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Habitat manipulation

– as a pest management tool in vegetable and fruit cropping systems, with the focus on insects and mites

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Foreword

Today, there is increasing interest among Swedish growers in biological diversity within the agricultural landscape. Many scientific studies have highlighted the services performed by beneficial organisms, which can help to improve the quantity and quality of crops. One tremendously important ecosystem service is biological control of pest insects and mites. The question is what growers can actually do to increase the abundance and diversity of natural enemies and whether this will have an impact on the pest population and, more importantly, on yield and quality of the crop. Another question is whether biodiversity is always positive for growers or whether there are negative aspects that should be dealt with. These relevant questions are addressed in the present report, the aim of which is to enlarge the current knowledge base on how to improve conditions for natural enemies, so-called habitat manipulation, within annual vegetable crops and perennial apple cropping systems. However, our aim was not to conduct a complete review of all available literature, but instead to select studies that may be of particular value for advisors and growers. We also chose to include the outcomes of a workshop on increasing diversity in apple orchards and interviews with advisors and vegetable growers to investigate the attitude and state of knowledge on habitat manipulation in Sweden today. We focus on natural enemies, arthropod pests and practices applied at field scale, and therefore exclude applications developed for greenhouse crops. Our hope is that advisors and interested growers in particular will find this report relevant and rewarding.

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Uppsala, April 2016
Maria Wivstad
Director, EPOK

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The importance of natural biological control

Natural enemies play a very important role in controlling pest insects in agricultural and horticultural crops. For instance, the economic value of these services has been estimated to be more than 400 billion US$ per year globally[1]. Despite this, the importance of natural enemies as pest regulators has been much neglected in the past five decades. Attention and resources have instead been directed towards synthetic insecticides. The negative side-effects of chemical pest control, such as pollution of groundwater, human toxicity, decreased biological diversity and reduced resilience, have increased public concerns and created a demand for more environmentally friendly pest control. Some progress has been made in this regard, for instance the European Union has launched a new directive aimed at reducing the use of synthetic pesticides by applying Integrated Pest Management (IPM)[2]. The IPM strategy was first developed in the United States in the 1950s as a response to unsustainable use of pesticides[3]. In IPM, a number of different methods are combined to control pest damage and preventive methods are favoured over curative approaches such as application of pesticides[4]. Biological control and measures to increase its efficacy are considered cornerstones of IPM[2].

What is biological control?

Pests' natural enemies can be exploited in order to protect agricultural and horticultural crops, natural ecosystems and forest plantations. This is called biological control and differs from other pest management methods by the fact that living organisms are used for pest control. The beneficial organisms are called biocontrol agents and can be either micro- or macro-organisms. Biological control depends on different mechanisms such as parasitism, predation and competition. For more information about biological control see fact box 1.

The kinds of resources needed in habitat manipulation are summarised as SNAP (Shelter, Nectar, Alternative prey and Pollen).

Habitat manipulation

Habitat manipulation aims to improve the living conditions for natural enemies within the agroecosystem, by introducing resources needed for fulfilment of their vital requirements, such as plants providing food in the form of nectar and pollen, additional non-pest prey, but also structural diversity for shelter from adverse weather and breeding and overwintering sites[5]. The natural enemies aimed to protect and benefit could be anything from microscopic organisms such as insect pathogenic fungi and nematodes, or insects and mites but also birds, amphibians and mammals. In essence, habitat manipulation aims to counter the negative effects caused by agriculture by increasing plant diversity in the agroecosystem. The ultimate goal of habitat manipulation is to improve biological control of crop pests. The kinds of resources needed in habitat manipulation are summarised as SNAP (Shelter, Nectar, Alternative prey and Pollen), an easy-to-remember acronym coined by Steve Wratten and Geoff Gurr, two scientists who have long been working on implementation of habitat manipulation in orchards and crop fields. Habitat manipulation can be performed at different scales, stretching from within-crop field to farm level and up to large-scale landscape level[6]. For success, the resources introduced must be temporarily available to the natural enemies when they are most needed and must also be spatially distributed so as to be easily accessed. However, unrealistic designs in terms

PART I

of costly arrangements and use of a high proportion of farmland for habitat manipulation schemes risk preventing implementation by growers.

Summary

- Natural biological control is an important ecosystem service with an economic value of more than 400 billion US$ globally
- In biological control, living organisms are used to control pests and diseases

SYRPHID FLIES ON AN APIACEAE PLANT. PHOTO: ULF NILSSON

Fact box 1. Different kinds of biological control

Typically, biological control aims to control pests to below economic damage thresholds and does not strive for complete eradication. By allowing a small tolerable population of e.g. pest or non-damaging insects within the crop, it is possible to ensure prey for natural enemies throughout the growing season and thereby decrease the risk of natural enemies migrating from the field.

There are three different strategies of biological control: classical, augmentation and conservation biological control.

1. Classical biological control
Today's global trade in living plant materials has resulted in unwanted introduction of pests into regions where they were not previously present. In these new regions, the normal natural enemies of the pests are often absent and the existing predator and parasitoid complex is not efficient enough for adequate control. However, control of these new "exotic" pests can be achieved by introducing natural enemies from their own geographical area. This strategy is called classical biological control. The hope is that the introduced natural enemy will multiply and lead to long-term establishment[5].

2. Augmentation biological control
Natural enemies can be purchased from companies specialising in multiplying beneficial natural enemies and applied in greenhouses and field crops when needed. This is called augmentation biological control. Another example is when growers move pieces of branches with predatory mites or bags with straw with earwigs from one orchard to another. When a large amount of natural enemies is used for a knock-out effect on the pest population, this is called inundative application[5]. In this technique the natural enemies do not multiply and hence the pest control is performed only by the released individuals. This is more or less analogous to pest control with synthetic pesticides. An example of this is the use of *Bacillus thuringiensis* to control lepidopteran larvae feeding on vegetable crops.

LADYBIRD ON CABBAGE. PHOTO: ULF NILSSON

Natural enemies can also be applied at critical periods when few other natural enemies are active, or established, with the goal of ensuring that the natural enemies settle and reproduce within the crop during the growing season. This strategy is called inoculation biological control[5]. However, in reality many growers re-introduce the natural enemies throughout the season to ensure sufficient pest control. For instance, in Swedish greenhouses, different biocontrol agents are applied in tomato and cucumber production several times throughout the growing season to protect the crop against aphids, spider mites, whiteflies and thrips.

3. Conservation biological control
Conservation biological control is a strategy within biological control that aims to improve the conditions for natural enemies already existing in the agricultural landscape[5] and thereby strengthen the control of crop pests. This can be achieved by protecting sensitive life stages of natural enemies from potentially damaging man-made disturbance, e.g. soil cultivation and insecticide spraying. Habitat manipulation is a sub-discipline within conservation biological control that aims to actively improve habitats for natural enemies in order to establish them in sufficient numbers to suppress crop pests below the economic threshold.


PHOTO: LUC VIATOUR GFDL, WIKIMEDIA COMMONS

Factors that influence the outcome of biological control

Agricultural practices

Modern agroecosystems are typically low in biodiversity and frequently disturbed by farming practices, making them hostile environments for many natural enemies. Biodiversity losses have increased rapidly during the past century and have occurred at different scales. Within the field, a few crops and cultivars are most typically grown as monocultures. These fields are often treated with chemical herbicides to control weeds, leaving few flowering plants producing nectar and pollen for natural enemies. Cultural crop practices in the form of mechanical soil treatment, i.e. ploughing and harrowing, can disturb the development of natural enemies in the field.

Landscape

The outcome of biological control in a crop is associated with the surrounding landscape[7, 8]. The establishment of larger and easier to manage fields has led to loss of structurally complex elements composed of herbs, shrubs and trees at the field borders. These are important overwintering and nesting sites for many natural enemies. Furthermore, at landscape level the losses of natural and semi-natural habitats such as wetlands, meadows and pastures have drastically changed the living conditions for birds, mammals and invertebrates. A more complex landscape can, to a higher extent, provide natural enemies with resources such as overwintering sites, prey/hosts and plant-derived food and can thereby sustain a greater abundance and species diversity than a simple landscape[9]. Natural enemies can spill over from the complex landscape into the production fields when pest prey is abundant. For instance, in a study led by the Swedish ecologist Örjan Östman[10], biological control was greater in fields embedded in a complex and vegetation-rich landscape in central Sweden than in fields situated in a low-complexity agricultural production landscape in southern Sweden. Furthermore, orchards situated next to more structural complex surroundings, such as habitats with a mixture of trees, shrubs and herbs, were found to have a greater diversity of natural enemy species than orchards in less complex surroundings[11].

Landscape connectivity

The efficacy of biological control in the field is also associated with the ability of natural enemies to disperse in the landscape between different habitat types[12]. Some natural enemies use green corridors, which connect complex and species-rich habitats such as forests with low diversity arable fields, as highways along which they can move more rapidly into arable fields and colonise crop plants attacked by pests. For instance, it was shown in a scientific study that a green corridor consisting of herbs and grasses, which cut through a field of vine stocks, improved predator and parasitoid movement between a natural habitat and the vineyard throughout the growing season, leading to a reduction in the numbers of some pest insects[13].

Annual and perennial cropping systems – what is the difference?

Agricultural cropping systems are unstable ecosystems characterised by a high degree of man-made disturbances such as soil tillage, weeding, spraying with pesticides and removal of biomass at harvest. All these practices have a negative impact on natural enemies and impede build-up of stable populations, reducing their potential to control pests. The level of disturbance is higher in annual cropping systems than in perennial systems, where the continued presence of the crop plant over time is often linked with higher stability of food webs, including pest species and their natural enemies[14]. A multi-stratum structure, with the presence of permanent vegetation cover in direct contact with the crop, offers an invaluable possibility to intervene in the system th-

PHOTO: ISTOCKPHOTO.COM

rough habitat manipulation, favouring natural enemies without affecting the productive area.

Summary

- Modern agroecosystems are low in biodiversity and frequently disturbed by farming practices, which makes them a hostile environment for natural enemies
- Perennial cropping systems are less disturbed than annual systems, which makes them more stable and favourable for most natural enemies
- The surrounding landscape has a great impact on the outcome of biological control in the field
- A more complex landscape, i.e. with a large proportion of natural habitats and forests, can harbour more species and larger numbers of natural enemies than a poor landscape characterised by large monocultures of annual crops.

Habitat manipulation based on vegetative diversity

Introduction of plant-related food is the most well-studied form of habitat manipulation for vegetables and fruit trees. However, as flowering plants can provide multiple benefits for natural enemies, for instance access to both alternative prey and nectar, it is not always easy to determine the exact mechanism for potential positive effects. Some studies have been able to demonstrate how natural enemies exploit introduced food resources by dissecting the insects or by using different markers on the food plant, such as stable isotopes or marking proteins, which are swallowed or adhere to the insect's body and can later be assessed in the laboratory[15,16].

Floral supplement

Food derived from plants can be of great importance for natural enemy performance in the field. Most predators and parasitoids have the ability to utilise nectar or pollen as additional food. Feeding on sugar-rich compounds such as nectar has been proven to prolong the life of parasitoids and promote their reproduction capacity, host search efficacy and pest control ability[17,18,19,20,21,22].

Intercropped flowering plants can also be important in attracting natural enemies into crop fields in periods when pest insect abundance is low. Early establishment of natural enemies before rapid pest population build-up is often crucial for successful pest control[23].

Predatory insects use plant-derived food for survival when their preferred insects prey is scarce[24,25], as a necessary complement to their carnivorous diet[26] or as the primary food during one development phase for so-called life-history omnivores. Examples of this are common green lacewing (*Crysoperla* spp.) and syrphids, whose larvae feed on insect prey while the adults feed on nectar, pollen and honeydew[27]. Similarly, many parasitic wasps use, and are dependent as adults, on plant-derived food[28,29], while some mostly feed on host larvae, so-called host feeding[30] or on honeydew excreted by homopteran insects, such as aphids[31].

Choice of flowers

Natural enemies may show preferences for certain plant species when searching for floral-derived food[22]. Selectivity can be based on different aspects such as innate attraction to certain plant cues and repellence to others[32]. Natural enemies can also change preference during their lifetime through learning.

Not all nectar and pollen are accessible for all natural enemies. Accessibility is a function of floral architecture and morphological structure of the insect's mouthparts[28,33]. Many natural enemies lack elongated mouthparts, which restricts them from feeding on flowers with a deep corolla[34]. For example, plants from the family Asteraceae have narrow, tubular flowers which may impede large and medium-sized parasitoids from nectar feeding. Small parasitoids, on the other hand, may be able to push their head through the flower and reach the nectar[28].

Other plants may not have open flowers during the time of the day when the natural enemies forage for plant-derived food. For instance, plants from the families Convolvulaceae, Geraniaceae, Cucurbitaceae, Malvaceae and Scrophulariaceae close their flowers at twilight, a period when lacewing (*Chrysoperla* spp.) adults actively search for nectar and pollen[35].

Naturally, the flowering period of the plant should also coincide with the nutritional requirements of the target natural enemy. Another important feature for plant species selection for habitat manipu-

Fact box 2. Necessities when selecting plants

There are several agronomic and biological issues that need to be addressed when selecting plant material for use in flower strips. Ramy Colfer[43], a scientist and horticultural advisor for a large organic vegetable company in California, identified the following necessities:

i) The plant species must be attractive and used by the target natural enemy and, to a lesser extent, must be attractive and utilised by potential pest insects.

ii) The plant species needs to be easily managed, competitive with weeds and inexpensive.

iii) The plants should quickly become attractive to natural enemies and stay so for the whole cropping season.

iv) The proportion of area planted with flowering nectar plants should not be too large relative to the cropping area, in order to be economically viable.

v) The plant species should not become a weed problem in the fields.

lation is for the plants to flower at different times, overlapping over a long period of time and thereby maximising the likelihood of benefiting a broader range of natural enemies. Furthermore, plants flowering early in the spring have been found to be important in supporting aphidophagous natural enemies in the UK, as this allows early build-up of natural enemy populations[36]. Choosing early flowering plants for flower strips is particularly important, as there are fewer flowering wild plants during early spring in Sweden than in late spring and summer.

Considering all the above-mentioned criteria, many habitat manipulation studies have focused on flowering plants with open exposed nectaries, easily accessible for many different natural enemies, and that continue to flower during a long period. In particular, plants from the family Apiaceae[37,38,21,39], Brassicaceae[22,16,39] and buckwheat have proven useful[40,41,42,22].

Nectar is important as food

Nectar can either be produced inside flowers, i.e. floral nectar, or in glands outside the flowers, i.e. extrafloral nectar. Floral nectar is the most well-studied form due to its great importance for mankind and ecosystems.

Floral nectar as food

Nectar can be seen as a reward for pollinating insects and other animals that transport pollen from one flower to another and thus help plants to reproduce. It is produced within a specific anatomical structure called floral nectaries inside the flowers.

Nectar is energy-rich and is used by natural enemy insects from different orders such as Diptera, Coleoptera and Hymenoptera. It consists of different sugar compounds (mainly sucrose, fructose and glucose) and smaller amounts of other compounds such as amino acids, lipids, alcohols and alkaloids[44]. The composition of nectar differs between plants and various growing conditions.

Extra-floral nectar as food

The composition of extra-floral nectar is similar to that of floral nectar, but the total sugar concentration is often higher[31]. The difference arises from where it is secreted. Extra-floral nectar is produced in glands outside the flower and can be found on leaves, stipules, stems, cotyledons and fruits[45]. It is produced during longer periods than floral nectar and it is easily accessible for most natural enemies and therefore useful for habitat manipulation programmes. For instance, in a laboratory study the parasitoid *Microplitis mediator* utilised extra-floral nectar which increased the longevity and parasitisation rates of its moth host in a similar way to floral nectar[46]. However, unlike the nectar produced in flowers, extrafloral nectaries are not advertised with brightly coloured flowers or floral odours, and are therefore more difficult to locate for food-searching natural enemies. In fact, olfactory cues emitted from cornflower (*Centaurea cyanus*) flowers were found to be needed for innate *M.*

SYRPHID FLY FEEDING ON TANSY (*TANACETUM VULGARE*). PHOTO: ULF NILSSON

mediator to successfully locate plants with extrafloral nectaries[47]. Parasitoids and other natural enemies can probably learn to identify cues associated with extra-floral nectaries after successful feeding events. This may facilitate future food foraging for extrafloral nectar.

Pollen as protein source

Pollen is a source of proteins and amino acids for many natural enemies. Pollen consists primarily of nitrogenous compounds, mainly proteins, and other less common compounds such as lipids and sterols[31].

The importance of pollen as a food for syrphid flies[15,48] and lacewings has been well studied[35]. However, lady beetles, predatory hemipteran bugs such as *Orius* spp. and predatory mites also benefit in terms of increased life length and reproduction capacity when feeding on pollen at times when animal prey is scarce[49,50,51]. Pollen feeding by parasitoids is less common, although it does occur (see Lu *et al.*, 2014[52] and references therein).

Natural enemies often show a preference for pollen from specific plants[53,35,54] and not all pollen types are equally well suited as natural enemy food. Moreover, plant pollen preference and natural enemy performance are not always strongly associated. This highlights the need for mechanistic laboratory studies where both the plant preferences and performance in terms of longevity and fecundity of natural enemies are studied together.

Shelter habitats

Providing shelter habitats within the field or at field edges is a strategy that can influence natural enemy abundance, diversity and distribution patterns within the crop during the growing season[55]. Shelter habitats can provide natural enemies with a safe haven from man-made disturbances such as ploughing and harvesting. They can also offer suitable sites for breeding and rest during hot days. However, the most well-known function is as overwintering sites for ground-living predators such as carabid beetles and spiders[56]. Grass margins, on the other hand, have been proven not to be as important for flying natural enemies[36].

Examples of shelter habitats outside the field can be hedgerows, ditches and field margins. Vegetation in these structures is often a mixture of grass, herbs, bushes and trees created by natural succession.

Shelter habitats within the field consist of grass and/or flowering herbs selected to be beneficial for natural enemies. They tend to be perennial structures that change their plant composition over the years. Maintenance may be required to avoid weeds or dominance of a few species[57]. Beetle banks are a well-known form of shelter habitat designed to offer suitable overwintering structures for beetles and spiders[56]. They are raised beds (1-3 m wide) sown with tussock-forming grass such as cock's-foot (*Dactylis glomerata*) that give shelter and protection from adverse weather conditions and extreme temperature shifts. Moreover, by placing beetle banks in the centre of large production fields, a more even distribution of predators can be achieved early in spring.

Alternative prey and host

Most natural enemies can feed on more than one type of prey, i.e. they are polyphagous. During periods when the preferred prey is absent, or only found in low numbers, natural enemies can shift to other prey of a suitable size, so-called alternative prey. Similarly, parasitoids that can parasitise and develop on more than one specific host species may benefit from having access to alternative hosts[58]. Alternative prey/host can thus be crucial for the survival and reproduction of natural enemies. From a biological control perspective, alternative prey can be a key resource to maintain natural enemies within a production area at times when pest populations are low in the field or before the crop is planted and after it has been harvested. Furthermore, availability of alternative prey in field margins early in the spring can increase the abundance of natural enemies and accelerate their colonisation of the crop field later on, when pest insect populations start to build up[59].

Risks associated with habitat management in the agroecosystem

It is important to recognise that pest insects, higher order predators and hyperparasitoids can also utilise food plants introduced into the agroecosystem, which may adversely affect the biological control outcome. For instance, if floral resources increase the fitness of both the pest insect and its natural enemies, then the potential positive effects of biological control may be concealed[60]. Scientists have therefore emphasised the importance of using selective food plants, mainly exploited by natural enemies[37,18,6]. Screening of suitable plant material intended as food resources for natural enemies should, ideally, also include the pest insects to avoid unpleasant surprises in the field. For example, in Australia the effects of different food plants on life span and fecundity were tested for both the potato pest *Phthorimaea operculella* and its primary parasitoid *Copidosoma koehleri*[38]. It was found that dill, borage and coriander significantly increased the longevity of the parasitoid. However, coriander was also found to increase the longevity of the pest, while borage did not. Borage was therefore suggested to be a suitable "selective" food plant for habitat manipulation programmes in the field.

However, it is unlikely that there are selective plants solely exploited by natural enemies, considering the vast complex of primary and secondary pest insects associated with different crops. Therefore, the selection procedure for food plants should focus on primary pest insects and their natural enemies.

Summary

- Introduction of plant-derived food is the most well-studied form of habitat manipulation for vegetables and fruit trees
- Most predators and parasitoids have the ability to utilise nectar or pollen as additional food
- Not all nectar and pollen are accessible for all natural enemies. Accessibility is a function of floral architecture and the morphological structure of insect mouthparts
- Shelter habitats can provide natural enemies with a safe haven from man-made disturbances such as ploughing and harvesting. They are also suitable sites for breeding and overwintering
- Pest insects, higher order predators and hyperparasitoids can also utilise food plants introduced into the agroecosystem. It is therefore important to use selective food plants that are mainly exploited by natural enemies.

COCK'S-FOOT (*DACTYLIS GLOMERATA*). PHOTO: PETR FILIPPOV, WIKIMEDIA COMMONS

Fact box 3. Different groups of insects

Insects are a class of arthropods and are divided into 30 different orders. In Northern Europe, pest insects that feed on cultivated plants are primarily found in six of these 30 orders. Natural enemies are represented in more than seven orders. Some orders contain both pest insects and important natural enemies. Descriptions of the main groups are given below.

Thysanoptera (thrips)

Thrips are small insects, usually around 1 mm long, with fringed wings. Herbivorous thrips pierce the plant tissue and suck up the sap. Heavy thrips infestation can lead to deformation of flowers, fruit and leaves, thus reducing the quality of the crop. Thrips can also be vectors for viruses. There are some examples of predatory thrips, mainly within the family Aelothripidae.

FIELD THRIPS (*THRIPS ANGUSTICEPS*) NYMPH ON A PEA LEAF. PHOTO: NIGEL CATTLIN/VISUALS UNLIMITED, INC.

Hemiptera

EUROPEAN TARNISHED PLANT BUG (*LYGUS RUGULIPENNIS*). PHOTO: MICK TALBOT, WIKIMEDIA COMMONS.

Hemiptera is a diverse group of insects with piercing-sucking mouthparts. More than 1700 species are known in Sweden and they are often subdivided into two groups, Heteroptera (true bugs) and Homoptera which include aphids, leaf hoppers, scale insects and cicadas. There are important plant pests within both Heteroptera (e.g. the tarnished plant bug (*Lygus* spp.)) and *Homoptera* (different aphid species). Hemiptera also comprise important natural enemies belonging primarily to two different families, the Anthocoridae and the Miridae. They are polyphagous and can feed on other insects, as well as on plant-derived food such as pollen.

Coleoptera

Coleoptera is an order of beetles with more than 4400 known species in Sweden. Beetles have chewing mouthparts. Some examples of pests are click beetle, pollen beetle and flea beetle. Natural enemies are primarily found among ground beetles (e.g. *Bembidion* spp.), staphylinids (e.g. *Aleochara* spp.) and ladybird beetles (e.g. *Coccinella septempunctata*).

LARVA OF A LADYBIRD (*COCCINELLA SEPTEMPUNCTATA*). PHOTO: ALVESGASPAR, WIKIMEDIA COMMONS

Lepidoptera

The order Lepidoptera contains moths and butterflies. These are insects characterised by their proboscis, a specialised mouthpart adapted for sucking liquids such as nectar, and by the scales covering their body and wings. There are many examples of pest insects among the lepidoptera. It is the larvae that cause damage, by feeding on different parts of the plant. Well-known examples are the great white butterfly (*Pieris brassicae*) and codling moth (*Cydia pomonella*).

GREAT WHITE BUTTERFLY CATERPILLAR (*PIERIS BRASSICAE*)
PHOTO: DIDIER DESCOUENS, WIKIMEDIA COMMONS

Diptera

Dipterans are insects with one pair of wings and one pair of halteres, a form of modified wings used as gyroscopes. Diptera are divided into two sub-orders, Nematocera (midges) and Brachycera (flies). This order consists of important natural enemies, but also many examples of economically important pests. Examples of natural enemies are the syrphid flies that feed on aphids and tachinid flies that mainly parasitise lepidopteran larvae. Important pests include cabbage root fly (*Delia radicum*) and carrot rust fly (*Psila rosae*).

CABBAGE ROOT FLY (*DELIA RADICUM*)
PHOTO: JAMES K. LINDSEY, WIKIMEDIA COMMONS

TURNIP SAWFLY (*ATHALIA ROSAE*)
PHOTO: MICHAEL BECKER, WIKIMEDIA COMMONS

Hymenoptera

Hymenoptera is a large insect order divided into two suborders, Symphyta and Apocrita. They have grinding or licking mouthparts and two pair of wings, often with reduced venation. The *Symphyta* include important plant pests, e.g. turnip sawfly (Athalia rosae) and apple sawfly (Hoplocampa testudinea). The Apocrita are insects with a narrow waist and include the parasitic wasps that are often highly specialised important natural enemies of different insect pests. They lay their eggs inside or on the bodies of their hosts and the hatched larvae feed on the host until it dies. In Sweden alone, there are more than 9000 species of parasitic wasps.

THE CABBAGE APHID (*BREVICORYNE BRASSICAE*) ON WHITE CABBAGE. PHOTO: ULF NILSSON

Key insect pests and natural enemies in annual vegetable cropping systems

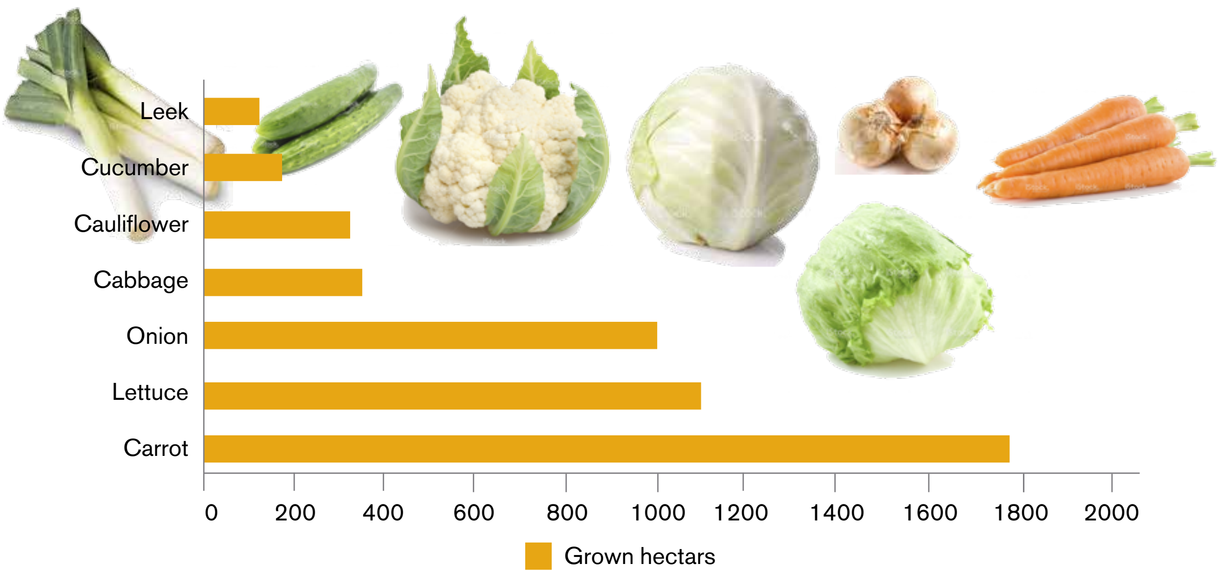

Figure 1. The top seven vegetable crops in terms of area (ha) grown in Sweden in 2013 (Statistiska meddelanden, 2014).

The most important vegetable crops in outdoor production in Sweden are carrots, lettuce and onions. These crops are all produced on an area of more than 1000 hectares[61]. Other important crops are cauliflower, cabbage, leeks and cucumbers. In addition to these, are also many other vegetable crops grown on an area of less than 100 ha, e.g. beetroot, parsnips and asparagus (Figure 1).

All of these vegetables have their own set of pests and diseases, such as different nematodes, insects, fungi, viruses and bacteria, which can cause quality and yield reductions. Among these pests, insects are generally considered to pose the greatest threat to Swedish production of vegetable crops[62]. Key insect pests can often be distinguished for each crop (Table 1). However, the severity of these major pests varies with e.g. geographical location, farming system and agricultural practices on the farm. For example, the tarnished plant bug (*Lygus rugulipennis*) is a serious pest on many different vegetable crops (e.g. carrots, cabbage and lettuce), especially in central and northern Sweden, whilst it is less relevant in the south. Another example is the carrot psyllid (*Trioza apicalis*), the most important carrot pest in central Sweden but not present in the southern county of Scania, where most Swedish carrot production is located. In Scania, carrot rust fly (*Psila rosae*) is considered the primary insect pest.

Creating a more favourable environment for natural enemies has the potential to increase plant protection by natural enemies already present in the landscape.

However, attention must be paid to the spatial and temporal dynamics of pests and their natural enemies. For instance, strategies aimed at enabling early colonisation of the vegetable crop by natural enemies are of great importance.

Plant family	Crop	Major pests
Brassicacae	Cabbage/Cauliflower	Cabbage root fly/Turnip root fly (*Delia radicum/D. floralis*)
		Different lepidopteran species
Apiaceae	Carrot	Carrot rust fly (*Psila rosae*)
		Carrot psyllid (*Trioza apicalis*)
Cucurbitaceae	Cucumber	Seed corn maggot/Bean seed maggot (*Delia platura/D. florilega*)
Asteraceae	Lettuce	Lettuce aphid (*Nasonovia ribis-nigri*)
Amaryllidaceae	Leek	Onion thrips (*Thrips tabaci*)
	Onion	Onion fly (*Delia antiqua*)

Table 1. Examples of key insect pests on some major vegetable crops in Sweden. Based on Anonymous (2001)[62].

Habitat manipulation is often more advantageous in horticultural crops than in agricultural crops. There are several reasons for this. First, vegetable crop fields are often smaller than cereal and oilseed crop fields and, as described earlier, small fields are easier for natural enemies to colonise, as the distance between resources needed in field hedges and the surrounding landscape is smaller. Second, vegetables have higher production value and growers can more easily bear the higher costs for introduction of habitat manipulation schemes, such as loss of production area and labour costs. However, vegetable production in open fields can never be separated from agricultural crops, since they are grown in the same spatial and temporal crop sequence.

Effect on homopteran pests in vegetables: aphids and scale insects

Aphids can cause considerable damage to most field-grown vegetables in Sweden. In addition to direct damage to the plant, aphids are also vectors for viruses. Some aphid species are specific for a certain crop, for instance the lettuce aphid (*Nasonovia ribisnigri*) that feeds on the youngest leaves on lettuce plants, whilst others have a broad range of host plants and can attack many different vegetable crops. For example, *Myzus persicae* can feed on vegetable crops from the families Solanaceae, Chenopodiaceae, Compositae and Brassicaceae. In fact, more than 100 different plants belonging to 40 different families are potential host plants for this extremely polyphagous aphid.

To date, floral supplementation has dominated habitat manipulation schemes aimed at controlling aphids in vegetable crops. Most studies have focused on improving the conditions for syrphid flies.

Within-crop flowers are used to control aphids in lettuce on a large commercial scale in California. The most economically important pest on lettuce is the lettuce aphid, an aphid that is difficult to control as it feeds from the innermost leaves of the lettuce plant, protected from agrochemical sprays. However, endemic populations of syrphid flies can eradicate aphid populations if the conditions are suitable. In order to enhance the biological control effect, many organic farmers use flower strips planted within the crop to provide nectar and pollen and thereby promote egg-laying by the aphid enemy in the lettuce crop[63]. Biological control of the lettuce aphid is successful because there are different syrphid species involved that complement each other with different feeding niches[63], but they all benefit from floral resources. It should be noted, however, that behind this successful example of habitat manipulation are many years of intensive research and field trials to optimise the system, which may give some indication of the amount of time and resources required to create successful

LACEWING (*CHRYSOPIDAE*). PHOTO: SLU.

systems in other crops and/or against other pests. Furthermore, it is not possible to directly translate the design of this Californian system to Swedish conditions. For example, in Sweden syrphids are most abundant during late summer and may therefore not effectively control aphids in early planted lettuce. A survey of the most important natural enemies of aphids during the whole cropping season needs first to be conducted in Sweden before habitat measures are taken.

In a study in England, wild flower strips were planted within a lettuce crop to determine the effects on biological control of lettuce aphid[64]. The flower strips consisted of a mix of 12 different species from the families Amaranthaceae, Apiaceae, Brassicaceae, Compositae and Leguminosae and particular attention was paid to the following functional groups of natural enemies: aerial dispersing natural enemies (e.g. green lacewings, syrphids and lady bird beetles), ground-dwelling predators (e.g. carabids and staphylinids), spiders and aphid pathogenic fungi. Aphid numbers were found to be reduced on plants in the immediate proximity of the wildflower strips early in the cropping season. Later in the season, no effect was found on the aphid population. The biological control of the aphids was mostly attributed to aerial dispersing natural enemies such as lacewings, syrphid flies, ladybirds and anthocorids. Moreover, the reducing effect on aphid numbers decreased with increasing distance from the wildflower strips and at 10 m distance only minor effects were observed. This confirms earlier findings that flower strips consisting of sweet alyssum have a significant effect on biological control of *Myzus persicae* in lettuce, but only up to 11 m away from the flowering plants[65]. Thus, the spatial arrangement of flower strips within the crop is of great importance for the biological control outcome.

Increased relative abundance of syrphid flies has also been found in cabbage fields bordered by flowering blue tansy (*Phacelia tanacetifolia*), with higher aphid populations found in fields without a floral border. Surprisingly, there was no difference in syrphid fly eggs between treatments. This result was partly ascribed to cross-treatment effects due to too small distance between experimental fields, i.e. syrphid flies fed in fields with floral resources while laying eggs in control fields[66].

Effect on dipteran pests in vegetables: flies and midges

Herbivorous dipteran larvae can cause considerable damage to cultivated crops by feeding on roots, stems and leaves. The most economically important pests in Sweden are carrot rust fly and cabbage root fly. Hatched larvae of both species tunnel into the roots and feed, leading to considerable qualitative damage and yield losses.

There are also a number of other pests that, depending on location and year, can cause substantial damage in the form of reduced yield and crop quality, for instance onion fly (*Delia antiqua*) and swede midge (*Contarinia nasturtii*). Habitat manipulation specifically aimed at controlling dipteran pests in vegetables is surprisingly rare considered the severity of these pests. One reason may be that many dipteran insects are dependent on adult feeding for egg maturation[67]. Providing within-crop floral resources can potentially increase the dipteran pest problem instead of reducing it. This was shown in a study in France where biological control of carrot rust fly was not enhanced in carrot fields surrounded by vegetation diverse borders and, instead, egg laying density of the pest increased[68]. This exemplifies why care must be taken when planning habitat manipulation schemes. In contrast to the French study, a Swedish study found that a flower strip consisting of grass, buckwheat and dill did not increase egg laying by cabbage root fly , while overall relative abundance of parasitoids was increased, but did not lead to increased parasitism[22,69]. It is likely that the cabbage root fly found other food sources in the diverse landscape surroundings the experimental fields in that study. Therefore, more general conclusions cannot be drawn from the study before it is repeated in a less diverse landscape where the pest insect has few alternative food sources other than the flower strip.

Flowering plant borders can also enhance parasitism of lettuce leafminers (Diptera: Agromyzidae) but only for some species[70]. In a study from 2010, floral resources increased parasitism by ectoparasitoids, while endoparasitoids were not positively affected as they were found to be less dependent on nectar resources. Furthermore, parasitism occurred earlier in lettuce fields with floral resources. Adult parasitoids were most likely attracted to the flowering plants from surrounding vegetation early in the season and were provided with nectar and shelter before their host insect appeared. However, despite increased parasitism by ectoparasitoids, no

FLOWERING BUCKWHEAT IN A CABBAGE FIELD.
PHOTO: LINDA-MARIE RÄNNBÄCK.

significant decrease in leafminers or the agromyzid population was found, an outcome attributed to a sub-optimal mixture of flowering plants. Consequently, inoculative release of commercially reared parasitoids combined with floral resources was suggested to achieve sufficient pest control, i.e. the naturally occurring natural enemies may not be efficient enough in this system[70].

Habitat manipulation effects on lepidopteran pests: moths and butterflies

Many habitat manipulation studies performed in vegetable crops have focused on lepidopteran pest insects. In particular, the effect of floral supplements has been studied for several different lepidopteran pests and their natural enemies. Most of these studies have focused on lepidopteran pests that feed on Brassicaceae plants, mainly white cabbage (*Brassica oleracea var. capitata*). Lepidopteran pests are often easily studied with the naked eye and most feed on aboveground plant parts, and can thereby be spotted without difficulty on the plant and collected for rearing in a controlled environment to study parasitism. Both multispecies plant mixes and single plant species have been evaluated as means to improve biological control of lepidopteran pests in vegetables[71,41,72]. Most of these studies have targeted both predators and parasitoids at different life stages, but with emphasis on larval parasitoids.

The importance of nectar for efficient biological control of lepidopteran pests has been elegantly shown in a semi-field experiment performed in the Netherlands[42]. It demonstrated a 100-fold increase in larval parasitism of the diamondback moth (*Plutella xylostella*) when the parasitoid *Diadegma semiclausum* had access to nectar of flowering buckwheat plants. The positive effects were partly attributed to a significantly longer reproductive time span for nectar-fed parasitoids (28 days, compared with only 1.2 days for parasitoids without access to nectar). However, such clear-cut results have not been found in full field experiments.

Addition of floral resources in the field to boost biological control of lepidopteran larvae in brassicaceae crops has generated mixed results that vary with study site, year and complex of pests and associated natural enemies studied[71,41,73,74]. For instance, establishing a border of buckwheat (*Fagopyrum esculentum*) around cabbage fields did not increase herbivore abundance of cabbage looper (*Trichoplusia ni*), small white butterfly (*Pieris rapae*), or diamondback moth, while parasitism rates on cabbage looper and small white butterfly were higher for all years studied. However, parasitism by *Diadegma insulare* on diamondback moth improved in only one out of four years[41].

Furthermore, adding another single plant resource, cornflower (*Centaurea cyanus*), into cabbage fields (*Brassica oleracea*) increased parasitisation and predation of the herbivore, the cabbage moth (*Mamestra brassicae*), and reduced herbivory rates and increased crop yield. However, all these positive effects were not found within the same year during the two-year study, so no clear evidence that adding floral resources would increase parasitism and reduce pests and thereby increase yield could be shown[74].

When a multispecies blend of flowers (24 species) was tested in a broccoli field, it increased the abundance of two lepidopteran pests, i.e. adult small white butterfly and larvae of the diamondback moth. However, a positive effect on biological control was found in the fields with flowers, as parasitism by *Cotesia rubecula* on the small white butterfly increased[71]. Whether the positive effects with the multispecies flower blend outweighed the negative for crop quality and yield was unfortunately not explored in that study. Similarly, habitat manipulation with a flower mixture did not lead to consistently improved biological control of cabbage moth or small white butterfly in a Swiss study[73]. Instead, the results varied with the pest-natural enemy complex studied and with the different study sites. For instance, egg and larvae parasitism was not improved in fields with a floral supplement, while egg predation was increased at one out of two study sites. Furthermore, larval parasitism of the small white butterfly was enhanced by floral supplements, but only at one of the study sites.

Increased biological control of lepidopteran pests can apparently be achieved by adding floral resources in vegetable fields, but it is still difficult to know what the direct effects will be. This makes it difficult to draw far-reaching general conclusions. Negative effects, i.e. increased abundance of lepidopteran pests, are easier to foresee when fewer well-studied flowers are used within fields or in field borders, and can therefore be a better approach than multispecies blends.

Summary

- A large proportion of the studies on habitat manipulation in vegetables have been concentrated to lettuce and brassicas (mainly broccoli and cabbage)
- In lettuce, the focus has been on aphids and their natural enemies, while lepidopteran caterpillars and natural enemies have been the main focus in brassicas
- It is possible to control vegetable pest insects to below the economic thresholds with habitat manipulation, as exemplified by aphid control in organically grown lettuce in California
- However, there are few other scientifically documented examples of habitat manipulation systems widely used by growers. Instead, most other examples originate from scientific studies rarely tested on a field scale and in different environments.

PILOT TRIALS IN SKÅNE. PHOTO: WERONIKA ŚWIERGIEL

Habitat manipulation in apple cropping systems

Apple is the most representative and economically and culturally important horticultural crop in Sweden, with annual production of around 22,000 metric tons per year and an acreage of about 1,500 ha[75]. Swedish apple orchards are attacked by a range of different insect and mite pests. The rosy apple aphid (*Dysaphis plantaginea*) is regarded as one of the critical pests for apple growers in Sweden[76], along with tortricid moths. However, unlike in other northern European regions, the codling moth (*Cydia pomonella*) is not the dominant pest in terms of final fruit damage. Instead, the most damaging pest is local assemblages of leafroller species, mostly dominated by *Archips podana* and *Spilonota ocellana*[77,75]. Other homopteran pests such as woolly apple aphid (*Eriosoma lanigerum*) and mussel scale insect (*Lepidosaphes ulmi*) have increased in the past years and can be locally relevant. The apple sawfly (*Hoplocampa testudinea*) and winter moth (*Operophtera brumata*) are important pests in organic orchards.

Effect on homopteran pests: aphids and scale insects

Most of the habitat manipulation efforts in apple orchards have been directed towards aphidophagous natural enemies and numerous studies have shown the importance of natural enemies for controlling the most damaging aphid species[78,79,80,81]. From the spectrum of taxa associated with aphid predation, relevant predators such as syrphid flies, lacewings and ladybirds may benefit from the addition of floral resources in the system. Syrphid flies and lacewings feed on pollen and nectar as adults, while ladybirds can use pollen as an alternative food source. Thus flower habitats can increase local attraction and improve fecundity in these natural enemies of aphids. The suitability of habitat manipulation for other relevant predators, such as predatory heteropterans and, in particular, predatory mirids is less well documented. However, the presence of pollen seems to be related to an increase in the abundance of some species[82].

ANTHOCORIS NEMORUM AND SYRPHID FLY LARVA PREYING ON A ROSY APPLE APHID COLONY. PHOTO: MARIO PORCEL.

Habitat manipulation practices in apple orchards have shown to be effective in a number of cases in achieving an increase in key specific natural enemies of aphids. Syrphid flies were associated with white clover flower strips (*Trifolium repens*), but no direct effect on biological control of apple aphid (*Aphis pomi*) could be established[83]. Similarly, the complexes of aphidophagous predators, mainly predatory heteropterans, ladybirds and lacewings, were recorded in higher abundance in trees under the influence of flower strips composed of selected plants[84]. This increase in natural enemies resulted in higher suppression of green apple aphid and rosy apple aphid[85]. In China, intercropping with aromatic plants in orchards proved to be an effective mean to achieve a significant population reduction (about 35%) in spirea aphid[86]. Moreover, lacewings, syrphid flies and ladybirds were more abundant in the presence of two of the three aromatic plants compared with grass-covered controls. In a study in the UK,

Fact box 4. Ant-aphid interactions

Almost all the aphid species present in Swedish apple orchards, including rosy apple aphid and green apple aphid, are tended by ants, increasing each other's survival capacity and population growth. In this ecological association, known as mutualism, ants obtain sugar-rich honeydew excreted as a by-product of aphid sap sucking activity and, in return, provide protection against natural enemies and sanitisation of aphid colonies. Ants literally patrol around aphid colonies attacking, driving out and even killing any predator or parasitoid that dares enter their area of influence. The link between ant abundance and higher infestation levels of aphids has been clearly established in apple orchards, in conjunction with lower presence of natural enemies[114]. This situation is widely recognised as a possible limitation for conservation biological control efforts such as habitat manipulation.

cornflower and corn chamomile (*Anthemis arvensis*) had the potential to increase the abundance of anthocorids, a key enemy of aphids in Swedish apple orchards[87]. The capacity of these natural enemies to exploit food resources from flower strips and move into the apple tree canopy has been documented in apple orchards. Insect marking has been used to reveal the movement of syrphid flies, lacewings and anthocorids from a sweet alyssum established habitat to apple trees[16]. That study, the only one considering the effect of habitat manipulation on woolly aphid predation, showed that an increase in aphidophagous predators resulted in greater suppression of woolly aphid colonies on potted trees.

However, a similar boosting effect on natural enemies has not been observed for other vegetation cover types. In a study performing separate tests on flower mixes of different plant families and single plants (*Asteraceae, Apiaceae,* white mustard and buckwheat) no evidence of an increase in aphidophagous insects was observed[88]. However, a mix of different flowering plants contributed to an increase in predatory heteroptera abundance in Czech Republic[89]. In contrast, no effect on green aphid infestation was observed associated to a mixture of annual flowering plants situated between tree rows, despite an increase in green lacewing individuals[90]. Likewise, other studies have found no impact of the presence of a flowering ground cover on rosy apple aphid and green aphid populations and predator abundance[91,92], although large amounts of syrphid flies were collected from the flower strip[91]. The researchers behind those studies identified several factors that could explain the lack of success of the strategy and concluded that the time lag observed between presence of the pest and flowering of the flower strip could explain the lack of increase in biocontrol. It has been also pointed out that the high dispersion capacity of some aphidophagous natural enemies can mask possible differences between flower strip and control plots, thus imposing experimental limitations[90]. The results of different experiments may also be affected by differences in aphid density distributions within orchards, as well as ant-aphid relationships, preventing effective control by natural enemies.

Habitat manipulation for aphid control in apple orchards has been shown not only to attract natural enemies as a source of pollen and nectar, but also to increase the abundance of species that are predators in all their life stages. An increase on apple trees of spiders, predators that cannot feed directly on plant-based compounds produced in flower covers, has been shown by several studies[93,94,95]. Web-spinning spiders can make use of the higher density of prey on the trees induced by the flower cover to increase in numbers towards autumn. At that time, a higher abundance of spiders may result in a higher density of webs, contributing to control of the rosy apple aphid, which migrates as a winged morph to apple trees in autumn for egg laying[94]. An increase in hunting spiders, which are more mobile than web-spinners and therefore able to feed on alternative prey in the vegetation cover, may also benefit early control of rosy apple aphid colony establishment[96]. Higher abundances of hunting spiders (stalkers and ambushers) have been related to the presence of a flower cover[95], but no apparent increase in aphid population control was noted in that study. However, the rosy apple aphid population was not measured.

Apart from the effect on more specialised aphid predators described above, the results reported for spider enhancement through habitat manipulation are rather inconsistent. Several studies found no increase in spider abundance or diversity as a result of habitat manipulation[97,92]. The reasons cited for this discrepancy include the presence of weeds in control plots and the size of the experimental flower strips[95].

For control of the most damaging aphid in Swedish apple cultivation, the rosy apple aphid, most of the research conducted to date on the influence of spiders suggests that these play a minor role in aphid predation during the development period of aphid colonies in spring[94,81,95]. Therefore, assessments of the impact of habitat manipulation strategies on spider biocontrol of aphids should focus on the pre-flowering increase in hunting spider abundance and predatory efficiency and on autumn increases in web spinners, spider webs and migrating aphid captures.

The mussel scale (*Lepidosaphes ulmi*) insect is a secondary pest in Swedish apple orchards that can downgrade fruit quality even at low population density by settling on the developing apple. Very little research has been carried out on the effect of predators on this pest in apple orchards[98] and therefore no information is available on the possible effect of habitat manipulation. Lacewing larvae and ladybirds have been reported to prey upon young crawling nymphs of scale insects[99,100] and could potentially be predators of this pest in Sweden that can be increased by means of habitat manipulation. However, more research is needed on the role of natural enemies on the population dynamics of this pest in order to establish the suitability of habitat management practices.

Considering that many species of parasitic wasps require, or can make use of, floral nectar to increase their survival, host searching activity and fecundity[6,82], it is surprising that none of the studies reviewed here have addressed the effect of habitat manipulation on aphid and scale parasitism rates. In general, the effect of parasitoids on homopteran pest suppression in apple orchards has attracted limited attention, partly because it is believed to be of little importance for pest regulation[101]. However, this does not mean that habitat manipulation does not have the potential to enhance aphid parasitism to an extent that, although limited, it might contribute to higher overall resilience of the system to leaf-dwelling aphids.

EARWIG (*FORFICULA AURICULARIA*) ON AN APPLE FRUITLET. PHOTO: MARIO PORCEL.

Effect on tortricid pests and other Lepidoptera

Predation pressure on tortricid moths in apple orchards has been less well explored than aphid predation. Several polyphagous predators have been identified as consumers of immature stages of tortricids, particularly eggs and young larvae. Earwigs are known to consume codling moth eggs and overwintering larvae, exerting a certain influence on the yearly cycle of this pest[102]. Video studies of leafroller larvae predation carried out in vine foliage revealed that earwigs were the dominant consu-

PHOTO: BÉLA MOLNAR

mers[103] and their presence has been correlated with predation of leafroller egg batches in apple orchards[104]. Earwigs are predacious insects in all their life stages, with limited dispersal habits in orchards. They cannot take advantage directly of supplementary food sources such as flowering plants, but could potentially benefit from sheltering structures such as hedgerows[105] and possibly alternative prey hosted by flower covers as observed for spiders[94]. Despite the fact that earwigs are also regarded as common aphid predators in the apple cropping system[79,81], the effect of habitat manipulation on this group has not been addressed to date.

Other generalist predators have been related to tortricid moth predation. Anthocorids and predatory mirids are believed to prey upon codling moth eggs and neonate larvae. Several ladybird species have been described as potential codling moth and leafroller predators when aphids are scarce, and clubionid spiders are known to consume leafroller larvae[102]. Several studies have shown that these predators can be increased by means of habitat manipulation[94,87,16] and could thus contribute to tortricid predation. However, this potential increase in predation has not been verified experimentally. At least one study has evaluated the impact of soil management for the enhancement of ground-dwelling predators for codling moth biological control[106]. It found that compost mulch spread under the tree canopy contributed to an increase in alternative prey and generalist predators, but no increase in codling moth predation was recorded.

Unlike parasitism of aphids, parasitism of tortricid moths and particularly of leafrollers can contribute markedly to pest regulation in apple orchards[101]. A great complex of parasitoid species attacks tortricids during all their immature development stages, from egg to pupae. As mentioned before, this particular guild of entomophagous insects can take considerable advantage of the food resources (mainly nectar) provided through habitat management. An early study observed that the presence of flowering plants in the vicinity of apple trees had an important impact on the parasitism rate of codling moth eggs[107]. Lower codling moth infestation levels were associated with a *Vicia* spp. cover crop and codling moth parasitoids were collected directly from the companion plants[93]. Since that early work on habitat manipulation for the control of tortricids in apple orchards, the emphasis in research has been on increasing the abundance and performance of parasitic wasps. The attractiveness of flowering plants for parasitoids is well documented in the apple system[40,87,108]. In a number of cases, this increase in abundance has translated into an enhancement of leafroller biocontrol. In New Zealand, the dynamics of the leafroller *Epiphyas postvittana* and one of its main parasitoids, *Dolichogenidea tasmanica* were studied in the presence of alyssum, phacelia and buckwheat. Higher parasitism rates were found in buckwheat and alyssum plots, along with smaller leafroller populations and less final damage to apples. The enhanced parasitoid performance was attributed to an increase in longevity and fecundity, as shown in laboratory feeding experiments[108]. Similar results had been previously reported for parasitism rates by using buckwheat alone as a habitat[40]. In Hungarian apple orchards, no effect of composite flower strips was observed on fruit damage caused by the codling moth and leafrollers[109]. However, higher parasitism rates were recorded for leafminers in flower strip plots.

The provision of nectar resources for adult parasitoids is probably the most widely studied habitat management strategy for increasing parasitism rates, but it is not the only strategy. In specific cases, highly efficient parasitoids might see their biocontrol activity hampered due to biological limitations such as the need for an alternative host. That is the case for the parasitoid *Colpoclypeus florus*, one of the most common leafroller parasitoids in apple orchards in both Europe and North America. It requires large tortricid larvae in the autumn as an overwintering host, forcing the species to fly long distances away from apple orchards for survival[110,58]. In a study carried out in Washington state, strawberry leafroller (*Ancylis comptana*), which attacks rose and strawberry plants, was identified as a suitable autumn host[110]. Particularly high *C. florus* parasitism rates were recorded in orchards in the vicinity of natural rose patches[111]. After creating artificial rose habitats and infesting them with *A. comptana*, successful establishment of the parasitoid

LEAFROLLER LARVA (*SPILONOTA OCELLANA*) FEEDING FROM AN APPLE LEAF. PHOTO: MARCO TASIN.

was detected in nearby orchards where it was not previously present[58].

Tachinid flies are parasitoids of several leafroller species in northern Europe and the species *Cyzenis albicans* and *Lypha dubia* are believed to contribute to biological control of the winter moth in Swedish apple orchards, especially in high prey density situations[101]. Little research has been carried out on the nutritional ecology of tachinids, although it is known that they feed on, and are attracted to, flowering plants[112]. To date, there is no information on the possible effect of habitat management on this group of natural enemies that could benefit from such practices in the apple agroecosystem.

Habitat manipulation effect on mites

Three different studies have addressed the effect of habitat manipulation on mite presence on apple trees. A flower mixture comprising cornflower, corn marigold and corn chamomile did not affect the population of European red spider mite (*Panonychus ulmi*) sampled from apple leaves[87]. Similarly, an alfalfa cover had no effect on two predatory and three different pest mites[113]. However, a complex mix of flowering plants situated in the alleys between tree rows was associated with higher abundance and diversity of phytoseiid predatory mites in Hungarian orchards[109]. These contradictory results concerning the effect of habitat manipulation on predatory mites suggest a differential impact of the plants used in the experimental flower habitats. Although none of the three studies recorded differences in spider mite presence, the potential to improve predatory mite populations in terms of abundance and diversity observed in Hungary[109] could theoretically contribute to a quicker and more effective response against possible spider mite outbreaks, although this has yet to be verified.

Summary

Habitat manipulation in apple orchards seems to be an effective strategy to attract aphidophagous predators that actively search for flowering plants as a food source during adulthood, namely lacewings and syrphidf lies. This practice can possibly increase the presence of other relevant aphid predators, such as ladybirds and anthocorids, and generalist predators such as spiders. There is evidence that these insects have the capacity to move back and forth from flowering habitats to apple trees and exert higher levels of aphid biocontrol. A number of studies have also shown the potential of habitat manipulation to increase the abundance of tortricid moth (codling moth and leafroller) predators, particularly earwigs and predatory bugs. However, most research efforts have been directed towards enhancement of parasitic wasps with a clear association between plant-based food resources and higher parasitism rates of tortricid larvae. Experimental data also suggest that habitat manipulation could play a role in predatory mite abundance in apple orchards, although available information is scarce and contradictory.

Nevertheless, inconsistent experimental results point out the necessity to optimise local habitat manipulation in order to achieve discernible positive effects. The development of new and complementary experimental methodologies to demonstrate any increases achieved in biological control is also highly desirable.

- Habitat manipulation in apple orchards seems to be an effective strategy to attract predators that feed from flowering plants during adulthood i.e. lacewings and syrphid flies and possibly increase the presence of other relevant aphid predators, such as ladybirds and anthocorids.

- The abundance of tortricid moth predators, particularly earwigs and predatory bugs can also be increased through this practise; however, most research efforts have been directed towards enhancement of parasitic wasps with a clear association between plant-based food resources and higher parasitism rates of tortricid larvae.
- Inconsistent experimental results, especially in biological control and pest regulation capacity, point out the necessity to optimise local habitat manipulation in order to achieve discernible positive effects.

ELISABETH GUTAVSSON, FARMER IN DALARNA.
PHOTO: ELISABETH ÖGREN

Interview with Eva Gustavsson, Solsyran, Dalarna

Eva started to produce organically grown vegetables at the end of the 1980s and has always been interested in sustainable farming. Before starting up her own farm Solsyran in Orsa, Dalarna, she worked with conventional farming, but doubts about how conventional production affects the environment and landscape changed her path. Eva sells her products, lacto-fermented vegetables, vegetables and berries, on the farm and to different local shops.

"Flowering plants have always been incorporated into my fields, since I believe that a high diversity within the farm can have many different positive effects on, for instance, pollination, microclimate and natural enemies, but I cannot say what the effect has actually been. Access to tools that can help me to evaluate this in a simple way would be desirable. Furthermore, flowering plants add an aesthetic value for the customers that come to my farm to shop" says Eva.

Eva has also planted windbreaks consisting of different trees such as alder (*Alnus* spp.), willow (*Salix* spp.), rowan (*Sorbus aucuparia*), whitebeam (*Sorbus intermedia*) and larch (*Larix decidua*) along her fields. These help to improve the microclimate, while also giving protection and food to pollinators, natural enemies and birds. Groves of plum trees are also planted within the production fields. A meadow has been created on a piece of the land considered too poor for crop production. A plethora of plants flower there during summer, such as hawkbit (*Leontodon* spp.), yarrow (*Achillea millefolium*) and teasel (*Dipsacus* spp.), which are important resources for many beneficial insects. However, Eva feels that it is difficult to find time to tend the meadow as she would like during the brief and intense growing season in central Sweden. Furthermore, she installed a raised perennial grass and flower strip this year with the intention of generating suitable overwintering sites for beetles and spiders. A seed mix designed for northern conditions was used for this purpose.

PHOTO: KRISTIAN PETERS, WIKIMEDIA COMMONS.

Flowering vetch is a good example of a plant that can provide different services in the field, for instance nitrogen fixation, attracting pollinating insects and potentially also acting as a trap and catch crop.

"I have also tested use of a trap crop consisting of hairy vetch (*Vicia villosa*) to protect my parsnips from Lygus bugs (*Lygus rugulipennis*). Those bugs can really destroy a sensitive crop. However, I cannot say what the actual effect was, since the cold spring and summer probably reduced the activity of the bugs this year. Still, when sweep netting the hairy vetch and parsnips at the end of August, we found almost twenty times as many Lygus bugs in the trap crop. So I guess there is potential in this approach."

PART IV

"I would very much like to increase my efforts to make my farm even more diverse. However, it all comes down to economics. Planning and maintenance of flower strips, beetle banks and meadows take time away from other tasks on the farm. I think it is a pity that today's economic subsidies (rural development programme) are so focused on supporting large farms in southern Sweden. Willingness by the government to also economically support small farms could be an efficient incentive for more growers to try biodiversity measures and would increase the practical knowledge of how to best do this on farms."

Eva believes that it is the consumers and to some extent scientists that have the best chances to convince the authorities and the Swedish government of the importance of more diverse farming systems. She would like to see changes in legislation and increased economic subsidies for growers actively working with this question. However, she doubts that she as a grower can influence the development in a significant way towards increased biological diversity in Swedish vegetable fields.

When asked about the state of knowledge today, she said there is enough knowledge for her to want to try different things to increase diversity and improve conditions for natural enemies. However, she does not think that we know what the outcome will actually be and she sees a need to optimise the systems to be more user-friendly in the field. Furthermore, she called for discussion groups where growers, advisors and scientists can meet to exchange knowledge and ideas.

"What I would like to get help with is doing an insect inventory on my farm to see what different beneficial insect species I have, how abundant they are and how the species composition changes throughout the season. These inventories should preferably be done every year to track changes over time. I could thereby get a feeling about whether my work with increasing vegetative diversity pays off in terms of increased abundance of pollinators and natural enemies. But I don't know how to get this help. I also see a need for development of simple tools that I can use myself to check the abundance without spending too much time on it."

Interview with Oskar Hansson – horticultural advisor in Skåne

OSKAR HANSSON, HORTICULTURAL ADVISOR AT HUSHÅLLNINGSSÄLLSKAPET. PHOTO: HS SKÅNE

Oskar Hansson is as a horticultural advisor for vegetable growers in Skåne, a county in southern Sweden. He works for Hushållningssällskapet, which is a national organization that provides advice and education to agricultural and horticultural enterprises. A large proportion of the Swedish-grown open field vegetables are produced in Skåne and most of Oskar's clients manage large-scale farms by Swedish standards. Oskar started on the job one year ago. His working year is divided into two separate cycles; the season and the off-season. During the growing season he works with more or less all vegetable crops that are produced in the area. However, he pays special interest to two of the crops, carrots and onions:

"Carrot is the crop grown on the largest area in the district for which I am responsible. Onion is another important crop, and for onion I am also responsible for an ERFA group. There, advisors and growers work together to solve various problems in the crop. For instance, right now we are looking at how we can create sustainable strategies to reduce weeds."

Some farms he visits more or less weekly during the season to scout for pests and diseases in the field and give advice on pest management. Other growers he visits less frequently. In the off-season, he works with different projects concerning plant protection, for instance within the platform Greppa näringen. In Greppa näringen farmers can get free consultations on how to reduce their use of pesticides and limit the losses of nutrients to water and air.

"Greppa näringen is a great way of meeting growers that normally doesn't use our services. This gives me opportunities for instance to explain the benefits with natural enemies and how to protect them to many more growers than those I meet in my daily work."

What is the potential of conservation biological control (CBC) in vegetables today?

Oskar finds it difficult to say how interested and generally knowledgeable vegetable growers in his district may be when it comes to conservation biological control. It all depends on the individual. The majority recognise the most iconic beneficial's such as adult ladybirds, while some growers are more interested in the biology and diversity of beneficial insects and want to know more about how to boost their populations. However, most growers do not have a strategy for protecting and improving their living conditions.

"As an advisor I sometimes try to convince growers to test different habitat manipulation methods. But they search for methods in the field that they know will function and pay back for the work they invested. I don't think CBC is there today. I might dare to promise an increase in diversity per se if flowers are planted, but not a direct positive effect on pest control. We therefore need more reasons to convince the growers to try this out and also more evidence that it can have an effect on pest populations and yield."

For practical reasons, most growers prefer to cultivate vegetables in straight square or rectangular fields, as this makes the use of machines and production more rational. Hence, there are often significant areas of the fields that are not used directly for vegetable production. These could be used for high quality flower strips or overwintering sites favouring pollinators and natural enemies instead, according to Oskar.

However, he was able to list some examples of how growers are actively working with CBC today:

"In Skåne it is quite common for carrot growers to store their carrots in the field during winter. They have to cover these carrots under a thick layer of straw to protect them from low temperatures and ground frost. I know some growers who actually let some hay bales remain untouched in the carrot field until next spring. These are intended as overwintering habitats within the field for ground-dwelling natural enemies, e.g. spiders and ground beetles. But I can't say if it is a suitable overwintering site or not."

A better designed "greening subsidy" could speed up the implementation of CBC

Oskar believes that the economic support system for the agricultural and horticultural sector that aims to increase the biodiversity at farms (the so-called greening subsidy could be much better designed to fulfill its purpose. At present, farms with an acreage of more than 15 ha and situated in the plains region of Sweden have a number of conditions they must meet to be guaranteed economic support. For instance, at least 5 percent of their acreage should consist of ecological focus area (EFA), e.g. areas with nitrogen-fixing plants, salix production and uncultivated field edges.

"Unfortunately, bare fallow soils are also considered EFA areas. This is not allowed in Germany. Today, many Swedish vegetable growers make use of this opportunity. I cannot see how this practice can actually improve biological diversity in the field. I would prefer the regulations on EFA areas to state that these areas should be planted with plants that can provide services to the soil and beneficial insects. In that way, growers would be motivated to create better conditions for the beneficial insects on their farms."

Moreover, Oskar claims that it is difficult for him as an advisor to know what flowers to recommend on farms with different growing conditions. His work is even more problematic when it comes to seed mixtures. This is an area where much more knowledge is needed.

"What good is it to sow a plant, with the specific aim of boosting the natural enemies, if it never flowers due to inappropriate growing conditions?" Oskar proposes that more experiments be performed on commercial farms, so that growers can come and visit the farm and learn more about the projects and also share their knowledge of what is functional or not. This would provide a much better basis for implementation of the best ideas in commercial cultivation further on.

Multifunctionality is the future!

Oskar believes in working with plants that can provide multiple services to the grower. For instance, vegetable growers have now started to show an interest in-between crops, which is also reflected in the substantial increase in orders of these seeds reported by seed companies this year. In-between

PHOTO: ULF NILSSON

crops are used for different reasons and grown temporarily in between main crops. Depending on the chosen crop, they provide different services. For instance some farmers use marigold (*Tagetes* spp.) for nematode sanitisation. Others choose crops that can reduce nutrient leakage in autumn or plants that can improve the soil structure and fixate nitrogen from the air. Oskar claims that we today know too little about the positive effects plants could also have on beneficial insects.

"Why not screen these different in-between crops in the field to see what beneficial insects land and feed on them? I'm sure it would be a lot easier to motivate farmers to work with improving the conditions of the beneficial insects by planting flowers if they also receive other agronomic benefits from the same crop"

There is also the possibility that in the future, more crops will be grown to produce biomass for biogas plants. Why not then grow crops that flower quickly and can provide nectar and pollen for the insects before harvest and processing? Another potentially interesting example of multifunctionality as Oskar sees it.

Who's driving?

When asked which stakeholders are most important to increase the biological diversity on vegetable farms, Oskar first mentioned the growers. There must be growers who dare to test and show what is possible to achieve. However, they need economic subsidies and relevant information from advisors to succeed.

"An interested advisor can have great influence on the growers she/he works with in these questions. But of course, all actors involved in food production, processing and retailing have a responsibility. For instance, retailers could pay extra for products that are produced in a more environmental friendly way. This would also give consumers a chance to make a more conscious choice."

Seminar on organic apple production

More than 40 growers, advisors, horticultural students and scientists met to learn about and discuss obstacles and opportunities within organic apple production at the meeting Framtidens frukt: Seminarium om ekologisk produktion av äpple i Norden on 21 April 2015 in Alnarp. The organisers were EPOK, the Department of Plant Protection Biology at Sveriges lantbruksuniversitet (SLU) and Partnerskap Alnarp. During the afternoon a workshop was arranged by Weronika Świergel and Birgitta Rämert (SLU) with the theme Is it possible to increase the biodiversity in apple production to achieve a higher degree of resilience to pests and diseases? Participants were divided into smaller groups and encouraged to identify one important obstacle to increasing the biodiversity in apple orchards and one important benefit. The responses were then discussed during a joint group discussion.

Much focus in the discussion was on the potential positive effects of biodiversity on pest control. However, other benefits of increased biodiversity were touched upon, such as an overall increase in insect and bird diversity and the different services that may be provided by these, e.g. pollination.

The following is a summary of the most important issues that were discussed during the workshop.

Increased biodiversity and pest control – general discussion

Many growers are interested in increasing biodiversity on their farms. Among the participants there was, as usual, a great range of opinions from those who said that we need to go slowly and evaluate methods on a small scale to those who see the need for more radical changes in existing farming systems by starting to cultivate polycultures instead of monocultures. However, most agreed that flower strips may be a good first step towards sustainable, high diversity, fruit production.

The basic dilemma is the trade-off between benefits and risks of enhancing the biodiversity and the lack of knowledge to make that judgment call. As pointed out in many of the discussion groups, there is still uncertainty about the effects that could be expected. Incorporating biodiversity elements, such as flower strips, must not have a negative impact on the produce. Growers cannot allow a system where increased biodiversity steals energy from the fruit trees (i.e. interspecific competition) and reduces the yield and quality. Furthermore, practical guidelines on how measures to increase biodiversity should be incorporated into orchards are still lacking. Therefore, as pointed out by workshop participants, for broad acceptance and application there is a need for more scientific evidence and practical evaluations in orchards with different conditions.

Still, as one person said "We are very much afraid of benefit pest insects disturbing the balance and thereby getting poor fruit quality when we increase the biodiversity within our farms. But when we apply Quassia (a plant extract) to control pests, we see its direct effect on the current problem and are not as afraid of the risks that this may impose to the natural enemies. Why are we more afraid of some risks than others?". That grower suggested that the cause may be the old pattern of transferring standardised knowledge from advisors to growers, instead of building empowerment by mutual construction of knowledge. There is a large potential in increasing the competence of managing local specific complexity in order to build robust farming systems and prevent pest damage.

Tools for local adaptation

The outcome of increased biodiversity within orchards is to a high degree landscape-dependent, which means that broad and general assumptions based on scientific results can be difficult to interpret down to local farm scale. Therefore, farmers and advisors must have access to easy-to-use tools that can help them follow the changes not just in pest populations, but also in the populations of natural enemies. Thresholds were also suggested to be determined for natural enemies, for example how many natural enemies are needed to get adequate control of a specific pest. This could help farmers avoid unnecessary pesticide spraying and, equally important, get a feeling for how natural enemy populations change in response to increased biodiversity over time. As one person rhetorically asked "Are we satisfied to only measure the effect on yield, without really knowing what happens in the field?"

Advisory

A concern was raised about whether horticultural advisors today have enough knowledge to advise growers on these questions. Furthermore, growers must start to believe in their own knowledge and not rely too much of what other people suggest, especially since the effects of increased biodiversity will differ depending on the location of the orchard. It is therefore essential that growers are involved in these processes from the beginning. The working approach of participatory action research (PAR) was suggested as a suitable working model for such involvement.

Practical concerns

As also pointed out, the positive effects of increased biodiversity may not be evident at the initial stage, i.e. the first growing season, which may impede broad implementation. In-Between Tractor Wheels (IBTW) strips of flowering herbs were seen by many participants, although not all, as a practical first step in increasing biodiversity on farms, as they are easy to establish and do not take farmland away from production. However, there are still great knowledge gaps on how best to arrange the biodiversity in the fields and what plant material is best adapted to the local conditions on the farm. One grower questioned whether it is a good idea for farmers to evaluate the plants themselves and pointed out that potential risks may only emerge a couple of years later and this could lead to drawbacks for more diverse production systems. A grower who tried IBTW strips found, however, that it may be difficult to maintain functionality over time because of competition from aggressive weeds. Another participant doubted that we are actually using the right mixture of plants and at the same time questioned what impact flower strips may have on pathogens and other microorganisms.

Implementation and the need for subsidies

Many participants felt that small-scale farms would find it easier to implement biodiversity in their orchards for many reasons, for example they are often accustomed to working with a variety of different crops and thereby cannot have as rational production as large farms, but also find it easier to add value to the product as they are often closer to consumers. Large-scale producers, on the other hand, might have more difficulties in adding added value when dealing with large retailers. For these producers, economic subsidies from the government may be crucial to speed up implementation.

Conclusions

The take-home message from the day was that there is great interest among farmers and advisors in working to increase biodiversity, but that we currently know too little of the effects of increased biodiversity to see large-scale implementation in orchards. More research is needed and it must be carried out in close collaboration between all players in the knowledge chain, i.e. growers, advisors, scientists and government authorities. Furthermore, to speed up the implementation process, government subsidies are needed and growers must become better at informing consumers of the overall benefits of practices such as reduced use of pesticides, increased diversity of flora and fauna, and a more attractive landscape.

General conclusions

In this review, we showed that habitat manipulation in apple and vegetable crops has the potential to benefit natural enemies of pests in various ways. Most studies to date have focused on providing food for natural enemies and only a few studies have investigated the impact of providing shelter. Laboratory studies have linked habitat manipulation to increased fecundity, improved host/prey search efficacy and prolonged longevity. In the field, higher abundance and diversity of natural enemies have regularly been observed. However, few studies have demonstrated in practice that increased abundance of specific natural enemies actually translates into better pest control, i.e. acceptable pest numbers from an agronomic perspective. This lack of information has been pointed out as an obstacle to implementation of biocontrol meusures also in earlier reviews[115].

This is most probably due to the complex interactions between different trophic levels and the influence of the surrounding landscape, which makes it difficult to draw general conclusions based on the knowledge available to date. Moreover, natural enemy and pest insect abundance also depend on agricultural practices at landscape and farm scale. All of these problems show the importance of more basic scientific studies, performed in different landscape types and at adequate scales, where the effects of habitat manipulation on food web structures are thoroughly examined and general knowledge is obtained to increase understanding of these systems.

Collaboration is needed

There is also still a lack of highly optimised habitat manipulation systems ready for use by growers. There is a need for deeper, long-term collaboration between growers, advisors and scientists in order to develop practical and functional systems. Today, we may know which plants to use to boost specific natural enemies, but we know considerably less about the quantities required or implementation strategies in terms of management and spatial arrangement to optimise their use in the field. To increase the possibility for farmers to implement habitat manipulation, multifunctionality should be sought, e.g. by combining this with catch crops.

The complexity and related local specificity of successful habitat manipulation points to the fact that research alone will not be able to prescribe packaged solutions for each situation. Therefore there is a demand for researchers contributing to enhance the skills of advisors and farmers to experiment with habitat manipulation and observe the results over time. Farmers are asking for more knowledge on pest and natural enemy life cycles and biology in order to find practical solutions on their farms to enhance natural biological control and counteract the spread of pests. They would like to have easy-to-use methods to observe the effects of habitat manipulation in order to evaluate its outcome. Farmers also want information on threshold values, the efficiency in damage control and risks of enhancing pests with habitat manipulation, since this is an important obstacle to implementation. Research could therefore focus on habitat manipulation, where higher risks of enhancing key pests may be anticipated, on inventories of natural enemy population dynamics over the season, on evaluating biocontrol efficiency and on developing threshold values.

Focus on easy-to-use methods

This review provides clues on factors that should be considered when designing farmer-driven observational trials. Due to the complex interactions, the focus should be on easy-to-use methods to observe the effects on key pests and their key natural enemies. If key pests are feeding on pollen and nectar, there is a need for more caution when selecting beneficial plants considering their morphology, flowering time and available information on other preference cues. If the key natural enemies are in need of connectivity, shelter and/or alternative hosts, these should be provided. Finally, landscape effects are of crucial importance for the success of natural biological control. Habitat manipulation is most likely to provide an enhancing effect in semi-diverse landscapes where there are some natural enemies around, but not so many so that e.g. a flower strip would make little difference. Diverse landscapes where there is connectivity are a policy issue, since farmers can only manipulate these to a limited extent.

Combine with other methods and use in marketing

Habitat manipulation is not a stand-alone pest control strategy. It must be integrated with other methods such as adequate cropping rotations, resistant varieties, spatial separation of fields with the same crop (to prevent pest insect movement during the growing season), suitable fertilisation regime and intercropping. It is also likely that augmentative release of commercially reared natural enemies that occur naturally in the Swedish fauna will become more common in vegetable fields and apple orchards in the future. Habitat manipulation will then be important to retain the released natural enemies at the site where the growers require them.

Increased vegetation diversity in the field may also help increase or sustain other values, such as higher abundance of pollinating insects and birds and a more aesthetically pleasing agricultural landscape. By implementing Conservation Biological Control (CBC), farmers are contributing to our common good while investing time and money and taking risks. In order for the benefits of CBC to achieve wide implementation at affordable prices to all consumers, it could be supported by the state providing competent advisory services and re-designing farm subsidies. Retailers could also benefit by attracting frequent customers with sustainability branding. In return, they could offer these farmers marketing services, long-term contracts and/or additional payments, without necessarily increasing consumer prices. CBC may also be of relevance to strengthen the interest for community-supported agriculture. These issues are important to remember when discussing habitat manipulation.

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Appendix 1.

Common pest arthropod species in Sweden

Class	order	Sub-order	Examples of pest insects				
			Latin name	**Common name**	**Swedish name**	**Host plant**	**Comment**
Insecta	Thysanoptera (Sw. Tripsar)		*Thrips tabaci*	Onion thrips	Nejliktrips	Different Allium plants	
	Hemiptera	Homoptera (Sw. växt-sugare)	*Aphis pomi*	Greesn apple aphid	Grön äpplebladlus	Apple	
			Dysaphis plantaginea	Rosy apple aphid	Röd äpplebladlus	Apple	
			Eriosoma lanigerum	Wooly apple aphid	Blodlus	Apple	
			Lepidosaphes ulmi	Mussel scale	Kommasköldlus	Apple	
			Myzus persicae	Green peach aphid	Persikbladlus	Many different host plants e.g. lettuce	
			Nasonovia ribisnigri	Lettuce aphid	Sallatsbladlus	Lettuce	
			Trioza apicalis	Carrot psyllid	Morotsbladloppa	Apiacea plants	
		Heteroptera	*Lygus rugulipennis*	European tarnished plant bug	Ludet ängsstinkfly	Polyphagous e.g. white cabbage and carrots	
	Coleoptera		*Phyllotreta* spp.	Flea beetles	Jordloppor	Brassica plants	
	Lepidoptera		*Ancylis comoptana*	Starwberry leafroller	smultronsikelvecklare	Strawberry	
			Archips podana	Large fruit-tree tortrix	Fruktträdsommarvecklare	Apple	
			Cydia pomonella	Codling moth	Äppelvecklare	Apple	
			Epiphyas postvittana	Light brown apple moth	Blek fruktvecklare	Apple	Not a pest in Sweden
			Mamestra brassicae	Cabbage moth	Kålfly	Brassica plants	

Common pest arthropod... continuation

			Pieris rapae	Small white	Rovfjäril	Brassica plants	
			Plutella xylostella	Diamondback moth	Kålmal	Brassica plants	
			Trichoplusia ni	Cabbage looper	Nifly	Brassica plants	
			Spilonota ocellana	Bud moth	Lövträdsknoppveck-lare	Apple	
	Diptera		*Contarinia nasturtii*	Swede midge	Kålgallmygga	Brassica plants	
			Delia antiqua	Onion fly	Lökfluga	Allium plants	
			Delia floralis	Turnip root fly	Stora kålflugan	Brassica plants	
			Delia florilega	Bean seed mag-got	Bönstjälkfluga	Polyphagous feeds on seedlings e.g. beans, corn and onion	
			Delia platura	Seed corn mag-got	Borststjälkfluga	Polyphagous feeds on seedlings e.g. beans, corn and onion	
			Delia radicum	Cabbage root fly	Lilla kålflugan	Brassica plants	
			Psila rosae	Carrot rust fly	Morotsfluga	Apiacea plants	
	Hymenoptera	Symphyta	*Athalia rosae*	The turnip sawfly	Kålbladstekel	Brassica plants	
Arachnida	Trombidifor-mes		*Panonychus ulmi*	European red spider mite	Frukträdsspinnkval-stret	E.g. Apple, pear and cherry trees	

Examples of natural enemies

Order	Latin name	Common name	Swedish name	Prey/host
Neuroptera	*Chrysoperla* spp.	Green lace-wings	Nätstinkflyn	Polyphagous
Hemiptera	*Orius* spp.	Flower bugs	Näbbskinnbaggar	Polyphagous
Hymenoptera	*Microplitis mediator*	Not given	Not given	Lepidopteran larvae eg. cabbage moth
	Trybliographa rapae	Not given	Not given	Dipteran larvae from the family of Anthomyiidae e.g. the cabbage root fly
	Diadegma semiclausum	Not given	Not given	Diamondback moth
	Diadegma insulare	Not given	Not given	Diamondback moth
	Cotesia rubecula	Not given	Not given	Small white butterfly
	Dolichogenidea tasmanica	Not given	Not given	Leafrollers e.g. *Epiphyas postvittana*
	Colpoclypeus florus	Not given	Not given	Leafrollers
Diptera	*Cyzenis albicans*	Not given	Not given	Leafrollers
	Lypha dubia	Not given	Not given	Leafrollers

There is increasing interest among Swedish growers in biological diversity within the agricultural landscape. Many scientific studies have highlighted the services performed by beneficial organisms, which can help to improve the quantity and quality of crops. One tremendously important ecosystem service is biological control of pest insects and mites. The question is what growers can actually do to increase the abundance and diversity of natural enemies and whether this will have an impact on the pest population and, more importantly, on yield and quality of the crop. Another question is whether biodiversity is always positive for growers or whether there are negative aspects that should be dealt with.

These relevant questions are addressed in the present report, the aim of which is to enlarge the current knowledge base on how to improve conditions for natural enemies, so-called habitat manipulation, within annual vegetable crops and perennial apple cropping systems.

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