Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture
and Crop Production Science

Assessment of functional agrobiodiversity in Swedish apple orchards

Field trials and participatory research

Michal Stranak

Degree Project – 30 credits
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Assessment of Functional AgroBiodiversity in Swedish apple orchards

- **Field trials and participatory action research**

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Abstract

The rate of biodiversity loss has in the last decades increased by rates unseen in the history of the humankind. Agricultural intensification has been one of the main contributors to biodiversity loss. In modern agricultural production, the concentration of land devoted to single crops causes several challenges. In the pest management, specialist crop herbivores have larger area of suitable host plants in monocultures, while the lack of plant diversity reduces environmental opportunities for natural enemies. Synthetic pesticides commonly used for controlling pests over the last decades are gradually losing their effectiveness due to increasing pesticide resistance of insects. Moreover, many pest control technologies have been linked to problems of pollution, high costs, or deregistration of insecticides because of safety concerns. Since January 2014, all fruit growers in EU are required to follow the Integrated Pest Management (IPM) standards, which incorporate a wide array of pest management practices and tactics for long-term pest control. Currently, the IPM still heavily relies on the use of pesticides but tries to promote prevention and alternative environmentally friendly pest management strategies. Functional agrobiodiversity (FAB) has been acknowledged as one of the methods for suppression of the insect pests in agro-ecosystems. The benefits of high diversity on agroecosystems have been discussed for almost decades. However, there is still lack of evidence about the real effects of different FAB practices. Apples are crops with the second highest pesticide use per hectare in Europe after grapes. Organic apple growers have access to less harmful pesticides with lower efficacy that often provide insufficient pest suppression. Therefore, the organic growers need to focus on preventive measures and alternative practices than application of pesticides. This thesis investigates effects of functional agro-biodiversity (FAB) in intensive organic apple production. It aims to understand whether end-user adapted monitoring methods for insect pests and their arthropod natural enemies used by farmers and advisors can support implementation of FAB practices for pest management. Moreover, this work investigates whether flower strips, as one of FAB practices, promote biological pest control in modern apple production. This is achieved through combination of qualitative and quantitative research, participatory research and field trials. This thesis is conducted under the umbrella of the EcoOrchard project that aims to assess how far functional biodiversity can reduce pest damage and pesticide use in organic apple orchards. During the EcoOrchard project, four approaches to FAB were identified. These approaches were adopted and further examined in this thesis. The approaches were interpreted by the growers as an increasing scale of action from observations and avoidance of harming beneficials until active promotion of them by introduction of specific FAB strategies. The participants suggested to create a program for a growing season, to introduce different tasks, and gradually learn through collaboration between research, advisors and growers. The tasks could include a recommended schedule of management practices that promote beneficial insects or recommended dates for use of specific monitoring methods. The economic aspect was of crucial importance for the implementation of FAB practices. This thesis also underlines the importance of monitoring of natural enemies in apple production for participatory development of more resilient and sustainable apple orchards. Better knowledge of biological processes can help growers to change their attitude towards more sustainable production. Functional agrobiodiversity is a complex approach to improve agroecosystems that requires understanding, knowledge and expertise in biological process of specific species and in agricultural production. While the results of the field trials failed to deliver convincing arguments for use the flower strips, as one of FAB practices for pest regulation, the study uncovered several benefits of the monitoring for the growers and the advisors. Further research is required to find plant species with desirable traits that could be applied for FAB in different conditions and for different crops.

Foreword

Before attending the agroecology masters' program, I worked in business and IT sectors. I found escape from the rat-race of the business world in our garden and wished to buy a small farm. I spent my free time by learning about modern agricultural practices. I was becoming more and more aware that the society needs more radical change, if we want to keep the planet in a good shape for next generations. However, I did not know, how to lead the change, how to make an impact on society. Therefore, I started looking for masters' programs that could help me gain skills and knowledge that I was lacking. Fortunately, I found the agroecology masters' program at the Swedish University of Agricultural Sciences.

Throughout my studies, I felt that my views and opinions are strongly influenced by my business background. I was unfamiliar with the research process and was used to get rather precise answers to my questions. Before I started, I maybe naively hoped that the masters' program will give me answers to my question how to save the world. I soon found out that the issues of food systems are far more complex. However, the program gave me valuable tools, knowledge and skills that can be applied in everchanging complex situations.

For my thesis I wanted to do a study in Swedish urban farming. It has been my passion for a long time and I wanted to contribute to the research in this field. I was searching for long for an innovative project that has not been studied and I found quite a high interest among students about urban agriculture. All the projects I found has already been studied and could not come up with a new approach. When searching for the projects, I realized that I want to know more about participatory research, group dynamics, knowledge exchange and change. Then an opportunity to join EcoOrchard project came across. It was exciting and a bit daunting at the same time. During my masters' program studies, I learned a great deal about benefits of natural enemies, risks of pesticides, biodiversity loss and environmental pollution. However, my knowledge about insect and plant species was very limited. The project gave me a chance to be a part of a running research process. It gave me new and deeper understanding of challenges that farmers, researchers and agricultural advisors face in every-day operations. I hope my findings will bring a new light on the development of practices for functional agrobiodiversity.

Michal Stranak, October 15th , 2017

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Thank you all.

Michal Stranak, October 15th , 2017

Contents

Introduction

Problem background

Life on earth is a result of millions of natural evolutionary interactions over millions of years that have allowed humans to come to the existence with their capabilities to survive and transform the world around them. During that time, organisms on the planet have developed complex systems for efficient use of available resources, recycling of resources and reproduction. Gundersson (2002) points out that "these ecosystem dynamics are crucial for sustaining and building adaptive capacity, and for securing the flow of critical ecosystem services". Humans have reached a position of dominant species able to modify natural processes for their benefit (Western, 2001). Nevertheless, the great achievements have taken their toll in a form of current environmental problems. They are generally direct consequences of human induced disturbances to natural ecosystems with the purpose to fuel population growth and human well-being (Western, 2001). If we wish to keep or increase the level of agricultural productivity over time and avoid environmental and social damages, we need to improve or reinvent modern agricultural practices to limit their environmental impacts and reverse negative effects of the current agroecosystems.

Biodiversity loss due to human activities has been progressing at an alarming rate over the last decades (Cardinale *et al.*, 2012). When comparing effects of environmental problems on ecological functions, biodiversity loss is on a similar magnitude as climate change (Hooper *et al.*, 2012). Extensive research has documented the negative effects of biodiversity loss on the physical formation of habitats, fluxes of elements in biogeochemical cycles, and the productivity of ecosystems (Cardinale *et al.*, 2012, Wilson, 1988). Hence, even human well-being is threatened by the deterioration of biodiversity related ecosystem services (Diaz *et al.* 2006). The main drivers of biodiversity loss are deforestation, especially in tropics (Ravenel and Granoff, 2004), overfishing (Allsopp *et al.*, 2009), ocean acidification and expansion of agricultural land to meet increasing demands for food or biofuels (Green *et al.*, 2005, Royal Society, 2009). The UN Millennium Ecosystem Assessment (2005) acknowledged degradation of ecosystem services as a threat for the society and the need to reverse the current trend as a matter of human survival in the long term. Impacts of diversity loss are just as serious in comparison to other drivers to environmental changes (Cardinale, 2012). Moreover, the European Academies Science Advisory Council (EASAC, 2009) concluded that the biodiversity loss and degradation of ecosystem services reached rates unseen in human history. According to a globally compiled index of all invertebrate population, there has been a 45 percent decline in invertebrate populations over the last 40 years (Dirzo et. al., 2014). Moreover, a monitoring of the mass of insect in Orbroicher Bruch nature reserve in Germany showed 78% decrease in collected insects in 24 years (Sorg, *et al.*, 2013). In general, reduction of diversity leads to less efficient use of available resources, such as nutrients, water, light and prey, by whole ecosystem communities, and consequently leads to a lower rate of conversion of these resources to biomass and to less efficient recycling of biological nutrients (Cardinale, 2012).

The Swedish Environmental Protection agency noted in their evaluation of the environmental objectives (Naturvårdsverket, 2016) that the rate of ecosystems recovery needs to accelerate to conserve biodiversity. However, the agency recognizes conflicts in agriculture and forestry between production and biodiversity goals. High demand for consumption goods and rising interest in, for example, production of biofuels is often clashing with mitigation of biodiversity loss and efforts to improve ecosystem services (Natursvårdverket, 2012). Hence, the agricultural practices need to be adapted to promote efficient and competitive models of sustainable production. The Swedish Government is developing plans and tools to improve the long-term functionality of ecosystems and increase resilience to other environmental issues (Naturvårdsverket, 2017).

The planetary boundaries model, illustrated at the figure 1, (Steffen et. al., 2015) identified biodiversity loss or state of biosphere integrity as one of major risk factors for the maintenance of the Earth system in a resilient and accommodating state. Genetic diversity in the model describes the long-term capacity of the biosphere to persist abrupt abiotic changes. The second variable, functional diversity, captures range, distribution, and relative abundance of functional traits of organisms present in an ecosystem (*ibid*). Although, restricted to a limited set of data, it was estimated that a preliminary boundary of 90% was already reached at the time of assessment

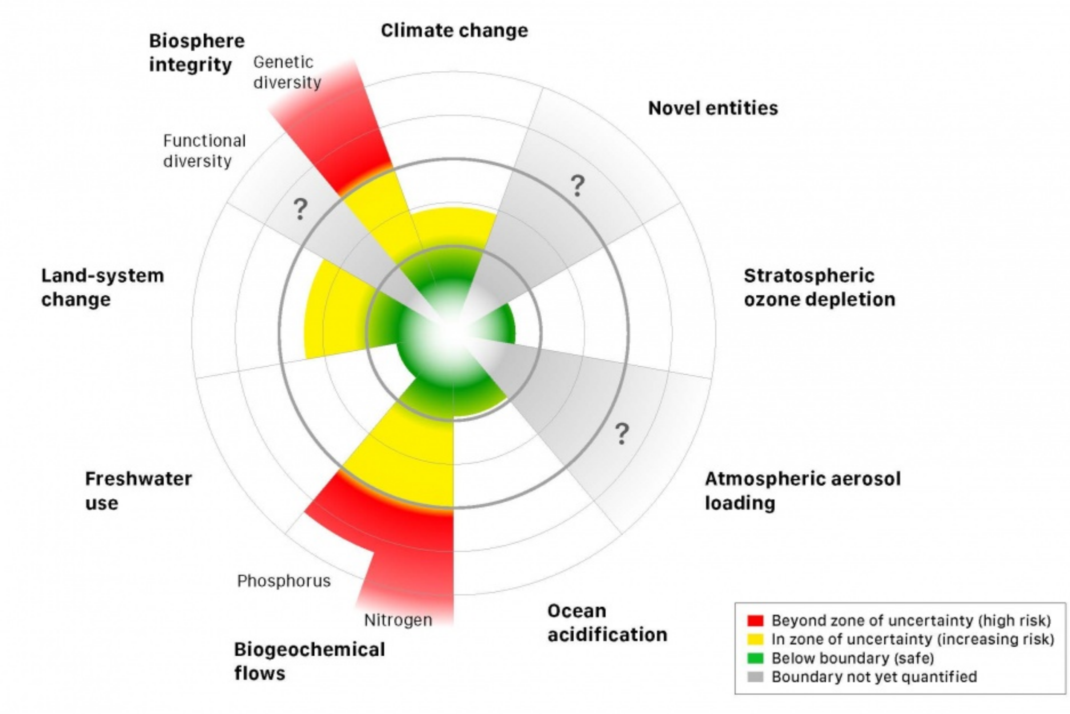

Figure 1 Planetary boundaries, source: Steffen et. al., 2015

Agricultural intensification has often been a significant contributor to the decrease in biodiversity (Donald *et al.*, 2002). The large-scale monocultures of today are often driven to reduce and control biodiversity to maintain uniformity of production (Gliessman, 2015). The expansion of monocultures today has resulted from political and economic forces that favor economies of scale (Altieri, 2005). In modern production the concentration of land devoted to single crops causes several challenges. For instance, in context of pest management, specialist crop herbivores have larger areas of suitable host plants in monocultures, while the lack of plant diversity reduces environmental opportunities for natural enemies (Papadopoulos, 2015). This creates conditions with higher risk of pest outbreaks and increases need for pest control. The global agricultural production faces on average about 30% potential losses in yields of many crops due to pests and diseases (Altieri, 2005, Oerke, 2006). Synthetic pesticides commonly used for controlling pests over the last decades are slowly losing their effectiveness due to increasing pesticide resistance of insects (Bellinger, 1996, Altieri, 2005). Moreover, many pest control technologies are connected to problems of pollution, cost, or deregistration of insecticides because of safety concerns (Gurr *et al.*, 2012). In the organic production, growers should use non-synthetic pesticides with lower efficacy. This contributes to 30-50% lower yields than in non-organic agricultural systems (Bravin, 2010, Bertschinger *et al.*, 2004). The yield losses due to pests and diseases are serious issues in agriculture and there is a dire need to develop more sustainable agroecosystems able to deliver desirable output for lower environmental and social costs.

Even though, biodiversity loss is a serious environmental issue, the current research is unable to provide specific recommendations to fully overcome this issue (Loreau et al., 2002). It is a consequence of a great complexity in biological processes, intra-species interactions within varied ecosystems, and strong influence of other external factors. There are limitations on successful application of current knowledge in real situations. However, it is the complexity of these ecological interactions that is a foundation of sustainable ecosystems (Gliessman, 2015).

The need for this research

Fruit production is an important sector of European agriculture. Fruit output (excluding grapes for wine production) in 2015 reached 11.6% of total European agricultural output in current producer prices (European Commission, 2016). Fruits are an important source of high-nutrient dense food in human diet. According to World Health Organization (WHO), the recommended daily intake of fresh fruits and vegetables is ≥400 g per day, not counting potatoes and other starchy tubers (WHO, 2015). However, the report shows that the mean fruit and vegetables intake in many countries is under recommended values. For example, in Sweden the daily consumption is only 237 g. This points out at the need for an increase in ratio of fruit in European diet. In this context and in case of an increased future demand for fruits and vegetables, there is a big potential for European fruit production to maintain and possibly even improve its position in agriculture.

With respect to fruit production, the EU countries face several challenges connected to globalization, socio-economic conditions and competitiveness in the world market. The European Fruit Research Institutes Network (EUFRIN) considers as one of the main challenges of the European fruit production the loss of its competitiveness. It is a consequence of gradual adaptation of modern agricultural practices and lower labor costs in countries outside of the EU and other developed countries (EUFRIN, 2011). On the other hand, EUFRIN underlines the strategic importance of fruit production from a perspective of food security and safety in the context of the global population growth. This highlights the importance of continuous enhancement of the fruit industry and the development of new innovations and technologies to maintain a functional and prosperous fruit network in Europe. Consequently, the competitiveness of the European fruit production depends on the innovations from research and development that can leverage lower labor cost in other countries. According to EUFRIN, it is crucial to develop new environmentally friendly and ecologically based methods to decrease environmental impacts and increase the yield of pome fruit orchards. The main objectives are optimization of production factors and resources, minimalization carbon emissions, reduced water use and use of mineral nutrients, decrease of pesticides foot-print and promotion of land-stewardship (EUFRIN, 2011).

Since January 2014, all fruit growers in the EU are required to follow the Integrated Pest Management (IPM) standards defined by Article 14 in Directive 2009/12/EC. The directive established a framework for community action to achieve the sustainable use of pesticides (European Parliament, 2009). It was inspired by the Integrated Production Management (IPM) that is defined as "the economical production of high quality fruit, giving priority to ecological safer methods, minimizing the undesirable side effect and use of agrochemicals, to enhance the safeguards to the environment and human health" (Cross, 2002). The framerwork includes monitoring of pests, weather conditions, conditions of plants to decide on appropriate treatment. It does not exclude use of pesticides or fungicides, but aims to lower the need for their application, as a solution of the last resort. It is required in the EU from 1 January 2014 to apply principles of IPM.

The International Organization of Biological and Integrated Control (IOBC) is one of the leading European institutions in promoting the development biological control methods within IPM. The major activities of the IOBC are concerned with testing the side-effects of pesticides on beneficial insects, pest and disease damage assessment, modelling in relation to pest and disease management, and practical implementation of biological and integrated controls for pests and diseases (IOBC, 2017). The IPM was defined by the IOBC as "a farming system that produces high quality food and other products by using natural resources and regulating mechanisms to replace polluting inputs and to secure sustainable farming." IP emphasizes firstly a holistic systems approach involving the entire farm as the basic unit, secondly the central role of agro-ecosystems, thirdly emphasizes balanced nutrient cycles, and lastly the welfare of all species in animal husbandry. The use of biological, technical and chemical methods is carefully balanced with focus on protection of the environment, profitability and social requirements (ibid).

Integrated Fruit Management incorporates a wide array of pest management practices and tactics for long-term pest control. Currently, IPM still heavily relies on the use of pesticides. However, a reassessment of pesticides introduced to the market before 1993 by the European commission led to removal of approximately 67% of substances used for pest control. The reassessment was conducted to eliminate substances that were shown to be unsafe for the environment and human health (Damos et. al., 2015). The reduction of allowed substances left growers with fewer available pesticides that can be applied as the last pest control option when other tools are not available or effective (ibid). Another alternative to synthetic pesticides are bio-pesticides that target specific pests and are less harmful for beneficial species and other non-target organisms. The bio-pesticides mainly based on bacterial pathogens, virus diseases, nematodes and entomopathogenic fungi. One of the most important and common bio-pesticides against moth species is *Bacillus thuringiensis* (Bt) which is pathogenic to larvae. The effectiveness of these products is often very sensitive to humidity level and/or temperature. This can lead to a lower pest suppression by the bio-pesticides in regions with lower average temperatures, especially in the beginning of the season. New developments in pest management introduced semiochemicals for mating disruption and mass trapping. These methods function on a principle of pheromone dispensers placed around an orchard for pest distruption during mating or by luring of flying insect pest to traps. Both methods eliminate risk of disturbances of non-target organisms and beneficial insects. Another practice promoted by IPM is the use of biological control. Biological control has been documented for the effective role of natural enemies in suppression of apple pests (Damos et. al., 2015). However, the use of insecticides can have adverse effects on biological control due to disruption of natural enemies. Therefore, it is important to develop pest management strategies and complementary tactics that reduce risks of harming non-target organisms.

Functional agro-biodiversity (FAB) has been acknowledged for suppression of the insect pests in agro-ecosystems. Barberi (2015) defined functional agro-biodiversity as *"as that part of total biodiversity composed of clusters of elements (at the gene, species or habitat level) providing the same ecosystem services, that is driven by within-cluster diversity."* The benefits of high diversity in agroecosystems have been discussed for almost decades, however there is still lack of evidence about the real effects of different FAB practices, such as pest suppression in specific crops by FAB (Nilsson, *et. al., 2016)*. Functional agro-biodiversity in general provides agriculture with a large array of ecosystems services. In general, ecosystem services are divided into four categories of provisioning, regulating, cultural and supporting services. Millennium Ecosystem Assessment developed a conceptual framework of ecosystem services arising from FAB including three of these categories. Pest control is defined as one of the main regulating ecosystem services .

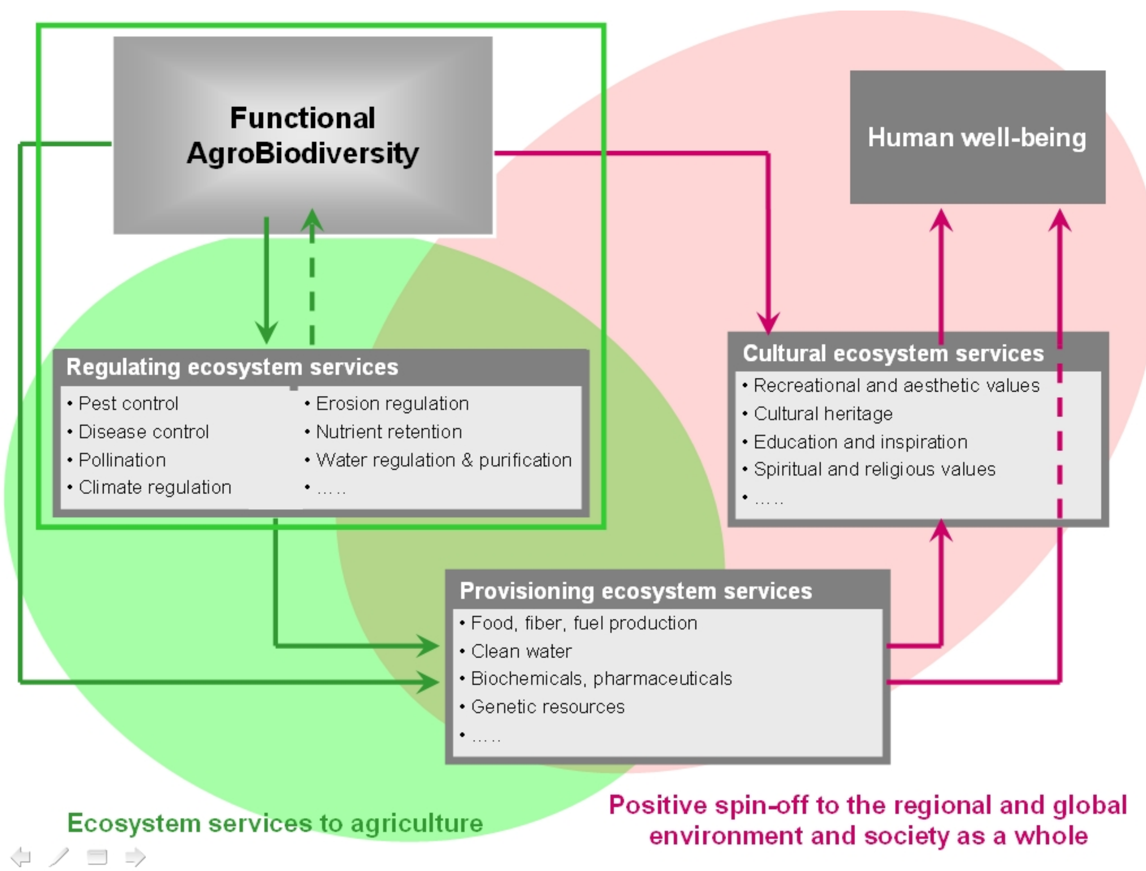

Figure 2 Conceptual diagram showing the relationships between FAB and ecosystem supporting services with benefits for agriculture and society. (Adapted from the Millennium Ecosystem Assessment, 2005

The backbone of functional agrobiodiversity is the use of science-based strategies to optimize ecosystem services of agroecosystems (ELN-FAB, 2012). The FAB approach promotes measures that have potential to deliver long-term improvements of multiple ecosystem services. Table 1 offers several examples of FAB-based practices suggested by the European Learning Network on Functional AgroBiodiversity (2012).

Table 1 Examples of ecosystem services provided by functional agro-biodiversity adopted from European Learning network on Functional AgroBiodiervsity, 2012

Example of FAB-based practice	**Types of ecosystem services provided**	**Benefits for farmers or society as a whole**
Provide habitat and resources to pollinators on farmland, through implementation or conservation of semi-natural landscape elements	Pollination	Increased yields and quality of farm crops that require pollination; landscape aesthetics
Mixed rotations	Biological pest and disease control; increased soil fertility	Reduced costs of external inputs; reduced environmental impacts; reduced pesticide residues; landscape aesthetics
Field margin management to provide alternative food sources and overwintering sites for pest natural enemies	Biological pest control	
Hedgerows	Soil and water conservation	Reduced soil erosion and water loss; less damage to infrastructure; landscape aesthetics
Reduced tillage for enhancing earthworm numbers and diversity	Maintenance of good soil structure; nutrient cycling	Improved water infiltration; less waterlogging; reduced soil erosion
Use of green manure cover crops, including legumes	Maintenance of good soil structure and nutrient cycling by a diverse community of soil organisms; retention of nutrients	Reduced dependence on external inputs; reduced environmental impacts
Production of rare, tradition crops, cultivars or animal breeds	Conservation of plant or animal genetic resources	Improved income from value-added specialty products; future adaptive capacity and resilience to disturbances

Despite all the benefits recognized by scientific community, FAB is sometimes criticized by advisors and growers as a ‘vague’ and popular term in agroecological research, with limited practical application in the actual agricultural production (Fernique, 2015). This consideration was brought up by an agricultural advisor, who found it in habitat manipulation study. The same advisor stated that growers are interested in consolidated methods which will pay back for their investment (Nilsson, *et. al.*, 2016). The development of such methods needs to be done in a long-term collaborative process with inclusion of growers, advisors and scientists to develop practical and functional systems (*ibid*). Considering the advantages that participatory methods conveys in comparison with the classical linear research, a long-term collaborative process with inclusion of growers, advisors and scientists is strongly recommended for the implementation of FAB.

Problem Statement

Apples are crops with the second highest pesticide use per hectare in Europe after grapes (European Commission, 2016). Gliesmann points out that pesticides and herbicides used in large quantities lead to elimination of beneficial insects and wildlife, and can lead to poisoning of the environment and farmworkers. The pesticides can further leach into streams, rivers and lakes and have negative effect on aquatic ecosystems (Gliessman, 2015). Integrated Pest Management approach and model of sustainable plant protection try to reduce dependence on pesticides that are still the heavily used as the main pest treatment in majority of orchards (Damos, *et. al*., 2015)

Organic apple growers face even bigger challenges connected to the pest management. They have access to less harmful pesticides with lower efficacy that do not always provide sufficient pest suppression. All pesticides for organic production need to pass more strict standards than the products used in IFP production. They need to be approved by the EU Organic Standing Committee (EC, 2007). Currently, there is a lack of effective products on the market against some pests in organic production (Bravin, *et. al.,* 2010, Bertschinger, *et al.*, 2004). Therefore, the organic growers need to better utilize preventive measures and alternative practices. Current high-yielding apple production faces challenges linked to biodiversity loss, diminishing ecosystem services, management methods and reliance on pesticides.

Purpose

This thesis investigates effects of functional agro-biodiversity (FAB) in intensive organic apple production. It aims to understand whether end-user adapted monitoring methods for insect pests and their arthropod natural enemies used by farmers and advisors can support implementation of FAB practices for pest management. Moreover, this work investigates whether flower strips, as one of FAB practices, promote biological pest control in modern apple production. This is achieved through combination of qualitative and quantitative research, participatory research and field trials.

The following research questions were developed to guide the thesis work:

1. What are the motivating factors for farmers for improvement of biodiversity in their orchards?
2. Which are growers' approaches to FAB, and how do the approaches relate to needs of growers and advisors for different monitoring methods for arthropod natural enemies?
3. How can monitoring of insect pests and their natural enemies be adapted to different needs of growers and advisors, and how can it help to improve implementation of FAB in apple production?
4. How relevant is the use of flower strips, as a FAB practice, for promotion of natural enemies and suppression of pests in apple production?

Frame of reference

Apple Production in Sweden

Farming development in Sweden has over the past decades predominantly followed the trend of agricultural intensification common to all developed countries. This has led to a decline of the position of farming in Swedish society (Swiergiel, 2015). Hence, the number of agricultural workers decreased by 79.6% between years 1951 and 2007 (SCB, 2017a). The area of land for crop production has declined by 28.7% during the same time (SCB, 2017b). Small and medium sized farms have been gradually replaced by farms larger than 100 ha (SCB, 2017b). New technologies have enabled higher labor productivity in farming and changed the face of rural Sweden (Swiergiel, 2015).

Apples are the most common commercially grown tree fruit in Sweden with 25 350 tons of apples produced and with 1494 hectares under cultivation in 2015 (Jordbruksverket, 2016). Most of the commercial apple production is in the Southern part of Sweden, Scania region, with approximately 86% of the total area under apple cultivation in Sweden. (Jordbruksverket, 2014). The climate in the Southern Sweden is suitable for agricultural production, with warmer winters and a longer growing season (Swedish board of agriculture, 2016). The milder winters increase the risk of insect and fungal infestations (Peltonen-Saino, 2012), which are the major challenges facing apple production (Tresnik, 2007). Climate change and increase in mean temperature could possibly increase the pest and disease pressure on agriculture in this region, which will require more efficient and more intensive management practices (Peltonen-Saino, 2012).

EcoOrchard Project

This thesis is conducted under the umbrella of the EcoOrchard project funded by Coordination of European Transnational Research in Organic Food and Farming Systems (CORE Organic). The aim of the project is “to assess how far functional biodiversity can reduce pest damage and pesticide use in organic apple orchards” (EcoOrchard, 2014). EcoOrchard is a participatory project including researchers, farmers and advisors from nine EU countries. The expected outcomes of the project are to develop innovative and practical tools to design and manage organic orchards with the focus on creation and management of functional flower strips. To do so, the project follows four objectives:

1. To identify promising techniques, tools and monitoring protocols to improve management of functional biodiversity, which consistently enhance the performance of natural enemies, reduce pest pressure and are adapted for farmers’ implementation.
2. To assess promising techniques, namely specific flora introduction to provide and optimize supplementary alternative food/prey for natural enemies, and specifically adapted habitat management.
3. To create a European-wide network of stakeholders for collecting, sharing and improving scientific and practical knowledge and experience in functional biodiversity management for resilient organic orchards.
4. To learn from a participatory approach about potential constraints that may hamper the adoption of innovative tools and how to solve these constraints by iterative re-evaluation.

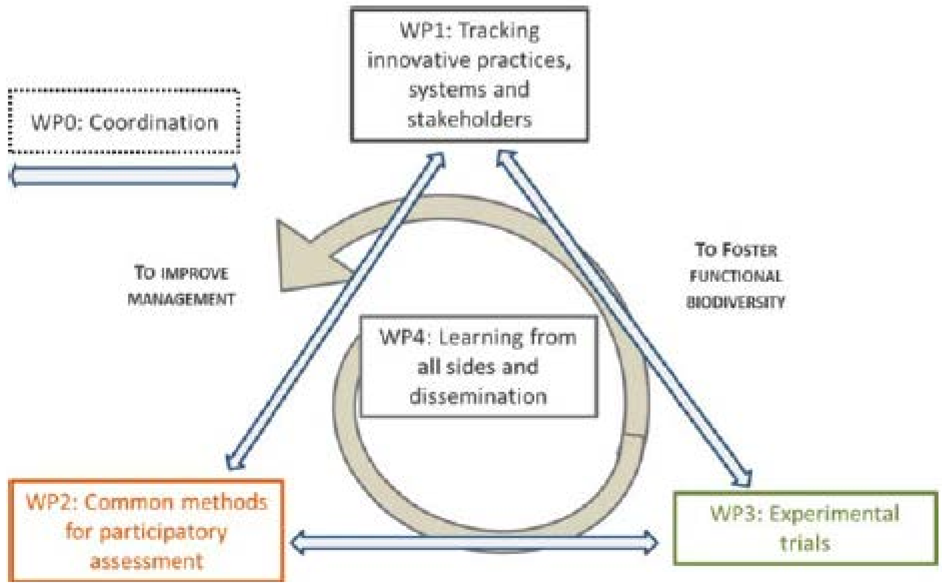

Figure 3 Coordination and interaction of the work packages of the ECOORCHARD project

The project was divided into four working packages (WP) pictured on the figure 3. The research for this thesis, within the project, was carried out between March and July 2017, during the WP3. During this phase, four monitoring methods of natural enemies were tested in orchards. The methods were selected by the EcoOrchard project after initial testing and literature review. The purposes of the monitoring methods were to:

1. Familiarize producers with simplified observation of beneficials.
2. Raise the awareness of producers to the natural regulations that are occurring in their orchards.
3. Engage the adaptation of plant protection practices in order to optimize these regulations.
4. When possible, observe the effect on biological control of agroecological infrastructures implemented in the orchard over space and time.

The EcoOrchard project is based on the notion that perennial cultures, such as organic apple orchards, are prone to fruit quality and yield loses due to pest and insect damage and there are no effective control measures for many of these pests. Hence, the project tests functional biodiversity as a promising approach to reduce use of pesticides by promoting beneficial insects. To augment natural enemies of insect pests, the project promotes ecological infrastructures that are providing beneficials with food, habitat and overwintering sites. Particularly flower strips were selected for the project and tested on farms in selected EU countries. The project hypothesizes that a flower strip design with the shortest possible distance to flower strips can provide better and more stable pest control (EcoOrchard, 2016).

Approaches to FAB

Another study under the umbrella of EcoOrchard project uncovered different approaches towards functional biodiversity by apple growers. Some growers perceive the term biodiversity as a very broad term, while others consider it to be an important part of their production system. A study conducted in France identified four different approaches (Fernique, 2015).

Table 2 - A presentation of approaches to FAB from a study about Identification and evaluation of technical innovations and for functional biodiversity in apple orchards (Fernique, 2015)

Approaches to FAB	
Passive approach	The approach is an observation of several positive and negative interactions between the environment and the orchards without efforts to interact. Growers with this view consider FAB as an external contribution, beneficial or harmful, to production and is not sought to be optimized by any techniques. This can be a result of insufficient information about the effects of FAB, or of an individual perception that FAB is not useful.
Naturalist approach	Highlights the importance of a general conservation and implementation of maximum plant and animal diversity at the heart of an orchard and in its immediate environment. Growers with this approach try to maintain as many different species as possible, promote the natural state of environment, and do the best with what is already naturally present in the environment.
Functional approach	Closely linked to research on the management of the orchard and its environment. This is a more interventional approach with focus on the functional aspect. The desired service from FAB is unique and aimed to solve a given problem. For example, the use of flower strips to promote natural pest predators and lower pest pressure, and consequently to achieve higher profitability and efficiency in orchard management.
Multifunctional approach	When there are multiple desired services from FAB such as the use of flower strips to achieve better biological pest control, improved pollination and other benefits. Another example can be use of hedgerows as windbreak and to increase biodiversity.

According to the study by Fernique (2015), most conventional farmers tend to have a 'passive' approach. Mixed producers following IPM or IFP tend to move towards the 'functional approach, by seeking ways to replace banned pesticides by contributions to biodiversity. Organic or biodynamic producers usually have 'multi-functional' approach in case the increase of biodiversity is incorporated in their overall operating strategy. Naturalist approach is common within growers with production practices strongly influenced by their philosophical relationship to nature (*ibid*).

Theoretical background

Agroecology as a theoretical framework

The meaning of the term 'agroecology', as a science, has been continuously developed since its first use by Bensin (1928), which he defined as "the application of ecology in agriculture". (Wezel et al., 2009). The early research of agroecology studied different components of agroecosystems, for example soil biology, or plant protection in agricultural landscapes (ibid). Currently, instead of looking at individual components of agroecosystems and their environmental, economic or social levels, agroecology emphasizes the interdependence of all these levels and the complex dynamics of ecological processes (Vandermeer, 1995). Agroecology arose from the understanding that environmental problems from 'ill producing agroecosystems' cannot be solved by overcoming only of specific causes via new technologies, but by "the application of ecological concepts and principles to the design and management of sustainable agroecosystem" (Altieri, 2005). Francis (2003) defined agroecology as "the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions." Some authors expand the framework by a fourth pillar of 'policy', or institutions and governance (UN, 2014). The broader definition underlines the complexity of the food system while highlights uniqueness of each place and its need for suitable solutions to its resources and constraints (ibid).

The topic of this thesis is studied through the lenses of environmental, social and economic agroecological dimensions. This is an integrative study and discussion of the problem in context of all pillars of agroecology that involves principles of landscape, society and bioregion with emphasis on uniqueness of place and the people, and other species that are present in that place (Francis *et al.*, 2003). Agroecology considers all dimensions as equally important for creation of sustainable food production systems. Figure 4 shows the concept of an agricultural system from the perspective or agroecology. The illustration presents complex interactions of the agricultural system with outside environment.

It would not be feasible to conduct a deep analysis of Swedish apple production including all factors and interaction within the time frame of this thesis. Moreover, creation of such analysis is not the main objective. Therefore, a simplified model of contextual boundaries was prepared to illustrate interactions influencing the aim of this work. The figure 5 briefly summarizes main factors in apple production with pest management as a part of biological system.

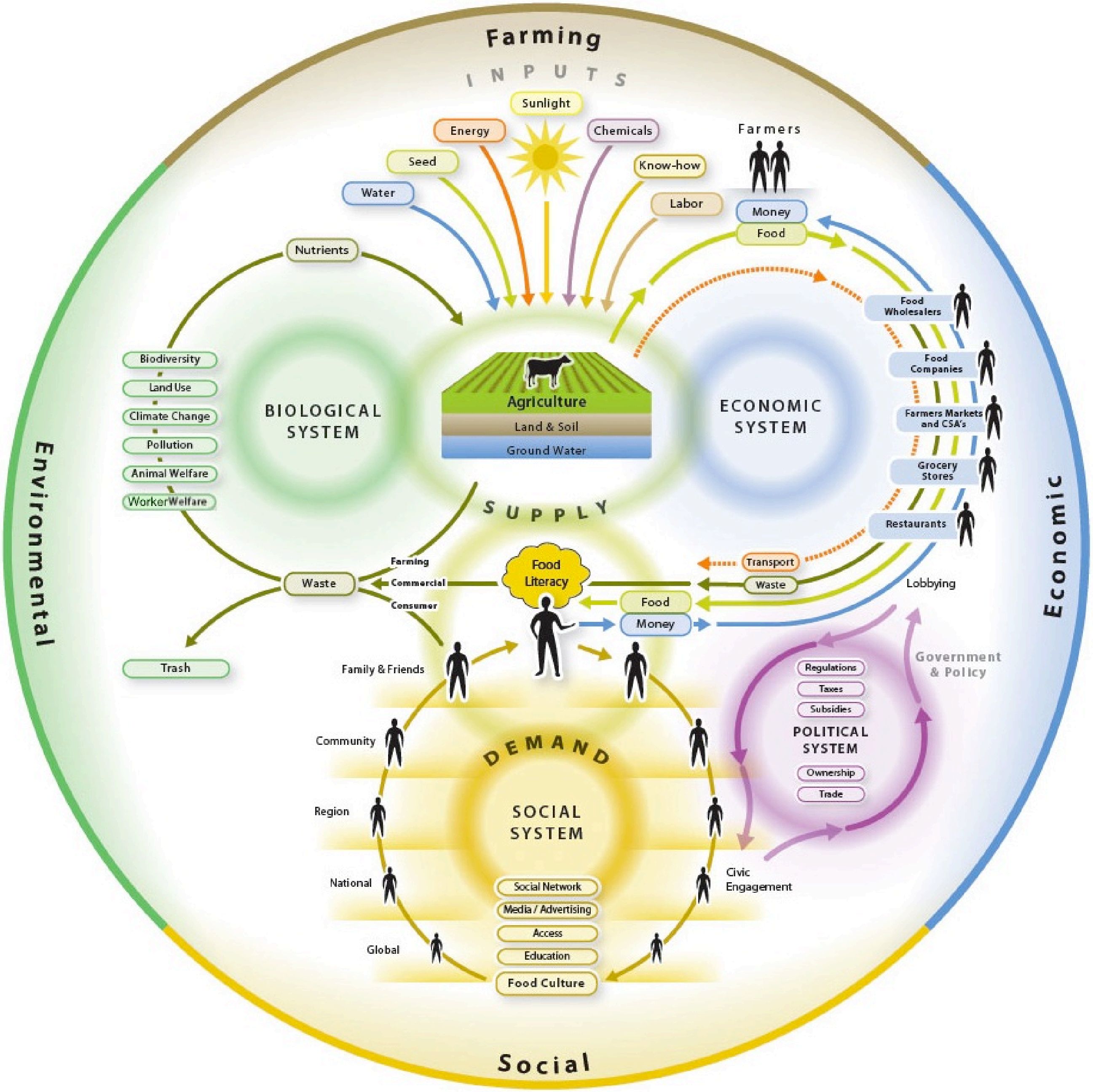

Figure 4 Food system map illustrating interconnection and flows present in food systems adapted from: [Nourish program](#)

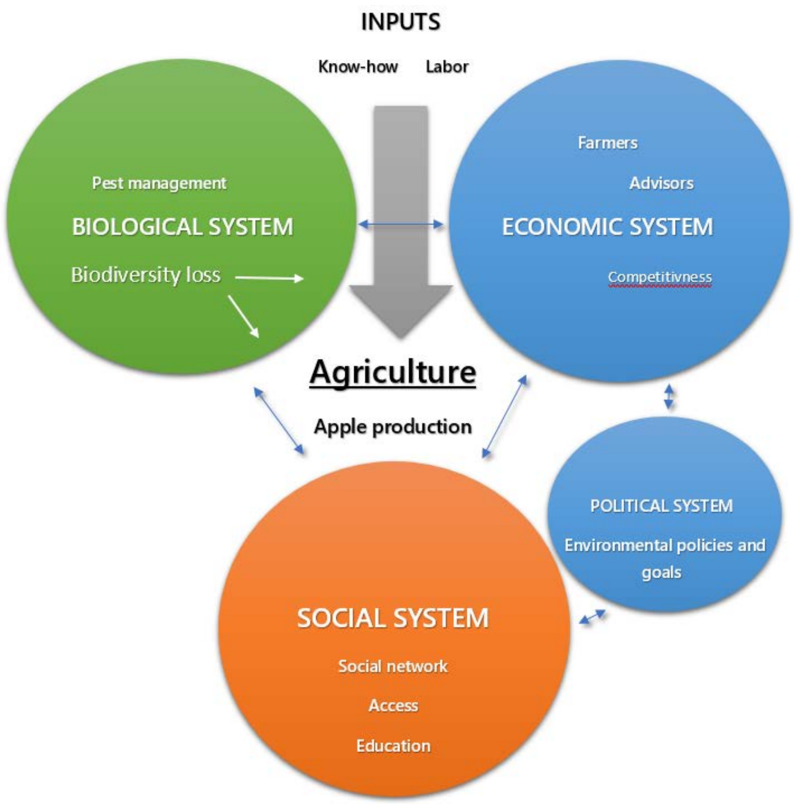

Figure 5 System diagram of the thesis project based on the agroecological dimensions

In an 'ideal' agroecosystem, agroecology aims to combine high species numbers and structural diversity, exploit the full range of microenvironments, maintain closed cycles of materials and wastes, rely on a complexity of biological interdependencies for high levels of biological pest suppression, lower levels of inputs and rely on locally adapted and resilient varieties of crops (Altieri, 2005). These commonalities were present in most traditional agriculture. However, Gliessman (2015) acknowledged that the transition to ecologically based agricultural management can bring potential reduction in yields and economic profits in the first years of the transition. He argues that much of farmer success depends on the ability to manage new economics of ecological based farm operation (ibid). The farmer need to calculate a new set of inputs and management costs connected to FAB practices underlined by Gliessman. Agroecological research is an ongoing process that vigorously seeks new ways to combine the old agricultural knowledge, understanding of natural ecological processes and new innovative approaches to food productions.

Systems thinking

Systems thinking is a research approach often applied in agroecology for design, analysis and management of farms, and for linking theory with farmer practices (Gliessman, 2007). It is a powerful way to treat systems or treat situations as systems, to gain a better understanding of unsolved complex problems. One of large contributors to development of systems thinking Checkland (1981) states that "*the central concept of a system embodies the idea of a set of elements connected together which form a whole, these showing properties which are properties of the whole, rather than properties of its component parts*". All parts of the system combined together gain an emergent property that is not present when the parts are treated individually. For instance, aphids alone in an isolated environment with access to food sources would thrive until their population increases to an extent that they run out of food. However, when we look at the natural environment for aphids with available food, other external factors and their natural enemies, a regulation of aphid populations emerges in the system. Hence, systems thinking is an approach that studies interactions and interdependencies within whole systems to understand underlying issues such as pests in their environment with their predators.

Adaptation of systems thinking for analysis and development of agricultural systems has been motivated by concerns of scientists about negative impacts of agricultural developments based on reductionist scientific research over the last century. Issues of reductionism are for example increasing of unequal food and income distribution, large-scale social change and negative environmental effect of agriculture (Schiere, 2004, Hofny-Collins, 2006). The reductionist science or technological approaches reduce a problem to smaller parts that can be experimentally tested by reduction of as many variables as possible. Reductionism in research and development has a great use for improvement of individual specific parts of the systems, however fails to consider the broader systemic effects of changes in single specific variables, especially in very complex natural environments. On the other hand, systems thinking is the process of understanding how things interact with other constituent parts of the system (Konkarikoski et al., 2010). Systems thinking is a cognitive process often used for understanding interrelated or interacting elements in agricultural research.

Over time, different branches of systems thinking have evolved as reactions to various needs and newly acquired knowledge. The first generation of systems thinking emerged in the first half of the twentieth century as an alternative to reductionist science and its failure to deal with the complexity of studied problems. There has been a rising sense of unease about the costs of progressive development fueled by narrow reductionism in research on the expense of fragile ecosystems. In the same time there has been an increasing pressure on farmers to change their practices to be less exploitative of natural resources and increase productivity under a harsher economic climate (Bawden et at., 1984). Hence, the first generation of systems thinking, also called hard systems thinking, brought multidisciplinary scientists and advisors together to tackle present issues in agricultural development (Hofny-Collins, 2006). Hard systems thinking, and its positivistic approach delivered new solutions and identified new technologies that would improve farm productivity under challenging conditions, in situations with well-defined boundaries and goals. However, it missed inclusion of social aspects of the systems and subjective insights of stakeholders into planning and decision-making processes (Midgley, 2000).

Because of the shortcomings criticized in the hard systems thinking approach, a new generation of systems thinking evolved with focus on inclusion of human beings with their subjective perspectives as crucial actors in the systems. Soft systems thinking moves from looking at well-defined systems and problems to focusing at a higher level of systems in real everyday human situations in more of a constructionistic way (Checkland, 2000). The new participatory approach aimed to make farmers more involved in the research and development process by closing the gap between researchers, scientists, advisors and farmers (Chambers and Jiggins, 1986; Chambers et al., 1989).

For purpose of thesis, I selected the pluralistic approach in combination of hard and soft systems thinking to bring a greater systematic understanding of studied topic. In this thesis, I applied hard systems methodology in the field experiments, which results were combined with the findings from soft systems approach.

Action Research and Participation

According to Carr and Kemmis (1986) *"action research is simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practices, their understanding of these practices, and the situations in which the practices are carried out"*. The action research can be basically understood as a learning process. However, the learning process of action research does not begin with a fixed hypothesis. It is a development process of an idea that is being continually checked in accordance to expected outcomes (McNiff, 2009). A crucial component of action research is critical reflection of each research cycle. Critical reflection on the first cycle of action research may lead to modifications and redefinition of the studied problem, which serve as a foundation for the subsequent cycle. Hence, action research can be understood as an ongoing cyclical process (figure 6) of planning, implementation, observation and reflection of the whole process.

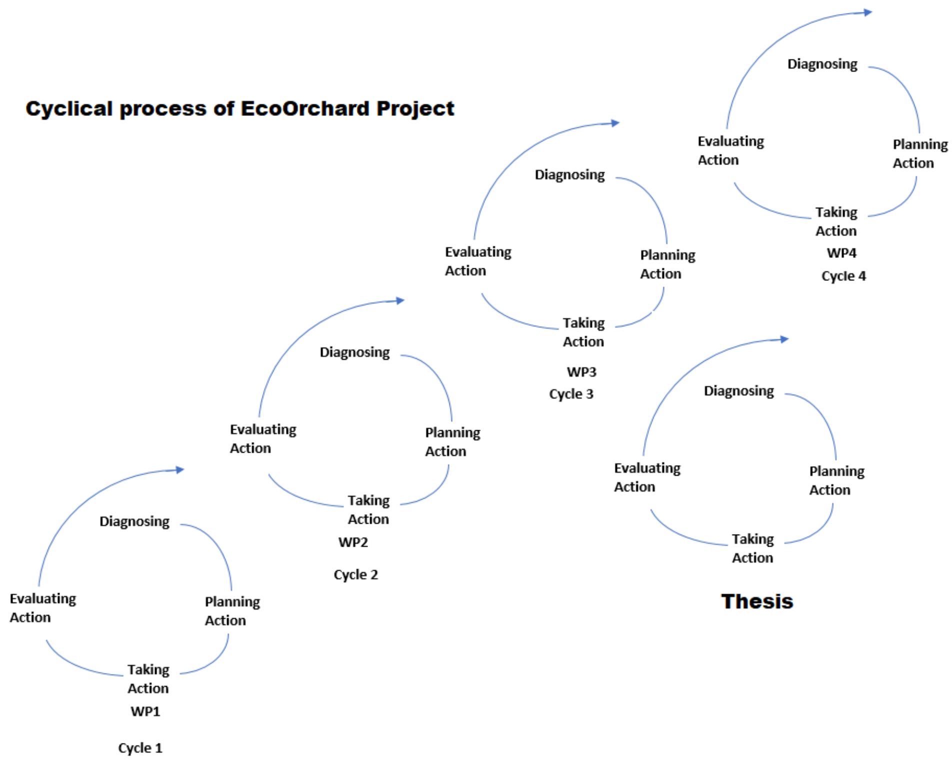

Figure 6 Spiral of action research cycles of EcoOrchard project and the thesis

The EcoOrchard project itself is based on participatory action research process. Each of its working packages can be seen as one cycle, which results are transferred and applied the other cycles. This master thesis is an individual research cycle between the third and the fourth cycles of the EcoOrchard project. The knowledge acquired in the previous cycles of the project is utilized for the thesis project in Sweden. Within the EcoOrchard project, the WP cycles are intertwined. They do not follow like individual steps of the project, but rather feed information from one cycle to another. Furthermore, this thesis is coming out a diagnosis made in the EcoOrchard project and its result will feed back into the iterative and interconnected cycles of the whole project

Participatory research is a systemic and group-learning process that tackles complex issues through use of interactive methods such as workshop used for this thesis project. Moreover, participatory research enables an investigator to grasp complex perspectives of various stakeholders. Furthermore, the facilitation of participatory research brings new changes and transformation of existing activities that need improvements. Lastly, the participatory methodologies offer to participants a learning environment through debate about changes and. Pretty (1995) describes participatory research as search for diversity that includes different perspectives of stakeholders and encourages group learning processes within the participants.

Methodology

For purpose of this thesis I used Checkland's model for systems thinking. It enabled to grasp the objectives of the study within a complex a wide systemic perspective (Checkland, 2000). The model has many applications in understanding large issues within their context. Moreover, the use of the model can be understood one of the cycles of research and learning. In the thesis, the problem situation is presented and defined in the introduction chapter. The thesis project started with unstructured problem situation within the predefined EcoOrchard project. After an extensive literature review in the problematic of FAB assessment and learning about the state of art in biodiversity and insect pests, the important influential systems emerged. Furthermore, the theoretical framework of agroecology presented a structured conceptual model used for analysis of the data as parts of different systems to be created. The conceptual model included mixed methods research approach. Afterwards, the findings were compared, and feasibility of desired changes evaluated in the discussion.

Because the subject of this thesis is interdisciplinary, pluralism of theory, methodology and methods was required. Such systematic enquiry allows data from qualitative and quantitative research to be combined. Figure 7 provides a representation of the organization of the research.

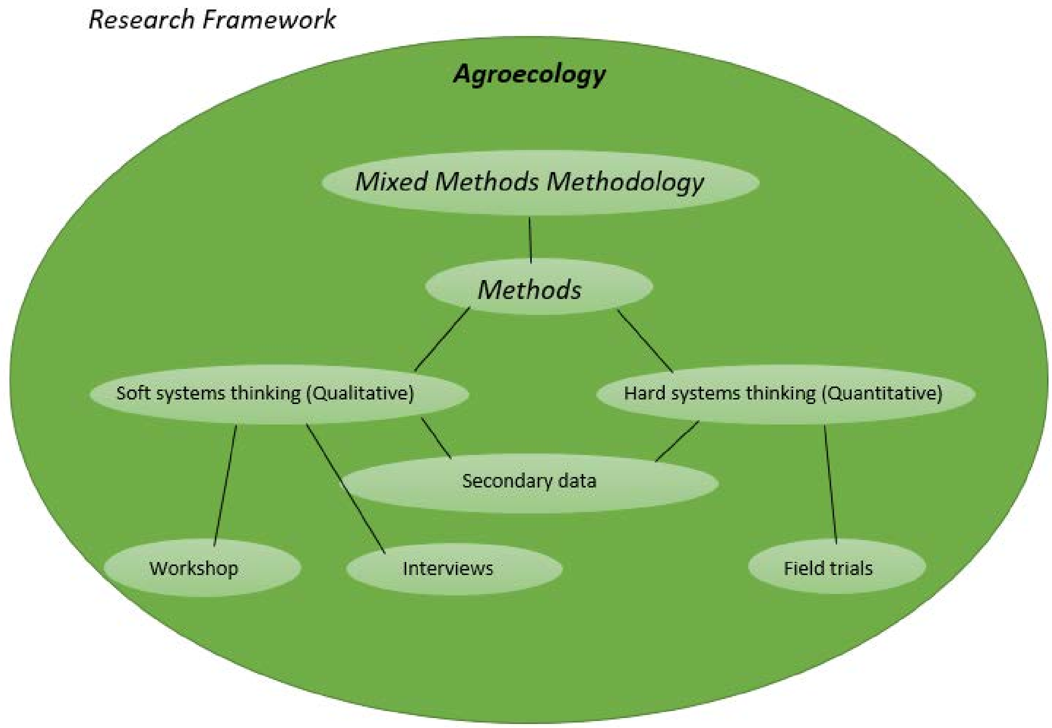

Figure 7 Conceptualization of the methodological pluralism used for the thesis

The thesis combines deductive and inductive research approaches. The natural science part of the research is based on the generally acknowledged benefits of more diverse environment on the number of beneficial insects and tested the effects of the flower strips on presence and activity of natural enemies and pests in the orchards. The thesis project used four monitoring methods for insect pests and their natural enemies to evaluate effectiveness of flower strips for pest suppression. Systemic boundaries for the practical assessment of FAB and monitoring methods is on the farm level. On the other hand, the social part of the research investigated farmer perceptions about FAB and the usefulness of selected monitoring methods according to their FAB approaches. Johnson (2005) describes mixed method research as "a class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, theories and or language into a single study." Ulmer and Wilson (2003) add that quantitative results need to be supplemented by qualitative findings. Qualitative research methodology is often used when the researcher carries out a systemic inquiry to discover issues in a new field of study (Creswell, 2007).

Materials and Methods

Field trials

Field experiments were conducted between May and July 2017. Two apple organic apple orchards were selected in Österlän region (Scania county). The region represents the typical apple growing landscape of southern Sweden consisting of crop and non-crop habitats, and settlements. Field sizes were 2,1 ha for Helenelust and 4,7 ha for Svinaberga.

Table 3 Summary about the farm in Helenelust

Farm surroundings	Surrounded by farms with crops
Distance to the next farm	closest field with apples at 0.5 km (organic, the same owner)
Farm size	35 ha
Apple proportion of the farm	12 ha organic apple (Most of the rest is IP apple production, some berries and other fruits). The total production area is spread into different fields (farms). The organic apple production is on two separate and distant fields. The organic field where the experiment was performed is 8 ha.)
No. of years of apple production	128 years (since 1888)
No. of years of organic production	8 years including 2 years conversion (since 2008)
Tree age	2-10 years (since 2006)
Tree varieties	Ribston, Greensleeves, K 1016 SLU, K 1160, K 1343, Holsteiner Cox, Ingbo, Blenheim Orange, James Grieve, Amorosa
Row distance	4 m
Interrow distance	1 m

Table 4 Summary about the farm in Svinaberga

Farm surroundings	**North:** 0.2 agricultural fields and at 0.6 km distance a forest patch of approximately 0,2 km then agricultural fields again; **East:** a hedge and then agricultural fields; **South:** Agricultural fields and after 0.5 small forest patches for approx. 0.4 km, then agricultural fields; **West:** Agricultural fields and at 0.6 km distance a forest patch of 0.2 km, then agricultural fields
Distance to the next farm	Surrounded by farms but not fruit orchards.
Farm size	30 ha
Apple proportion of the farm	2 ha
No. of years of apple production	9
No. of years of organic production	16 for the farm in general (including conversion)
Tree age	2-9 years (all trees within experiment are 9 years old, 2 years old are newly planted this year (2 rows))
Tree varieties	Frida, Collina, Rubinola, Amorosa, Santana
Row distance	3.5 m
Interrow distance	1.25 m

The design for the field trial consisted of 2 blocks of trees with In-between-tractor-wheels (BTW) flower strips and 2 blocks without the flower strips. The measuring zone for each block was 3 rows of at least 12 trees with at least 2 rows of buffer trees on each side of the measuring zone. The flower strips were planted with mixture of 7 grasses and 25 flower species. These species were selected based on Lucas Pfiffner's criterias for suitable sown wildflower strips to enhance natural enemies of agricultural pests (Pfiffner, et.al., 2004). The fields were treated with products against pests and diseases approved for organic apple production in Sweden. For pest management Raptol with natural pyretrin (5 gr/L) was applied in Helenelust in quantity 4 liters per ha. In Svinaberga 1,5 liters per ha of Raptol and 1 kg per hectare of Turex with *Bacillus thuringiensis* (50%) was applied.

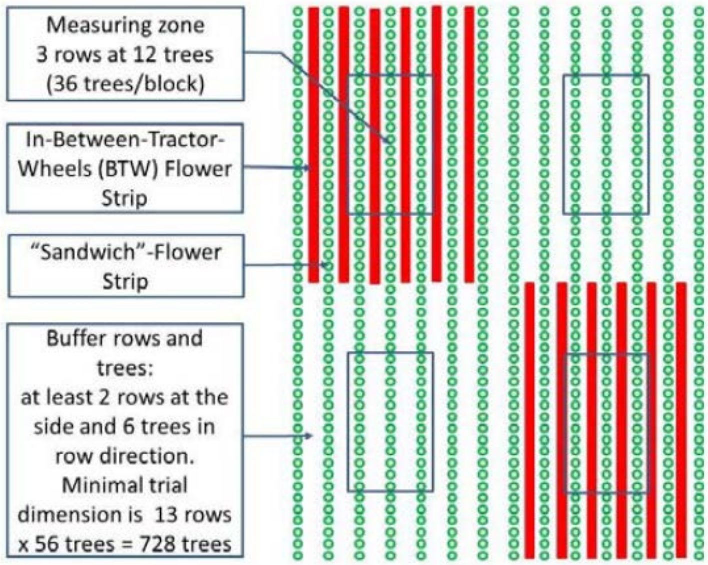

Figure 8 Minimal experimental design for the trial to test the effect of 'in between tractor wheels' flower strips and 'Sandwich' flower strips, adapted from EcoOrchard project, 2016

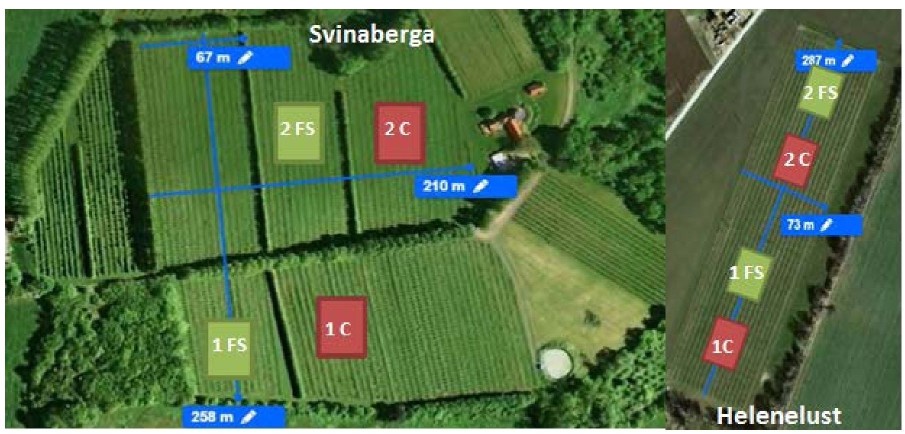

Figure 9 placement of experimental blocks in Svinaberga and Helenelust

Monitoring methods

For monitoring of natural enemies, this thesis adopted methods used in the EcoOrchard project, which were selected after literature review and initial testing. For purpose of the thesis three methods were selected: visual observation of the rosy apple aphid, beating and egg predation cards.

Following recommendations from the IOBC, samples of 10 trees per each row, 30 per treatment plot, were randomly selected without looking at branches and 6 flower clusters from the lower half of the tree were assessed from all orientation. In total, 60 flower cluster were collected per each row in each stage of observations. The field observations were done in three phenological development stages of apples based on BBCH-scale. BBCH59 is a stage when the most flowers with petals start forming a hollow ball. BBCH69-70 marks the end of flowering and petals fall, and BBCH74 is a stage when fruit diameter reaches up to 40 mm. To assess aphid infestation (*Dysaphis plantaginea*, *D. devecta* and *Rhopalosiphum insertum*) and infestation by other pests

(*Lepidoptera* Larvae, *Psyllidae*, *Cicadelidae*, *Phyllobius*, scales, spider mites, blossom weevil), the clusters closest to the tree trunk were collected. The samples were collected into plastic bags and were frozen after return from the fields to avoid predation in the bags. The sorting of all samples from all stages of visual observations took approximately 100 laboratory hours. A stereo microscope was used to examine all flower clusters and leaves. In the grow stages BBCH69-70 and BBCH 74, 10 aphid colonies in each row were randomly selected and marked to assess dynamics of aphids and their natural enemies. Edge trees were not considered in the monitoring. The infestation rates of aphids, other pests and presence of natural enemies were analyzed by General Linear model ANOVA (GLM ANOVA) with confidence 95% and confidence interval ($p<0,05$). Due to non-normal distribution of the results, data were transformed by logarithmic transformation $y=ln(x+1)$.

The assessment by beating was done at the stage BBCH 69-70 after the visual controls. The beating was performed when the leaves were dry. Per treatment block, 30 measuring trees were randomly selected (10 per row) and one horizontal branch of older wood was beaten firmly 3 times. The falling insects were collected into a white net, 45 x 45 cm in size. The samples from all rows were carefully transferred to plastic bags and were analyzed later in the laboratory. Beating provides a representation of the arthropods population in the canopy with a favorable bias towards bigger arthropods. The method particularly targets ladybirds, green lacewings, spiders, predatory bugs and earwigs. The findings from the beating were strongly non-normally distributed. Therefore, One Proportion Test with confidence interval was used to analyze the beating samples.

Egg predation cards with sentinel eggs of *Ephestia kuehniella*, a flour moth harmless to crops, were prepared in the laboratory. *Ephestia kuehniella* is a species which attacks cereal flour in storage facilities and do not inflict any damage in apples. Therefore, we selected these species, in order to evaluate biological control and at the same time avoid injury of fruits. Between 15 to 25 eggs were glued on pieces of paper (2x2 cm) by egg white which was used as the glue. The cards were kept in small refrigerated containers (+5 C). In the field, the cards were placed on apple leaves, not too close to the trunk, to prevent predation by slugs or ants. The cards were placed in each row (5 per row, 15 per treatment) and after 24 hours were collected for analysis. In the laboratory, the number of eaten or parasitized eggs was counted. The cards were placed in the orchards on three occasions in BBCH stages 70, 74 and 78. The findings were analyzed by General Linear model ANOVA (GLM ANOVA) with confidence 95% and confidence interval ($p<0,05$) logarithmic transformation $y=ln(x+1)$.

Qualitative Methods

The workshop was a part of the EcoOrchard WP3. Workshop is a problem-solving research method for applying and testing concepts and models, and for inductive theorizing based on information provided by participants (Fischer, 2004). Participants of the workshop were two apple growers, an advisor from the Apple Grower Economic Association (Äppelriket), an advisor for organic apple production, a retired agricultural advisor with vast experience with apple growing and IPM, and an expert in crop protection biology from the Swedish University of Agricultural Sciences. The main objective of the workshop was to receive feedback on selected monitoring methods and handbook instructions developed by EcoOrchard for participating growers. Furthermore, misunderstandings and unclarities in the handbook were discussed and suggestions for improvements were made. In the second half of the workshop, the participants discussed approaches to functional agrobiodiversity (Fernique, 2015) in the context of a suitable monitoring program.

After the workshop, semi-structured interviews were conducted to gain a deeper insight into about the applicability of suggested monitoring methods and about FAB approaches of the growers. Semi-structured interviews are widely used in qualitative research for deeper examination of interviewee's personal opinions (DiCicco-Bloom and Crabtree, 2006). The semi-structured interview follows a predefined interview guide with open-ended question that gives room for collection of rich data and enable discussing new leads that can emerge during the interview (Bryman, 2008).

Based on an initial literature review and project proposal, an interview guide with open-ended questions was prepared. The questions were adapted during the interview according to situation and new emerging themes. Nevertheless, all the main areas from the interview guide were covered. Regarding the interview with the advisor, the questions were fitted to her field of work. In total three in-depth interviews were conducted between the 8 th of May and the 16th of June. One interview was face-to-face on a farm and two by phone. All the interviews were recorded. The duration of the interviews varied between 40-97 minutes. The face-to-face interview took longer time, because of a friendly atmosphere and a small language barrier. English language was used during all interviews.

Purposive sampling method was used for selection of interviewees. It is a non-probable sampling method based on a specific purpose to acquire data from settings and persons (Teddlie and Yu, 2007). The monitoring of arthropod natural enemies is usually not done by Swedish apple growers. Thus, only growers familiar with in the monitoring that participated in the EcoOrchard project in Sweden were contacted. Under these conditions, this work did not attempt to present generalized results about the whole community of Swedish apple growers. Instead, the thesis examined the topic within the specific context (Bryman 2008). The researchers from SLU participating in the EcoOrchard project in Sweden were the key informants for suitable interviewees.

The qualitative data were analyzed by thematic analysis. Themes and patterns were identified from transcribed conversations and important findings listed, quoted and compared. The quotations were important in the analysis to capture the 'voices' of the growers. Furthermore, in the thematic analysis the data are related to the already classified patterns and combined into sub-themes (Aronson, 1995). Three main coding categories were defined based on preliminary research (perception of FAB by growers, usefulness of monitoring, knowledge about FAB). During the interviews, new emerging themes were identified and included in the paper. All the results were divided into the categories to make a clear comparison of the results. Leininger (1985) states that the coherence of the ideas rests on the analyst who carefully examined the data and linked them together in a meaningful way.

The interviewed growers were a couple of experienced IP apple growers that have been cultivating fruit trees for over 40 years, and a younger organic grower with 8 years of experience with growing apples. Both farms were in the Southern Sweden. The growers from both farms participated in EcoOrchard project and were familiar with FAB. The IP Growers run a apple farm on 50 ha of land with 80% of land dedicated to apples, and the rest to pears and plums. They have grown apples for a long time and are interested in FAB. The farm is located in Österlen region of Scania country that is well-known for apple production. They were interviewed together and are represented in the discussion under code ‘IP Grower’. The Organic Grower had 70 ha of agricultural land with vegetables and fruits under cultivation. About 7 ha of the land is dedicated to apples. The first trees on the organic farm were planted in 2009 and the size has been increasing by 2 ha every other year. The farm is located Blekinge county of the Southeast Sweden. All participants were contacted in advance and introduced to the purpose of the interview. Participants from both farm were also present in the EcoOrchard workshop. The selected growers were a small sample of motivated growers that try to apply FAB in their production. The last participant of the interviews was an advisor from the Swedish Apple Growers Association who also attended the workshop. All participants were informed about the purpose of the research project, and made clear why they were selected to participate. They were reassured about the confidentiality of any information provided and given an opportunity to ask any questions, or give a feedback.

Results

The term 'functional agro-biodiversity' was not fully recognized by the farmers. It is probably due to only rather recent occurrence of the term in environmental discussions after its introduction in 2005 (Millennium Ecosystem Assessment). However, the growers were familiar with terms biodiversity or 'natural balance' and claimed its importance in agricultural production. Hence, the interviews were led to uncover farmers approaches towards development of the FAB by deduction of their views through terms familiar for them, such as diversity, natural balance.

Research question 1: Approaches to FAB

In classification of approaches to FAB according to Fernique (2015), the findings showed mixed approaches of the growers. The IP growers seem to be in transition from the passive towards the multi-functional approach. They have had hedgerows around the orchard since they started growing apples and in early years they considered them as a source of pests. Over time their perception of the hedges has changed, and they would like to know more about how to improve them. Another interesting observation from the interview was, that the IP growers often referred to their source of information as “they”. It seemed to be a generalisation of information from advisors and other growers that they considered as a fact. The IP Growers wished to learn more about FAB and how to manage areas around and inside the orchard in a better way to promote biodiversity in the future.

“In that time when we only sprayed .... we also sprayed the hedge. We thought that there could be something bad in there in the hedge. We wouldn't even dream about it today. That is one thing. But if we should have a perfect hedge, what should we have for good insect. We don't really know what to have. ‘They’ talk more and more that when you have a hedge for a wind break, it's very important to have more than one kind of tree. And for example, to have flowers that bee like. It's very important. We don't cut the grass too much and we cut every second row to have more flowers, and we have the hedge around. I don't like people that cut grass and flowers besides the road. Often, it is a good place for flowers in summer. They just cut it. Many times, it is not important to cut it. (IP Growers).”

The IP Grower stated that one needs to realize shortcomings of spraying, insufficient pest treatment products available and the importance of other measures to protect apples.

“There is small market for chemicals, so we have problem to find chemicals. We have a small selection of products. I think that the most decisive thing is that the sprayer does not solve all your problems. Or…, that there are other ways to solve the problems than with the sprayer. (IP Grower).”

The Organic Grower had more straight-forward multi-functional approach. She claimed that see sees many functions of various FAB practices and she tries to utilize them, such as wind break function, attraction of pollinators, or promotion of natural enemies of insect pest.

“I think it's little of everything. Wind break, pollination. The nature is fantastic. Because everything has its meaning or a role, and everything goes around. Sometimes we found help (from the nature) that we didn't know it was there (Organic Grower).”

Moreover, she stated that her decision to grow organic and utilize ecosystem services on the farm, including promoting functional biodiversity, was based on her personal ideology and for economic reasons. However, she stated that planting the flower strips and promotion of beneficial insects can be contradictory with other orchard management practices.

"We think a lot about how we can do things in a way that will not disturb the practical work. Because flower strips in the middle of the orchard can sometimes feel like you are dedicating a lot of time and money on something and then you have to cut it sometimes. For example, when there is the late frost in May. Then the frost warning must be prioritized, and you need to cut everything. Then, you rather wish to put the flower strips around the orchards. Then, you want all the time to have corridors for the beneficials into the orchard, and the question is if one… Is it worth to sacrifice a tree row and have flower strips there? It is square meters and tractor driving. And what the sprayer also can… I mean that it counteracts. Because sometimes it feels as if one is working very hard on high levels of beneficials and then they (flower strips and spraying) cancel each other out. That you work to build up a bank of something and then you destroy it in another action. (Organic Grower)."

The growers stated that late frost poses a challenge in establishing the flower strips. A common practice in apple growing is to mow down grass short to uncover as much soil as possible. The soil accumulates the heat from the sun and releases it during the night. A high soil cover blocks the sun light to reach the ground and consequently lowers soil potential for heat absorption.
The approaches on both farms were mixed with one dominant approach. The IP Growers were in transition from passive to multifunctional approach, and the Organic Grower had more of multi-functional approach with influence of her ideology that could be seemed as naturalist approach.

Research question 1: Use of monitoring methods in relation to different approaches

The biodiversity approaches were discussed during the workshop together with the growers and advisors. The approaches were interpreted by the growers as an increasing scale of action from observations and avoidance of harming beneficials until active promotion of them by introduction of specific FAB strategies. They claimed that it was somehow difficult to comprehend what each approach implied and the usefulness of division of the monitoring methods into different approaches disappeared during the discussion. One purpose of the division of the approaches seem to be identification of growers with different levels of interest and finding suitable ways to raise their interest about FAB and the monitoring. The participants suggested to create a program for a growing season, to introduce different tasks, and gradually learn through collaboration between research, advisors and growers. The tasks could include a recommended schedule of management practices that promote beneficial insects or recommended dates for use of specific monitoring methods. For example, information for growers about when it is not good to cut the grass based on the lifecycles of beneficials, or when it is a good time to start monitoring based on the lifecycles of observed insects. It could benefit in the future for development of better tools, scientific knowledge, practical competences, and division of mentioned tasks.

"It would help us to have information about when not to cut the grass, when it is time when natural enemies are for example laying eggs and when they fly away, and we can cut the grass. Because sometimes we maybe do things that don't support the biodiversity. We don't know that we do something bad, but we do it because we don't have the knowledge, for example when ladybirds are

doing something. That would be a very good help to us to have some schedule for it. Maybe have some system to inform growers when not to cut the grass or other do other things. Because it's too much happening in the orchard and sometimes you miss. It is not possible to keep everything in head all the time. Maybe even information, if we should cut grass in the day-time or in the night-time there, what time is there very much activity. That's something we don't know. That could be something interesting (Organic Grower).”

There were several dilemmas in the discussion. For example, the monitoring methods could be potentially useful for growers with the passive approach towards biodiversity in case on the interest in reduction of unnecessary spraying cost. This would require more frequent monitoring for purpose of protection of the beneficial natural enemies. Consequently, the cost reduction for spraying could be negated by increased labour cost for the monitoring. Suddenly, when a grower not interested in FAB, but interested cost reduction, his or her passive approach transforms into the active reductional approach with a specific objective. This created a confusion during the workshop about the different approaches to functional agrobiodiversity that were presented to the participants during the workshop. However, we need to distinguish the difference between the approach to FAB and use of monitoring for natural enemies. A grower can have passive approach to FAB but still can find monitoring methods for natural enemies useful, for example to reduce spraying. The approach of a grower can change from one to another, in the moment when the grower takes any action. There is a thin boundary between passive, reductional and multi-functional approaches which can change based on various incentives for the farmer.

Research question 2: Motivation for applying FAB

The interviewed farmers had slightly different motivations to promote FAB in their orchards. The IP growers recognize the need for FAB as a natural method for pest regulation. The IP growers were more concerned with application of pesticides and elimination of its negative effects on the orchard’s ecosystem. The organic grower has been since she started farming, deeply convinced about the need for sustainable agricultural practices, utilization of the natural resources and protection of the beneficial organisms in the orchard. During many years of their work in apple orchards, the IP growers have observed extreme cases of disturbances to natural control mechanisms for pests caused by use of strong broad-spectrum pesticides. In the past, the IP fruit growers used to follow a spraying calendar without concerns of negative effects of the pesticides. According to the IP growers, it was a common practice to follow the spraying calendar in the past. All areas of the orchard and around the orchard were treated by pesticides. Even hedges around the orchards that were considered a possible source of pest infestation. Today, the IP growers try to limit the use of pesticides as much as possible to protect the beneficials. According to the growers, there was a lack of knowledge about the pesticides, the insects and their interspecies interactions. The broad-spectrum pesticides used at that time generally killed all insects and left the orchard with little ‘natural balance’. Over years have the IP growers gained an understanding of the importance of biodiversity preservation.

"We have been fruit growers for a long time, so we have been fruit growers when people talked about spraying insecticides one time before flowering, one time after and then one time around midsummer. I am quite sure that nobody knew what they were spraying with. They didn't know what insects, how they looked like or what it was. It was like, they only did it. They knew nothing about life-cycles of the insects. So, they killed everything. And how interesting is that? It's much

more interesting to learn about it and to, how shall I say..., to try to give nature time to deal with it itself. And the more you do that the more interesting you find it (IP Growers)."

The use of pesticides resonated during the larger part of the interview with the IP growers. Apples are their main crop that generates about 80% of total farm revenue. Therefore, according to them the use of pesticides is an important control measure to achieve good yields and quality of the final product. However, the growers felt lack of approved pesticides on the Swedish market due to the new restrictions and environmental concerns. Even though, they try to reduce the amount of pesticides used, they need efficient curative methods against pests and diseases. On the other hand, the growers have had very negative experiences with several strong broad-spectrum pesticides in the past and understand the need for resilient and diverse agro-ecosystems.

"Who likes to spray. I think it is more interesting to go out and look, not just go out and spray. I think, I have always been interesting in having a 'balance' (in the orchards). I think it was many years ago now. We had very much of apple mealy bugs. We understood that very quickly that when we used one insecticide, it was very strong, effective, too effective I would say. We maybe had a little of this mealy bug before, but with that insecticide, there was an explosion of these bugs, because they had no enemies anymore after we sprayed. And after that we thought that we must (spray), we can do it. Apples were black. Then we thought, that it cannot be worse, why not to stop spraying that and we didn't. After that we had it (mealbugs) a little bit, and then I think much more disappeared. Then you start to think. Now we are right, now we are ok. We have this discussion about new chemicals. We say also in a big group that it is very dangerous to spray, for example three times. One time before flowering is the best. Before all the insect is coming, the good insect. We sprayed three times, I think that year, and we had to take down the trees. One must be careful. [...] (IP Growers)."

The personal experience with negative effects after the application of strong broad-spectrum pesticides in the past, which forced the IP growers to cut down all the damaged trees, gave the IP growers an extreme but realistic first-hand example of possible harm scarcity of natural enemies due to applications of pesticides. The experience had raised the growers interest for learning about biodiversity.

In comparison to the IP growers, the organic grower was less concerned with pesticides. The organic apple growers have in general a limited number of available curative pesticide treatments on the market. Hence, there is a higher need for long-term strategies for pest management in organic production. The organic grower acknowledged the need sustainable and resilient production and for long-term strategies to prevent issues in advance.

"*Bad thing is that [in organic apple growing] it is very risky, you never know how things are going to be. It makes it hard to plan in the long-term. At the same time, you have to plan in the long-run when you grow organic. Because everything takes very long time, when you don't use this "magical treatment [pesticides] so to say (Organic Grower)."*

The difficulties to create long-term strategies in natural environment of apple orchards with many external factors were also recognized by the advisor from Äppleriket.

"I think the biggest challenge, as a grower, it is very hard to foresee what will come. You can't predict the weather, or the frost. For example, this year was a lot of frost damage and many growers will suffer from it. It's the whole culture, because things are linked together as the biology is. If you have one problem and you want to manage that problem, then there will be effect on something else. There are very complex connections in the system (Äppelriket)."

The organic grower started cultivating apples in 2009, when the drawbacks of pesticides were better recognized by growers and public than in 1970s when the IP growers started. The organic grower clearly stated her personal "ideology" and motivation to grow organic food and utilize ecosystem services from a more diverse environment. She feels a sense of satisfaction when they succeed without pesticides and sees it as a necessity to work with nature in organic apple growing.

"I can say, if I couldn't grow organic, I would have another work, to be a nurse or something. Because conventional growing doesn't fit me. I like to understand the nature and work with it and not to use it and not to take everything it can give me[...] I want to give back to say so. I want to be a part of it and that's[...] why. It's both ideological and economical. And I like the way we work. The daily work I like very much (Organic Grower)."

The IP and organic growers shared the same basic motivation for developing of FAB in their orchards. It is an awareness of insufficiency and potential risks or downsides of pesticides. While the IP growers were largely influenced by their personal experience over the years, in the case of the organic grower it comes mostly from a personal 'ideology' about producing healthy food 'together' with nature and not 'against' it.

Research question 3: Adaptation of monitoring for different needs of growers and advisors

The participants of the workshop and the interviews proposed several purposes regarding different needs of growers and advisors for monitoring and FAB. The main point was to minimize spraying of pesticides for economic reasons, saving costs on pesticides and time on their application, and for protection of natural enemies and their recognized benefits against pests. The minimum amount of observations was suggested to be based on the population peak and the life cycle of insects as described in the conceptual model. Especially, for growers that are not willing or do not have time to do it often. A psychological value of frequent checks was recognized during the workshop. Higher number and frequency of observation gives a grower confidence about presence and benefits of natural enemies, which can consequently serve as a decision support for reduced spraying. If the monitoring is used to decide about the spraying, it probably needs to be done per cultivar since they have different needs and at different times. This could help in early recognition of hot-spots that could be treated by low-toxic compounds, to conserve the beneficials and environment. Moreover, frequent controls could help to understand effects on insects under different seasonal and climatic conditions.

Another potential use of monitoring methods discussed in the workshop was to attract more growers to implement FAB. In this case, the methods need to be rather simple and easy to understand. Visual observations and beating appeared to be suitable methods for introduction of growers to FAB. The beating sampling and visual observation of aphids, other pests and natural enemies were the main monitoring methods suggested by the growers. The growers were also interested in egg predation cards. However, there is no retailer of these cards in Sweden and they were manually created in a SLU laboratory and distributed to the interested growers.

Research question 3: How can monitoring methods improve implementation of FAB in apple production and what are obstacles for the implementation

The participants agreed that monitoring methods significantly contribute to learning about individual orchard, cultivars, locational specifics of the orchard, and can help in learning about effects of introduced FAB techniques. The monitoring, according to the growers, makes the work more interesting, enjoyable and helps the growers learn more about their farms even after many years of apple growing.

"It's nicer to go out and have a look than sit down, mix and spray. Then you don't know what you have in your orchard and against what you are spraying. Now you go out first and I say, "here we must absolutely do something". [...] I must say that one is more motivated to do things, change things, when you understand your orchard better. Such as that we keep the alley-ways, that you… do not cut it as easily, because it should look nice. As one example. (IP Growers)"

"I mean, a lot of the motivation for this is so that one can see what one has in the orchard. It also helps us when I think what should I do when I plant a new orchard block? Were the conditions better here? Should we select this spot or that? Which are the pros and cons? (Organic Grower)."

Moreover, the monitoring can help farmers uncover pest issues in different areas in the orchards or infestation of different cultivars. The monitoring gave growers an opportunity to discover infestation hot-spots and helps them in observation of infestation or parasitation rate of natural enemies. The better overview of diversity in the orchards can motivate grower to implement further FAB improvements. Hence, it offers a useful information needed for the long-term optimization of orchards. The growers also stated that once they acquired the knowledge and skills for monitoring, they got a 'feeling' for it, which makes the monitoring faster and easier. Once they reached a certain level of expertise, the growers felt that they no longer need record sheets and to count specific amounts of pests or natural enemies.

"You get to come out to the orchard. That you have a loupe and that you find… Because each time you are out, you see more things. And I usually think, when I feel it take a lot of time, that if you don't see the natural enemies, then you see a drip irrigation tube which is not working or something else. It takes time, but my experience tells me it is worth it. (Organic Grower)."

"All of those things work like this. The more you do the more you learn. You build up knowledge. I cannot do it in this weather, this is the time of day… The more one learns the more one realises how little one knows. If I express, it that way. The more one does this (counting insects) the more you don't need to count because you see, if it is a lot or little. (IP Grower)".

Visual observations of predatory bugs in apple leaf midge (*Dasineura mali*) rolled leaves also made some growers confident enough to avoid spraying and this stopped the huge problems with apple leaf midge which the growers had in the 90s. Hence, it was concluded that visual observation of natural enemies in relation to important pests is crucial for growers.

The growers wish to have threshold values as decision support. But, they realize that there are no threshold values available at the moment and that it is very complex for many of pests and natural enemies. Many factors influence insects and a threshold value may be too simple. So instead they wished to learn themselves by continuous observations and knowledge exchange to better understand what affects what and what they should do under different conditions. If the observations can lead to future guiding threshold, they would be interested in them. The Organic Grower stated that it is not always necessary to have threshold values, but the monitoring helps promote holistic thinking about the orchard, its environment and management practices as a whole.

"It's also like this that you don't just interpret the results and think that this is how it is in my place. It starts, and that is the most important thing. Why is it like this? Why did this happen? Why was it not like this last time? And you don't need to get a super answer. I can feel that that is not the point of this in a way. Sure, you can long for this, 'I had five and that is the threshold value so I should do this'. But it brings up questions all the time, holistic thoughts about what one is doing. That is the most important thing I believe. Until now, it's been like "ahh, of course it's good with flowers strips, hedgerows, ... but you never know what they do", but now when we are putting out for example the egg predation cards and you see that 24 hours later there is nothing on the paper, then you know that it has an effect. It's very cool when you understand the symbiosis between biodiversity and pests. (Organic Grower)"

In contradiction, the same grower said in the interview that her opinion about benefits of FAB is mostly a feeling despite using the monitoring methods, which was for her little worrying.

"My dream is to be better [in recognizing pests and natural enemies] and then I can do the beating and count. Now I am just looking and have a feeling all the time. What I really want, is to have like a count, maybe to have a system for myself to go out and check every month or how often you need it to have more facts. I can feel that it is little worrying, because it is always only feeling. What I really want is to have like knowledge and exact information/data that this is good, this is enough, or here we need some more spiders or something (Organic Grower)."

The contradiction offers an interesting observation about grower's opinion about FAB and monitoring. On one hand, she underlines the benefits of monitoring without exact thresholds for purpose of holistic thinking about own farm. On the other hand, she is not always sure in insect identification in different and wishes to have exact information and thresholds about how much natural enemies are enough, or if she needs to do something more to improve FAB in her orchard.

Research question 4: Field trials for assessment of functional agrobiodiversity potential of flower strips

The raw data from visual control were non-normally distributed and were transformed by logarithm *ln(y+1)*. For aphid infestation, the GLM ANOVA analysis showed insignificant variance between flower strips and control *(F = 0,00, P = 0,96).* However, factors stage (*F=11,76, P<0,001)*, block (*F=6,45, P=0,014)* had a significant effect and row almost significant effect (*F=2,71, P=0,075)* on aphids.

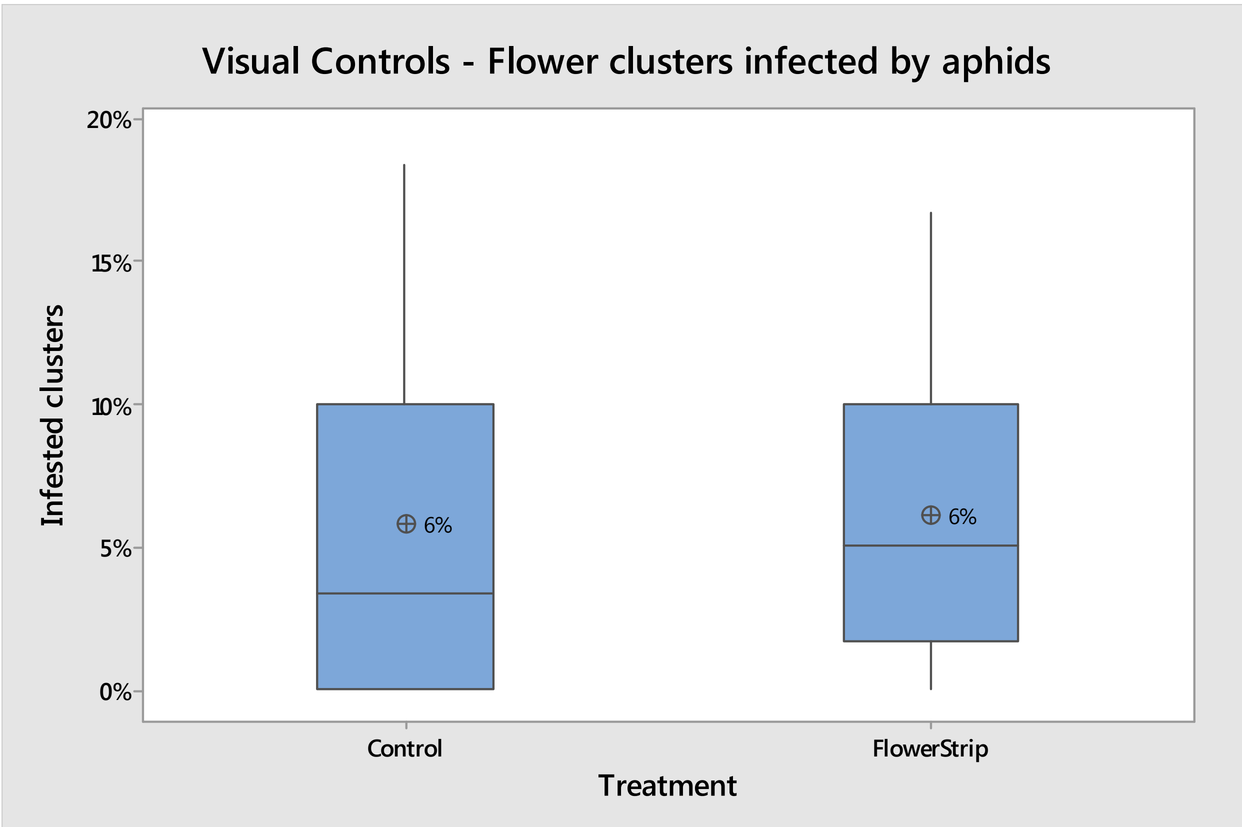

Figure 10 Comparison of average aphid infestation in control plots and flower strips on both farms

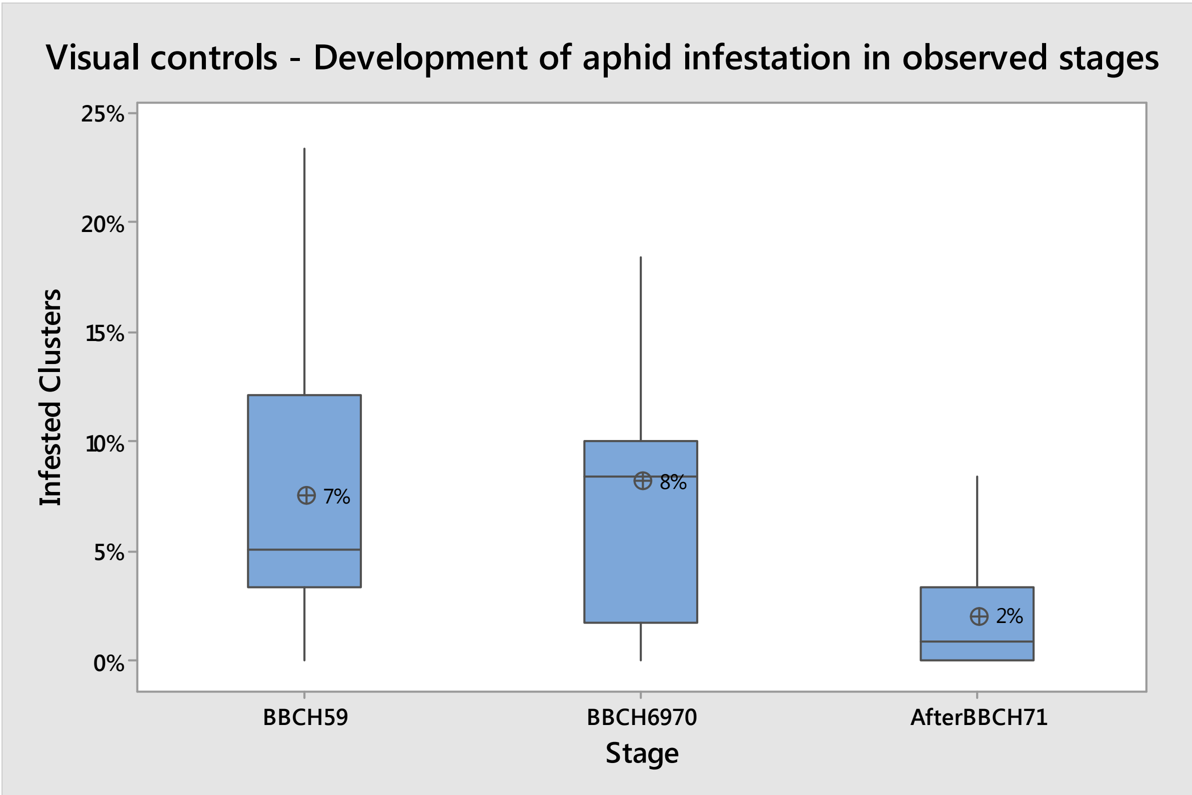

Figure 11 Development of average aphid infestation rate in three observed stages

Analysis of clusters infested by aphids showed strong block effect (*F=6,26, P=0,019)* and effect of row (*F=6,14, P=0,007)* in Helenelust. The cultivar Rubinola in the first row had on average 167% higher aphid infestation than cultivar Collina. In Svinaberga, aphids infested significantly (*F=16,34, P<0,001)* higher number of clusters in stages BBCH59 and BBCH69-70 than in the last stage of visual controls after BBCH71. The average visual infestation in Svinaberga during BBCH59 was 10,2% and 1,1% in the last stage.

Infestation by non-aphid pests, predominantly by tortricids, was on average insignificantly 1,8% higher in control rows (GLM ANOVA, *F = 0,21, P = 0,65)*. However, there was a significant difference in non-aphid pests between different monitoring stages (GLM ANOVA , *F = 63,77, P < 0,001*) and between farms (GLM ANOVA , *F =49,64, P < 0,001*). The highest rates of infestation by non-aphid pests was observed in BBCH59, with average of 42,1% infested clusters. The infestation after the June drop was on average 3,9%. In comparison of the infestation rate by non-aphid pests between farms, Svinaberga had 20,8% more infested cluster.

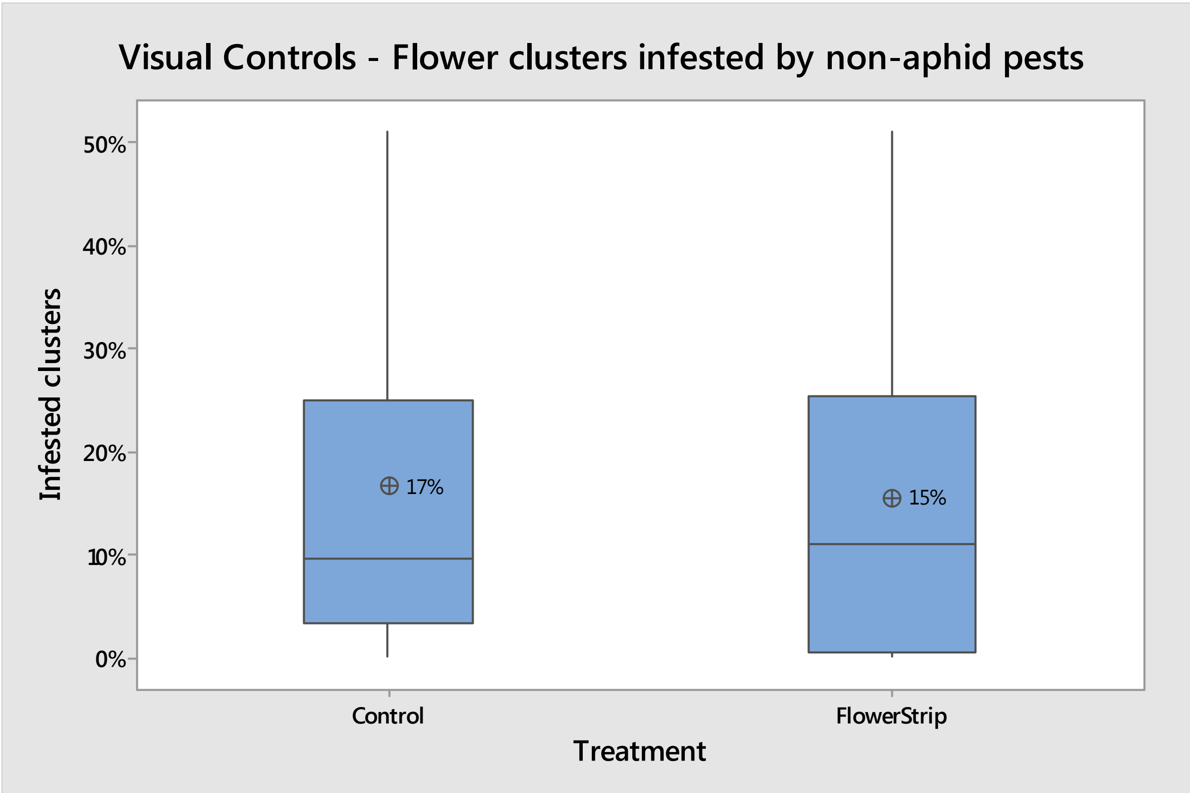

Figure 12 Comparison of non-aphid infestation in control plots and flower strips on both farms

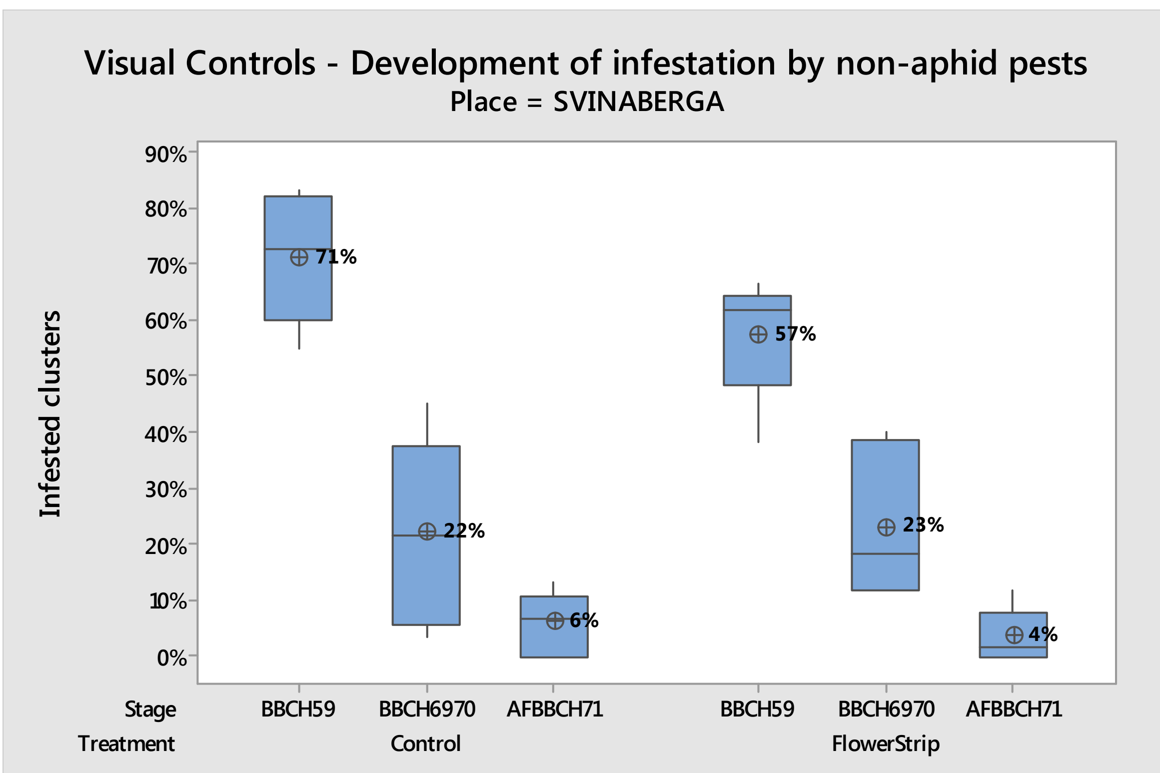

Figure 13 Development of average non-aphid infestation rate in three observed stages in Svinaberga

The infestation by non-aphid pests in Svinaberga (figure 13) was on average 71,1% of clusters in control rows and 57,2% in flower strips in BBCH59. In comparison, non-aphid pests infested in Helenelust in BBCH59 was 17,2% clusters in control, and 22,8% clusters in FS.

There was 32,5% (GLM ANOVA, *F = 0,27, P = 0,6*) more natural enemies (*Syrphidae, Chrysopidae, Coccinellidae, Forficulidae, Anthocoridae, Miridae* families, and *Araneae* order) collected during visual controls from the rows with flower strips. Most present natural enemies in FS were anthocorids, mirids and spiders. Moreover, mirids, syrphids, spiders and ladybirds were more frequent in FS. Results for natural enemies showed significantly less (GLM ANOVA *F=18,03, P<0,001)* natural enemies in BBCH59 than in the later stages. The most predators were on Helenelust in the last stage of visual controls, and in Svinaberga the number of natural enemies peaked in BBCH69-70.

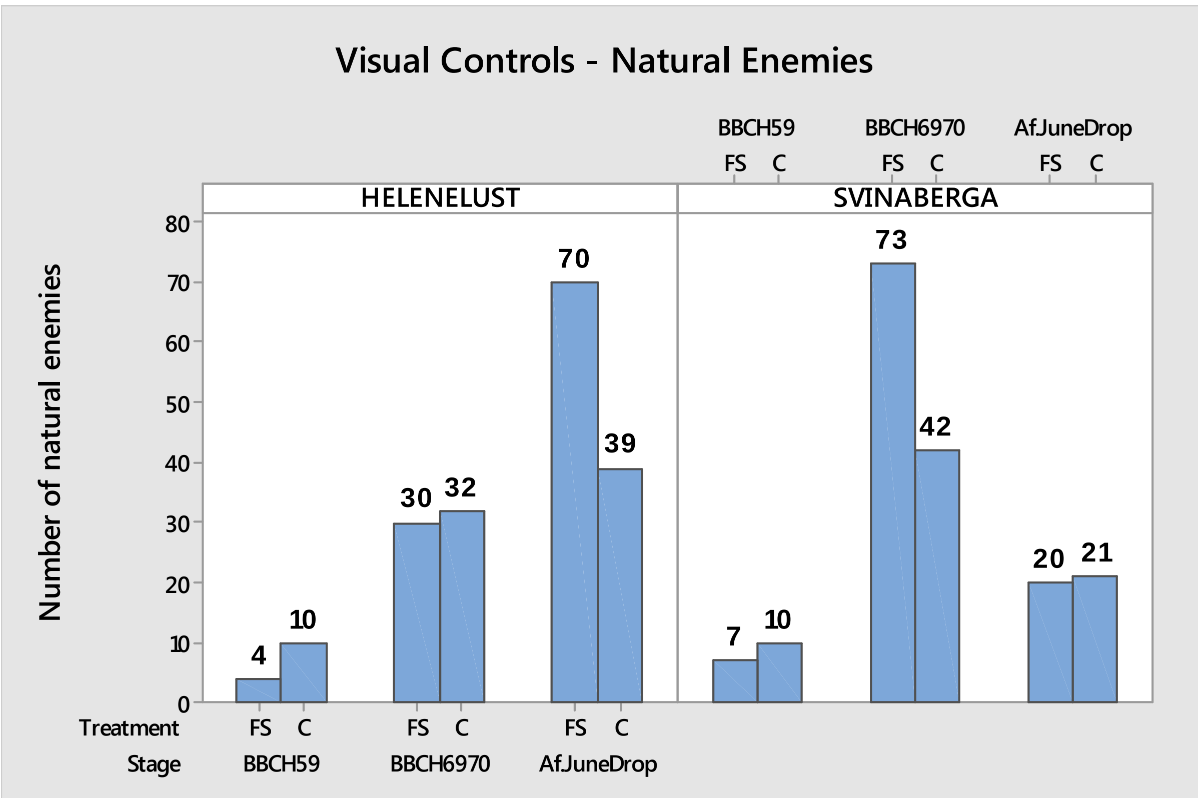

Figure 14 Comparison of distribution of natural enemies during observed stages

Observation of survival rate of aphid colonies also confirmed higher presence of aphids in rows with flower strips. The distribution was strongly non-normal, Two-Sample Poission Rates test was used to analyze the findings. There were 27% more live aphid colonies in the flower strips. While, there was a higher number of live aphid colonies in the rows with flower strips, the number of curled leaves cause by aphids in the control rows was insignificantly higher (GLM *ANOVA, F = 1,9, P = 0,169*).

The beating sampling is a monitoring method that provides information about arthropods population presence in the canopy of trees with favorable bias towards bigger arthropods (EcoOrchard, 2017). For purpose of the thesis, the beating was conducted once in the phenological stage BBCH69. For analysis of beating samples was used basic statistical test and confidence interval for one proportion due to only one replicate and non-normality of the data after transformation. The data from beating sampling showed lower number of natural enemies (sample p = 0,46, P = 0,991, n = 681) in the rows with flower strips and more herbivorous insects (*sample p = 0,57, P = 1, n =* 2280) than in control. One-sample proportion analysis did not confirm the hypothesis that flower strip will cause less pests and higher number of natural enemies. However, there was significantly more predators in Helenelust (*sample p = 0,72, P < 0,001, n = 681*) and less herbivores (sample p = 0,25, P < 0,001, n = 2280). The beating showed correlation between higher number of natural predators with lower number of herbivores in Helenelust in comparison to Svinaberga. In Helenelust was according to beating sampling significantly less aphids in the treatment with flower strips (sample p = 0,24, P < 0,001, n = 450). Other pests were present in Helenelust in lower number and tortricids were evenly distributed in both treatments. However, there was significantly more anthocorids in the control (*sample p = 0,59, P < 0,001, n = 374*). On the other hand, in Svinaberga was significantly more mirids in the rows with flower strips (*sample p = 0,69, P < 0,001, n = 71*) and significantly less tortricids (*sample p = 0,32, P < 0,001, n = 152*).

The monitoring by sentinel prey cards examined activity of predators in the orchards. The data were analyzed by GLM ANOVA with factors stage, farm, treatment, block, row and cultivar. The data were normally distributed and covariation between the number of removed and sucked eggs was observed. The number of removed eggs was insignificantly higher in the flower strip rows with average of 47,6% eggs removed (GLM ANOVA = *0,26, F = 0,16, P = 0,690*). The only significant factor was stage with less removed eggs in BBCH 70 (*P < 0,001*). In BBCH 70, 24,6% were removed in comparison to BBCH 74-75 with 69,4% of removed eggs. On the other hand, more eggs were sucked early in the season in BBCH 70 with 14,23% of sucked eggs and in the later stage with 4,35% (GLM ANOVA, F = 7,64, P = 0,009). Moreover, natural predators with sucking mouthparts were insignificantly more active in the rows with flower strips. Another significant factor was observed between farms. Helenelust with average of 11,24% had 54,3% more sucked eggs than Svinaberga.

In conclusion, the monitoring methods gave a good overview about insect presence in the orchards. The analysis pointed out that there were slightly more aphids in the flower strip treatment, but they activity was partially inhibited by natural predators. This reflected in lower number of the curled leaves during the aphid colony survival visual controls.

Emerging Themes

During the work on the thesis knowledge gaps became an evident emerging theme broadly discussed in the workshop and the interviews. This section presents findings about these gaps and possibilities to overcome them uncovered during the research process.

Knowledge gaps

The growers could identify common pest species and well-known natural enemies, such as adult ladybirds. However, they were uncertain about interactions of different natural enemies, pests, their behaviour, life-cycles, and how to observe them. Also, several new questions emerged during the discussion.

"When you have it down (samples from beating), for 90% you don't know what it is. But you know at least some of them, if it is an aphid, or larvae. I am not an expert on this, but you must know where you should look, on the leaves, on the stem or in the flowers or ... if you look for special insect, and when should you look, I would like to learn more about life of the insects in winter. are they in the soil or do they hide in the stem or where are they. (IP Grower)."

The organic grower added that it would be possible for her to get more detailed information about pests and natural enemies from her advisor, and probably she needs to become better in asking the questions. She had a good contact with researchers from SLU and advisors from Jordbruksverket and Äppelriket. She also uses online group with some other growers, where she can ask for help to identify some insects. However, some of the questions in the discussion were more complex and would require more research.

"How to benefit different beneficials at different times, for instance which flower should be present in order to benefit the adult form of different beneficials at most, when should winter quarters be hanged out? (Agricultural Advisor 2)".
"How much good is enough" It's just the feeling that this is good but how good? How much can I trust it? Should I do more? It's about getting experience, data and… because the time is not limitless for either of us. I think that what we all the time strive for is to get threshold values. It is very nice if one can have those. And it feels a bit as if we should have that as the goal of all the measurements, to find threshold values. To know later, is it so many per trap or below this number of infected clusters? Then you can be calm. Is it above? We need to act. (Organic Grower)."

Secondly, the participating growers face the complexity of managing FAB and wish to have more knowledge about suitable plants for promotion of beneficial insects. They try to maintain as much diverse vegetation in and around the orchards as possible, but they lack the knowledge about what flowers, grasses and trees can contribute to FAB and which can be negative for the orchard. There is a need for better data about beneficial plant species suitable for Nordic regions. The plants need to be adapted to different soil and seasonal conditions, while providing food for beneficials with shelter, overwintering sites, alternative prey or hosts, and nectar and pollen, throughout the season. An advisor suggested that the information about suitable flowers should be present at what time to benefit natural enemies the most would also be very useful.

"We have the hedge around. But if we should have a perfect hedge, what should we have for good insect. We don't really know. We only know that we must have many different kinds and many kinds of flowers, but we don't know what is best, better than other. (IP Grower)."

"I would like to know what flowers do I need and are good in the orchard. (Organic Grower)."

Need for more participatory research and learning

The participants of the workshop agreed that continuous knowledge exchange between farmers, advisors and researchers is the foundation of a successful future development of FAB and the monitoring methods. The participants of the workshop agreed that role of research is to develop the knowledge important species to identify and observe, and when and how to do it in the best way. Such research findings could be communicated to farmers through advisors or during multi-stakeholder meetings. The growers stated that currently there are not enough meetings, especially field visits, in which could growers acquire new knowledge, exchange experiences and get advice.

"Many years ago, we had these groups. We met, especially before flowering and during flowering. We were meeting for example here (at the farm) and all people who wanted could come here. We were looking, and we were beating. Then we examined the samples together with an advisor and he showed us where we had very good balance and where we didn't. I think it was that what made me interested. Because, if we can do this and then find the balance, it is the best. It is important to have a leader that organizes it. Then, we started with groups with ourselves. He wasn't there every time. When he retired, nobody took up this again and that's it. It's a very good idea to meet in a small group and have a room for a discussion. If you have a big meeting, people are afraid to talk about problems on their farms. Maybe it could be about 6-7 people from around here and then we went out. That was very interesting (IP Grower)".

"I miss these meetings when we walked out in the orchard and then we were picking all insects and checking what is what. So, you can see it. I have many conventional growers, because we share many problems and I have good communication with them. But unfortunately, we are here alone, and we are very far away, so we don't go and just look at other orchards. I want to go another orchard in the season, but in the season, I don't have time for it. It is so hard to decide on the date. I can go when it rains but I can't when it doesn't. I don't know what happens a day before. If something at the farm gets broken, we need to fix it. Then we wish we had more meetings, but it's a little hard. Maybe it would be cool to have like videos and interviews with other farmers, walking around the orchard and look how I do things. But it's, I hope it would work. Because some people are afraid that they are doing something wrong. (Organic Grower)."

The growers found it important to meet in more inclusive smaller groups, where they feel comfortable to share their experiences. Such meetings were according to them a great place to become more interested about new practices. However, they acknowledged that it is not always easy to find time for such activities. The organic grower speculated about use of video recordings to share information from field visits for growers that could not attend them. An important aspect of the meetings was a 'leader' or an initiator facilitating the activities. The issue with lack of meetings was also discussed with the advisor from the association of apple growers. She agreed with the importance of the meetings and aims to organize more of them in the future. On the other hand, it would be beneficial to have more advisors and more funding to facilitate enough meetings for all growers.

"What the growers need is to be out in the field together, but also not too many of them and with an advisor and maybe other experts. This is going to be build up again. It wasn't working for a while, but I want to build this up again. One of the problem is with finding time. When there is a lot happening in the orchard with pests and natural enemies, farmers are usually the busiest. Some growers want me to come every week, have a look at the whole orchard and tell them what to do. Imagine if there was a team of 10 people specialized in different fields working with growers. But the issue is that who is going to pay for that service. That is the basic problem. Nobody wants to pay more, but everyone wants the best and most complex service. Also, I think that it's not the best idea to divide IP and organic growers. They have similar issues and it's good to have them together. They can learn from each other. We can really do so much, we can improve so much. The only limit is time and funding (Advisor Äppelriket)."

One possibility to involve more growers mention in the discussion was organizing of workshops with growers, advisors and experts from research. What the growers found important, was to include both IP growers and organic growers, because they grow the same fruit and have in general the same issues in the production. The advisor considered the workshops as a good way to meet and exchange knowledge, but stated again that growers prefer to meet in small groups and it could be difficult to invite experts from research for more meetings.

"It's very good. I very much try to go there. I learn a lot (Organic Grower)."

"The last workshop we had last year, there were only two IP apple growers and others were organic growers and I think it was a pity, because we also must learn about it. The organic growers have to learn it, but I think we IP growers must learn it too. I really like these meetings when it's not only growers, but also researchers and advisors. Everyone knows something and can add something to the discussion. That mix is very good. (IP Grower)."

Moreover, the meetings, workshops or any other participatory actions were highly regarded by growers. Not only because of their educational value, but also as an important part of farmer's social life.

"All farmers are usually very lonely. And farmer sees only his orchard. These meetings can be important for a little social life in the work. And in small groups we can learn how the 'colleague' is thinking. Some are so conservative and are afraid of something new (IP Grower)."

Development of FAB as a continuous process

The continuous learning about apple production and pest control appeared to be crucial for development of more sustainable production systems. The IP growers saw it as a continuous process starting at the stage of ignorance about the role of biodiversity in agricultural production, then through understanding of the importance of diverse systems, to development and implementation of appropriate strategies. The organic grower acknowledged the fact that implementation of FAB and creation of more stable agrosystems requires longer time to see results.

“This is a process, from destroying everything and mentality of solving everything with spraying, then we must save the hedge, we must have more flowers and the next step is, what kind of flowers, what kind of hedge (IP Growers)”

" Like with biodiversity for example. It takes years to make it work and maybe the first year you have some insect that destroys lot of your fruit, but you have to go on and maybe next year or year after it gets better. "(Organic Grower).

There is uncertainty about application of FAB, as it is difficult to fully understand the complexity of the agricultural systems while dealing with seasonal variability. This leads, according to the organic grower, to a higher risk of pest or disease problems in production that is directly linked to economic risks of production. To overcome the issues in organic growing the farmer underlines the importance of combination of different orchard management practices that take time to adapt and develop.

Labour is one of the highest costs in Swedish apple production. Efficient utilization of working hours has a strong influence on the overall economy of a farm. Therefore, interviewed farmers are concerned about spending their time only on on-farm activities that are beneficial to the farm’s economy. Achieving positive economic results is the prime function of a farm and environmental protection or implementation of FAB is possible only to a ‘reasonable’ extent.

“The biggest limitation is time. It’s about priorities. You know, when somebody calls and wants to buy something, you serve that one and don’t go to check your insects instead. It’s all the sprayings and everything. Things break and so on. (Organic Grower)

An advisor expressed during the workshop an opinion that it is very important to feel that it is worthwhile to do the monitoring. The time spent needs to be paid back in way of yield increases or reduction of spraying. The growers in the workshop claimed that they see economic benefits of FAB in the long run, but they were not sure how much and it was more a feeling that FAB is good. This also reflects the unsolved dilemma about economic value of ecosystem services.

Table 5 Conceptual summary of the findings based on agroecological framework

	Biological system	**Social System**	**Economic System**
FAB Approaches and Motivation	> The growers claimed benefits of FAB. > The approaches were characterized as a scale of interest from observation and avoiding to harm beneficials to active promotion of FAB for single or multiple purposes. >	> The approaches are not constant and can change over time based on >> new knowledge about biological processes, negative impacts of agricultural practices, >> negative experiences from use of pesticides >>lack of available curative methods >> personal ideology	> Growers claimed their economic motivation to use environmentally friendly methods – higher profit potential of organic apples > Growers claimed visible economic benefits of FAB in the long-term. > Need for economic evaluation of ecosystem services. Growers need to know that the investments will pay back.
Monitoring methods and FAB approaches	> Growers with passive approach to FAB can still find monitoring methods useful for reduction of spraying. It would require more frequent monitoring. > Growers with naturalistic approach could use less frequent monitoring for general overview of arthropod natural enemies.	>Monitoring methods and better knowledge of biological processes can help growers to change their mentality. From resilience on spraying to implementation of FAB practices.	
Monitoring methods	>Growers gain a better understanding about own orchard and biological process in it. Ideally performed by growers with optional assistance of advisors. > Recognition of hotspots: In combination of frequent monitoring can help to take a prompt treatment and use low-toxic compounds. > Recognition of cultivars with high infestation > More time spent in the orchard may help grower to uncover other issues, for example dripping irrigation line, > Lack of thresholds	>Psychological factor of monitoring. Especially more frequent monitoring can give growers confidence about presence of natural enemies. > Growers claimed that monitoring makes the work more interesting and enjoyable. > Monitoring can promote holistic thinking about own orchard and rise interest in more learning. >>Continuous collaborative development of practices	>Potential of lowering costs for spraying. > Need for a simple and time-effective program for a growing season to reduce necessary time. > Uncertainty about cost saving potential of monitoring / less spraying

Knowledge and Participatory learning	Knowledge Gaps: > Identification of natural enemies and pests. Could be solved by creation of a handbook or instructions for distinguishing features of important arthropods > Need for teaching of grow stages (BBCH) for synthesis of observations and following BBCH based instructions > Need of monitoring models and recording sheets for different purposes. Minimizing spraying, protecting beneficials, learning about effects of FAB practices > How to benefit different beneficials? > What plants are good for hedgerows, flower strips and which should be avoided? > How much is good enough? How much biodiversity, how many natural enemies? > Big gaps in knowledge about fruit management between growers	Need for participatory research and learning: > Growers and advisors would like to have more participatory research and learning. More field seminars, meetings, and workshops. > Video clips where farmers/advisors/researchers present FAB & monitoring practices. > Development of a monitoring mobile application with illustrations of insects and easy recording for of their presence. It could simplify recording and enable to gather and share data over years > Small inclusive groups are important for growers to feel comfortable to share their experiences and issues in production > Need for inclusion of all growers, IP and organic. > Meetings are important for social life and networking of farmers. > Need for facilitators and leaders for the meetings. >Not all growers are interested in FAB	> The main limitations for more participatory actions is limited funding and lack of time. > Funding for extensive advisory services and organizing of the meetings. Consequently, less time to deliver these services to growers. > The growers are usually the busiest when there is the most happening in the orchard and when there is good time for field observations.

Discussion

The previous chapter presented results from the study about approaches to functional biodiversity, potential of adaptation of arthropods monitoring methods based on these approaches or other needs of growers and advisors, and examined pest control potential of flower strips. Furthermore, the thesis identified emerging themes knowledge gaps and need for more participatory research in this field.

Approaches to functional agrobiodiversity

The growers expressed predominantly multifunctional FAB approaches during the discussions. Nevertheless, the categories of FAB approaches had a certain degree of flexibility. Thus, a grower could have a mixed overall approach in case of transition from passive to more functional approach and similarly multifunctional approach did not exclude the naturalist one (Fernique, 2015). It became obvious, that the FAB approaches are mostly related to the degree of action to implement and promote FAB, while the naturalist approach was founded mainly on a personal ideology about connection of agriculture to the nature (Fernique, 2015). At the same time, the degree of engagement or interest was to a large extent linked to the degree of personal knowledge about FAB practices, personal believes or experiences. Lewan & Söderqvist (2002) and Salequzzaman & Stocker (2001) supports this result and state that human preferences tend to depend on their knowledge, access to information, propaganda and advertising, formal regulations or informal norms As a matter of fact, above average degree of knowledge of growers about FAB acquired during their participation in EcoOrchard project, may have contributed to their tendencies for multifunctional approach.

To gain even a deeper insight into approaches of the growers, the interviews examined their main motivations to adapt FAB practices. For the older grower with many years of experience in apple management, the main incentive came from the realisation of shortcomings of pesticides, due to a small number of allowed pesticides on the market, and the notion that spraying does not solve all the problems. It has been documented that use of synthetic pyrethroids have negative effect on *Phytoseiidae* mite populations that leads to outbreaks of phytophagous mites (Nagy, 2015). Predatory mites are important natural predators that feed on thrips and other mite species (van de Vrie, 1985; Solomon et al., 2000; Gregory et al., 2013). Therefore, it is crucial to look for other alternative preventive pest control practices that can reduce pest pressure before it is too late (Bale, et. al., 2007). The organic grower was strongly motivated by her strong ideology to produce food with minimum use of chemicals, and for economic reasons such as higher market value of organic products. However, in study of organic apple production in Poland, organic production was slightly less profitable than conventional production (Brzozowski & Zamarlicki, 2012). On the contrary, a Swiss study found a higher return of investment and potential generated capital in organic apple production (Bravin, *et al*, 2010). On the other hand, the same study acknowledged higher risk of capital loss and labour deficit for the organic production. Moreover, organic apple growers lack pesticides for several major apple pests and consequently are more dependent on preventive control measures that increases the risks of pests and diseases (EC, 2007).

The economic aspect was of crucial importance for the implementation of FAB practices. Even though, the focus of the thesis was on FAB and the monitoring methods, several valuable notions surfaced during the discussion. There is an economic motivation to create a FAB “buffer” against pests, especially for certified organic growers producing apples under more strict regulations on allowed bio-pesticides (Bravin, *et al.*, 2010). Even so, implementation of for example flower strips between rows and planting flowers and grasses with aim to promote natural enemies can be costly and time demanding. Furthermore, in the years with sever late frost the growers use to cut the grass down to reduce frost damages in the orchards. Hence, in such cases the time and money invested into the BTW flower strips are lost. While the growers claimed to see long-term benefits of FAB, it is important to specify which FAB practice they have in mind, how much time and money they need to spend on it. For example, cutting grass in every second row instead of all at once, or keeping hedgerow that has been in place for decades, do not have any effect on the production costs. On the contrary, purposeful planting of specific plant species and additional cultivation of them can become costly. Therefore, growers would like to know that their investments will eventually pay back.

Understanding of grower’s motivation to pursue implementation of sustainable agricultural practices can help identify some of potential benefits and limitations of FAB and the monitoring methods. Moreover, farmers’ experience and occupation are key factors for reliability of information source for other farmers (Blackstock et al., 2010). Thus, other farmers are more inclined to adapt new practices, if they were already tested and proven efficient by another grower with similar growing conditions. By understanding opinions and experiences of the growers engaged in FAB, we can gain valuable information for further research and development.

Monitoring methods

A good monitoring program is a necessity for ecologically sound pest decisions (Landis, *et. al*., 2002, Jordbruksverket, 2016). The Swedish apple growers today already follow practices of the Integrated Pest Management and use pest control measures with low environmental impact only after monitoring in the field (Swedish Ministry for Rural Affairs, 2013). The growers need to document their decision for application of pesticides, record used products and location of application. They need to investigate individual fields with for need application of any curative products (Jordbruksverket, 2016). But in fact, the requirements for monitoring and reporting of monitoring in Swedish fruit production are not clearly defined. When IPM was implemented in Sweden, it was decided to not control growers at the level of detail, but help them to do the right things (Jordbruksverket, 2017).

This thesis only underlines the importance of monitoring in apple production for participatory development of more resilient and sustainable apple orchards. Even the growers with the passive approach to functional biodiversity could benefit from the monitoring methods in their production planning and design of the orchards, in an early prevention of pest outbreaks and for prompt application of low-toxic pesticides if needed. While, it is a responsibility of the grower to follow given requirements for IPM or for organic production, it is a role of the advisory services, research and governmental agencies to deliver simple methods, protocols, recording sheets and instructions for efficient assessment of agroecosystems (ELN-FAB, 2012). However, these tools need to be developed in a collaboration with growers to understand and meet their actual needs. According to FAO, the government institutions need to develop new farm technologies and practices in partnership with farmers (Polman, 2002).

Moreover, monitoring enables growers to recognize for example infestation hotspots, less resilient cultivars. Besides, monitoring gives growers better and more detailed overview of their own orchards and about biological processes in them. Mejer *et. al.* (2014) argues that factors such as knowledge, perceptions and attitudes have a crucial role in adaptation of new agricultural innovations and practices. Better knowledge of biological processes can help growers to change their attitude towards more sustainable production. From resilience on spraying to implementation of FAB practices. The objective of IPM is to reduce application of pesticides, use of preventive ecologically based measures to reduce pest pressure, and monitoring methods are used to decide on appropriate treatment (Cross, 2002). The monitoring can have a strong psychological role in pest management. Especially, more frequent monitoring can give growers better understanding about pest population and confidence about presence of natural enemies, that can consequently lead to less disturbing pest control measures for environment and preservation of beneficials. Mankad (2016) states that there is a strong positive relation between one's knowledge and the attitude object, such as benefits of FAB. For example, a grower less knowledgeable about the effects of biodiversity and high presence of natural enemies on pest population, would be less inclined to take any actions to promote them. Also, better understanding of FAB could lead to lowering costs for spraying. In addition, the growers claimed that monitoring makes the work more interesting and enjoyable. It can promote holistic thinking about own orchard and rise interest in more learning.

A large concern of the growers is quality of the data gained from the monitoring, uncertainty about the results, the ideal times for monitoring, and cost saving potential of it. The data collected by farmers or 'citizens' may also result in reduced accuracy and errors of misidentification (Gardiner, *et. al.*, 2012, Dickinson, *et. al.*, 2010). A study about monitoring of lady bugs (Gardiner, *et. al., 2012)* states that data collected by citizens and verified by scientists can improve confidence in quality of such data. In short, more needs to be done in research of ecology of fruit production and pest control to better understand interactions between pests and their natural enemies, pest suppression potential of natural enemies, and evaluation of FAB practices in production and economic sense. Given these points, monitoring by growers offers potential to enhance the research and development in the field of fruit production.

Assessment of functional agrobiodiversity in the field trials

The field trials observed possible effects of flower strips on beneficial insects and their potential to promote pest suppression in the apple orchard. The monitoring methods are powerful tools for observation of presence and development of insect species through the growing season and across the entire farm.

The visual observations do not require any specific equipment and can offer a good overview about insect presence in the orchard, information about pest hotspots, observe dynamics between predators and herbivores, influences of phenological stages, or higher susceptibility or resilience of certain cultivars to pests. One of the shortcomings of visual observations is a rather long time needed to sort the samples and analyse collected data. It depends on the depth of the investigator, how exact results he or she aims to have. The growers expressed that the visual controls took quite a long time in the learning stage, but once they became acquainted with the method, they acquired a 'feeling' for it and were able to do it faster. However, this can lead to errors and misidentifications as mention by Gardiner *et. al.* (2012). If the data collected by farmers were to be used for scientific purposed, they tend to be of lower scientific quality than when are the data collected by scientists and carefully examined in a laboratory analysed according to common scientific practices (*ibid*). Such was the approach of the monitoring for this thesis. A great deal of attention was given to data evaluation and it offered a better understanding of the biological processes within insect species under the treatment with flower strips.

Aphid colonies and natural enemies were the main target populations of the visual observations (EcoOrchard, 2017). The findings were insignificant, and the monitoring showed slightly higher number of active aphid colonies in the area with flower strips. Much stronger effects on the aphids were the BBCH stages and location. Therefore, the analysis would require a larger sampling size from more replicates and from more locations, to get more reliable results. A research project examining flower strips in apple production in the United Kingdom detected no effect of flower strips on aphids, while aphidophagous and non-apdidophagous natural enemies showed abundance near the flower strips (Campbell, *et. al.*, 2017). Probable explanation could be lower response of aphidophagous taxa to flower resources in comparison to other natural enemies (*ibid*). The effects of flower strips on aphids would require systematic observations over several years (*ibid*).

Other species important for apple production were enhanced by the flower strips. The composition of present flower species influenced the densities of natural enemies with their preference for open-nectar plants (Campbell, *et. al.*, 2017). This supports the idea of multi-functionality of FAB and points out at its potential to support higher richness of species in agricultural landscapes (ELN-FAB, 2012). Hence, the flower strips can partially contribute to mitigation of biodiversity loss. In the thesis project, only differences between the blocks and rows with different cultivars were found. However, the monitoring investigated only variables; pests, natural enemies, and factors treatment, stage and location. Other potential factors, such as presence of mutualistic relationship aphids with ants or other factors that could be responsible for slightly higher occurrence of aphids in the flower strip rows were not examined by the monitoring. On the contrary, the comparison of leaves curled by aphids was insignificantly lower in the rows with flower strips and the composition of predators slightly differed between the treatments.

Mirids, syrphids, spiders and ladybird bugs that are known natural predators of apple pests were more frequent in the flower strips. In overall, predators were more present on trees next to the flower strips. The population of natural enemies built up over time with the lowest density in the first stage of monitoring. The monitoring method with egg predation cards showed that more eggs were sucked in the first stage of the field trials, with a lower proportion of sucked eggs later in the season, due to higher number of removed eggs. The predators with sucking mouthparts were more active in on trees near the flower strips. We could conclude the beneficial with sucking mouthpart respond better to the flower strips early in the season, when the aphid colonies can still be controlled before they do too much damage. Nevertheless, the findings were insignificant form the statistical standpoint. However, the analysis of beating samples showed difference in composition of natural predators between the farms and difference in number of pests. While the natural enemies in total were more present in control rows, investigation of species showed that a higher number of predacious species, was linked to lower levels of species from *Lepidoptera* order. The second group of predators, such as *Atractotomus mali,* that are both predacious and phytophagous, seemed to have a lower impact on pest suppression. At the same time, the different compositions of insect populations were between the farms could influence the higher pest infestation in one of the farms. The non-aphid pests, predominantly *Lepidopteras,* that are one of the main pests in Sweden, seemed to be influenced by the more diverse vegetation with flowers. In the pooled dataset for both farms for all stages, the difference was insignificant. However, an observation of *Lepidoptera spp.* in the early stage of the monitoring clearly showed lower infestation by non-aphid species in the rows with BTW flower strips. The share of infested flower clusters in the first stage in the control rows exceeded 70% and was below 60% in the flower strips rows in one of the orchards.

Another consideration in the assessment of the flower strips can be the quality of the strips. The botanical assessment of planted species was not included in this thesis project. The question is, how well have the flower strips established during the project. FAB practices usually require longer time until they establish and start to provide desirable benefits. There was an uncertainty also within growers, what flower or plant species are good for promotion of natural enemies in apple growing. Based on the results of the field trials, the flower strips do not seem to be a viable FAB practice for suppression of pests. However, the data for the thesis were collected only during one season and from two farms, which could be insufficient for making any strong conclusions. The EcoOrchard project has monitored the orchards during three seasons in 9 countries and the larger sampling size would mean a more valid data. Moreover, there was quite a lot of weeds under the trees also in the control rows, since the growers for various reason were not able to fulfil the management as planned. The presence of weeds could negate the effect of the flower strips.

Knowledge and participatory learning

The thesis project revealed several constrains that hinder practical assessment of FAB and its implementation to Swedish apple production. Firstly, insufficient scientific understanding of interspecies interactions under location specific conditions, pest suppression potential of natural enemies, and suitable growing conditions for FAB plant species in various environments. The desirable traits of FAB practices may vary via different aspects of their distribution in a community, their influence can change over time and traits of FAB may influence processes at different levels of the natural hierarchy (Holzwarth, *et. al,* 2015) Secondly, knowledge gaps of growers in identification of natural enemies and pests.

The development of feasible practices for functional agrobiodiversity is and ongoing process that requires continuous and long-term research to fully observe potential benefits of individual FAB practices. In contradiction, Bhullar (2015) argues that the extended time of the research needed in complex multi-disciplinary collaboration such as functional agrobiodiversity, extends time to publication of result, which is against current expectations from scientists However, the time needed to reach the full potential of FAB is usually longer than is a usual time of field research projects. Therefore, inclusion of farmers in the research and motivating them to use standardized monitoring methods and recording sheets is crucial for collection of valid data of higher scientific quality. Moreover, Gardiner *et. al* (2012) has shown in his study that engagement of farmers in the monitoring under supervision of scientists may bring valid results and reduce costs and time needed for the research. Farmers are great assets and the main force of agriculture, therefore their inclusion in the research is extremely important. However, to achieve better results from assessment of FAB practices by farmers, once we succeed to motivate them to test them, it is important to educate the growers about observed species. For this purpose, a mobile application could be help record the species they find. The collected and shared data could be further analysed and used for future development of pest management and FAB.

The growers stated that they lack knowledge about different insect species and had difficulty to tell which ones are important in the orchard. This could be solved by creation of a handbook or instructions for growers. Moreover, the instruction should be based on phenological development stages of crops for synthesis of observations. The instruction need to be simple and adapted for different purposed, based on needs of the growers. However, such manual would have positive effect only once the growers are willing to test new FAB practices and see benefits in spending time monitoring. Moreover, the research needs to fill in knowledge gaps about beneficial ways to promote natural enemies. For example, what plant species are suitable for which natural predators, which plants to be avoided. There is a wide research in benefits of flower strips for various crops. However, engagement of growers could enhance the pace of the research.

Furthermore, growers and advisors seem to be very interested in more participatory research and learning. The value of field seminars, meetings and workshop is highly appreciated by growers and offer a great environment for learning, knowledge exchange and group evaluation of different agricultural practices. The advantages of the results from participatory research are the local applicability and transferability of results to other communities (Macaulay, et.al., 1999). As stated in the results section, small groups are of a great advantage for learning and knowledge transfer. They give farmers a sense of inclusion that contributes to their willingness to participate and share their valuable experiences or raise sensitive question. In addition, it is relevant to include both IP and organic growers. While, organic growers are more depended on alternative environmentally friendly pest management practices, both groups grow the same crop and share to a great extend the same issues. On the other hand, not all growers are interested in FAB. Despite the lower interest of some, the more motivated and engaged growers could significantly contribute to spread new feasible practices. The meetings are also a meaningful form for improvement of farmer's social life and networking. At the same time, there is a need for a skilled facilitator or a leader that is capable to create a productive environment. Usually, it is the role of the advisor or the researcher that leads a project. However, implementation and testing of FAB is usually not the main task on advisor's agenda, and research projects are often time- or funding-limited. A drawback of the participatory methods in a practical setting, especially of the field seminars, is the high workload of apple growers in the time of the season, when there is the highest insect activity and the best conditions for observations. To overcome the time barrier for field seminars, video recordings from orchards could help spread different practices and results. There are many benefits, but also barriers for more extensive participatory research.

The economic aspect is the main limitation for testing or adaptation of FAB by growers. A farmer needs to consider all aspects of his or hers farm such as location, climate, economic aspects, cultivation practices, social factors or norms, and legislations. The farmer's profession is a complex job that requires vast knowledge, understanding and expertise of all these aspects to reach an equilibrium in which individual farmers achieve desirable yields and profits. In general, professional farmers have one objective in common. It is profitability of their farms and improvement of its environment. Hence, participatory development of FAB might be desirable by growers, but the interviews indicates that they are limited by time and money to do so. Likewise, the advisor claims willingness to increase farmer's engagement, sharing and promotion of FAB, but there is a limit on how much time is the advisor able to invest to FAB. This brings up the question stated in the interview about who will pay for it. The question of funding is open for future discussion.

Conclusions

Functional agrobiodiversity is a complex approach to improve agroecosystems that requires understanding, knowledge and expertise in biological process of specific species and in agricultural production. While the results of the field trials failed to deliver convincing arguments for use the flower strips, as one of FAB practices for pest regulation, the study uncovered several benefits of the monitoring for the growers and the advisors. The inability to gain stronger evidence of pest regulation by the FAB flower strips might be connected to the sampling size used for the thesis project and insufficient weed management in the orchards. The research in the field of the flower strips indicates the need for adaptation of different flower species for different purposes. Hence, the future research and development might bring ideal mixtures of plant species for enhancement of desired traits of the flower strips for pest regulation in apple production. Moreover, FAB practices need to be tailored with consideration of location differences in mind. Soil conditions, temperature, humidity, surrounding landscape and other factors can significantly influence the efficiency of implemented FAB practice.

The thesis project highlights potentials and barriers for implementation of new sustainable agricultural practice. The general findings could be applied in varied agrosystems with different crops. Farmers in general have different degrees of knowledge about sustainability issues of their production. FAB is not recognized by all growers and some of the new growers still need to learn more about the basics of crop management and pest control. The farmers will more likely adapt new sustainable agricultural practices or help in their development, if they are aware of negative impacts of their current practices and benefits of sustainable alternatives. Moreover, it is important to realize that for long-term implementation of new practices, outside of scientific field projects, the farmers need to see that the practices will eventually pay back in the long-run in economic way. The knowledge gaps about efficiency of FAB and their economic potential are therefore seen as the main limitations of sustainable agricultural development.

A viable solution to overcome the gaps could be improved collaboration of scientists, advisors and growers. The participatory multi-disciplinary research has potential to promote development of locally adapted practices and enhance knowledge exchange. Small collaborative research groups could develop new instructions, standards and tools for crop management and the monitoring. The use of technologies could help farmers understand the importance of the transition to the functional sustainable practices, and simplify the process of data collection. Many innovative growers from all fields of agriculture already share their experiences online and create a valuable content for others. However, the quality of such content could be further improved by scientific validation. Therefore, the findings of participatory research would benefit from better sharing of the findings not only via publications, but also via online videos from field observations or interviews with scientists, growers and advisors. The main benefit of this methods is it availability to many stakeholders that are unable to participate in field trials, meetings or seminars during the busy growing season. Another technological method for enhancement of the field research by growers would be development of mobile applications that are capable to deliver simple methods for recording of field observations. Consequently, such data could be further shared and analyzed. The collaboration of the scientific community with the growers, and promotion of the grower-based data collection has potential to reduce costs of the research, speed up the research process and provide data from different locations with different conditions.

To conclude, the FAB has proved to promote species richness in agricultural landscapes that could help reduce for example dependence of growers on pesticides and contribute to mitigation of biodiversity loss. However, further research is required to find plant species with desirable traits that could be applied for FAB in different conditions and for different crops. The analysis through the lenses of agroecology clearly showed that all the dimensions of the FAB practices are equally important. Without consideration of all the dimensions the future research might be not able to deliver new knowledge that is practically applicable in varied environmental, social and economic conditions.

Critical reflections on the thesis project

It would be relevant for this thesis to include a broader spectrum of stakeholders and search for solutions for the questions that arose during the project. Unfortunately, due to my limited knowledge about insects and biology in general, I required vast learning about insect basics that consumed much of my time in the initial stages of the project. The natural science part of the thesis has been challenging and the final quality of the paper could have been improved by deeper analysis of species in the orchards and by botanical and quality assessment of the flower strips. I consider it to be a shortcoming of multi-disciplinary research that requires expertise in different fields of science. Agroecology taught me to see the big picture and gave me skills for facilitation changes and transformation of agroecosystems. However, only during the writing process I realized that while my previous business education was valid background in discussions, group projects or participatory exercises, it was difficult to apply it in natural science part of my research. However, the thesis project under the umbrella of EcoOrchard project was invaluable learning process that greatly contributed to my understanding about research process. It was an opportunity to test and improve my skills as a researcher and gave me new expertise that will benefit me in my future work.

Reliability, validity of data and sources of error

Since the qualitative research of this thesis required specific participants familiar with FAB practices and with the monitoring methods, it was challenging to find more participants for the interviews during the growing season. However, the sample of participants of the interviews and the workshop was considered appropriate for a deep qualitative study. The thesis aimed to uncover issues of interested apple growers that are willing to participate in development of FAB in Sweden and could potentially lead the change towards FAB practices within the community of apple growers.

One of the challenges and possible sources of error was the language barrier during the qualitative part of the project. Since, I am not Swedish all the interviews were conducted in English. While all the participants had a good level of English, there is a possibility that some of the meanings and ideas were lost in translation. Moreover, the workshop was facilitated by a researcher from SLU and fully conducted in Swedish, which I found doable, but rather challenging. However, the transcript was translated that enabled the data analysis of the workshop. Moreover, I might at times have received insufficient information due to translation errors. While my skills for qualitative research have been well practiced over years, I have been constantly learning during the thesis project.

However, the quantitative natural science part and the analysis of the findings has been the most challenging due to my very strong background in social science. I had no previous experience with conducting research in natural sciences. Thankfully, I received a guidance from the EcoOrchard project team, my supervisors and researches from the university that made it possible to overcome this issue. I received a set of instructions to follow during the data collection, sorting and analysis of data that helped reduce potential errors in interpretation analysis of the findings Moreover, the research process guided by Checkland's model of soft systems methodology and agroecological framework adopted for this thesis, helped me to reflect on all the data and improve their validity.

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