449 m. The maximum foraging range of *B. hortorum*, obtained by Hagen, et al (2011), was 1300 m.

Natural enemies that can lower population numbers of *V. faba* pests are the carabid *Bembidion quadrimaculatum*, coccinellids *Adalia bipunctata*, *Coccinella septempunctata*, *Hippodamia variegata*, *Propylea quatuordecimpunctata*, Braconidae *Aphidius ervi*, Pteromalidae *Dinarmus acutus*, *Nabidae* spp. and *Orius* spp. The habitat preferences of *A. ervi* and *C. septempunctata* are already evaluated in paragraph 3.3.1 and *Nabidae* spp. in paragraph 3.3.3. Since little data about *Nabidae* spp. was available, this information is mainly based on Heteropterans in general. This group also includes *Orius* spp., which is why these species will not be discussed further here.

Pywell, et al. (2005) found that the base of **mature hedgerows** and **tussocky grass field margins** provided overwintering habitat for high numbers of *B. quadrimaculatum*. Another study found significantly higher densities of beneficial arthropods, among which *B. quadrimaculatum*, in ‘**beetle banks**’ than in other types of field boundaries (MacLeod, et al., 2004). *B. quadrimaculatum* shows preference for **lighter, dry soils** and is primarily carnivorous, but can also be herbivorous to smaller extents (Ingerson-Mahar, 2014). Lys, et al. (1994) found a significant increase in the abundance of a carabid community, including *B. quadrimaculatum*, in cereal fields that managed **flower strips** compared to cereal fields without flower strips. They suggest that the flower strips provide food supplies and suitable overwintering sites (Lys, et al., 1994). Frank, et al. (2009), confirms these results and further elaborates that carabid numbers increase with the age of wildflower strips. These findings suggest that a **permanent establishment of perennial plants** are of great importance.

P. quatuordecimpunctata shows preference to hibernate in leaf litter in the inner part of a forest (Hemptinne, 1988). In contrast, *A. bipunctata* mostly hibernates in **trees**. In rural areas in the Netherlands, it shows preference for species of ***Tilia*, *Salix*, *Populus* and *Platanus*** (Brakefield, 1985). According to Honek (1985), *A. bipunctata* selects its prey from a wide range of host plants, but shows preference for **shrubs**. He found most individuals on ***Sambucus spp.*** (Honek, 1985). In many coccinellid species, egg production is related to the amount of available prey (Wright & Laing, 1980). However, a laboratory study found that *H. variegata* on ***Sonchus oleraceus* and *Brassica nigra*** had increased oviposition rates compared to other plants (Bertolaccini, et al., 2008). An explanation might be that *H. variegata* also forages nectar and pollen from those species of plants and therefore increases its fitness and fecundity. Although, Xueqing and Sigsgaard (2019) studied the effect of a floral diet on *A. bipunctata* and found that it did increase longevity considerably, but not reproduction, when combined with aphids. *P. quatuordecimpunctata*, on the other hand, is a true generalist and is able to survive on solely nectar and pollen if necessary (Pervez & Omkar, 2011). Hatt, et al. (2019) studied the traits of perennial flower mixes that affected the abundance of several predators and found that *P. quatuordecimpunctata* preferred mixes with a high flower cover and a high percentage of ultraviolet patterns (flowers of which the UV-reflectance of the internal part differs from the external part).

The habitat preferences of *D. acutus* are not yet extensively studied, with the exception of Steinhauer (1955) and Leong (1971), who both conducted a small-scale study on the overwintering habitat. They agree that *D. acutus* overwinters in moss on **oak trees**. In general, the dispersal of Pteromalidae is low when sufficient food is available. For example, in Machtinger, et al. (2015), 68.9% of the recorded parasitism by related *Spalangia cameroni* happened within 5 m from the release site

3.3.5 *T. aestevium*

Natural enemies that can lower population numbers of *T. aestevium* pests are the parasitoids *Aphidius rhopalosiphi*, *Aphidius uzbekistanicus*, *Alloxysta victrix*, *Asaphes suspensus*, *Asaphes vulgaris* and *Dendrocerus carpenteri* and the lacewing *Chrysoperla carnea*. The literature which evaluates the habitat requirements of *C. carnea* is discussed in paragraph 3.3.3. Also, the habitat preferences of *A. victrix*, *A. suspensus*, *A. vulgaris* and *D. carpenter* is not extensively studied yet. Therefore, these species will mostly be evaluated as parasitoids in general.

Generally, parasitoids have poor dispersal abilities. Several studies point out that they therefore don't seem to respond to resources at landscape-scale (Brewer, et al., 2008) (Caballero-López,

et al., 2012). This demonstrates the importance of carefully considering the mobility of the species and the spatial distribution of resources. For example, an extensive field study in France found no relationship between the parasitoid abundance and any of the explanatory variables at a 1200 m scale, however they found a positive relationship between parasitoid and **hedges** at a 200-500 m scale, due to the additional floral resources they provide (Alignier, et al., 2014). Fraser, et al. (2007) also suggest that **woodland habitat** with high species richness can maximize diversity of parasitoids. Vollhardt, et al. (2010) studied the effect of the distribution of floral resources on a smaller scale and found that strip management did not significantly increase aphid parasitism, neither when it was at the field margins nor within the crop. However, **flower sources randomly distributed** throughout the crop did increase parasitism rates at low aphid densities. A British study demonstrates that parasitoids have a strong preference for flowers with short corollas. Flower strips that contained a mixture of flowers with long and short corollas, were visited 50% less by parasitoids than strips that only contained flowers with short corollas (Campbell, et al., 2012). The short-corolla mix contained *Fagopyrum esculentum*, *Coriandrum sativum* and *Ammi majus*, which are all exotic to the Netherlands. However, most native *Apiaceae* and *Asteraceae* have a similar a flower structure (Cruydt-Hoeck, 2019). Damien, et al. (2020) demonstrate the importance of flower preference and nectar quality. They found that *A. rhopalosiphi* had greater longevity and higher egg maturation rate when fed on *Fagopyrum esculentum*, compared to *Centaurea cyanus* (Damien, et al., 2020). Rand, et al. (2012) studied the effect of landscape complexity on several natural enemies and found that parasitism rates by both *A. uzbekistanicus* and *A. rhopalosiphi* were not related to landscape complexity, which can probably be explained by their poor dispersal abilities. *A. vulgaris*, however, showed significantly higher levels of parasitism in landscapes with higher complexity (Rand, et al., 2012). These findings are supported by Zhao, et al (2013), who found that *A. vulgaris* was 54% more numerous in **complex landscapes** (containing more field margins, hedges, woodlands and grasslands) and *A. suspensus* 46%. Additionally, in Rand, et al. (2012), *A. vulgaris* showed particularly high emergence numbers on *Urtica dioica*, suggesting that it might benefit from alternative hosts.

4. Case study

4.1 Decision making process

Each target parcel of the BEESPOKE project is examined by the means of an expert assessment. The assessment involves careful determination whether a parcel is currently suitable for the cultivation of the target crop through evaluation of absence, presence and access (within the range of the target species) of the landscape elements that have proven to be beneficial for attracting target pollinators and natural enemies in the literature review (appendix VI). Within this set of landscape elements (LE), a distinction is made between critical LE's, on which one or more species directly depends [red], LE's that are valuable because they are used by more than 3 species [green], beneficial LE's, on which no species directly depend, but are likely to attract a greater abundance of target species [orange] and small, non-plant LE's that are easy to add [yellow] (table 13). In some cases, these criteria show overlap. The hierarchy is then based on the sequence as described above (red, green, orange, yellow). The decision making in the case study is based on this knowledge.

Table 13. Overview of all landscape elements found in the literature review, in which the number of species that makes use of the element is given per crop. A distinction is made between critical LE's [red], beneficial LE's [orange], easy to add LE's [yellow] and LE's that are valuable because they are used by more than 3 species [green]. See text for clarification red, orange, yellow and green. Abbr.: BE – biotic elements, AE – abiotic elements, ART – artificial elements, LLE – linear landscape elements, OM – organic matter.

Category	Landscape elements	C. pep	B. nap	S. tub	V. fab	T. aes
BE	<i>Salix spp.</i>		2 ^e	1 ^e	1 ^e	
	Coniferous trees	1 ^a	1			
	<i>Rubus spp.</i>	1 ^b				
	Tussock	2	2	3	3	
	Fallow	3	2			
	Grassland	1		1		
	<i>Quercus spp.</i>		1		1	
	Solitary tree				2	
	Forest					1
AE	Bare ground		1 ^c	1		
	Steep slope				1 ^g	
	Water		1 ^d			
	Hill (south facing slope)	1				
	Pond	1				
	Pebbles	1	1	1		
	Rocks	1	2	1	1	
ART	Beetle bank				1	
	Buildings					1
	Bee hotel		1			
LLE	Hedgerow	3	4	6	3	1
	Flower strip	5	5	6	6	
	Forest edge	1	2	3 ^f	1	
	Grassy strip	2	2	3	3	
	Weedy strip	3	2			
	Fence	1	2	1		
OM	Leaf litter			1		1
	Compost/decaying mat.	1		1		
	Manure	1				

Explanation critical elements: [a] hibernation site for *T. perfectus*, [b] nesting site for *C. cyanea*, [c] nesting site for *Andrena* spp., [d] development site for *Eristalis* larvae (however: strong flyer so within large range), [e] foraging site for early emerging *Bombus* queens, [f] overwintering site for *Dermapterans*, [g] nesting site for *A. plumipes*.

Easy to add LE's are not distinguishable on maps and are therefore not counted as absent elements. For each site that requires one or more of these landscape elements, it is included as a recommendation. Additionally, flower strips will be created on each parcel for the project of BEESPOKE. These are not yet presented on the used maps and are therefore not counted as absent. However, due to the limited time available before the first sowing possibility, the first flower mixes were a draft. These still need refining and therefore additional, species-specific floral preferences per crop will be recommended per site. Additionally, none of the sites was on sandy soil and is therefore not suitable for *Halictus confusus*.

4.2 Site 5

This site contains a 9090 m² parcel owned by agricultural business Minnema. Figure 11 shows the location and table 14 the count, surface and length of all landscape elements within the ranges of 16, 45, 100, 450 and 900 meter, in which 900 m is the range of the most mobile target species of all three crops. A map of this parcel at a 1:4.000 scale is added to appendix VII. During the three consecutive years of the BEESPOKE project, *B. napus*, *T. aestivum* and *V. faba* will be rotated on this parcel: each year another crop. The present landscape elements are compared to the needs of pollinators and natural enemies of these different crops in table 15.

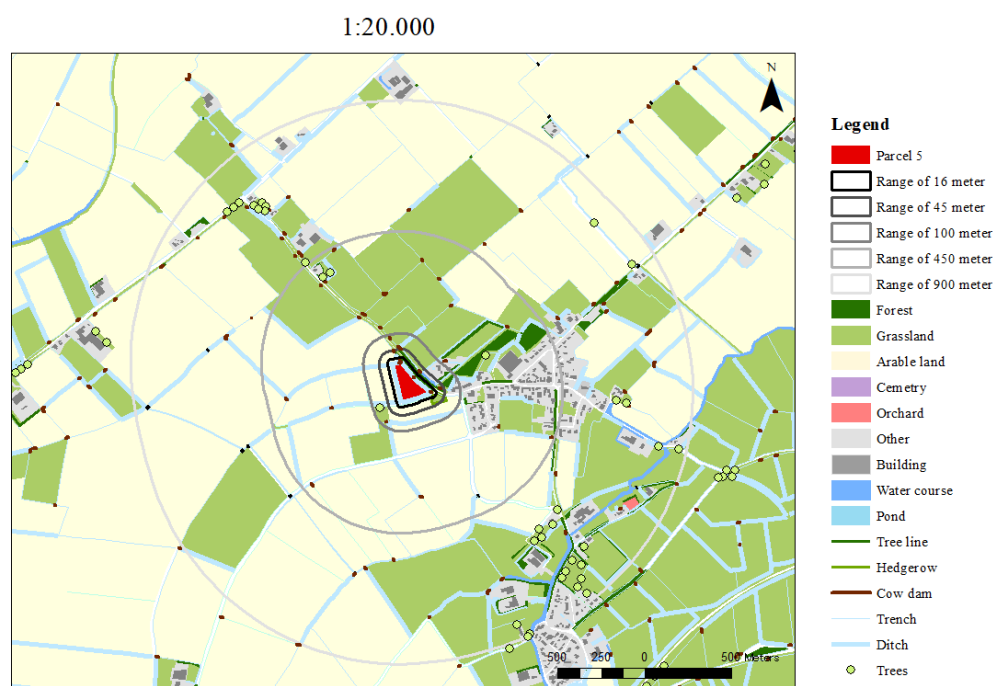


Figure 11. Map of parcel 5 and its surrounding landscape elements on a 1:20.000 scale, in which 5 buffer zones are visualized (16, 45, 100, 450 and 900 m).

Table 14. Summarizing table in which present landscape elements within ranges of 16, 45, 100, 450 and 900 meter from the parcel 5 are given. For each landscape element the amount, length (m) or surface (m²) is given, where relevant.

		Landscape elements																
Range (m)		Forest	Grassland	Arable land	Cemetery	Orchard	Other	Buildings	Water course	Pond	Tree line	Hedgerow	Cow dam	Trench	Ditch	Trees	Total	
16	Present	no	yes	yes	no	no	no	no	no	no	yes	yes	yes	yes	yes	no		
	Count								0	0	0	1	1	4			0	6
	Length (m)											162	26	26	113	447		774
	Surface (m ²)	0	2209	12504	0	0	0	0	0	0								14713
45	Present	yes	yes	yes	no	no	yes	no	yes	no	yes	yes	yes	yes	yes	no		
	Count								0	2	0	2	1	7			0	12
	Length (m)											400	108	50	145	697		1400
	Surface (m ²)	142	7662	22366	0	0	727	0	356	0								31253
100	Present	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		
	Count								8	2	1	2	1	11			1	26
	Length (m)											405	146	78	202	1492		2323
	Surface (m ²)	1888	21211	49765	0	0	4786	807	174	84								78715
450	Present	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		
	Count								81	2	1	4	1	32			4	125
	Length (m)											672	146	234	1899	9457		12408
	Surface (m ²)	22049	273603	445289	0	0	62979	15771	356	84								820131
900	Present	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		
	Count								184	15	7	10	1	73			34	324
	Length (m)											1986	146	555	5168	28875		36730
	Surface (m ²)	40123	8830567	1728908	2592	1478	170595	36177	12926	2385								10825751

Table 15. Overview table of landscape elements that proved to have a positive relationship with the target species of *B. napus* (*B. nap*), *V. faba* (*V. fab*) or *T. aestivum* (*T. aes*), in which the distance to the nearest element to parcel 5 is compared to the range of the least mobile target species associated with it. Letters represent: might be a problem for a - *Eristalis spp.* (however, doubtful: see paragraph 4.2), b - *Pteromalidae* (*S. gracilis*, *T. perfectus*, *M. morys*), c - *Carabidae* (specifically *P. madidus*), d - *Braconidae* (specifically *Aphidius spp.*). Abb. FV – field visit, DTN – distance to nearest (measured from edge of the parcel).

Relevant LE's within 900 m													LE's not present within 900 m on map								
		Forest	Grassland	Building	Water course	Pond	Tree line	Hedgerow	Cow dam	Trench	Ditch	Tree	Fallow	Tussock	Fence	Beetle bank	Bare ground	Coniferous tree	Quercus spp.	Salix spp.	Flower strip
	DTN (m)	41	1	98	44	104	13	18	0	12	0	126	10298		4108						0
	Verify by FV											x	x	x	x	x	x	x	x	x	x
B. nap	Required	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no	yes	yes	yes	yes	yes
	Within (m)	285	100	900	13 ^a	13 ^a	450	5 ^b	450	13 ^a	13 ^a		5 ^b		100 ^c		500	5	900	450	250
V. fab	Required	yes	no	no	no	no	no	yes	no	no	no	yes	no	yes	no	yes	no	no	yes	no	yes
	Within (m)	900						449				449		449		450			5		449
T. aes	Required	yes	no	yes	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	no	no	no
	Within (m)	16 ^d		>40 km				16 ^d													

4.2.1 *B. napus*

Within the range of pollinator *O. bicornis* (900 meter), forest, grassland, arable land, a cemetery, an orchard and other terrains were identified, along with the landscape elements buildings, water courses, ponds, tree lines, hedgerows, cow dams, trenches, ditches and solitary trees. *O. bicornis* showed preference for dead wood, flower strips, buildings, oak trees and artificial nesting facilities, such as bee hotels. Bee hotels cannot be identified on maps, but should be added to optimize pollination by this species. Assuming that dead wood is present in forests, this species should not experience difficulties reaching parcel 5. Within the range of pollinators *B. lapidarius* and *B. terrestris* (450 meter), forest, grassland, arable land and other terrains were identified, along with the same landscape elements present in the 900 meter range. These species can be attracted by the presence of willows, fences, rocks, linear landscape elements and flower strips. Willows and rocks were identified at this parcel within their flight range during a field visit. Besides fences, all elements were present within the range of these species. The absence of fences might cause *B. lapidarius* difficulties finding suitable nesting places. However, this species also nests in other places and does not directly depend on this landscape element. Within the plausible range of carabid beetles (100 meter) the same terrains and landscape elements as in the 450 meter range were identified. The carabids show preference for hedgerows, fences, grassy strips and weedy strips. Weedy strips are included as flower strips. All elements are present within the range, with the exception of fences. The abundance of *P. cupreus* seems to be related to fence margins. Adding to the fact that *B. lapidarius* prefers to nest close to fences, implementation of this landscape element would elevate the quality of this parcel. Within the range of *A. aphidimyza* (45 meter), forest, grassland, arable land and other landscape elements were present, along with water courses, hedgerows, cow dams, trenches and ditches. This species is associated with field margins and hedgerows. This landscape element is also required for all parasitoid species, of which the smallest range is 5 meter (*Pteromalidae*). Their small foraging distances makes them restricted to elements present directly adjacent to the parcel or on the parcel itself. These species are additionally associated with fallow patches, coniferous trees and flower strips. The absence of a fallow patch or coniferous tree within this range is verified during a field visit and the distance to the nearest hedgerow is 150 meter, which is therefore not accessible for any of these species. In order to attract these species to the parcel, these elements should be implemented on an unused or less productive corner of the parcel. Within the range of 16 m, which is comparable to the range of *B. napus* pollinator *Eristalis spp.*, only grassland, arable land, a tree line, cow dams, trenches and ditches are present. The only requirement for this species is that the larvae of *Eristalis spp.* need water with organic matter for development. The presence of trenches and ditches should be sufficient for these purposes. Additionally, *Andrena spp.* rely on bare soil for nesting within a range of 500 meter. The presence of this element within that range is verified during a field visit. *H. rubicundus* shows preference for nesting amid pebbles. These are not detectable on maps, nor is it possible to observe the presence in a range of 250 meter during a field visit. However, it is recommended to implement. All pollinators of *B. napus* are polylectic in their floral preference. However, *Sonchus oleraceus* acts as reservoir of *P. volucre* and *coccinellids* show preference for *Compositae* and *Umbelliferae*. Additionally, the presence of *Capsella bursa-pastoris* might cause lower mortality rates in *A. similata*, however this species, together with *Senecio vulgaris* are important hosts for TuYV and BMV. Carabids in general strongly prefer permanent establishments of floral resources. Therefore, perennial flower species are recommended. **Recommendation:** leave corner to establish fallow vegetation, plant hedgerow at parcel edge and implement fence margins within a range of 100 meter, create perennial flower strips including *S. oleraceus*, *Compositae*, *Umbelliferae*. Removal of *C. bursa-pastoris* and *S. vulgaris* at the site is recommended.

4.2.2 V. faba

The three main pollinators of *V. faba* generally have quite large dispersal abilities. *A. plumipes* can disperse up to 3.2 km, whereas *B. pascuorum* and *B. hortorum* approximately disperse over distances up to 449 m and 1300 m, respectively. These species show preference for flower strips, hedgerows, *Salix spp.* and tussock grasses. A field visit confirmed the presence of tussock grasses. All these elements are present within their range. However, *A. plumipes* is restricted by their strong dependence on bare ground on steep slopes for nesting. A field visit confirmed the presence of such suitable nesting sites. Coccinellidae, which fulfil a natural pest control function in this crop, have dispersal ranges up to 4 km. They can be attracted by the presence of hedgerows, tussock grasses, rocks, south or west facing forest edges, trees (preferably *Tilia*, *Salix*, *Populus* or *Platanus spp.*) and flower strips. Field visit confirmed the presence of *Salix spp.*, however no *Tilia*, *Platanus* or *Populus spp.* could be identified. This should not cause major difficulties, due to the large dispersal range and the presence of *Salix*. The presence of rocks could also not be certified, however it is very likely that this element is present within their large dispersal range. All other elements were present within their range. To improve the natural pest control function of coccinellids, it is recommended to distribute small elements throughout the parcel, as shown in figure 13. The minimum expected range of *B. quadrimaculatum* is 100 m. This species can be attracted by the presence of hedgerows, tussock grasses, flower strips and a beetle bank. The field visit confirmed that a beetle bank was the only absent element within its range. The natural pest control function of this species might be improved when a beetle bank is implemented on or nearby the parcel. The 16 m dispersal range of *A. ervi* is relatively small. However, this species shows no strong habitat preferences besides the presence of flower strips. Therefore, it should not experience difficulties reaching the parcel. *D. acutus* is the least mobile natural enemy connected to *V. faba*, with a mobility range of approximately 5 m. The presence of this species depends on oak trees, as it provides habitat for overwintering. No *Quercus spp.* was identified during the field visit within this small range. Planting a line of oak trees at the edge of the parcel might make the difference for the presence of this natural enemy, although this cannot be supported by literature, as the importance and habitat requirements of this species is not studied well enough. The Heteropterans *Nabidae* and *Orius* are likely to have dispersal abilities of a few hundred meters. Their only known habitat requirements are mixed hedgerows (with preference for *Sambucus nigra*, *Fraxinus excelsior* and *Coryllus avellana*) and flower strips. The nearest hedgerow of this parcel is at 18 m away from the edge. During a field visit it is observed that all preferred plant species were present in this hedgerow. Most species have shown to be attracted to flower strips, of which *B. quadrimaculatum* and Heteropterans have strong preference for perennial flowers. Both *Bombus spp.* show preference for *Vicia sepium*, *Trifolium repens*, *Trifolium pratense*, *Lamium album*, *Symphytum officinale* and *Digitalis purpurea*. *A. ervi*, however, seems to be repelled by *Achillea millefolium*, *T. pratense*, whereas *V. sepium* and *Trifolium spp.* and *Vicia spp.* appear to be host plants of BYMV. Therefore, it is recommended to leave these species out of flower strips. Additionally, oviposition of *H. variegata* is optimized on *Sonchus oleraceus* and *Brassica nigra*. **Recommendation:** implement shrubs or trees evenly distributed throughout the parcel (as previously shown in figure 13), create a beetle bank along an edge, plant several oak trees (max. 5 m distance in between), create perennial flower strip including *L. album*, *S. officinale*, *D. purpurea*, *S. oleraceus* and *B. nigra*.

4.2.3 T. aestivum

T. aestivum does not rely on insects for pollination, which makes this crop much less demanding in terms of surrounding landscape quality than the others. The natural enemies that are beneficial for this crop are mainly parasitoids and *C. carnea*. *C. carnea* has enormous dispersal abilities, which can run up to 40 km. Their only requirements are the presence of leaf

litter and buildings. Assuming that leaf litter covers forest floors, both these elements are present within a range of 100 m. The parasitoids, however, are likely to have a very small dispersal range of approximately 16 m. Their habitat requirements are the presence of hedgerows and forest. Both of these elements are not present within their range. However, the nearest hedgerow is located at 18 m from the edge of the plot, which exceeds the assumed dispersal range by 2 m. Adding up to the fact that Alignier, et al. (2014) measured the positive relationship of this landscape element and parasitoid abundance at a 200-500 m scale, it is expected that the distance to this element will not influence the natural pest control function provided by parasitoids. The nearest forest, however, is located at 41 m distance from the edge of the parcel. Even with the addition of a ‘stepping stone’ tree patch at the edge, this might not be accessible for them. According to Fraser, et al. (2007) a woodland habitat with high species richness increases parasitoid diversity. To create a substitute element, it is suggested that a small-scale patch is planted with mixed hedges and several tree species. These tree and shrub species should be in accordance with the species preferences of Heteropterans and Coccinellidae (natural enemies *V. faba*) in order to create a permanent and multi-functional habitat patch throughout the years of the BEESPOKE project. To maximize the natural pest control of this crop, it is not strongly required to plant a flower strip. However, *Urtica dioica* acts as a reservoir of *C. carnea* and they show additional preference for *Asteraceae*, *Chenopodiaceae*, *Gramineae* and *Ranunculeae*. Parasitoids may be attracted to flowers with short corolla's, which can be represented by most *Apiaceae* and *Asteraceae*. **Recommendation:** implement a small patch with shrubs (preferably *S. nigra*, *F. excelsior*, *C. avellana*) and trees (preferably *Salix*, *Tilia*, *Populus*, *Platanus*).

4.3 Site 2

Site 2 contains three parcels of 4350, 3170 and 9480 m², owned by G. T. Fokkema. Figure 12 shows the location and table 16 the count, surface and length of all landscape elements within the ranges of 16, 45, 100, 200 and 450 m. A map of this parcel at a 1:4.000 scale is added to appendix VII. During the three years of BEESPOKE, *C. pepo*, *V. faba* and another unrelated crop will be rotated on this parcel. The present landscape elements are compared to the needs of pollinators and natural enemies of these different crops in table 17.

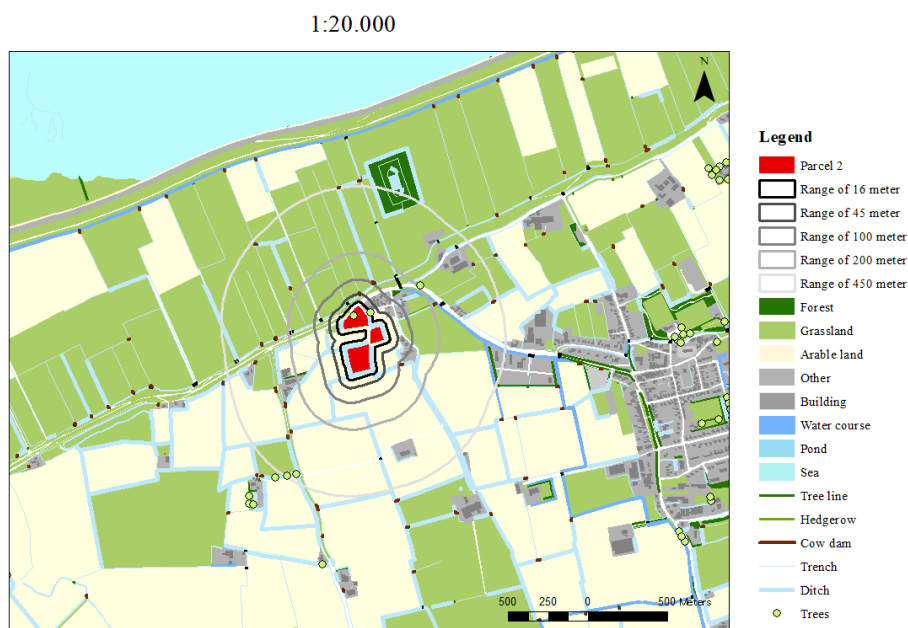


Figure 12. Map of parcel 2 and its surrounding landscape elements on a 1:20.000 scale, in which 5 buffer zones are visualized (16, 45, 100, 200 and 450 m).

Table 16. Summarizing table in which present landscape elements within ranges of 16, 45, 100, 200 and 450 meter from parcel 2 are given. For each landscape element the amount, length (m) or surface (m²) is given, where relevant.

Landscape elements														
Range (m)		Forest	Grassland	Arable land	Other	Buildings	Tree line	Hedgerow	Cow dam	Trench	Ditch	Trees	Total	
16	Present	no	yes	yes	yes	yes	no	no	no	yes	yes	yes		
	Count						4	0	0	0			1	5
	Length (m)						0	0	0	232	692		924	
	Surface (m ²)	0	882	30068	322	198							31470	
45	Present	no	yes	yes	yes	yes	no	no	yes	yes	yes	yes		
	Count						6	0	0	1			2	9
	Length (m)						0	0	2	263	1021		1286	
	Surface (m ²)	0	4956	51982	1616	684							59238	
100	Present	no	yes	yes	yes	yes	no	yes	yes	yes	yes	yes		
	Count						22	0	1	2			2	27
	Length (m)						0	9	10	366	1901		2286	
	Surface (m ²)	0	21716	85199	10033	2600							119548	
200	Present	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes		
	Count						25	0	1	3			2	31
	Length (m)						0	109	29	366	4141		4645	
	Surface (m ²)	1203	93801	157954	17138	3411							273507	
450	Present	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		
	Count						48	1	1	18			5	73
	Length (m)							137	120	143	922	11951		13273
	Surface (m ²)	11583	428000	423846	51952	10655							926036	

Table 17. Overview table of landscape elements that proved to have a positive relationship with the target species of *C. pepo* (*C. pepo*) or *V. faba* (*V. faba*), in which the distance to the nearest element to parcel 2 is compared to the range of the least mobile target species associated with it. Letters represent: might be a problem for a – *E. aeneus*, b – *Dichyphus spp.*, c – *D. errans* and/or *M. pygmaeus*, d – *B. quadrimaculatum*. Abb. FV – field visit, DTN – distance to nearest (measured from edge of the parcel).

Relevant LE's within 450 m							LE's not present within 450 m on map				
	Forest	Grassland	Water course	Hedgerow	Tree	Pond	Tussock	Beetle bank	Coniferous tree	Quercus spp.	Flower strip
	DTN (m)	201	1	260	152	0	782				
	Verify by FV				x			x	x	x	x
C. pepo	Required	yes	yes	yes	yes	no	yes	yes	no	yes	yes
	Within (m)	4000	100	25 ^a	100 ^b		25 ^c	4000		5	900
V. faba	Required	yes	no	no	yes	yes	no	yes	yes	no	yes
	Within (m)	900			100 ^d	449		449	450		5

4.3.1 *C. pepo*

Pollinators *Halictus spp.* and *Lasioglossum spp.* both need bare ground on a slope facing south within a range of 250 m for nesting, whereas *C. cyanea* relies on the presence of *Rubus spp.* within a range of approximately 200 m. A field visit confirmed that such nesting sites are present at this parcel. However, some *Halictus* species prefer to nest under flat pebbles, which are not detectable on maps or during field visits. It is advised to add these to small patches of bare ground in a sunny place. *E. aeneus* has a relatively small home range of 25 m and the larvae need water with rotting materials to develop. The nearest water body to provide such circumstances is located at 260 m away from the edge of the parcel. Although this is out of reach, it is not expected to negatively influence the presence of this species, since the larvae can also develop in alternative environments, such as manure or muddy puddles. As long as the parcel is not kept too dry or clean, this species should not experience difficulty. Hedgerows are associated with the presence of parasitoids, coccinellids and the mirid genus *Dicyphus*. The nearest hedgerow is located at 152 m from the parcel. The minimum mobility of these species is approximately around 16 m, 4 km and 100 m, respectively. For the parasitoids and *D. errans*, the hedgerow is out of reach. In order for these species to be supported in their needs and be able to reach all parcels, it is recommended to strategically place a hedgerow at the north side of the southern parcel or west side of the eastern parcel. The *Miridae* need flower strips and fallow vegetation within their range of 100 m, in which fallow vegetation is missing. Considering the small dispersal range of this species, it is advised to leave several small corners fallow, distributed over all three parcels. All other required elements are within the reach of the target species. All bee species and most natural enemies can be attracted by flower strips, in which perennial strips even act as winter shelter for mirid beetles. *Halictus spp.*, *Lasioglossum spp.* and *C. cyanea* are quite generalistic. However, *Sonchus oleraceus* acts as reservoir of *P. volucre*. **Recommendation:** place a hedgerow at the north side of the southern parcel or west side of the eastern parcel, leave several small corners fallow, distributed over all three parcels, implement *S. oleraceus* in flower strip. Try to remove *Tripleurospermum maritimum*, *Stellaria media*, *Trifolium repens*, *Ranunculus sardous*, *Senecio vulgaris* and *Matricaria discoidea* as much as possible, as these are proven to be natural reservoirs of ZYMV.

4.3.2 V. faba

The pollinators of *V. faba* show preference for flower strips, hedgerows, *Salix spp.* and tussock grasses, and *A. plumipes* depends on bare ground on steep slopes, such as dikes, for nesting. The presence of such nesting sites, *salix spp.* and tussock grasses were confirmed during a field visit and the location to the nearest dikes is approximately 1.2 km. All these elements are present within their range of 3.2 km, 449 m and 1300 m, respectively. The coccinellids associated with *V. faba* can be attracted by hedgerows, tussock grasses, rocks, south or west facing forest edges, trees (preferably *Tilia*, *Salix*, *Populus* or *Platanus spp.*) and flower strips within their dispersal range of 4 km. Only the presence of *Salix spp.* could be confirmed during a field visit. The presence of rocks could also not be certified; however, it is very likely that these tree species and rocks are present within their large dispersal range and will therefore not cause these species any difficulty reaching the parcels. All other elements were present within their range. To improve the natural pest control function of coccinellids, it is recommended to distribute small elements throughout the parcel, as shown in figure 13. The minimum expected range of *B. quadrimaculatum*, *Nabidae* and *Orius spp.* is 100 m. All landscape preferences are within their reach, with the exception of a (mixed) hedgerow and a beetle bank. For the cultivation of *C. pepo* on this parcel it was already recommended to place a hedgerow at the north side of the southern parcel or west side of the eastern parcel. To create a durable landscape element that benefits the cultivation of both crops, it is recommended to implement *Sambucus nigra*, *Fraxinus excelsior* or *Coryllus avellana*, which are preferred plant species of the Heteropterans. It might be difficult to acquire plant material of *F. excelsior*, due to the Ash dieback disease in the Netherlands. Therefore, the other two species are preferred. It is also advised to implement a beetle bank at one of these edges. Additionally, the small dispersal range of *D. acutus*, makes it a critical species, which strongly relies on the presence of oak trees, as it provides habitat for overwintering. The presence of several *Quercus* individuals was identified during the field visit within this small range. Therefore, this species should not experience difficulty reaching this parcel. All other required landscape elements were present within the range of the target species in and around these parcels. The flower strips should form a permanent establishment of perennial flowers, since this benefits *B. quadrimaculatum*, *Nabidae* and *Orius spp.* The recommended flower composition is explained in paragraph 4.2.2. **Recommendation:** implement a hedgerow containing *Sambucus nigra* and *Coryllus avellana* and a beetle bank along the north side of the southern parcel or west side of the eastern parcel, plant *Salix spp.*, create perennial flower strip including *T. repens*, *L. album*, *S. officinale*, *D. purpurea*, *S. oleraceus* and *B. nigra*.

5. Discussion

5.1 Research questions

The main question of this study was how crop-specific pollination and natural pest control can be improved by the implementation of landscape elements. To answer this question, the relationship between [1] crops and pollinators, [2] crop pests and natural enemies and [3] pollinators, natural enemies and landscape elements had to be understood. The results of these questions will be evaluated and discussed in the following paragraphs.

5.1.1 The relationship between crops and pollinators

This study found that all pollinators of *C. pepo*, *B. napus*, *S. tuberosum* and *V. faba* were either bees or hoverflies. The set of pollinating species mostly differed per crop and only showed overlap of *Halictus spp.*, which pollinate *C. pepo*, *B. napus* and, to some extent, *S. tuberosum*, *Lasioglossum spp.*, which pollinate *C. pepo* and *S. tuberosum* and *Eristalinus aeneus*, which pollinate both *C. pepo* and *B. napus*. Although the overall floral structure of these three crops is very different, the length of the corolla, an important feature for pollination, is similar: on average 8, 7.86 and 6 mm, respectively (Paris, et al., 2012) (Pierre, 2001). Many studies have proven that tongue length is an important determinant in the floral visitation patterns of pollinators. When the proboscis is shorter than the nectar tubes, foraging either becomes impossible or handling time increases and foraging efficiency is lower. In contrast, when the proboscis is longer than the nectar tubes, foraging is still possible, but the amount of nectar is not rewarding enough in shallow flowers, also resulting in foraging inefficiency (Klumpers, et al., 2019). *E. aeneus*, *Lasioglossum spp.* and *Halictus spp.* are all generalistic in their flower preferences, however, the length of the proboscis of *Halictus spp.* and *Lasioglossum spp.* (2-6 mm), limits their options to flowers with a corolla of approximately 6-10 mm (Willmer, 2011), which is what might explain the small overlap. This is reflected in the findings of this study. All pollinators of *V. faba* are long-tongued, whereas, most associated bees of *C. pepo*, *B. napus* and *S. tuberosum* are short-tongued species, with the exception of *C. cyanea*, *B. lapidarius*, *B. sensu stricto* and *O. bicornis* (Fortel, et al., 2014). Although these species are able to forage from these crops, it is likely that these species will show preference for flowers with slightly deeper corollas when these are provided, for example in adjacent flower strips. Interestingly, most pollinating bees of *C. pepo*, *B. napus* and *S. tuberosum* are on average much smaller than pollinators of *V. faba*. For example, *A. plumipes* (14-16 mm) or *B. ruderatus* (11-18) are almost twice the size of *C. cyanea* (5-7 mm), *O. bicornis* (8-12 mm), *H. confusus* (6,5-8 mm) and *H. rubicundus* (9-11mm) (Peeters, 2012). The body size of pollinators is important for the effectiveness of pollination, as is shown that large- and middle-sized pollinators are more likely to make contact with the sexual organs in deeper flowers (Solís-Montero & Vallejo-Marín, 2007), such as *V. faba*. Larger pollinators are generally also stronger, which enables them to push themselves into the closed floral structure to access the nectar and pollen (Stoddard & Bond, 1987). These findings underline the value of attracting the 'right sized' bees to each crop, and could be implemented in the design of crop-specific flower mixes by selecting flower species on floral structure and corolla depth.

5.1.2 The relationship between crop pests and natural enemies

In total, 42 species or families were found to be associated with the pests of target crops in this study, of which 8 with *C. pepo*, 14 with *B. napus*, 16 with *S. tuberosum*, 9 with *V. faba* and 7 with *T. aestivum*. Aphids were the most abundant transmitters of pests of *C. pepo*, *S. tuberosum* and *T. aestivum*, whereas beetles were most common in *B. napus* and weevils in

V. faba. This reflects in the dominance of natural enemy groups of the crops: parasitoid wasps in C. pepo, S. tuberosum and T. aestivum, *Carabidae* in B. napus and *Coccinellidae* in V. faba. All natural enemies of C. pepo are also associated with other crops, in which most overlap is present between C. pepo, B. napus and S. tuberosum. Between the other crops, very little to no overlap was found. The similarity between these natural enemies is partly due to the fact that their related viruses (ZYMV for C. pepo, BMV and TuYV for B. napus and PVY for S. tuberosum) are primarily transmitted by the same aphid, *Myzus persicae*, and infestations of the greenhouse whitefly in both C. pepo and S. tuberosum.

5.1.3 The relationship between target insects and landscape elements

Certain landscape elements seemed to attract more pollinators and beneficial insects than others. For example, hedgerows seemed to attract target insects of all crops in this study. This woody element functions as overwintering sites for coccinellids, carabids, parasitoids and spiders. Vegetation associated with this landscape element, such as *Crataegus spp.*, *Ilex spp.* or *Cornus spp.*, provide alternative sources of nectar and pollen and support alternative prey for parasitoids and predators (Bianchi, et al., 2006). The presence of alternative prey has proven to increase parasitoid and predator populations and the longevity and fecundity of parasitoids is increased when nectar is available, both factors improving natural pest control (Bianchi & Van der Werf, 2003). The value of hedgerows lies in its stability of floral resources during the season, whereas herbal vegetation generally has a shorter blooming season and the crop itself provides floral resources only very temporarily (Mondarin & Kremen, 2013). These factors result in a stable habitat that can support a large variety of target species during many of their life stages. Additionally, the structure of hedgerows creates more moderate temperatures compared to its surrounding, which benefits insects that are sensitive to heat and might even induce earlier season emergence (Dryer & Landis, 1996). Another significant element were flower strips, which attracted the highest diversity of target insects of all crops, but T. aestivum. Flower strips contain a diversity of plant species that provide most pollinators and natural enemies with alternative food sources. Flight time differs per pollinator and bumblebees, for example, have relatively long flight times throughout the season that must be 'covered' by food sources. A large variety of flower species in these strips can ensure the supply of food throughout the year, because flowering time varies per plant. Species composition is an important determinant for the attraction of pollinators. For example, it is crucial to determine whether a specific insect beneficial to the crop relies on one genus or family and implement their floral preferences. In this study, most plant species found to be preferred by pollinators were typical for grasslands, whereas natural enemies showed preference for plant species typical for dry, disturbed environments. The difference in preference might be explained by the difference in traits that drive the effectiveness of the flower strips. Natural enemies seem to be attracted by older age and more variation in structure. For example, abundance of overwintering arthropods is generally higher flower strips with a more complex structure and spiders and carabids are more abundant and diverse in older flower strips, which highlights the value of perennials over annuals (Frank, et al., 2012). In general vegetation of dry, disturbed environments has more variation in structure and is generally older than vegetation of grassland, as a result of regular mowing in grasslands. Regular mowing is also less favourable for ground-dwelling species using it as shelter, whereas it is less destructive for (more mobile) flying insects using it as foraging ground.

In this study, *Trifolium repens*, *Centaurea cyanus*, *Glebionis segetum*, *Tripleurospermum spp.* and *Brassica napus* were preferred plant species of beneficial insects associated with most crops (all but T. aestivum), whereas *Brassica napus* was preferred by most beneficial insects, followed by *Taraxacum officinale*. In the Netherlands, both species are abundant early in the

season and hold a long flowering time, which makes them a valuable resource for many insects (Arboretum, 2001). Planning and management play a crucial role in the effectivity of flower strips, which emphasises the importance of acting on species-specific knowledge and careful case-specific evaluations. For example, flower strips can also attract or increase populations of pests or act as reservoirs of certain viruses (Desbiez & Lecoq, 1997) (Schliephake, et al., 2000) (Gadh & Bernier, 1984). Additionally, in many cases, this landscape element is implemented along the field margins, which increases the possibility that pollinator populations might concentrate at edges of the crop and decrease pollination services in the field centres (Campbell, et al., 2017). In contrast, flower strips implemented throughout the crop, or even along the middle axis of it, might allow more intensive interaction between the crop and the flower strips (Cahenzli, et al., 2019).

5.2 Error discussion

5.2.1 Literature

The literature review revealed a lack of consistent, species-specific research in the field of the ecology of pollinators and natural enemies, as well as the processes of wild pollination and natural pest control itself. The pollination-, natural pest control function or habitat requirements of many species was either not studied, the methodology was too divergent to draw general results, results were contradictory or literature was not openly accessible. None of the articles on pollination used in this study applied a ‘before-after’ methodology, and only 50% used a ‘control-impact’ methodology. Articles on natural pest control was even more inconsistent, in which the findings used for this study were sometimes (unintended) by-catch, instead of well-structured results. These inconsistencies result in gaps of valuable knowledge and require more research with standardized study methods.

5.2.2 Dispersal ranges

This study highlights the importance of taking dispersal of target species into account. Species with small dispersal abilities are more sensitive to changes on a small-scale and generally experience more difficulty reaching the crop. To support these species, implementing beneficial landscape elements along field margins is not always enough and often requires implementation of landscape elements within the crop itself, which results in a loss of productive surface or more effort of management practices. However, these suggestions are difficult to recommend, because the maximum dispersal ability of many species is not studied or studies demonstrate very variable results. Studying insect dispersal is challenging, since many factors influence the results. For example, some species, such as lacewings can disperse by the use of wind, which allows them to travel over much larger distances when the wind is advantageous (Duelli, 1980). Dispersal also highly depends on the life stage and is often subject to surrounding environmental cues, i.e. food availability or population density (Osborne, et al., 2002). Decision-making in this study was based on the lowest dispersal abilities of the target species found in the literature or, when information was absent, the dispersal of related species. This results in the lowest risk of excluding beneficial insects from the target parcels, but might also lead to unnecessary recommendations.

5.2.3 Undetectable elements

Additionally, many landscape elements were not detectable on the used maps, such as bare soil, rocks, decaying wood, landscaping pebbles, bee hotels, etc. Patches with bare soil are very common in an agricultural landscape, although there are often temporary and/or seasonal. Also, for some elements, it was assumed that they were present in other elements, such as decaying

wood and rocks in forests or hedgerows and landscaping pebbles and bee hotels in towns. In this study, both cases were located closely to towns. Gardens in towns provide small-scale biodiversity in which these small landscape elements are often present. In intensively managed agricultural areas, gardens have proven to enhance pollination services of crops (Samnegard, et al., 2011). However, in this study, it was unmanageable to verify these elements during a field visit, map these elements separately and determine whether one is present and accessible in the range of the target species. The higher the dispersal abilities of the target species, the more likely it will be these small elements are accessible to them. These minor inaccuracies suggest the need of generating standardized methods for collection of data on small landscape elements, including gardens, within cities or towns.

5.2.4 Landscape complexity

In an intensely managed agricultural landscape, landscape elements may be islands of suitable habitat for many insect species outside of the crop's productive period. Maintaining heterogeneity in such landscapes has proven to be a challenge and improving overall biodiversity does not automatically improve pollination or natural pest control. For example, complex landscapes often provide high availability of alternative resources, which benefits both pests and their natural enemies. According to Martin, et al. (2015), this results in a similar amount of pest reduction as in more simple landscapes, in which both pest and natural enemy cannot thrive. However, the effect of landscape complexity is not yet fully understood; the available literature is often contradicting (Bianchi, et al., 2006). The results of this study highlight that optimizing the pollination and natural pest control function from an agronomic point of view requires location-, case- and species-specific knowledge on how pollinators, pests and natural enemies respond to certain landscape elements and within which scales.

6. Conclusion

What is the relationship between BEESPOKE's target crops and their wild pollinators and natural pest control insects?

In summary, short-tongued bees and hoverflies are the most effective pollinators of *C. pepo*, *S. tuberosum* and *B. napus*, whereas long-tongued bees were more valuable for pollination of *V. faba*. The differences in pollinators are due to the floral structure of the crops. This floral structure should be taken into account when designing crop-specific flower strips, in order to attract the most beneficial pollinators. The dominant pests in *C. pepo*, *S. tuberosum* and *T. aestivum* are aphids, whereas *B. napus* is more often infested with beetles and *V. faba* with weevils. This reflects in the differences of natural enemy groups: parasitoids for *C. pepo*, *S. tuberosum* and *T. aestivum*, carabids for *B. napus* and coccinellids for *V. faba*.

What is the impact of the implementation of landscape elements on these wild pollinators and natural pest control insects?

In general, hedgerows and flower strips proved to be the most valuable landscape elements for all crops in this study, providing diverse and stable alternative food sources and overwintering sites. Pollinators seem to have floral preference for species associated with grassland vegetation, which are more often mown, whereas natural enemies are rather drawn to variety in structure in older vegetation, which is a characteristic of dry, disturbed environments. This highlights the value of perennial flower strips over annuals. *Trifolium repens*, *Centaurea cyanus*, *Glebionis segetum*, *Tripleurospermum spp.* were preferred by target species of all crops. However, *Taraxacum officinale* and *Brassica napus* were preferred by the highest number of beneficial insects, due to their abundance early in the season and their long flowering time.

What is the current situation with respect to landscape elements on BEESPOKE's demonstration sites and which changes can be made in order to create an optimal environment for wild pollinators and natural pest control insects?

On both demonstration sites, most landscape elements were already present within the ranges of the target insects. The most important recommendations for both parcels were the implementation of a beetle bank, a fallow patch and a hedgerow. The floral preference of target insects required implementation of *Sonchus oleraceus*, *Trifolium repens*, *Lamium album*, *Symphytum officinale*, *Digitalis purpurea* and *Brassica nigra*.

How can landscape elements be implemented in order to optimize crop-specific pollination and natural pest control, and improve general biodiversity of pollinators in the Waadrâne area?

The answer to the main question is given in the sub-questions. However, in general, the findings of this study highlight the importance of a case-specific assessment in order to advice land owners on the implementation of landscape elements to optimize pollination and natural pest control. Decision-making requires species-, crop- and location-specific knowledge, which is in many cases not available because [1] it is either not studied, [2] the methodology is too divergent to draw general results and/or [3] results are contradictory. Therefore, it questions the value of the end goal to create an application as a practical tool for location- or crop- specific advice. This would require an extensive database of data that does not yet exist. In order to avoid recommendations based on unsupported generalization, this study highlights the need for more research, standardized study methods and clear results as an important first step instead.

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Appendix I: Design flower mixes

The design of flower mixes is based on decision-making criteria, given in paragraph 2.5. Slight alterations are recommended for each crop, given the fact that each crop has a different set of beneficial insects. Species marked in green attract crop-specific pollinators of natural enemies and grey marked species attract beneficial insects, but did not come through evaluation of other criteria or does not occur naturally in the area of the Waadrâne. Red marked species repel beneficial insects or act as reservoir of crop-related pests. Yellow marked species both attract and repel beneficial insects.

BEESPOKE flower mix	Aesthetics	Development	Taproot	Nitrogen-fixing	Early flowering	Flower depth
<i>Achillea millefolium</i>	x	Perennial				Shallow
<i>Anthriscus sylvestris</i>	x	Perennial				Shallow
<i>Centaurea cyanus</i>	x	Annual	x			Shallow
<i>Centaurea jacea</i>	x	Perennial				Shallow
<i>Cichorium intybus</i>	x	Biennial	x			Shallow
<i>Crepis capillaris</i>		Annual	x			Shallow
<i>Daucus carota</i>	x	Perennial	x			Shallow
<i>Galium mollugo</i>		Perennial			x	Shallow
<i>Glebionis segetum</i>		Annual				Shallow
<i>Lathyrus pratensis</i>	x	Perennial		x		Shallow
<i>Leontodon autumnalis</i>		Perennial				Deep
<i>Leucanthemum vulgare</i>	x	Biennial			x	Shallow
<i>Lotus corniculatus</i>		Perennial	x	x	x	Shallow
<i>Matricaria chamomilla</i>	x	Annual			x	Deep
<i>Medicago lupulina</i>		Annual	x	x	x	Shallow
<i>Melilotus albus</i>	x	Annual	x	x		Deep
<i>Papaver rhoeas</i>	x	Annual				Deep
<i>Pastinaca sativa subsp. Sativa</i>	x	Perennial	x			Shallow
<i>Plantago lanceolata</i>		Perennial			x	Shallow
<i>Prunella vulgaris</i>		Perennial			x	Shallow
<i>Ranunculus acris</i>	x	Perennial			x	Deep
<i>Rumex acetosa</i>		Perennial	x		x	Shallow
<i>Tanacetum vulgare</i>	x	Perennial				Shallow
<i>Trifolium dubium</i>		Annual		x		Deep
<i>Trifolium pratense</i>		Perennial	x	x		Deep
<i>Trifolium repens</i>		Perennial		x		Deep
<i>Tripleurospermum maritimum</i>	x	Perennial				Shallow
<i>Vicia cracca</i>	x	Perennial		x		Deep

C. Pepo	B. napus	S. Tuberosum	V. Faba	T. Aestevium
<i>Achillea millefolium</i>	<i>Achillea millefolium</i>	<i>Achillea millefolium</i>	<i>Achillea millefolium</i>	<i>Achillea millefolium</i>
<i>Anthriscus sylvestris</i>	<i>Anthriscus sylvestris</i>	<i>Anthriscus sylvestris</i>	<i>Anthriscus sylvestris</i>	<i>Anthriscus sylvestris</i>
<i>Centaurea cyanus</i>	<i>Centaurea cyanus</i>	<i>Centaurea cyanus</i>	<i>Centaurea cyanus</i>	<i>Centaurea cyanus</i>
<i>Centaurea jacea</i>	<i>Centaurea jacea</i>	<i>Centaurea jacea</i>	<i>Centaurea jacea</i>	<i>Centaurea jacea</i>
<i>Cichorium intybus</i>	<i>Cichorium intybus</i>	<i>Cichorium intybus</i>	<i>Cichorium intybus</i>	<i>Cichorium intybus</i>
<i>Crepis capillaris</i>	<i>Crepis capillaris</i>	<i>Crepis capillaris</i>	<i>Crepis capillaris</i>	<i>Crepis capillaris</i>
<i>Daucus carota</i>	<i>Daucus carota</i>	<i>Daucus carota</i>	<i>Daucus carota</i>	<i>Daucus carota</i>
<i>Galium mollugo</i>	<i>Galium mollugo</i>	<i>Galium mollugo</i>	<i>Galium mollugo</i>	<i>Galium mollugo</i>
<i>Glebionis segetum</i>	<i>Glebionis segetum</i>	<i>Glebionis segetum</i>	<i>Glebionis segetum</i>	<i>Glebionis segetum</i>
<i>Lathyrus pratensis</i>	<i>Lathyrus pratensis</i>	<i>Lathyrus pratensis</i>	<i>Lathyrus pratensis</i>	<i>Lathyrus pratensis</i>
<i>Leontodon autumnalis</i>	<i>Leontodon autumnalis</i>	<i>Leontodon autumnalis</i>	<i>Leontodon autumnalis</i>	<i>Leontodon autumnalis</i>
<i>Leucanthemum vulgare</i>	<i>Leucanthemum vulgare</i>	<i>Leucanthemum vulgare</i>	<i>Leucanthemum vulgare</i>	<i>Leucanthemum vulgare</i>
<i>Lotus corniculatus</i>	<i>Lotus corniculatus</i>	<i>Lotus corniculatus</i>	<i>Lotus corniculatus</i>	<i>Lotus corniculatus</i>
<i>Matricaria chamomilla</i>	<i>Matricaria chamomilla</i>	<i>Matricaria chamomilla</i>	<i>Matricaria chamomilla</i>	<i>Matricaria chamomilla</i>
<i>Medicago lupulina</i>	<i>Medicago lupulina</i>	<i>Medicago lupulina</i>	<i>Medicago lupulina</i>	<i>Medicago lupulina</i>
<i>Melilotus albus</i>	<i>Melilotus albus</i>	<i>Melilotus albus</i>	<i>Melilotus albus</i>	<i>Melilotus albus</i>
<i>Papaver rhoeas</i>	<i>Papaver rhoeas</i>	<i>Papaver rhoeas</i>	<i>Papaver rhoeas</i>	<i>Papaver rhoeas</i>
<i>Pastinaca sativa</i> subsp. <i>Sativa</i>	<i>Pastinaca sativa</i> subsp. <i>Sativa</i>	<i>Pastinaca sativa</i> subsp. <i>Sativa</i>	<i>Pastinaca sativa</i> subsp. <i>Sativa</i>	<i>Pastinaca sativa</i> subsp. <i>Sativa</i>
<i>Plantago lanceolata</i>	<i>Plantago lanceolata</i>	<i>Plantago lanceolata</i>	<i>Plantago lanceolata</i>	<i>Plantago lanceolata</i>
<i>Prunella vulgaris</i>	<i>Prunella vulgaris</i>	<i>Prunella vulgaris</i>	<i>Prunella vulgaris</i>	<i>Prunella vulgaris</i>
<i>Ranunculus acris</i>	<i>Ranunculus acris</i>	<i>Ranunculus acris</i>	<i>Ranunculus acris</i>	<i>Ranunculus acris</i>
<i>Rumex acetosa</i>	<i>Rumex acetosa</i>	<i>Rumex acetosa</i>	<i>Rumex acetosa</i>	<i>Rumex acetosa</i>
<i>Tanacetum vulgare</i>	<i>Tanacetum vulgare</i>	<i>Tanacetum vulgare</i>	<i>Tanacetum vulgare</i>	<i>Tanacetum vulgare</i>
<i>Trifolium dubium</i>	<i>Trifolium dubium</i>	<i>Trifolium dubium</i>	<i>Trifolium dubium</i>	<i>Trifolium dubium</i>
<i>Trifolium pratense</i>	<i>Trifolium pratense</i>	<i>Trifolium pratense</i>	<i>Trifolium pratense</i>	<i>Trifolium pratense</i>
<i>Trifolium repens</i>	<i>Trifolium repens</i>	<i>Trifolium repens</i>	<i>Trifolium repens</i>	<i>Trifolium repens</i>
<i>Tripleurospermum maritimum</i>	<i>Tripleurospermum maritimum</i>	<i>Tripleurospermum maritimum</i>	<i>Tripleurospermum maritimum</i>	<i>Tripleurospermum maritimum</i>
<i>Vicia cracca</i>	<i>Vicia cracca</i>	<i>Vicia cracca</i>	<i>Vicia cracca</i>	<i>Vicia cracca</i>
<i>Erigeron annuus</i>	<i>Taraxacum officinale</i>	<i>Taraxacum officinale</i>	<i>Digitalis purpurea</i>	<i>Urtica dioica</i>
<i>Echium vulgare</i>	<i>Glechoma hederacea</i>	<i>Barbarea vulgaris</i>	<i>Lamium album</i>	
<i>Jasione montana</i>	<i>Eupatorium cannabinum</i>	<i>Hypochaeris radicata</i>	<i>Symphytum officinale</i>	
<i>Hieracium pilosella</i>	<i>Centaurea nigra</i>	<i>Solidago virgaurea</i>	<i>Sonchus oleraceus</i>	
<i>Calendula officinalis</i>	<i>Pulicaria dysenterica</i>	<i>Stellaria media</i>	<i>Brassica nigra</i>	
<i>Verbascum thapsus</i>	<i>Capsella bursa-pastoris</i>	<i>Urtica dioica</i>		
<i>Anthemis arvensis</i>	<i>Sonchus oleraceus</i>	<i>Verbascum thapsus</i>		
<i>Origanum vulgare</i>	<i>Cisrium arvense</i>	<i>Calendula officinalis</i>		
<i>Brassica napus</i>	<i>Anthemis arvensis</i>	<i>Aegopodium podagraria</i>		
<i>Taraxacum officinale</i>	<i>Origanum vulgare</i>	<i>Origanum vulgare</i>		
	<i>Aegopodium podagraria</i>	<i>Brassica napus</i>		

Appendix II: Species composition herb-rich grassland

Five representative vegetation associations for herb-rich grassland with their associated plant composition, excluding grasses, mosses, wind-pollinated plants, poisonous or unwanted plants for fodder crops and rare plants.

Lychnido-Hypericetum tetrapteris		
<i>Angelica sylvestris</i>	<i>Eupatorium cannabinum</i>	<i>Ranunculus acris</i>
<i>Cardamine pratensis</i>	<i>Galium palustre</i>	<i>Rhinanthus angustifolius</i>
<i>Cerastium fontanum subsp. vulgare</i>	<i>Hypericum tetrapterum</i>	<i>Silene flos-cuculi</i>
<i>Cirsium palustre</i>	<i>Lotus pendunculatus</i>	<i>Valeriana officinalis</i>
<i>Dactylorhiza praetermissa</i>	<i>Lycopus europaeus</i>	
Ranunculo-Senecionetum aquatici		
<i>Achillea ptarmica</i>	<i>Leontodon autumnalis</i>	<i>Ranunculus acris</i>
<i>Angelica sylvestris</i>	<i>Lysimachia nummularia</i>	<i>Ranunculus repens</i>
<i>Bellis perennis</i>	<i>Lythrum salarica</i>	<i>Rhinanthus angustifolius</i>
<i>Cardamine pratensis</i>	<i>Mentha aquatica</i>	<i>Silene flos-cuculi</i>
<i>Cerastium fontanum subsp. vulgare</i>	<i>Myosotis palustris</i>	<i>Taraxacum officinale</i>
<i>Cirsium palustre</i>	<i>Persicaria amphibia</i>	<i>Trifolium pratense</i>
<i>Filipendula ulmaria</i>	<i>Plantago lanceolata</i>	<i>Trifolium repens</i>
<i>Galium palustre</i>	<i>Prunella vulgaris</i>	<i>Vicia cracca</i>
Fritillario-Alopencuretum pratensis		
<i>Bellis perennis</i>	<i>Leontodon autumnalis</i>	<i>Symphytum officinale</i>
<i>Cardamine pratensis</i>	<i>Persicaria amphibia</i>	<i>Taraxacum officinale</i>
<i>Cerastium fontanum subsp. vulgare</i>	<i>Plantago lanceolata</i>	<i>Trifolium pratense</i>
<i>Filipendula ulmaria</i>	<i>Ranunculus acris</i>	<i>Trifolium repens</i>
<i>Glechoma hederacae</i>	<i>Sanguisorba officinalis</i>	<i>Vicia cracca</i>
<i>Lathyrus pratensis</i>	<i>Silene flos-cuculi</i>	
Arrhenatherum elatioris		
<i>Achillea millefolium</i>	<i>Glechoma hederacae</i>	<i>Ranunculus acris</i>
<i>Anthriscus sylvestris</i>	<i>Heracleum sphondylium</i>	<i>Ranunculus bulbosus</i>
<i>Bellis perennis</i>	<i>Hypochaeris radicata</i>	<i>Ranunculus repens</i>
<i>Cardamine pratensis</i>	<i>Lathyrus pratensis</i>	<i>Taraxacum officinale</i>
<i>Centaurea jacea</i>	<i>Leucanthemum vulgare</i>	<i>Trifolium dubium</i>
<i>Cerastium arvense</i>	<i>Medicago lupulina</i>	<i>Trifolium pratense</i>
<i>Cerastium fontanum subsp. vulgare</i>	<i>Pastinaca sativa</i>	<i>Trifolium repens</i>
<i>Crepis biennis</i>	<i>Plantago lanceolata</i>	<i>Veronica chamaedrys</i>
<i>Daucus carota</i>	<i>Potentilla reptans</i>	<i>Vicia cracca</i>
<i>Galium mollugo</i>	<i>Prunella vulgaris</i>	
Nardetea		
<i>Achillea millefolium</i>	<i>Hypochaeris radicata</i>	<i>Rhinanthus minor</i>
<i>Campanula rotundifolia</i>	<i>Leontodon saxatilis</i>	<i>Rumex acetosella</i>
<i>Galium mollugo</i>	<i>Leucanthemum vulgare</i>	<i>Succisa pratensis</i>
<i>Galium verum</i>	<i>Lotus corniculatus</i>	<i>Veronica officinalis</i>
<i>Hieracium umbellatum</i>	<i>Potentilla erecta</i>	
<i>Hypericum perforatum</i>	<i>Prunella vulgaris</i>	

Appendix III: Literature overview - Pollination

Author	Species	Methodology	Results
<i>Cucurbita pepo</i>			
(Mudssar, et al., 2014)	<i>Lassioglossum spp.</i> , <i>Halictus spp.</i> , <i>Eristalinus aeneus</i>	At 7-day intervals throughout flowering season, 15 minute observations on staminate and pistillate flowers were made, 5 times a day. Pollinator abundance and visitation frequency (number of visits per flower per 15 min) were measured. Pollen harvest and deposition was measured on caged flowers, opened only for a single visit, after which (on staminate flowers) the pollinator was caught and (on pistillate flowers) the stigma removed. The number of pollen grains were examined on both and fruit set was measured. Additionally, fruit set of fifty floral buds in open-pollinated flowers were also measured (control-impact)	Stay time was highest for <i>Halictus spp.</i> , followed by <i>Lassioglossum spp.</i> , whereas <i>Nomia spp.</i> (not native to the Netherland) had the highest visitation rates and <i>Halictus spp.</i> the lowest. <i>Nomia spp.</i> both collected and deposited the maximum number of pollen grains, followed by <i>Halictus spp.</i> and in terms of fruit set, <i>Nomia spp.</i> revealed to be the best pollinator, followed by <i>Halictus spp.</i>
<i>Brassica napus</i>			
(Jauker, et al., 2012)	<i>Osmia bicornis</i> , <i>Eristalis tenax</i> , <i>Episyrphus balteatus</i>	Fields of <i>B. napus</i> were covered with 14 cages with different densities of <i>O. bicornis</i> , 12 cages with different densities of <i>E. tenax</i> and <i>E. balteatus</i> , and 4 control cages: with honey bees and without pollinators. Random plant samples were harvested in each treatment and fruit set was calculated with the ratio pods/unfertilized flowers per plant, along with seeds per pod and seed weight (control-impact).	Fruit set was positively affected by pollinator density for both treatments, although the effect was stronger for <i>O. bicornis</i> than the hoverflies. Fruit set in honey bee plots were highest, but seeds per pod was highest for <i>O. bicornis</i> with increasing densities.
(Jauker & Wolters, 2008)	<i>Episyrphus balteatus</i>	Two years in a row, 12 plots of 1.5 m were sown with 4 short strips of <i>B. napus</i> . The plots received 3 different treatments with 4 replicates: no pollinators, low density of <i>E. balteatus</i> (3 individuals/m ²) and high density of <i>E. balteatus</i> (6.25/m ²). Plants with closed pods were harvested for examining number of pods per plant, seeds per pod and seed weight for each treatment (control-impact).	Hover flies significantly increased the mean number of seeds per pod from 17.75 in the control plots to 22.25 in the low-density treatment and 20.50 in the high-density treatment and the number of seeds per pod was also significantly greatest in the low-density treatment.

(Stanley, et al., 2013)	<i>Bombus sensu stricto, Bombus lapidarius, Eristalinus spp.</i>	Three locations were visited 7 times. Each location had 6 patches of <i>B. napus</i> , in which all flower visiting insects were identified along with the number of flowers visited in 5 minutes. In 2 fields, visitors were caught and pollen grains carried per individual were identified and counted. Seed set was measured in 4 plots which received different treatments: 1. un-manipulated, open pollination, 2. bagged flower heads (to prevent insect pollination), 3. supplemented natural pollination. After 6-8 weeks, seed pods were collected, number of seeds were counted and mean seed weight per pod was calculated (control-impact).	<i>B. lapidarius</i> and <i>B. sensu stricto</i> had highest visitation rates. <i>B. hortorum</i> carried the most pollen grains, followed by honey bees and <i>Andrena</i> spp., but <i>Eristalis</i> spp. was the most abundant flower visitor. Also, bagged flowers produced significantly less seeds per pod and the seed weight per pod was also lower. Flowers with supplemented pollen added did not produce more seed than open pollination.
(Mudssar , et al., 2011)	<i>Halictus spp., Andrena spp., Episyrrhus balteatus, Eupeodes corollae, Eristalinus aeneus</i>	On 30 plants, pollinator abundance and visitation frequency was observed for 60 seconds, 6 times a day at 3-day intervals throughout flowering season. Pollination effectiveness was measured by counting pollen grains of a caged stigma opened for a single pollinator visit. The stigma was re-caged after the visit and pod weight, pod length, number of seeds per pod and seed weight per pod were measured.	<i>Halictus</i> spp. was the best pollen depositor, followed by <i>Andrena</i> spp., although pollination by <i>Halictus</i> spp. resulted in more seeds per pod. Maximum pod weight was measured after visits by <i>Halictus</i> spp., followed by <i>E. balteatus</i> and <i>E. aeneus</i> .
<i>Solanum tuberosum</i>			
(Buchanan, et al., 2017)	<i>Halictus rubicundus, Lasioglossum leucozonium</i>	The bee community were surveyed for a month, using bowl and blue vane traps in 12 potato fields. Each trap was emptied and set up again after 48. Traps were set out in transects of 4 traps, (1 st - outside, 2 nd – edge, 3 rd – 10 m into the field, 4 th – 30 m into the field).	58 species of bees from 16 genera and 5 families were captured, of which 73% were <i>Lasioglossum</i> spp. (with <i>Halictus rubicundus</i> , <i>H. confusus</i> , <i>L. leucozonium</i> and <i>L. zonulum</i> being native to the Netherlands).
<i>Vicia faba</i>			
(Kendall & Smith, 1975)	<i>Bombus terrestris, Bombus lucorum</i>	Plants in one plot of <i>V. faba</i> were covered by a mesh cage to exclude insects. The cages were removed temporarily to allow pollination. Each pollinating bee was identified and its behaviour observed. Visited flowers were marked (colour coded on pollinating species) and its pods and seeds within	Bee-visited flowers produced the highest number of pods and set, but no significant difference between pollinating efficiency of honey bees and bumblebees was measured. Robbing was carried out by short-tongued

		weighed and counted. Unvisited and hand pollinated flowers were used as control variables (control-impact)	species and honeybees and resulted in lower yield than legal visits, although robbed flowers still produced more pods than unvisited flowers.
(Marzinzig, et al., 2018)	<i>Bees</i>	During 54 transects walks in two fields, all bees observed were identified and their behaviour recorded (1. legal pollination, 2. nectar robbing, 3. extrafloral nectaries visit). After each walk, the number open flowers of ten randomly chosen plants was counted. Seed set was measured by excluding pollinators with a mesh cage. After removing the cage, allowing for a single visit, each visitor was identified and resulting mature pods counted. 5 individuals of <i>B. terrestris</i> , <i>B. hortorum</i> and honey bees were collected and carried pollen pellets removed, after which the grains were counted.	2106 bees belonging to 6 species had been detected, dominated by honey bees (56.1%) and <i>B. terrestris</i> (36.6%). Nectar robbing behaviour was most frequently observed, specifically by <i>B. terrestris</i> . Seed set resulting from <i>B. hortorum</i> visits were highest and the highest proportion of <i>V. faba</i> pollen were carried by honey bees and <i>B. hortorum</i> .
(Poulsen, 1973)	<i>Bombus terrestris</i> , <i>B. hortorum</i> , <i>B. lapidarius</i>	Within one field, 20 counting stations with each 5 plots were sampled twice a day for foraging bees and their behaviour in 1969 and 1970. The time of flower visits were measured by counting the numbers of flowers and plants visited in a known time.	Foraging by bumblebees was limited: 77 in 1969 and 277 in 1970, compared to honey bees: 684 and 2599 respectively. However, honey bees made the lowest number of positive visits: 4.3/min, whereas <i>B. terrestris</i> made 8.6 positive visits per minute and <i>B. hortorum</i> 10.3/min.

Appendix IV: Literature overview – Natural pest control

Author	Species	Methodology	Results
<i>Cucurbita pepo</i>			
(De Backer, et al., 2015)	<i>M. persicae</i>	Under greenhouse conditions, different densities - 0, 16, 32 and 48 - of <i>Macrolophus pygmaeus</i> were introduced to 16 cages containing 4 pepper plants and 10 aphids (early infestation) each. To determine the effect on large aphid colonies, 16 individuals of <i>M. pygmaeus</i> were released in 8 cages containing 4 plants and 200 aphids. Aphids and predators were counted every second day, until all aphids were eaten or <i>M. pygmaeus</i> nymphs appeared (control-impact).	In control cages, aphid populations grew to 885 individuals, whereas cages with 16, 32 and 48 predators, 110, 42 and 0 aphids were counted respectively. The large aphid colonies had 1894 individuals after 14 days in control cages and 1099 in presence of 16 <i>M. pygmaeus</i> individuals (42% lower). A significant difference in aphid population size was observed after 5 days.
(Cabral, et al., 2009)	<i>M. persicae</i>	In laboratory conditions, individuals of <i>Coccinella undecimpunctata</i> (4 th instar, adult female and adult male) were provided with <i>M. persicae</i> prey densities of 10, 30, 50, 70, 90, 110, 130, 150 and 170. Natural prey mortality was evaluated with the same prey densities in the absence of predators. Voracity was calculated as the 'density of aphids provided minus aphids alive after 24h multiplied by ratio of aphids alive after 24h in the control treatment. (control-impact).	The number of prey eaten by larvae increased significantly with prey density, reaching maximum value with 130 aphids (47.21 ± 1.38 consumed). For adult satiation was attained at prey density of 90 (39.85 ± 0.63 and 39.02 ± 1.42 for males and females, respectively).
(Kavallieratos, et al., 2004)	<i>M. persicae</i>	In a 1 ha field of tobacco plants heavily infested with <i>M. persicae</i> , 20 leaves were collected from ten randomly chosen plants (2 leaves per plant), every ten days for 3 months, 2 years in a row. Aphids on the leaflets were counted, after which mummies were separated from living ones and put in a growth cabinet until parasitoids emerged. These were identified to species level.	<i>M. persicae</i> was parasitized by <i>Aphidius colemani</i> , <i>A. ervi</i> , <i>A. matricariae</i> , <i>Praon staryi</i> and <i>P. volucre</i> . The mean numbers of <i>P. volucre</i> (0.69 in the first year and 2.07 in the second) was significantly higher than <i>A. colemani</i> (0.20, 0.03), <i>A. ervi</i> (0.03), <i>A. matricariae</i> (0.01-0.05) and <i>P. staryi</i> (0.01-0.05)

(Peric, et al., 2009)	<i>T. vaporariorum</i>	Leaves of cultivated and weed plants infested with <i>T. vaporariorum</i> were collected in greenhouses from May to October. They were kept in cardboard cylinders until whiteflies and parasitoids emerged. Parasitoids were separated by species and transferred to a controlled environment for further observation.	<i>Encarsia tricolor</i> , <i>E. Formosa</i> , <i>E. partenopea</i> and <i>E. lutea</i> were identified as parasitoids of <i>T. vaporariorum</i> and <i>Dicyphus errans</i> , <i>Exolygus pratensis</i> , <i>Nabis ferus</i> , <i>N. pseudoferus</i> , <i>N. brevis</i> , <i>Orius majusculus</i> , <i>Chrysopa carnea</i> , <i>C. phyllochroma</i> , <i>Clitostethus arcuatus</i> , <i>Synharmonia conglobata</i> , <i>Adalia bipunctata</i> , <i>Propylea quatuordecimpunctata</i> , <i>Tytthaspis sedecimpunctata</i> , <i>Hippodamia tredecimpunctata</i> and <i>Adonia variegata</i> were identified as predators. <i>D. errans</i> was the dominant predator, feeding on 15 larvae of different age.
<i>Brassica napus</i>			
(Veromann, et al., 2006)	<i>M. aeneus</i>	Insects were sampled in two 1 ha fields of spring oilseed rape (SOSR) and two 1 ha fields of winter oilseed rape (WOSR), one sprayed with insecticides and one untreated, with six yellow water traps per plot. Traps were emptied weekly from May-August. In the lab, target cruciferous specialists and their key parasitoids were identified to species-level and counted. Parasitization levels were estimated by collecting <i>M. aeneus</i> larvae from the flowers of 25 randomly chosen plants per plot.	11177 specimens were collected from SOSR and 1742 from WOSR. <i>M. aeneus</i> was the most numerous pest species, accounting for 98.6% of crucifer-specialist caught on SOSR. No parasitization was observed in the insecticide-treated field and second generation of <i>M. aeneus</i> was more abundant in treated fields. <i>Diospilus capito</i> , <i>Phradis morionellus</i> and <i>P. interstitialis</i> were identified as parasitoid of <i>M. aeneus</i> , of which <i>D. capito</i> was most abundant. Parasitization rate was 0-7.4%, depending on insecticide treatment (greater in unsprayed fields)
(Williams, et al., 2010)	<i>P. chrysocephala</i> and <i>M. aeneus</i>	Plant and insect samples were taken from each of 36 or 40 spatially referenced sampling locations arranged as a grid across the crop. <i>P. chrysocephala</i> adults were caught in water trays during autumn and <i>M. aeneus</i> larvae during early summer. Carabids were caught in pitfall traps. Spatial association of the carabids and pests were compared using SADIE.	In autumn, three species of carabid dominated pitfalls: <i>Trechus quadristiatus</i> , <i>Nebria brevicollis</i> and <i>Pterostichus madidus</i> , of which <i>T. quadristiatus</i> and <i>P. madidus</i> were spatially associated with <i>P. chrysocephala</i> . In summer, <i>Amara similata</i> , <i>Anchomenus dorsalis</i> , <i>N. brevicollis</i> , <i>Asaphidion spp.</i> and <i>Loricera pilicornis</i> were most abundant in pitfalls, of which <i>A. similata</i> , <i>N. brevicollis</i> and <i>Asaphidion spp.</i> were spatially associated with <i>M. aeneus</i> .

(Zaller, et al., 2009)	<i>M. aeneus and C. pallidactylus</i>	In each of four fields of WOSR, five cages were randomly distributed per treatment (1. ground-dwelling arthropods removed, 2. 50 adults of <i>A. dorsalis</i> , 3. 50 adults of <i>P. cupreus</i> , 4. open access for ground-dwelling predators). Numbers of <i>M. aeneus</i> and <i>C. pallidactylus</i> were measured by using emergence traps within the different treatment cages in June and August (control-impact).	Numbers of <i>M. aeneus</i> and <i>C. pallidactylus</i> were similar between treatment plots. In August, four times more <i>M. aeneus</i> emerged in treatment 4 and 1 ($131 \pm 77 \text{ m}^2$) than in 2 and 3 ($28 \pm 9 \text{ m}^2$). In June and August, significantly more <i>C. pallidactylus</i> emerged in cages with <i>P. cupreus</i> ($298 \pm 81 \text{ m}^2$) than <i>A. dorsalis</i> ($126 \pm 45 \text{ m}^2$).
(Veromann, et al., 2011)	<i>C. assimilis</i>	Pods were collected from randomly chosen plants on 15 experimental plots, distributed over 9 fields of WOSR, 4 years in a row. Infestation of <i>C. assimilis</i> was assessed and pods were incubated in the lab, into which parasitoids and <i>C. assimilis</i> emerged. After four weeks, all individuals were identified and counted, along with their exit holes.	Infestation of <i>C. assimilis</i> increased each year. Mean percentage of parasitism on <i>C. assimilis</i> decreased from 19.85% in 2004 to 7.03% in 2005, but then increased to 67% in 2006 and 96% in 2007. The most common parasitoids were <i>Trichomalus perfectus</i> , <i>Mesopholobus morys</i> and <i>Stenomalina gracilis</i> , of which <i>T. perfectus</i> was 12.7 times as abundant as <i>M. morys</i> and 10.3 times as <i>S. gracilis</i> .
(Alford, et al., 1995)	<i>C. assimilis</i>	Oilseed rape pods were collected from randomly chosen plants of two sites in 1992, 1993 and 1994. Pods were dissected and live, dead and (by <i>Trichomalus perfectus</i>) parasitized <i>C. assimilis</i> larvae were counted, along with <i>C. assimilis</i> exit holes. The number of parasitized larvae was divided by total number of <i>C. assimilis</i> larvae and exit holes to determine the level of parasitism and number of seeds eaten by parasitized and healthy larvae were counted.	Parasitism rate was 39-73% in WOSR and 25% in SOSR. The mean number of seeds eaten by parasitized larvae was 3.2, whereas healthy larvae ate 5.2 seeds per pod on average, leading to a 38% decline in damage as a result of parasitism by <i>T. perfectus</i> .
(Klukowski & Kelm, 2000)	<i>C. napi</i>	Twelve samples were collected from 50 randomly selected WOSR plants during April-May in Poland. Eggs and larvae of <i>C. napi</i> and <i>C. pallidactylus</i> were kept in a lab until parasitoids reared.	In total, 371 larvae of <i>C. napi</i> and 166 of <i>C. pallidactylus</i> were collected. No parasitoids reared from eggs, but 18 parasitoids reared from larvae. 3 of these individuals were <i>Stenomalina gracilis</i> .

(Zhang & Hassan, 2003)	<i>B. brassicae</i>	In a laboratory, a leaf with 100-150 aphids of four age groups (1-2 days old, 3-4 days old, 5-6 days old or 8-9 days old) were kept in cages, to which 3 pairs of <i>Diaretiella rapa</i> were released. 10 days later, mummies on the leaf were counted every second day and removed from the leaf. A second experiment kept 30 aphids (with the same age groups) in cages with exposure to <i>D. rapae</i> for 24h. Then aphid offspring was recorded and removed daily. Non-parasitized aphids were used as control (control-impact).	One female of <i>Diaeretiella rapae</i> produced 42.8 mummies on average, showing no preference between larval stages. When 150 nymphs of 1-2 day and 3-4 day age were offered to 3 pairs of <i>D. rapae</i> , they produced an average of 115.6 and 126.7 mummies, respectively. Parasitism rates were up to 88.9% in the first generation of <i>D. rapae</i> . The number of offspring of parasitized adult aphids was 0 for aphids younger than 4 days, 3.1 for age group 5-6 days and 15.3 for aphids older than 7 days, whereas this was 38.1 for unparasitized aphids.
(Duchovskiene, et al., 2012)	<i>B. brassicae</i>	12 plots of cabbage received 3 different treatments; 1. control (non-fertilized), 2. manure from cows and 3. synthetic fertilizers. Each treatment had 4 replicas. Every 4-5 days, healthy <i>B. brassicae</i> individuals and parasitized mummies were observed on 10 plants per plot, along with larvae of lady beetles and cecidomyiids. Parasitization (%) was determined as parasitized aphids x 100 / (parasitized aphids + non-parasitized aphids). Number of aphids, parasitoids and predators were compared among treatments.	In all treatments, <i>B. brassicae</i> colonized cabbage plants at the same time, but the highest mean number of aphids was observed in cabbage treated with manure. Highest parasitization was measured in non-fertilized and manure-fertilized plots, 64.6% and 67.5%, respectively. <i>D. rapae</i> reduced the population of aphids by 28.5% on average in non-fertilized plants, whereas on manure- and synthetically fertilized plants this was 13% and 15.6%, respectively. <i>Coccinella septempunctata</i> and <i>Aphidoletes aphidimyza</i> were observed predators of <i>B. brassicae</i> on single plants, which is why no regression or correlation for these two are calculated.
<i>Solanum tuberosum</i>			
(Heimpel & Hough-Goldstein, 1992)	<i>L. decemlineata</i>	8 randomly chosen plots within 4 potato fields were sampled 5 times in June and July, two years in a row. Each plot contained 2 transects of 2m. In 4 plots, all entomophagous insects were recorded. In the other 4, plants were beaten over an enamel pan, after which insects that fell into the pan were identified in the lab. <i>Pterostichus chalcites</i> , <i>Coleomegilla maculata</i> and <i>Coccinella septempunctata</i> were offered larvae and eggs	In 1990 238 individuals of <i>L. decemlineata</i> natural predators were caught and in 1991 178. The most abundantly observed species were <i>C. maculata</i> , <i>Chrysoperla carnea</i> and <i>Lebia grandis</i> , whereas the most abundant species in pitfall traps was <i>Pterostichus chalcites</i> . Phalangium opilio was another very abundant predator. Laboratory feeding tests showed that <i>C. maculata</i> and <i>P. chalcites</i> fed on both large and

		of <i>L. decemlineata</i> in the lab. They were checked twice daily for signs of predation for 3 days.	small eggs and larvae, but <i>C. septempunctata</i> rejected larvae and ate very sparingly of eggs.
(Fox & MacLellan, 1956)	<i>A. sputator</i>	A precipitin tests was used to determine the percentage of larval and adult carabids and staphylinids feeding on wireworms. Predators were collected in 1954 and 1955 and the counted and identified to species level, except for 88 adults and 133 larvae, who were identifiable to only family.	The percentage of both adult carabids and staphylinids shown to have fed on wireworms (36.3% and 36.9%, respectively) were slightly higher than larvae (33.9% and 29.6%, respectively). <i>Amara spp.</i> (mainly <i>Amara familiaris</i>) was the most numerous carabid species, of which 29.8% fed on wireworms, whereas 54% of all <i>Harpalus spp.</i> (mainly <i>Harpalus affinis</i>) were tested positive. Of the staphylinids, <i>Philonthus spp.</i> showed to feed on wireworms the most (27.7%), but <i>Tachyporus spp.</i> were by far the most numerous.
(Van Herk, et al., 2015)	<i>A. obscurus</i>	In the laboratory, one small (1.7 – 6.7 mg), medium (16.1 – 22.0 mg) and large (27.3 – 39.8 mg) larvae of <i>A. obscurus</i> was added to four containers, each containing one larvae of thervid <i>Thereva nobilitata</i> . After predation, <i>A. obscurus</i> larvae were replaced with an individual of similar size. Observations on predation and pupation of <i>T. nobilitata</i> were done weekly from June-August.	One therevid fed on all wireworms after 5 days and initiated pupation after 40 days. The second only consumed the smallest wireworm after 5 days and initiated pupation after 34 days. The third consumed the medium-sized wireworm after 4 days and initiated pupation after 40 days. The fourth did not feed and initiated pupation after 50 days.
<i>Vicia faba</i>			
(Vankosky, et al., 2010)	<i>S. lineatus</i>	13 species of ground beetles were starved for 48h and then put in a petri dish or rearing dish with a 20 eggs of <i>S. lineatus</i> . Remaining eggs, presence/absence of egg debris and beetle and egg location were recorded. Beetles were killed and identified after the experiment. Control dishes without a predator were added. Intraguild predation and competition was measured by exposing <i>S. lineatus</i> eggs to <i>Pt. melanarius</i> and <i>B. quadrimaculatum</i> simultaneously for 48 h (control-impact).	<i>B. quadrimaculatum</i> removed the most <i>S. lineatus</i> eggs (98%), compared to <i>Pt. melanarius</i> , who removed the least eggs (11.75%). <i>Staphylinidae</i> consumed more eggs, on average, than <i>P. lucublandus</i> , <i>M. linearis</i> and <i>Pt. melanarius</i> . Simultaneous exposure of <i>S. lineatus</i> to <i>Pt. melanarius</i> and <i>B. quadrimaculatum</i> resulted in higher egg removal rate than exposure to <i>Pt. melanarius</i> alone. However, compared to exposure to <i>B. quadrimaculatum</i> alone, simultaneous exposure reduced egg removal to 75.3%.

(Hamon, et al., 1990)	<i>S. lineatus</i>	8 field-grown plants were placed in a radioactive solution for 24 h. Simultaneously, 300 adult <i>S. lineatus</i> were starved, after which they were placed on radioactive plants. Radioactive adults were added to an 8 m ³ field cage, in which a 180x10x8 cm pitfall trap was placed. Radioactive larvae were left on the plant and pitfall traps were placed at 30 cm radius around the plants. Every 24h, pitfall traps were emptied and large carabid species identified, counted, and tested for radioactivity (control-impact).	In total, 216 individual carabids caught and 7.84% of them consumed one or more <i>S. lineatus</i> individual. Fewer carabids had larvae in the gut than adults; out of 71 carabids tested, only 3 tested positive for radioactivity (mean predation rate 4.22%) and mortality rate of larvae varied from 0.6%-10.5%, whereas mortality rate of adults varied from 2.6% and 23.8%. The only carabid eating larvae was <i>P. madidus</i> .
(Shannag & Obeidat, 2008)	<i>A. fabae</i>	Under greenhouse conditions resistant V. faba cultivars (79S4) and regular V. faba plants were grown in trays. Each 10 out of 40 plants received different treatments: 1. 79S4 with 5 adult aphids, 2. 79S4 with 5 aphids and 1 hatched larva of <i>Coccinella septempunctata</i> , 3. regular V. faba with 5 aphids and 4. V. faba with 5 aphids and 1 <i>C. septempunctata</i> . Aphid density was monitored at 3-day intervals until the predators became prepupa (control-impact).	The number of aphids without predators were significantly lower on the 79S4 cultivar. <i>C. septempunctata</i> larva significantly reduced aphid density to 32.8% and 57.2% in regular V. faba and 79S4, respectively. The combination of plant resistance and predation was more effective in controlling <i>A. fabae</i> populations than resistance or predation alone.
(Farhadi, et al., 2010)	<i>A. fabae</i>	Adults and four different larval stages of <i>Hippodamia variegata</i> were provided with different densities of <i>A. fabae</i> (1 st instar: 2,4,8,10,15; 2 nd instar: 2,4,8,16,22,28; 3 rd instar: 2,4,8,16,32,45,65; 4 th instar: 2,4,8,16,32,64,100,130; adult males and females: 2,4,8,16,40,60,80,100). After 24h the number of aphids consumed were recorded. Experiments were replicated 15-20 times, simultaneously.	The number of consumed prey increased with prey densities. All developmental stages of <i>H. variegata</i> showed a type II response to <i>A. fabae</i> . Attack rate was greatest for adult males and 4 th instar larvae (0.1589 and 0.1138, respectively), whereas adult females and 3 rd instar larvae showed the shortest handling time (0.4098 and 0.4547 h, respectively).

(Ximenez-Embun, et al., 2014)	<i>A. pisum</i>	In 2009-2010, during spring, summer and autumn, six <i>A. pisum</i> individuals were mounted in a plastic card and randomly placed in 42-63 sampling points in alfalfa fields, separated by 4 m. 2 cards were placed in each sampling point, one on the ground and one 20-30 cm up in the foliage. Cards were monitored for 24 h, with 3 h intervals and each observed predator was identified to species level.	302 predators were observed feeding on cards, of which coccinellids were most abundant (51%). Other predators were Syrphidae, Nabidae, Lygaeidae and Aranae. In spring larva of <i>Hippodamia variegata</i> were the most frequent predator (16) and adults of <i>Eriopis connexa</i> in summer and autumn (60 and 21, respectively). More predator activity was observed in the foliage than on the ground (74% and 26%, respectively).
(Giles, et al., 1994)	<i>A. pisum</i>	Alfalfa fields were sampled by sweep nets during April-June, two years in a row. Four 100-sweep samples were taken from 4 linear transects in 49 x 49 m areas. Contents of the nets were sorted and identified in the lab. To calculate spatial correlation between predator and prey, the number of individuals (100-sweep) were calculated for prey and predator categories.	The most abundant predator was <i>Coccinella maculata</i> , representing 95 and 80% of the coccinellids in the first and second year, respectively. Populations of <i>C. maculata</i> was highly correlated with the <i>A. pisum</i> population. <i>Hippodamia tredecimpunctata</i> , <i>H. parenthesis</i> , <i>Coccinella septempunctata</i> , <i>Cycloneda munda</i> and <i>Adalia bipunctata</i> were also correlated with the population of <i>A. pisum</i> and represented 4.8 and 20.5% of the coccinellids collected in the first and second year.
(Takemoto, et al., 2009)	<i>A. pisum</i>	Individuals of <i>Aphidius ervi</i> were kept on broad bean plants with 100 aphids and received different treatments (1. wasps emerged from mummies on host-infested plants (complex-experienced), 2. Wasps emerged from mummies in plastic cage without aphids or plants (naïve), 3. Wasps emerged from mummies in a PET tube with (visual) openings, next to which host infested plant volatiles were placed (volatiles-experienced). 60 <i>A. ervi</i> individuals were released, one by one, in Y-tubes with infested plants on one end and intact plants on the other (control-impact).	Naïve wasps did not show preference between intact plants and host-infested plants (34 and 26 visits, respectively), whereas complex-experienced wasps showed a significant preference for infested plants (42 visits, compared to 18 on intact plants). Volatiles-experienced wasps also significantly preferred host-infested plants over intact plants (45 and 15 visits, respectively).

(Nakashima & Akashi, 2005)	<i>A. pisum</i>	Every 10 days from May-November, sweep net samples were obtained from a 4ha alfalfa field. 15 samples, obtained from randomly chosen locations, of ten sweeps were obtained within a 1mx1m quadrat. Aphids and their natural enemies from samples were counted and identified in the lab. Parasitism rates were evaluated by rearing 30 aphids on plants exposed to parasitoids and predators caught.	Twelve species of natural enemies were collected in the survey, of which the families Aphididae, Coccinellidae, Syrphidae, Anthocoridae and Nabidae were represented. Parasitism rates of <i>A. pisum</i> was highest by <i>A. ervi</i> , reaching 31% during two peaks in early May and July, whereas parasitism rates by <i>Praon barbatum</i> reached its peak in July and early August (8%).
(Straub, et al., 2013)	<i>A. pisum</i>	A factorial experiment included Fava bean plants receiving 4 treatments: 1. monoculture with predator (<i>Nabis spp.</i>) present, 2. monoculture with predator absent, 3. polyculture with predator present and 4. polyculture with predator absent. Each plant was covered with Microcosms and 10 aphids were added. Each of the four treatments was replicated ten times. Two adult <i>Nabis</i> were added to predator treatments. Each day, 1-2 observations were made with a total of 10 observations (control-impact).	Predator-aphid ratio increased through time and was higher in polycultures than monocultures. Mean numbers of <i>A. pisum</i> were significantly reduced by the presence of <i>Nabis</i> from 100 in predator absence treatments to 20 in predator present/monoculture treatments and 8 in predator present/polyculture treatments.
<i>Triticum aestivum</i>			
(Smyrnioudis, et al., 2001)	<i>R. padi</i>	Two experiments were executed in the lab. 30 BYDV-infected aphids and one <i>Coccinella septempunctata</i> were placed on the centre of 3 trays with 33 wheat plants. In the centre of another 3 trays, 10 BYDV-infected aphids and one <i>Aphidius rhopalosiphi</i> were placed. Three natural enemy-free trays were used as control. One tray of each treatment was sprayed with a systemic insecticide after 2, 7 and 14 days. After the first two spray times, 42 and 58 aphids were collected randomly to be observed for mummy formation (control-impact).	After the first spray time, 21% of the collected aphids were parasitized and after the second time 36%. For both predators, the number of aphids was significantly reduced between the first and second spray time. With <i>C. septempunctata</i> present, the number of infected plants differed significantly between treatment and control. Infection also had spread less far from the centre of the tray with a predator present

(Lozzia, et al., 1998)	<i>R. padi</i>	40 females of <i>Chrysoperla carnea</i> were placed on isolated corn leafs (either genetically modified or traditional) within a glass container. fed with a free growing colony of <i>R. padi</i> . Daily observations recorded times relative to pupation and emergence of adults, as well as deaths that occurred before the end of the experiment.	No significant developmental differences were found between <i>C. carnea</i> fed on aphids grown on genetically modified or traditional corn. Total immature development time (1 st instar to adult) was 17.9 days on average for both aphid treatments.
(Chambers, et al., 1986)	<i>S. avenae</i>	Two sample sites were established in 10 (1980) and 9 (1981) wheat fields, 150 m ² in the middle and 150 m ² 5 m from the edge. Sites were sampled by counting and identifying aphids on 25 randomly chosen shoots, weekly from March-July. Parasitoid spp. were identified by the shape and colour of the siphunculi and other predators were recorded when found in the shoots. Sweep net samples were taken along crop margins and sampling sites.	<i>S. avenae</i> was the most abundant aphid at all sites, except two (3-96 per shoot). Syrphid larvae were present in all 10 sites, coccinellid adults and larvae in 7 and chrysopid larvae in 3. Aphids increased in May and mid-June, when aphid-specific predators were very few. <i>Aphidius uzbekistanicus</i> , <i>A. picipes</i> , <i>A. ervi</i> and <i>Asaphes vulgaris</i> were most common parasitoids that emerged from mummies. <i>Metasyrphus corolla</i> , <i>Episyrphus balteatus</i> , <i>Platycheirus clypeatus</i> , <i>P. manicatus</i> and <i>P. peltatus</i> were the most common syrphid predators.
(Legrand, et al., 2005)	<i>S. avenae</i>	Four batches of 30 pots with each 10 seedlings of <i>T. aestivum</i> were placed in cages under outdoor conditions. Two batches received 100 aphids and 20 <i>Aphidius rhopalosiphii</i> per pot and the other two only 100 aphids. Every 3 weeks, five pots were randomly removed from each batch and all aphids and mummies were counted. Living aphids were incubated until mummies formed and parasitoids emerged (control-impact).	The aphid population grew rapidly from February-April in control treatments. In the presence of parasitoids it decreased from November-December, after which it showed no significant increase in spring. Parasitism rates were lowest in November-January and peaked in February (up to 35%).

(Tomanovic, et al., 2008)	<i>R. padi</i>, <i>S. avenae</i> and <i>M. dirhodum</i>	Every week, from April-June, 100 samples of 20 cm long stems were randomly collected at a distance of at least 50 m from the edge of a cereal field of 5-6 ha (average 500-600 plants/m ²). The mean number of aphids and the percentage of mummified aphids on the stems were identified and calculated in the lab. Aphids were identified to species level. Parasitoids were collected from mummies and kept in growth cabinets. When they emerged, they were also identified to species level.	The primary parasitoids of <i>S. avenae</i> were <i>Aphidius uzbekistanicus</i> (39,91%) and <i>Aphidius ervi</i> (33.51%), whereas <i>A. rhopalosiphi</i> (33.91% and <i>P. gallicum</i> (39.57%) were the most dominant parasitoid of <i>M. dirhodum</i> and <i>P. gallicum</i> (42.86%) of <i>R. padi</i> . The rate of mummification of <i>S. avenae</i> and <i>M. dirhodum</i> were 60% and 100%, respectively
(Dean, et al., 1981)	<i>S. avenae</i> and <i>M. dirhodum</i>	A 2ha wheat field was sampled weekly for live aphids and mummies from June-August from 1973 to 1979. From 1973-77, numbers were counted from 20 0.3 m rows and in 1978-99 sampled of ten adjacent shoots. Mummies were collected and inspected regularly for emerging Hymenoptera, which were then identified and counted. Numbers of each adult parasite emerged were expressed as percentages of the total number of mummies collected each week.	The average parasitism rate of both <i>S. avenae</i> (2.2%) and <i>M. dirhodum</i> (15.8) was highest in July. The most common emerging parasite of <i>S. avenae</i> was <i>Aphidius picipes</i> and the most common hyperparasite <i>Phaenoglyphis villosa</i> , whereas <i>A. uzbekistanicus</i> was the most common parasite of <i>M. dirhodum</i> and <i>Alloxysta victrix</i> the most common hyperparasite.

Appendix V: Target crops and their pollinators and natural enemies

	Target crops				
	<i>C. pepo</i>	<i>B. napus</i>	<i>S. tuber.</i>	<i>V. faba</i>	<i>T. aest.</i>
Pollinators					
<i>Ceratina cyanea</i>	x				
<i>Lasioglossum spp.</i>	x				
<i>Halictus spp.</i>	x	x			
<i>Eristalinus aeneus</i>	x	x			
<i>Andrena spp.</i>		x			
<i>Bombus lapidarius</i>		x			
<i>Bombus sensu stricto</i>		x			
<i>Episyrphus balteatus</i>		x			
<i>Eristalinus spp.</i>		x			
<i>Eupeodes corolla</i>		x			
<i>Osmia bicornis</i>		x			
<i>Bombus spp.</i>			x		
<i>Halictus confusus</i>			x		
<i>Halictus rubicundus</i>			x		
<i>Lasioglossum leucozonium</i>			x		
<i>Lasioglossum zonulum</i>			x		
<i>Anthophora plumipes</i>				x	
<i>Bombus hortorum</i>				x	
<i>Bombus pascuorum</i>				x	
<i>Bombus ruderatus</i>				x	
Natural enemies					
<i>Amara similata</i>		x			
<i>Anchomenus dorsalis</i>		x			
<i>Aphidoletes aphidimyza</i>		x			
<i>Asaphidion spp.</i>		x			
<i>Diaeretiella rapae</i>		x			
<i>Diospilus capito</i>		x			
<i>Mesopolobus morys</i>		x			
<i>Nebria brevicollis</i>		x			
<i>Poecilus cupreus</i>		x			
<i>Pterostichus madidus</i>		x			
<i>Stenomalina gracilis</i>		x			
<i>Trechus quadristiatus</i>		x			
<i>Trichomalus perfectus</i>		x			
<i>Coccinella septempunctata</i>	x	x	x	x	
<i>Aphidius ervi</i>	x	x	x	x	
<i>Coccinella undecimpunctata</i>	x	x	x		
<i>Aphidius matricariae</i>	x	x	x		
<i>Macrolophus pygmaeus</i>	x	x	x		
<i>Praon volucre</i>	x	x	x		
<i>Dichyphus errans</i>	x		x		
<i>Encarsia tricolor</i>	x		x		

<i>Amara familiaris</i>	X		
<i>Aranea spp.</i>	X		
<i>Dermaptera spp.</i>	X		
<i>Harpalus affinis</i>	X		
<i>Opiliones spp.</i>	X		
<i>Phalangium opilio</i>	X		
<i>Thereva nobilitata</i>	X		
<i>Chrysoperla carnea</i>	X		X
<i>Nabidae spp.</i>	X	X	
<i>Adalia bipunctata</i>		X	
<i>Bembidion quadrimaculatum</i>		X	
<i>Dinarmus acutus</i>		X	
<i>Hippodamia variegata</i>		X	
<i>Orius spp.</i>		X	
<i>Propylea quatuordecimpunctata</i>		X	
<i>Alloxysta victrix</i>			X
<i>Aphidius rhopalosiphi</i>			X
<i>Aphidius uzbekistanicus</i>			X
<i>Asaphes suspensus</i>			X
<i>Asaphes vulgaris</i>			X
<i>Dendrocerus carpenti</i>			X

Appendix VI: Overview table of landscape elements per crop

<i>C. pepo</i>	Landscape elements	Floral preference	Additional remarks	Dispersal	G/S
<i>Halictus spp. and Lassiglossum spp.</i>	Pebbles, flower strips, slope facing south	<i>Compositae, Taraxacum officinale, Barbarea vulgaris, Trifolium repens, T. pratense, Achillea millefolium, Erigeron annuus, Leucanthemum vulgare.</i>	Patches with hard and soft soil, low acidity	250 m	G
<i>C. cyanea</i>	Flower strip, <i>rubus spp.</i>	<i>Verbascum spp. Hieracium pilosella, Echium vulgare, Jasione montana</i>		200 m	
<i>E. aeneus</i>	Fresh water pond	<i>Yellow composites, white umbellifers, Daucus carota, Cirsium arvense</i>	Manure/ rotting material	25 m	
<i>D. errans, M. pygmaeus</i>	Fallow vegetation, hedgerow, grassland, flower strip	<i>Calendula officinalis, Geraniaceae spp., Lamiaceae spp.</i>		100 m	
<i>C. septempunctata, C. undecimpunctata</i>	Hedgerow, grass tussock, rocks, forest edge (facing south or west)	<i>Athemis arvensis, Centaurea cyanus, Glebionis segetum, Tripleurospermum spp. Anthriscus spp. Compositae, Umbelliferae</i>	Several small elements evenly distributed in the landscape, elements in sunny places	Up to 4 km	
<i>A. ervi, A. matricariae, P. volucre</i>	Flower strip, hedgerow	<i>Fagopyrum esculentum, Phacelia tanacetifolia, Aegopodium podagraria, Origanum vulgare, Brassica napus, Sonchus oleraceus</i>		16 m	G
<i>E. tricolor</i>	Unknown				

B. napus	Landscape elements	Floral preference	Additional remarks	Dispersal	G/S
<i>Andrena spp.</i>	Patches with bare soil, flower strip, <i>Salix spp.</i>	<i>Asteraceae, Apiaceae, Bryonia, Dipsaceae, Ericaceae, Vicia/Latyrhus spp.</i>	Bare soil in sunny places, sheltered from wind	500-1150 m	G/S
<i>Halictus spp.</i>	Pebbles, flower strip	<i>Taraxacum officinale, Barbarea vulgaris, Trifolium repens, T. pratense, Achillea millefolium, Erigeron annuus, Leucenanthemum vulgare.</i>	Patch with soft soil, slope facing South	250 m	
<i>O. bicornis</i>	Dead wood, bee hotel, flower strip, buildings, <i>Quercus spp.</i>	<i>Ranunculus, Rosa canina</i>	High sun exposure, tubes of bee hotel should be 6-12 mm	900 m	G
<i>B. lapidarius, B. terrestris</i>	<i>Salix spp.</i> , fences, rocks, LLE's, flower strip	<i>Glechoma hederacea, Taraxacum officinale, Asteraceae</i>	Smaller pastures	450-3000 m	G
<i>E. balteatus, E. corollae</i>	Hedgerow, forest edges, water	<i>Compositae: pulicaria dysenterica, Eupatorium cannabinum, Centaurea nigra</i>	Organic matter	285 m	G
<i>Eristalis spp.</i>	Water			13 m	
<i>A. similata, A. dorsalis, Asaphidion spp., P. cupreus, P. madidus, T. quadristiatus, N. brevicollis</i>	Hedgerow, fence, grassy strip, weedy strip	<i>Capsella bursa-pastoris</i>		100 m	
<i>C. septempunctata</i>	Hedgerow, grass tussock, rocks, forest edge (facing south or west)	<i>Athemis arvensis, Centaurea cyanus, Glebionis segetum, Tripleurospermum spp. Anthriscus spp. Compositae, Umbelliferae,</i>		Up to 4 km	

<i>A. ervi</i> , <i>A. matricariae</i> , <i>P. volucre</i>	Flower strip, hedgerow	<i>Fagopyrum esculentum</i> , <i>Phacelia tanacetifolia</i> , <i>Aegopodium podagraria</i> , <i>Origanum vulgare</i> , <i>Brassica napus</i> , <i>Sonchus oleraceus</i>		16m	
<i>S. gracilis</i> , <i>T. perfectus</i> , <i>M. morys</i>	Fallow patch, tree (coniferous), flower strip, hedgerow	<i>Cirsium arvense</i> , <i>Brassica rapa</i> , <i>Brassica napus</i>	Repelled by violet coloured flowers	5 m	G
<i>A. aphidimyza</i>	Field margin or hedgerow		Compost, healthy soil, artificial hanging substrate (when web-forming spiders are absent)	45 m	

S. tuberosum	Landscape elements	Floral preference	Additional remarks	Dispersal	G/S
<i>Bombus spp.</i>	Hedgerow, <i>Salix spp.</i> , tussock-type vegetation, forest edge, flower strip	<i>Fabaceae</i> , <i>Lamiaceae</i> , <i>Orobanchaceae</i> , <i>Boraginaceae</i>		231-2000 m	G
<i>H. confusus</i> , <i>H. rubicundus</i>	Pebbles, bare ground, flower strip	<i>Taraxacum officinale</i> , <i>Tanacetum vulgare</i> , <i>Barbarea vulgaris</i> , <i>Trifolium repens</i> , <i>T. pratense</i>	<i>H. confusus</i> exclusively occurs on sandy soil	250 m	G
<i>L. leucozonium</i> , <i>L. zonulum</i>	Flower strip	Yellow composites: <i>Hypochaeris radicata</i> , <i>Hieracium spp.</i> , <i>Crepis spp.</i> , <i>Solidago virgaurea</i> .	Nests in flat surfaces sandy soil	250 m	
<i>A. familiaris</i> , <i>H. affinis</i>	Field margins, hedgerow (or other wooded linear features), roadside verges	<i>Stellaria media</i> , <i>Taraxacum officinale</i> , <i>Trifolium pratense</i> , <i>Digitaria sanguinalis</i> , <i>Polygonum aviculare</i> , <i>Poa annua</i> , <i>Brassica spp.</i>	High pH, <i>S. media</i> crucial	100 m	

<i>A. ervi</i> , <i>A. matricariae</i> , <i>P. volucre</i>	Flower strip	<i>Fagopyrum esculentum</i> , <i>Phacelia tanacetifolia</i> , <i>Aegopodium podagraria</i> , <i>Origanum vulgare</i> , <i>Brassica napus</i> , <i>Sonchus oleraceus</i>		16 m	G
<i>C. undecimpunctata</i>	Hedgerow, grass tussock, rocks, forest edge (facing south or west)	<i>Athemis arvensis</i> , <i>Centaurea cyanus</i> , <i>Glebionis segetum</i> , <i>Tripleurospermum spp.</i> , <i>Anthriscus spp.</i> , <i>Compositae</i> , <i>Umbelliferae</i> ,	Several small elements evenly distributed in the landscape, elements in sunny places	Up to 4 km	
<i>E. tricolor</i>	Unknown				
<i>D. errans</i> , <i>M. pygmaeus</i>	Fallow vegetation, hedgerow, grassland, flower strip	<i>Calendula officinalis</i> , <i>Geraniaceae spp.</i> , <i>Lamiaceae spp.</i>		100 m	
<i>T. nobilitata</i>	Decaying wood		Pioneer shrub vegetation on sand		
<i>C. carnea</i>	Leaf litter, buildings	<i>Asteraceae</i> , <i>Chenopodiaceae</i> , <i>Gramineae</i> , <i>Ranunculaceae</i> , <i>Urtica dioica</i>	Ivy tufts	Up to 40 km	G
<i>Dermaptera spp.</i>	Hedgerow, forest edge		Stones, pieces of wood		
<i>Nabidae</i>	Hedgerow, flower strips	Perennial flowers		few 100 m	
<i>Araneae</i>	Herbaceous field margin, hedgerow, buildings				
<i>Opiliones spp.</i> , <i>Phalangium opilio</i>	Hedgerow (or other woody linear features), grassland	Natural regeneration	Pinewood		

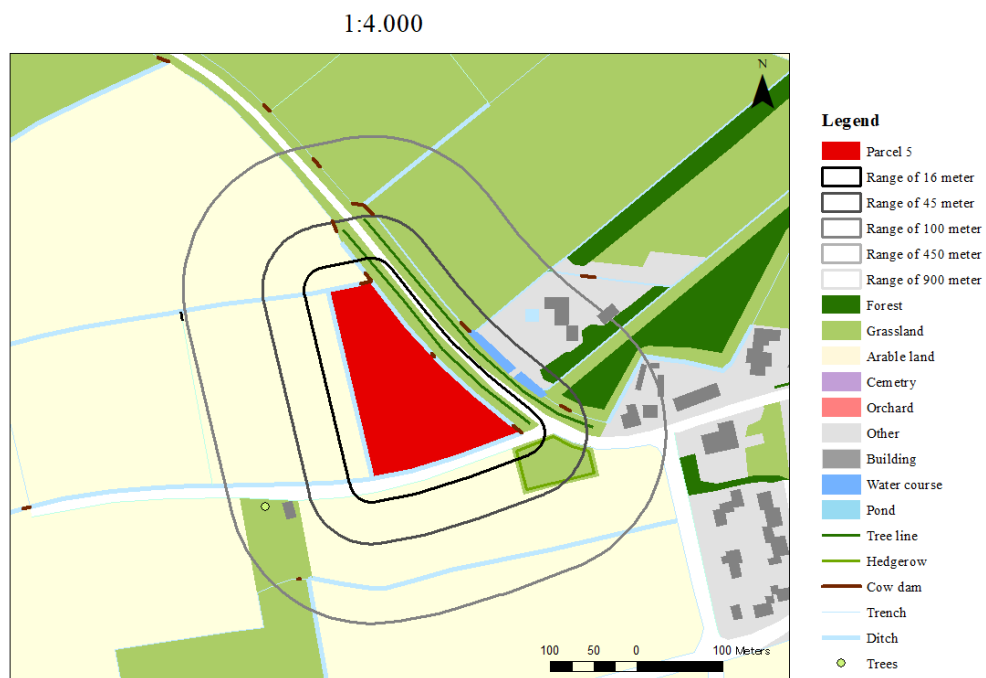
edge, road verge, fence,
garden, buildings

V. faba	Landscape elements	Floral preference	Additional remarks	Dispersal	G/S
<i>A. plumipes</i>	See additional remarks, flower strip	<i>Labriatae, Primulaceae, Fumariaceae,</i> <i>Fabaceae, Boraginaceae</i>	Restricted to bare ground on dikes/ river banks/ quarries or hollow roads	Up to 3.2 km	
<i>B. hortorum, B.</i> <i>pascuorum</i>	Tussock, hedgerow, trees, flower strip	<i>Vicia sepium, Trifolium repens, Digitalis</i> <i>purpurea, Lamium album, Symphytum</i> <i>officinale</i>		449-1300 m	
<i>B. quadrimaculatum</i>	Hedgerow, tussock, beetle bank, flower strip	Perennial flowers	Light, dry soil	100 m	
<i>C. septempunctata, A.</i> <i>bipunctata, P.</i> <i>quatuordecimpunctata,</i> <i>H. variegata</i>	Hedgerow, tussock, rocks, forest edge (facing south or west), trees (i.e. <i>Tilia, Salix,</i> <i>Populus, Platanus</i>), flower strip	<i>Athemis arvensis, Centaurea cyanus,</i> <i>Glebionis segetum, Tripleurospermum spp.</i> <i>Anthriscus spp. Compositae, Umbelliferae,</i> <i>Sonchus oleraceus, Brassica nigra</i>	Several small elements evenly distributed in the landscape, elements in sunny places, high flower cover	Up to 4 km	
<i>A. ervi</i>	Flower strip	<i>Fagopyrum esculentum, Phacelia</i> <i>tanacetifolia, Aegopodium podagraria,</i> <i>Origanum vulgare, Brassica napus,</i> <i>Sonchus oleraceus</i>		16 m	G
<i>D. acutus</i> <i>Nabidae and Orius spp.</i>	<i>Quercus spp.</i> Mixed hedge (<i>Sambucus</i> <i>nigra, Fraxinus excelsior,</i> <i>Coryllus avellana</i>), flower strips	Perennial flowers		5 m few 100 m	

T. aestevium	Landscape elements	Floral preference	Additional remarks	Dispersal	G/S
<i>A. rhopalosiphi</i> , <i>A. uzbekistanicus</i> , <i>A. victrix</i> , <i>A. suspensus</i> , <i>A. vulgaris</i> , <i>D. carpenteri</i>	Hedgerow, forest	<i>Apiaceae</i> , <i>Asteraceae</i> , <i>Urtica dioica</i>	Complex landscapes, floral resources randomly distributed throughout crop	16 m	
<i>C. carnea</i>	Leaf litter, buildings	<i>Asteraceae</i> , <i>Chenopodiaceae</i> , <i>Gramineae</i> , <i>Ranunculaceae</i> , <i>Urtica dioica</i>	Ivy tufts	Up to 40 km	G

Appendix VII: 1:4.000 maps of site 2 and 5

Site 5



Site 2

