The natural pest control potential of different landscapes

Mapping the ecosystem service in three regions of Sweden

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Preface

My background lies in agricultural science, where most students focus on one specific part of the big picture. Anyone who knows me or has seen the record of courses I took is aware that rather than specializing (and especially choosing against a specialty), I am passionate about a large variety of subjects. It was this - my interests in both ruminant biology, grassland management and agricultural politics (and, and…) - that has led me to 'specialize' in Agroecology – the study of systems, where all threads come together.
The Master's program Agroecology explores systems both by zooming in and zooming out. At the small scale, we investigated the system of a field and of a farm business, leading farmer interviews, and reading case studies from all over the world. This has improved my methodological skills and deepened my applied knowledge. On a larger scale, Agroecology explores the food system, from input suppliers and farmers, to processors, retailers, and consumers. Especially the insights into political issues and social movements have broadened my horizon. Studying in Alnarp and being surrounded by landscape architects and foresters has also helped me add an additional angle on the multifunctionality of agricultural landscapes and eventually shaped my choice of thesis topic.
The underlying idea of my thesis is that agriculture is a central part of our landscapes, shaping it tremendously but equally being influenced by it. Changing our point of view to see agriculture as part of the greater ecosystem in which spaces are shared is the basic premise of the agroecological transformation. The negative externalities, both ecological and social, of many of the current farming practices are well studied and repeatedly topic of many political and societal debates. However, the (admittedly largely untapped) potential of agriculture to dampen environmental issues through carbon sequestration or conserving farmland biodiversity for instance is often overlooked in these conversations. With my thesis I want to underline that agriculture fulfills multiple functions beside simply the production of food and fiber, a notion that I will also work to carry forward after my studies.

A final point that I have learnt through studying the program is that pure knowledge about something does not translate into proper understanding. And that a deep understanding of an issue is not proven by knowing every biochemical aspect behind it. The challenges we are facing as soon to have graduated Agroecologists will not be solved by us being able to recite the nitrogen cycle by heart. They can be solved by understanding the different components, stakeholders and perspectives connected to it, and by acknowledging that listening humbly is always the first step.

Abstract

Natural pest control describes the process of natural enemies suppressing pests and thus reducing crop damage and stabilizing yields. How well these beneficial arthropod predators and parasitoids can thrive in a landscape is influenced by the land-use types in the vicinity, such as forest patches, pastures, or agricultural fields, and their ability to provide resources. While the relationship between these landscape structures and specific insects is relatively well explored, up-scaling these findings from field experiments to larger areas is difficult. This thesis aims to contribute to a better understanding of this issue by mapping the natural pest control potential of three agricultural landscapes in Sweden, based on the presence of specific landscape factors.

In order to do so, an expert survey was conducted with the aim to generate quantitative scores linking the influential land-use types to the abundance of natural enemies, which is used as an indicator for the natural pest control potential. Factors investigated were: Herbaceous and forested semi-natural habitat, as well as agricultural fields defined by variations of management types, field size and crop rotation diversity. The entirety of natural enemies was divided into three groups to account for a more precise response: complete generalists, more specialized predators, and parasitoids. These scores were then included in a spatially explicit model, based on which comprehensive maps depicting the natural pest control potential in parts of Dalarna, Västra Götaland and Scania were created. The experts rated herbaceous habitat and forest edges highly in their ability to support natural enemies. The scores of agricultural fields were equally high or partially higher if managed organically, having a small field size and a diverse crop rotation, while ratings were lower for conventional, large scale fields with a simplified rotation. The maps reveal that Scania and Västra Götaland have large amounts of high natural pest control potential, the largely forested Dalarna has lower values.

While modelling this process required many simplifications and the reliability of the data is only ‘moderate’, the results can still give valuable insights into the complex issue. Especially promising are the high scores attributed to the diversification and extensification of agricultural fields, allowing to increase natural pest control without having to convert production areas to semi-natural habitats. Concrete farming practices identified include among others the reduced application of pesticides, the cultivation of fields at a smaller width and longer crop rotations, as well as a reduction of tillage and the cultivation of flower strips. The implementation of these practices on a landscape level requires policy makers to incentivize them properly and support farmers in making these changes. Furthermore, stakeholders need to create land management plans to increase the structural diversity in landscapes through e.g., the amount of semi-natural habitats. The thus increased natural pest control in our agricultural landscapes can contribute greatly to reducing the reliance on insecticides and the environmental damages connected to them, and plays a vital part in the transition to an ecological intensification.

Keywords: natural pest control, natural enemies, landscapes, agricultural diversification, pesticide reduction, mapping, ecosystem service, ecological intensification, agroecology

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Abbreviations

EI	Ecological Intensification
ES	Ecosystem Service/-s
LPIS	Land Parcel Identification System
NE	Natural Enemy/-ies
NPC	Natural Pest Control
NPCP	Natural Pest Control Potential
SNH	Semi-Natural Habitat/-s

1. General introduction

Since humans first roamed this earth, we have shaped our surrounding landscapes, first as a matter of pure survival and later as part of more structured agricultural production and economic activity.
In the past century especially, our landscapes have witnessed radical changes, as the agricultural sector has undergone a transition towards intensification and homogenization. To increase production, many natural habitats were turned into agricultural fields, farms underwent a process of specialization, with among others the decoupling of livestock- and crop production (Robinson & Sutherland 2002). Along with more intensive management practices through the application of pesticides and synthetic fertilizers, increased use of machinery and shorter crop rotations, these changes have come with a notable negative impact on the surrounding environment (Gliessman 2015). Some examples of this are the degradation of soils, the imbalance of hydrological systems and the pollution of ecosystems through harmful substances. Intact ecosystems, however, are vital to sustain human life, through providing basic biological processes, which can be exploited by humans as Ecosystem Services (ES). The production of food and fiber largely relies on ES, since water retention, nutrient cycling and pollination for instance are central to the functioning of agriculture. Understanding these ES and harnessing them to increase agricultural production is part of the Ecological Intensification, an alternative approach to keeping yields high while reducing the negative impact on the environment and ending the input dependencies of the 'conventional' intensification (Bommarco et al. 2013).
The ES focused on in this report is Natural pest control (NPC), an integral part of biological control (Stenberg et al. 2021). It describes the process in which natural enemies (NE), in this case insects, suppress pest populations by preying on them, and thus reducing the damage done to crops and minimizing the need for pesticides. Natural and agricultural fields can offer suitable habitats to NE such as parasitoids, ground-dwelling and flying predators by providing refuge and food resources. What natural structures a landscape contains and which farming practices define it strongly influence the abundance of NE, and their possibility to provide NPC.

Despite recent developments in the literature on NPC, transferring findings from samples of locations or field experiments to larger areas at a bigger scale remains difficult considering the variability of landscapes, NE and pests that influence the provision of this ES. A commonly used tool for upscaling scientific findings and making the knowledge more accessible to a wider audience, such as for various stakeholders, is the mapping of ES (Burkhard & Maes 2017).

1.1. Objectives

This thesis aims to better understand the relationship between NPC provided by NE and semi-natural and agricultural landscape factors in Sweden.
The objective is to model and map the NPC potential (NPCP) of three agricultural landscapes in Sweden, using the abundance of NE as an indicator for the highly complex system of NPC, since it is its main driver (Chaplin-Kramer et al. 2011). The model used describes the influence of the surrounding semi-natural and agricultural land-use on the NPCP in the agricultural center field and is based on the work of Rega et al. (2018), who recently mapped NPC throughout Europe. Their approach is developed further by including a larger variety of influencing factors as well as by dividing natural enemies into sub-groups. To do so, an expert survey in the style of the 'Ecosystem services matrix' (Campagne & Roche 2018) is conducted that gives insight into how these different elements are linked to specific, relevant insect groups. The final result shall serve as a base for comparison between the areas with different landscape. Based on this, future changes to better harness the ES NPC can be recommended, and how practitioners and stakeholders can contribute to this. Finally, further research matters are identified.

This thesis starts with background information on underlying concepts and issues, after which the methods are introduced. Then, the results are presented, discussed, and placed in a bigger context.

2. Background

2.1. Intensification and homogenization

The agricultural sector in Northern Europe – similarly to many other regions in the world – underwent large changes in the past century (Robinson & Sutherland 2002). Farms used to include both crop and livestock production, since animal manure and nitrogen-fixing plants were relied on to secure soil health, all forming a closed nutrient cycle. Due to constant financial pressure and a new availability of external inputs since the 1950s (Spiertz 2009), farms increasingly specialized and a comprehensive decoupling of crop and livestock production took place. This also led to a simplification of crop rotations and an abiding dependence on synthetic fertilizers to sustain the nutrition of crops. The regular application of chemical plant protectant agents guarantees that the ecosystem within the field is shaped in a way that leaves room only for the crop (Wretenberg et al. 2006).
This shift in management choices of individual fields has long shaped the larger landscape setting as well. Large parts of southern Sweden are now completely cereal-based growing systems. The deep reliance on machinery has led to the comprehensive aggregation of fields to allow for greater operator efficiency. Like in many other European countries, the mean field size in Sweden has grown drastically (Josefsson 2015). As a direct outcome of this, field margins, hedge rows and other ecologically valuable landscape elements have largely disappeared (Stoate et al. 2009). A further result of the intensification of the agricultural sector is the turning of more natural ecosystems into arable land and the minimization of extensively used areas such as semi-natural pastures (Bärring et al. 2003; Tscharntke et al. 2005).

The intensification, homogenization and simplification of farming has led to notable increases in yield necessary to feed a growing population on earth. The ecological downsides it brings, however, are evident: the climate issues intensified by this energy intensive farming system, the erosion and the damage of human and ecosystem health and are just a few examples out of many issues (Gliessman 2015). Especially the loss of natural habitat and of farmland biodiversity connected to the intensification (Robinson & Sutherland 2002) are influencing the decline of the beneficial arthropods focused on in this report. This and the general degradation of ecosystems hamper the provision of basic biological services, called Ecosystem Services, that are necessary for agricultural production and human livelihood.

2.2. Ecosystem services

The concept of ES is frequently used in science as well as policy making and links the intact functioning of local and global natural systems to the provision of basic services necessary for human livelihood. The *Common International Classification of Ecosystem Services (CICES)*, as proposed by the European Environmental Agency in 2009, categorizes ES into three groups (Haines-Young & Potschin 2018):

- Provisioning ES are defined as those that benefit humans the most directly, such as the physical provisioning of goods including timber, agricultural crops, or game.
- Regulating ES are more indirect; they constitute the underlying ecological processes that help create a safe and healthy living environment. Examples for this are the filtration of water, erosion control and soil formative processes.
- Cultural ES fulfill the spiritual and intellectual needs of humans. This can include symbolic interactions with nature out of traditional values, the possibility for recreational activities as well as knowledge retrieval.

To further understand the concept of ES, their provision must be investigated more deeply. While there are many definitions and concepts around the ES, the conceptual framework used in this report leans on the Ecosystem Service cascade first introduced by Haines-Young & Potschin (2010) and later developed further by La Notte et al. (2017). As Figure 1 shows, the starting point of this scheme is the ecosystem itself ('Biophysical Structure'), including various flows of matter and energy. The ecological processes that contribute to the smooth working of the ecosystem can be categorized as 'Functions', an example of which would be the provision of suitable habitats for various organisms, omnivorous insects for instance. Those functions that directly or indirectly contribute to the wellbeing of humans are termed 'Services' (ES), such as the preying of said insects on herbivorous pests. The 'Benefits' describe a concrete welfare advantage that humans can receive from the function, such as a recreational value, flood control or – to continue the previous example – a reduced need for insecticides through natural pest suppression while ensuring the provision of yield. In many considerations of the topic, the cascade is extended by one step: the valuation of the received benefit, based on monetary, aesthetic or other values (Costanza et al. 1997). This step is not investigated further since is not a central part of the report and because it has been criticized for its potential negative implications. As Bengtsson (2015) pointed out, there is high risk of focusing solely on the final product while neglecting important intermediate steps and the bearing of the cascade's underlying processes.

All in all, the great strength of the cascade is its description of the trickle-down effect from one end to the other as well as the dependency of the benefits on all the previous steps in the cascade, first and foremost on the intact and well-functioning ecosystems.

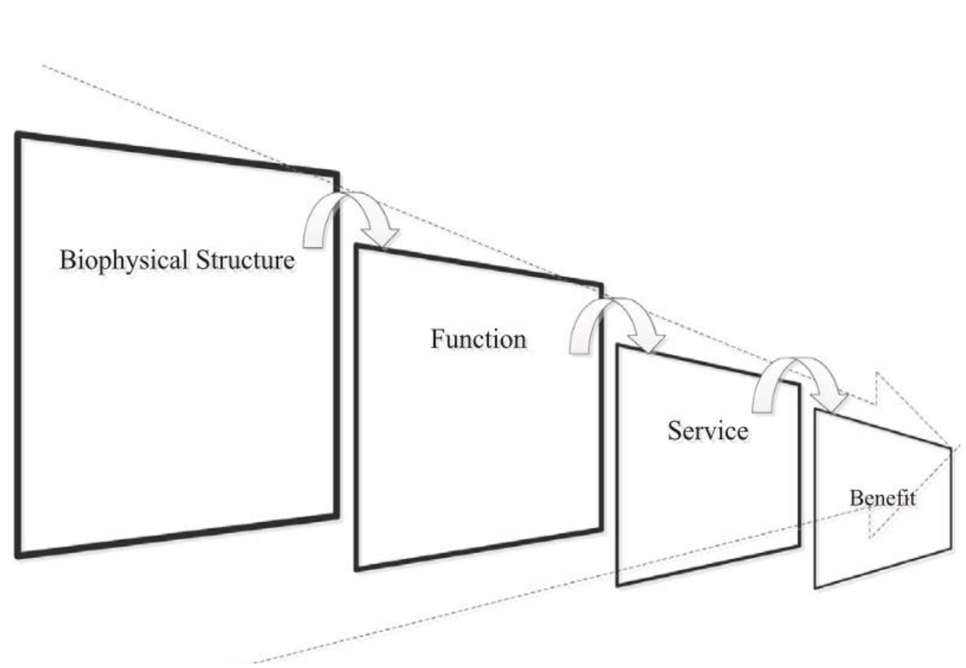


Figure 1: "Re-interpretation of the [ES] cascade framework". Taken from: La Notte et al. (2017). The arrow visualizes the hierarchical complexity of the steps.

2.3. Ecosystem services and agriculture

As “humankind's largest engineered ecosystem” (Zhang et al. 2007, p.253), agriculture can be seen as the first step in the cascade, the biophysical structure providing ES and influencing the provisioning properties of the ecosystems around it. It produces food and fiber, which in themselves are provisioning ES. As less direct examples of services, climate change mitigation through restorative agriculture and the preservation of cultural landscapes can be named. Additionally, Zhang et al. (2007) point out that the current way of farming can also produce ecosystem dis-services, describing how certain practices harm the surrounding environment, through nutrient run-off of sub-optimally applied fertilizers for instance, or the damaging of non-target insects by pesticides. This, in turn, can have negative effects on the productivity of a field, since pests are suppressed less by naturally occurring enemies, leading to an even stronger reliance on pesticides, and eventually resulting in a negative feedback-loop (Matson et al. 1997).

In addition to its role as influencing the provision of ES, agriculture is also the recipient of ES and relies largely on their availability. Water and nutrient cycling, but also pollination and pest control are central for the production of many crops. Similarly, however, agriculture can also suffer from ecosystem dis-services, such as the competition for nutrients with non-crop plants or herbivory by pests (Zhang et al. 2007).

The concept of a focused harnessing of these services beneficial to agricultural production is termed the **Ecological Intensification** (EI). In contrast to the 'conventional' intensification of the agricultural sector in the 20^{th} century, which relied largely on external inputs such as pesticides and synthetic fertilizers, EI aims to reduce this dependency (Bommarco et al. 2013). It offers an alternative approach to meeting the rising demand for food without the negative environmental issues and the harmful feedback-loops connected to the 'conventional' intensification described earlier.
There are different ways in which EI manifests itself in practice. As an example, soil services, such as a healthy water retention or long-term fertility, can be enhanced by managing soil organic matter, through a reduction of tillage, the application of manure, proper residue management or the cultivation of perennials (Paul et al. 1996). This way, the reliance on synthetic fertilizers can be strongly decreased and other issues connected to intensive farming, such as erosion or drought, can be counteracted. All in all, even if external inputs are not abandoned completely, ES can still contribute greatly to achieving the highest yield potential as well as stability and resilience over time (Bommarco et al. 2013). In the case of natural pest control, the use of and dependence on pesticides can be reduced. In the long run this can have economic advantages for the farmer, and the negative environmental effects can be reduced.

2.4. Natural pest control

The ES focused on in this report is the provision of 'Natural pest control' in agricultural fields, which describes the process of NE suppressing arthropod pests that damage crops. This can ultimately lead to a 'natural' buffer against plant damage and diminished yields (Bengtsson 2015), stabilizing or even increasing economic output and reducing the dependency on pesticides.

The organisms that drive NPC are numerous. While birds (Barbaro et al. 2017), nematodes (Ramirez et al. 2009) and entomopathogens (Roy & Cottrell 2013) contribute as well, this thesis focuses exclusively on insect predators and parasitoids, which in itself is a diverse grouping and consists of different orders. Spiders (*Araneae*), ground beetles (*Coleoptera*, *Carabidae*) and rove beetles (*Staphylinidae*) are examples of <u>ground dwelling generalists</u> that predate on a wide array of pests. Due to their broad range of prey they are often already present in a field before the pest arrives and can react to its presence immediately (Östman 2002). They also have been shown to cope well in fields with frequent disturbance

(Öberg 2007), which makes them especially important in areas of intensive agriculture and their effectiveness in suppressing pests has been documented by numerous studies (e.g. Snyder & Wise 2001; Snyder & Ives 2003). Predators with a slightly more specialized diet are ladybirds (*Coccinellidae*), lace wings (*Neuroptera*) and hover flies (*Syrphidae*) for instance. These predators are flying and therefore also have a prey array that includes pests living on leaves or flowers. Parasitoids, such as wasps (*Braconidae, Ichneumonidae*), contribute to the suppression of pests through ovipositing, meaning the laying of eggs into the host, which ends fatally for the latter. They are characterized by having a very specialized array of hosts, they develop quickly relative to the pest, and thus show a quick growth in numbers shortly after a pest outbreak occurs, making them an important part of NPC (Hawkins et al. 1997).

The importance of different natural enemy groups varies depending on the establishment phase of the pest, the crop in focus and the general complexity of the surrounding landscape (Östman et al. 2001; Rusch et al. 2013). One of the most researched examples is the suppression of the bird-cherry oat aphid (*Rhopalosiphum padi L*) in cereal fields. Besides damaging the crop by sucking the sap in the plants, the aphid also vectors serious viruses such as the *barley yellow dwarf virus* and is considered a major pest in Sweden. This pest is attacked by nearly all NE mentioned above. Spiders, rove beetles and carabids (Ekbom 2008), as well as ladybirds, their larvae, lace wings, hoverflies (Östman et al. 2003) and certain parasitoid wasps (Snyder & Ives 2003) contribute to suppressing the cereal aphid. Another example is that of oilseed rape, an economically important crop in Sweden where the main insect pests are the cabbage stem flea beetle (*Psylloides chrysocephala*) and the pollen beetle (*Meligethes aeneus*) as well as multiple weevils (e.g. *Ceutorhynchus assimilis*, *C. napi*, *C. pallidactylus*). Here, parasitoids (e.g. *Braconidae, Ichneumonidae*) play an especially large role, while predators contribute less (Alford 2000).
Literature shows conflicting results on whether a diverse NE community can suppress pests better than one with only a few species (Schmidt et al. 2003; Finke & Denno 2004). Snyder & Ives (2003) show, that even though there is intraguild predation where e.g. predators such as carabids prey on parasitoid wasp pupae, the suppressive effects of the two groups are mostly additive. As Redlich et al. (2018, p. 2423) conclude, "enemy abundance drives the magnitude of biological control, whereas species richness is mostly thought to increase the stability of this ecosystem service (see e.g. Shackelford et al. 2013; Harrison et al. 2014)".

While there is a rising number of studies conducted on the individual components of this process, very few investigate the final effect on yield and the exact economic value of NPC is hard to pinpoint. Östman et al. (2003) calculated the reduction of aphid damage in barley fields in Sweden in 1999 by ground-dwelling predators to be approximately 40 € ha^{-1} (corresponding to approx. 50 US$ ha^{-1}). Similar results were found in a New Zealand study conducted in 2004, which values NPC between US$ 35-70 ha^{-1} (corresponding to approx. 30-60 € ha^{-1}), depending on the management type and crop at hand (Sandhu et al. 2010). Since we cannot map the actual NPC provided, this thesis depicts it through using the abundance of NE as an indicator, as is done frequently (e.g. Rega et al. 2018). The results produced in the thesis therefore show the potential of NPC (NPCP) based on the presence of NE driving its provision. With the main focus of this report being on NE, their response to how we shape the landscape is of special interest. Recent studies suggest that the degree at which NE can thrive in an environment and consequently how strong a community's pest suppressing properties are, depends largely on the composition of the landscape (e.g. Bianchi et al. 2006). Both the proportion of semi-natural habitats (SNH) and various factors shaping agricultural fields play a role in this.

2.5. Natural enemies and land-use types

NE species have certain needs within a habitat, depending on the diet, the season, their life cycle stage and many other functional traits (Bianchi et al. 2006; Tscharntke et al. 2007). The scale at which the NE respond to their surrounding landscape also differs between taxa. In studies investigating these differences, influential radii vary from a few hundred meters to several kilometers, however, findings vary strongly and contradict also within insect groups. Chaplin-Kramer et al. (2011) show that many studies have found parasitoids reacting to the landscape on a smaller (e.g. below 1000m) and predators on a larger spatial scale. On the other hand, Thies et al. (2005) conducted a three year study finding that parasitoids are significantly influenced by their landscape at a scale of up to 2 km and Aviron et al. (2005) show that larger carabids react to wooded structures and crops at a scale of 250m.

Qualities that make a certain habitat favorable include the availability of feeding resources, the presence of prey for instance, as well as refuge. Herbaceous habitats, such as pastures or permanent leys, offer plant food sources including pollen and nectar (Bianchi et al. 2006), from and contain flowering plants throughout the season. Similar to other undisturbed areas, they also provide important overwintering sites, the presence of which allows for an early colonization in the adjacent agricultural fields in the spring (Collins et al. 2002). Forest edges are unique in the sense that two ecosystems overlap, creating a large diversity of habitats. They also act as a windbreak, which has been shown to increase the number of flying insects (Whitaker et al. 2011).
Besides SNH, cultivated fields also play an important role in supporting NE. They are not only the area in which an effective NPC is desired, but also a vital source of resources. The quality of a crop as a food resource depends on its provision of mainly pollen, nectar but also of edible plant parts (Lu et al. 2014). Since the ability of a specific crop to provide feeding resources varies strongly among the seasons, a high crop diversity in the landscape - characterized by long crop rotations and small fields - can provide a larger variety of resources in reachable vicinity, which can profit NE (Rusch et al. 2013).
One of the main characteristics of agricultural fields is that they are subject to regular disturbances. Specific management practices that affect NE are the use of pesticides, frequent tillage, or mowing (Puech et al. 2014; Nagy et al. 2020).

Organic management is seen as an alternative that excludes many of the practices considered harmful to insects. The EU organic regulations (European Comission 2020) prohibit the use of synthetic fertilizers and chemical plant protection agents, and to adopt to the restrictions, many organic farmers have longer crop rotations and more perennials on their fields, which are shown to benefit NE (Jonsson et al. 2012).

Species respond to these disturbances differently. While predators can cope well with this and some are known to hibernate in cultivated fields (Holland et al. 2009), many taxa are forced to move out of fields at certain times, e.g. at harvest, to then reenter it. Having adjacent semi-natural structures allows them to easily re-colonize crop fields (Östman 2004), and is also vital for NE that rely on nectar from natural spaces additional to their prey in the fields (Caballero-López et al. 2012).

Conclusively it can be said that while there is a lot of research conducted on the response of NE on land-use types, many of these findings are contradicting, which emphasizes the complexity of the system and the variability in the different taxa's responses.

3. Materials and Methods

In order to achieve the aims set for this thesis, an expert survey was conducted to generate quantitative scores of each land-use type. These were then introduced into the model to construct the maps illustrating the potential natural pest control in three areas in Sweden. The process followed 4 main steps:

- Selection of factors
- Expert elicitation
- Analysis of the survey
- Modelling and mapping

3.1. Selection of factors

To identify the most influential factors, literature on the interaction between land-use types (both natural and agricultural), natural enemies and natural pest control was reviewed using a variety of search terms in Google Scholar; ‘*Crop rotation, carabids, Sweden’* and ‘*natural pest control, landscape’* for instance. The search results were supplemented using the ‘Snowballing’ technique (Wohlin 2014), in which literature referred to in an insightful paper was consulted as well. The following criteria were used for the selection of articles:

- Reporting significant results on the abundance of different NE in relation to landscape and/or agricultural factors.
- Offering primary sources of data or transparent meta-analyses.
- Publication date preferably after 2000, except for literature that was referred to in more recent papers as an older primary source.
- Having a regional focus on Scandinavia, states surrounding the Baltic Sea, northern France, the Benelux states, Switzerland, Austria, and the UK. More distant but climatically similar areas included Canada, the US, and New Zealand.

From this literature, information on the cropping system, semi-natural and agricultural factors, targeted natural enemy insects, corresponding pests, the effects between factor(s) and natural enemies as well as the distance at which the effects were studied were recorded. In addition, background information, i.e. statistical data, was found through the search engine Ecosia, using search terms such as *'average field size Sweden*' or '*crop rotation Sweden'*. Data and information from governmental organizations, i.e. The Swedish Board of Agriculture were consulted. The dependent variable, the entirety of all natural enemies, was divided into three groups, to allow for a more accurate response depiction. Based on the recorded data, three semi-natural habitat types were selected as factors; herbaceous, wooded interior and wooded edge, as well as three criteria defining agricultural fields; management type, field size and crop rotation.

Insect groups

Literature concurs that different taxa react differently to their surrounding landscape (e.g. Caballero-López et al. 2012). To account for the different traits of insect natural enemies without overwhelming the experts in the survey, NE are divided into three groups:

- 'Complete generalists' (Carabids, spiders, ground beetles…),
- 'More specialized predators' (ladybirds, lacewings, hoverflies…)
- 'Parasitoids' (parasitic wasps…)

These categories are based on the prey specialization trait as well as on the nature of the relationship between NE and pest (as prey or host). Similar categorizations are often used in literature (Alford 2000; Chaplin-Kramer et al. 2011) and were therefore thought to be intuitively understood.

Semi-natural habitats

The **wooded semi-natural habitat** is categorized as an area with more than 30% of wooded canopy cover per 5x5m raster, meaning perennial plants such as trees or shrubs at a height greater than 1m. Based on literature (Moonen et al. 2016), which shows that the habitat properties of forest parts vary depending on their distance from the edge, we distinguished between the **interior** and the 10m **edge** of a forested area. The **herbaceous semi-natural habitat** is defined by containing less than 30% of wooded canopy cover per 5x5m raster. Additionally, the area should not have been ploughed for a minimum of 5 years but can be mowed or grazed to be kept from being overgrown by trees. The following ecosystem types fall in this category: permanent and semi-natural pastures and permanent ley fields.

Agricultural factors

At the field level, the production intensity was indicated by the (binomial factor) **management type**, where we distinguished between organic and conventional management. While the application of synthetic fertilizers and especially chemical plant protection agents is prohibited on **organic** fields, these substances are allowed in **conventional** management. Organic production is here defined as following the EU standards (European Comission 2020). Even though in practice the borders of these two ‘types’ are more fluent, they are practical indicators to use in our case because organically cultivated fields are well documented in Sweden. Furthermore, the strict guidelines of organic agriculture in the EU organic regulations make the distinction for the experts as well as for potential future communication to stakeholders very clear.

Another agricultural factor is the **crop rotation**, which was used as an indicator for temporal crop diversity in the field, as well as for spatial crop diversity in the landscape. It is well suited as a proxy for the latter since diversifying the crop rotation on a field level practically results in a higher crop diversity in the landscape. While there are other methods of accounting for spatial crop diversity (e.g. counting the number of different crops in a certain radius), this indicator was chosen because it can be determined at a field scale like the other factors and was thus the most practical way to model it.

The factor was categorized based on the number of functional groups rather than single species the crop rotation of a field contains, because they depict the effects on insects better. For example, winter wheat and oats have similar ecological traits, since they provide insects with similar resources and are therefore grouped into one category (‘cereal’). Additionally, many rotation benefits or disadvantages are also based on such categories rather than on crop species specifically, an example for which is the spread of pests and diseases between cereals of different species. Therefore, all crops grown in arable fields in Sweden were sorted into 9 functional groups (Table 1), which largely lean on those used by Redlich et al (2018) and Aguilera et al (2020). In this study, only the main crop, usually grown over summer, determines how many functional groups a rotation contains, while secondary cover crops over winter are not counted.

The factor ‘crop rotation’ has three categories, which are defined by the number of functional groups present in a crop rotation: **simple** (max 2 functional groups), **average** (3) and **diverse** (minimum 4 functional groups and/or containing ley). A crop rotation that contains ley is automatically categorized as diverse due to its insect friendly properties (Langer 2001). The categories are based on the Swedish average crop rotation. Even though farming structures vary strongly throughout the country, the average of 3 functional groups in the rotation can be found both in the intensive arable fields of the south (e.g. ‘barley-oil seed rape-winter wheat-sugar beets’ (soilcare-project.eu 2018)) and the ley-based systems of regions farther north (e.g. ’barley-ley-ley-barley fodder mix-forage rape’ (Parsons et al. 2018)).

Table 1: Definition of functional groups in a crop rotation

Crop group	Definition
Legumes	Field beans, peas, lentils…
Cereal	Wheat, rye, barley, oat… (spring and fall sown)
Corn	Corn crops
Grass	For seed production (e.g., clover), harvested only once
Ley	For production of silage and hey, also fodder crop mixes: Cut several times per year, usually occupies min. one winter
Flowering crops	Oilseed rape, sunflowers (non-legume and non-ley)
Vegetables	Horticultural crops (e.g. spinach, cabbage...)
Roots	Sugar beet, potatoes, fodder beet…
Others	Marginal crops

The agricultural factor **field size** was used as a proxy for several mechanisms, such as how far insects can penetrate a field (Caballero-López et al. 2012) as well as the amount of field borders there are in an area (Bosem Baillod et al. 2017). The field size can also give a clearer insight into crop diversity on a landscape level since multiple smaller fields can contain a larger variety of crops in a certain range than fewer large ones (Sirami et al. 2019). To categorize this factor, average field sizes in the different regions of Sweden were determined by using block data from the 2016 Swedish Land Parcel Identification System (LPIS), which is based on farmers declarations (European Court of Auditors 2016). The differences between the regions leads to largely varying average field sizes. The chosen 'medium' category was set to include both the relatively large average size of the intensive production areas of the South (around 6.5ha in Scania and Västra Götaland) as well as the more extensive ones further North (around 3.2ha in Dalarna). The following three categories were created: **small** (< 3 ha), **medium** (3 – 7 ha), and **large** (> 7 ha).

3.2. Expert elicitation

3.2.1. Method background

The model that was used to create the map is centered around scores linking the abundance of natural enemies to land-use types. In order to perform a time and cost efficient study, the use of estimates of the ecosystem service was chosen (Campagne et al. 2017). Since the model does not include details about the underlying process and the map aims to give a rough overview rather than an exact amount of natural pest control in the landscape (see appendix 9.1.1), the structured expert knowledge elicitation through the 'Ecosystem service matrix' approach was chosen as the method, similar to Burkhard & Maes (2017) or Campagne & Roche (2018). This method is fast, easily adapted to the need of the study and easily accessible for the respondents and users.

In the 'Ecosystem service matrix' approach, experts are asked to directly rate the capacity of different ecosystems or land-use types to fulfil a variety of ecosystem services. Unlike in the original approach, the survey conducted for this thesis only focused on one ecosystem service, the natural pest control. The matrix 'form', however, was still applied because the influence of the landscape factors was investigated on different insect groups. The method is additionally defined by having a fixed protocol to be followed and a transparent description of the method to reduce potential biases. Unlike Campagne & Roche (2018), who propose to conduct a workshop to capture expert opinions, a survey was conducted for this thesis. Organizing and conducting an expert workshop to generate a consensus-based result exceeded the time frame of the project and would not have been advisable in times of Covid-19. The choice of a survey had the further advantage that biases connected to group dynamics could be avoided and that the statistical analysis was more straight-forward.

3.2.2. The survey

Introduction

The survey (Appendix 9.1.2) provided an introduction, which aimed to give the expert an insight into the overall project in a way that triggers interest and explains the role of their contribution without overwhelming them with information. Campagne & Roche (2018) point out that "a detailed presentation of the approach, the methodology and all definitions can help narrow differences in interpretations" (p.7), which can reduce individual biases. The landscape factors as well as the insect groups were defined precisely to guarantee that the scores given by the experts match the landscape factors in the map later. This included pointing out the limitations of each category (e.g. 5 years not ploughed for SNH herbaceous). Landscape factors that were originally planned to be included (e.g. difference SNH areal shape vs linear shape) had to be left out to avoid "difficulties for experts to provide estimates on closely-related Ecosystem types (here: land-use types)" (Campagne & Roche 2018, p.6). Furthermore, a hypothetical focus landscape was introduced, in order "to achieve the best common understanding between the members of the expert panel" (Campagne & Roche 2018, p.5). It includes all land-use factors investigated in the survey and represents an 'average' Swedish scenario. Since the distance, cover area, configuration and shape of the landscape elements should not influence the scores given, this was verbalized precisely. Finally, it had to be guaranteed that the respondents understand how to answer the questions. For this reason, a verbal explanation of the different question types was given, including examples from a related ecological field.

The questions

The questions of the survey were divided into four parts. The **first** part consisted of two introduction questions about the expert's experience in the work field. This was done to ease the experts into the survey as well as to give an insight into the experience levels. In the next steps, the scores for the model were generated. There is a total of 63 scores, including the 9 SNH scores (three insect groups x 3 SNH types) and 18 different factor combinations that a cultivated field can be categorized as (management type, field size, crop rotation), since a field is always defined by all three agricultural factors. Asking the experts to directly rate this number of scores would have required too much time and would be difficult due to the very small details of differences between some of the agricultural fields with combined factors. Therefore, the agricultural scores were developed in a **two-step process**: including part two, where an agricultural base score is generated, and part three of the questions, in which the percentage of change of one factor is quantified. Part **two** contained the direct scoring questions, in which the experts rated the capacity of one specific land-use type to support the three NE groups in the overall landscape. As proposed by Burkhard and Maes (2017), a scale from 0-10 reaching from 'no relevant capacity' to 'very high relevant capacity' was used. The combination of numbers with verbal explanations was done to make the answers more differentiable. The option of 'I don't know' was included to avoid 'pseudo opinions' (Rowley 2014). This question type was used to generate the scores for the semi-natural habitat, and the 'average' Swedish field, which is defined as conventionally managed, medium size and medium crop rotation.
In the next step the experts are confronted with a change occurring in one single agricultural factor, e.g. a different management type, other than which all characteristics stay the same. Here, the experts were asked to give a percentage indicating how much better or worse this changed scenario can support the natural enemies. In this **third** part of the survey, they could choose between 8 categories of change, ranging from -100% ('considerably worse') to +200% ('extremely better'). This way the influence of each change could be singled out and quantified for the agricultural factors, and later combined with the other factors in the analysis.

Additional to each content question, the expert was asked to state their **confidence** (scale 1-3) on the rating they have given. In the ES rating approach of Campagne et al. (2017), "many participants expressed the importance of having a confidence score in the capacity matrix to let them moderate their self-reliability on their own knowledge." Beside its intrinsic value, the confidence scores can be used to identify whether there are specific land-use types or insect groups that experts might be generally less confident about, or whether certain question types were harder to answer than others. It can also be used to communicate the quality of the data generated through the survey. Part **four** of the questionnaire consisted of a question in which experts were asked to indicate the scale at which each of the three insect groups is influenced by their surroundings. A distance between 0m and 2000m could be chosen from. This scale reflects the distances most often used in the literature (Chaplin-Kramer et al. 2011). This last part also included two open questions in which experts could describe their ideal agricultural landscape for natural enemies as well as the role pesticides would play in this perfect landscape, and an open comment section.

The survey was designed in 'Alchemer', previously called 'Surveygizmo'. This platform allowed for an online distribution, a respondent-friendly and easily understandable design (Rowley 2014) (see Appendix 9.1.3) and an automatic recording of the response data.

<u>Sending out the survey</u>

Before the survey was sent out to the experts, a trial run was conducted with two expert colleagues, to guarantee that it is understandable for someone who had not designed it themselves. Proposed changes were discussed and most of them were included.

The transparent **selection of experts** plays an essential part in avoiding biases. Since the survey focuses on specialized technical knowledge, experts were defined by their work and experience specifically in the field of natural enemies in agricultural landscapes. An expert is therefore someone who:

1. Works in academia and has published a minimum of one paper on natural pest control
2. Or works for a governmental organization or NGO and has notable professional experience as an agricultural or policy advisor for instance
3. AND: has gained at least part of their work experience in a geographical context around Scandinavia, the Baltic Sea, the Benelux states, Switzerland, Austria, France, or the UK.

Many authors of papers read in the literature search were selected as experts, as well as co-authors of other papers they had written. Additionally, in the invitation e-mail, experts were asked to name further people that they see as suitable experts.

If they fitted into the definition of 'expert' named above, they were added to the list. This resulted in a total of 124 experts being asked to participate in the survey. After the first personalized invitational e-mail, which included the experts' names, the experts were reminded of the possibility to participate in another group e-mail a week later. After another week, a final personalized reminder was written to the ones that hadn't participated yet. Experts from France were written to in French, and those from Germany, Austria, and Switzerland in German. Since experts in Sweden are assumed to give the most accurate responses due to their deep understanding of the local ecosystems, Swedish experts that hadn't participated by the end of the third week were asked to participate a fourth time by Linda-Maria Dimitrova Mårtensson or Pierre Chopin, hoping to reach them on a more personal level.

The survey was accessible online and open for responses for a total of 3 weeks, from the 20th of April until the 7th of May.

3.3. Analysis of the survey

The expert survey can be termed non-experimental research, since experts were picked specifically for their technical knowledge rather than as a randomized sample to indicate connections existing in the overall population (Jacobs et al. 2015). Therefore, the analysis of the data was restricted to descriptive statistics, as well as tests of validity through inter-rater reliability. Analysis of the data was done in Excel and R, and is described in this chapter.

The scores

The median of answers given in the direct scoring questions of all experts was used to generate the scores for the model. The generation of the combinational agricultural scores was conducted for each expert separately: The percentage changes for varieties deviating from the 'average' were added to the agricultural base score by addition. After this was done for every expert, the median for each factor was calculated. The median was chosen because it is less susceptible to single extreme answers, of which some were detected in the data. The answers of the experts were weighed equally. To better compare between the agricultural factors, the average of the percentage of change was calculated, based on the direct percentage answers from the survey.

The confidence was not analyzed for each individual score due to the combinational approach taken to generate the agricultural scores. However, the mean of confidence was calculated to compare between factors: land use types, changes in agricultural fields, insect groups as well as question types. The distance at which insects are influenced by their surrounding was calculated by using the median, which was rounded up to the next hundred for better communication.

Validity

For each score as well as the distance of influence, the inter-quartile range was calculated. Like the variance or the standard deviation, this offers a first insight into the reliability of the data, but is a tool better fit for work with the median (Campagne & Roche 2018).
To test for validity, the inter-rater reliability was calculated, which indicates how well experts agree with each other on the scores they gave. It is a versatile measure that is not limited by the number of raters and can incorporate missing ('I don't know') data. Calculations were done in R, using the 'irr' package, running the code for Krippendorff's alpha. The evaluation of the output is based on Krippendorff (2018) interpretation advice.

Open questions

The open questions in the survey were analyzed through a *qualitative content analysis* (Mayring 2010). After all the answers were read once, they were divided into thematic categories that were created inductively, meaning based on the answers themselves rather than on predefined categories taken from literature (deductive). Each answer was divided into single statements, which were then sorted into these categories. One experts answer often contained different statements that were put in different categories. The answers were quantified, by counting the frequency at which experts mentioned them. To visualize this and facilitate comparison, a histogram was created.

3.4. Modelling and mapping

The calculation of NPCP was conducted for the three parts of Sweden. While the model and data per se can be applied anywhere in Sweden, limiting the surface reduces the time needed to run the model. The three specific areas were chosen because they depict well the differences in farming system intensity found in Sweden: Scania as a very intensive agricultural area, Dalarna as a forest dominated and livestock based system and Västra Götaland as a middle ground. The area focused on in Dalarna consists of the communes Falun, Borlänge, Säter, Hedemora and Avesta. The communes covered in Västra Götaland are Lidköping, Vårgårda, Grästorp, Essunga, Herrljunga, Vara, Vänersborg, Trollhättan, Alingsås, Skara and Fallköping. Scania was analyzed as a whole, since it is largely dominated by agriculture and thus offers the largest potential for NPC to take effect.

3.4.1. The model

An additive model is used to simplify the complexity of NPC. The positive impact of every factor is added to each other to calculate a potential for NPC in a central focal field. The model is based on the one developed by Rega et al. (2018), and developed further by adding a larger variety of influencing factors.

$$NPCP_x = \sum_{i=1}^{n} f(r_i) \sum_{j=1}^{21} P_{ji} * s_j$$

with

NPCP = natural pest control potential

x = target cell

i = influencing / source cell

j = land use type

r_i = distance function between *i* and *x*

$f(r_i)$ = value at distance *r*, distance-weighted

n = number of cells surrounding *i* in a certain radius

P = proportion of *j*-th land use type in cell *i*

S_j = expert score of *j*-th land use type

The agricultural field (target cell, *x*) for which the aggregated score (NPCP) was calculated, lies at the center of a landscape that is divided into raster, made up of cells of 100m x 100m. For each raster cell, the contained proportions of each land-use type (p_j) are multiplied with the respective expert scores (s_j). The bell-shaped distance functions (Figure 2) automatically weigh raster close to the center as more important than those further away.

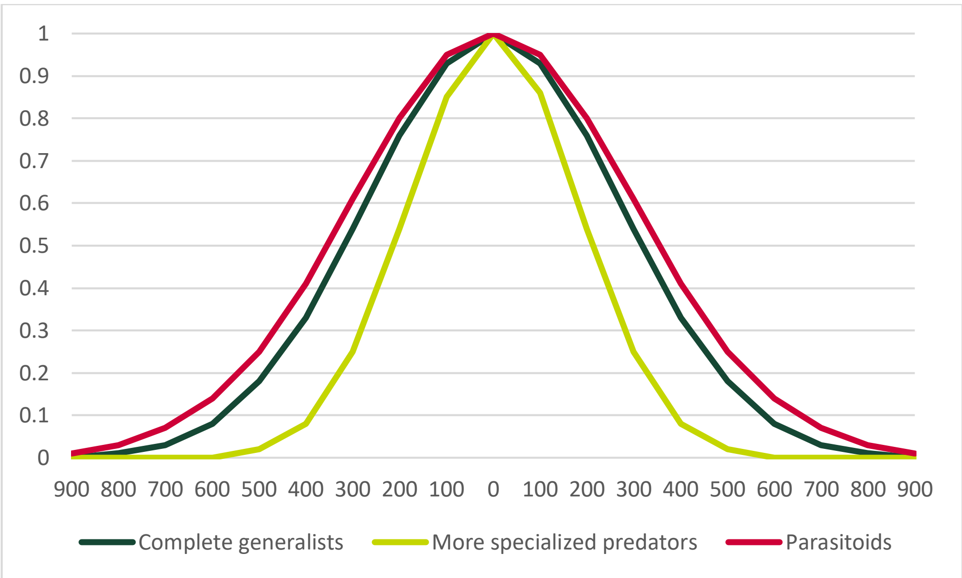


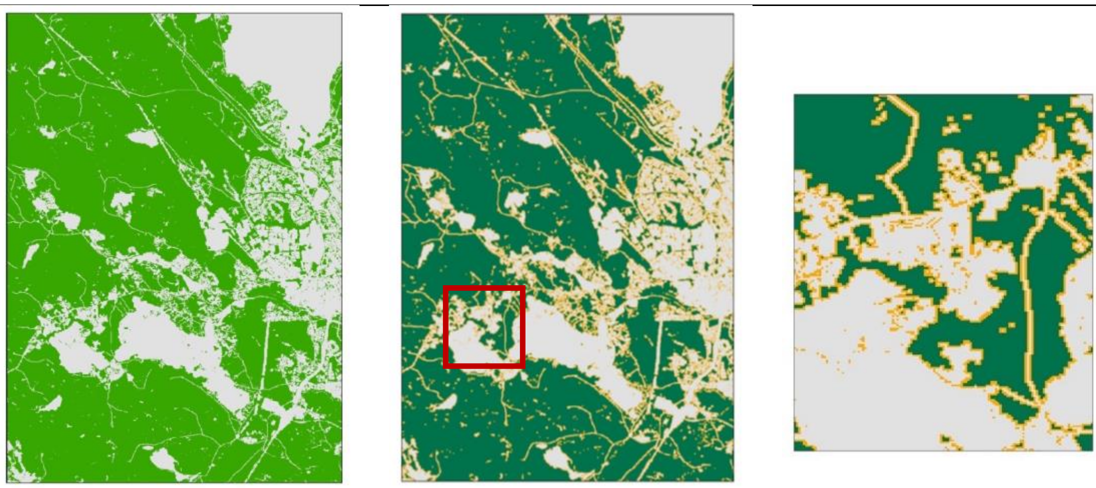
Figure 2: Distance function for the three insect groups, at 800m, 500m and 900m radius respectively. Own representation

3.4.2. Creation of land-use type map

To model the NPCP in the landscape, the first step was to create the input maps that contain the needed information about the distribution of the land-use types. This was done by firstly inserting fine-grid spatial data from different sources, which was then rasterized into 100x100m cells for better application of the model. The rasterization was a means to simplify the input map which allowed for a less time-consuming running of the model, while the information lost (where exactly in a raster is which land-use type) only negligibly lowers the precision of the model.

Each layer of land-use type information (wooded area, herbaceous area, agricultural fields…) is based on a different source of data and was included one by one. The geographical data for the **herbaceous SNH** is based on two sources: Firstly, fields that were declared as grassland and environmental areas in the 2016 LPIS were included (European Court of Auditors 2016). This was merged with information from the Land-Use Classification 'CadasterENV' (Naturvårdsverket) which includes data on vegetation in open and non-open areas. 'CadasterENV' was also used as the data base about the **wooded SNH**. This forest input data was analyzed with the Morphological spatial pattern analysis (MSPA), resulting in a categorization into three different forested areas (int./edge/other), of which edge and interior were included in the input map.

These single layer maps, which had a resolution of 10m were then reclassified each and aggregated into the 100x100m rasters, each cell with the information of the containing proportion of the respective SNH type. Figure 3 shows this process exemplarily on wooded SNH in Dalarna.



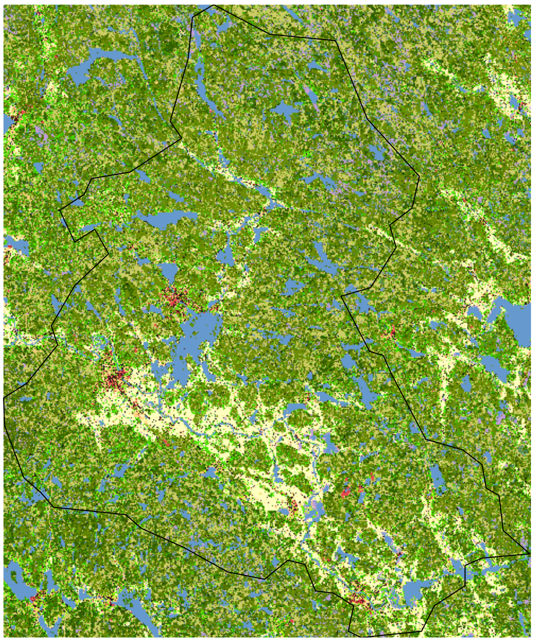
***A:** Forested area based on 'CadasterENV' data (10m resolution)*

B:** Division into interior and edge of forested area (10m resolution). Circled area marks location of **C.

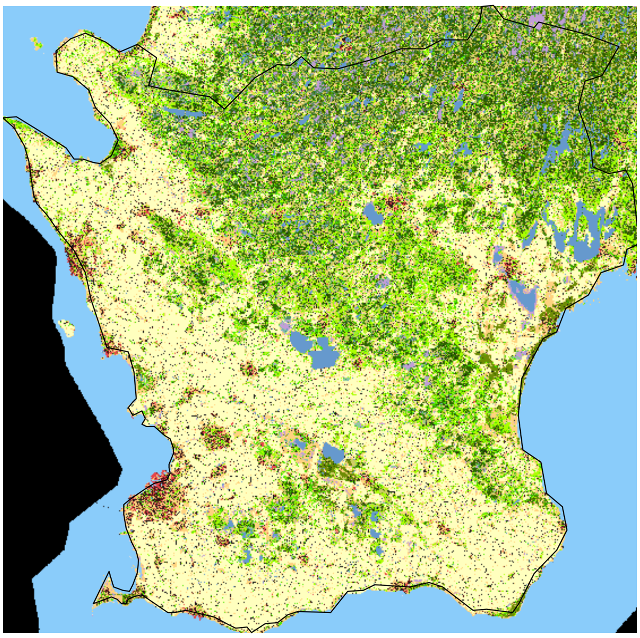
***C:** Rasterization of a fraction of B to 100x100m cells.*

Figure 3: The processing of data to its rasterized form applied in the model. Representation: Pierre Chopin, SLU.

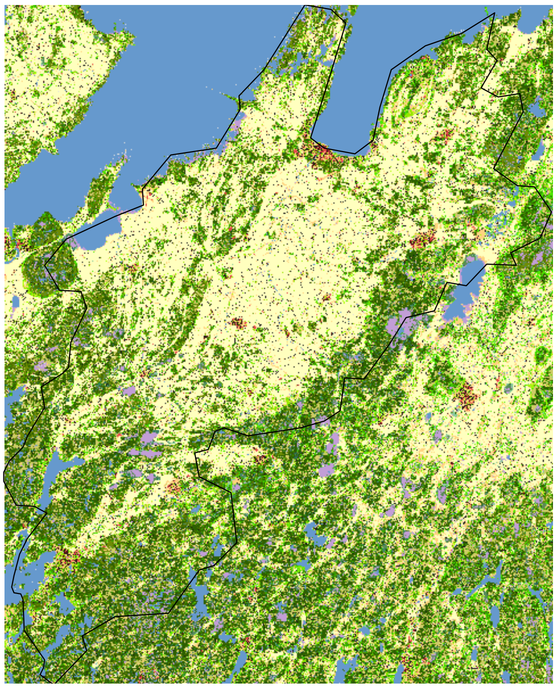
The three SNH layers of information (SNH herbaceous, wooded edge and interior) are then layered to result in the SNH input maps (Figure 4: A, B, C).



***A**: SNH layers in the area in Dalarna*



***B**: SNH layers in Scania*



***C:** SNH layers in Västra Götaland*

Figure 4: Aggregated SNH information. Different areas shown in A, B, C. Representation: Pierre Chopin, SLU.

The layer of agricultural field types is based on two sources: the 2016 Excel database of the Swedish Board of Agriculture, offering data on the management type (conventional-organic) as well as on the 2016 LPIS shapefile, which provided the input about field sizes and the individual farm's crop area and number of cultivated crops. Input data about the factor crop rotation was therefore not used on a field- but on a farm-scale as a means of simplification. These two data sets together were used to divide fields into the 18 combinations (=codes) of agricultural factors (See Table 10 in Appendix 9.2.3). Again, this was rasterized to cells of 100x100m. Unlike the information about the proportions of different SNH types in a raster, each raster only contained one type of the 18 agricultural combinations, the one with the highest proportion. The information within a raster could exemplarily look like this: 10% herbaceous, 10% wooded edge, 20% wooded interior, 60% Agriculture (code 12). Figure 5 shows the agricultural layer for Scania exemplarily, colorized based on the 18 different agricultural factor combinations. The legend is a simplified representation of only management type and diversity (for a more detailed breakdown of the colors consult codes in table 10, Appendix 9.2.3). The exact area (ha) of each type of agriculture / code in the three regions can be found in the subsequent tables in Appendix 9.3.2.

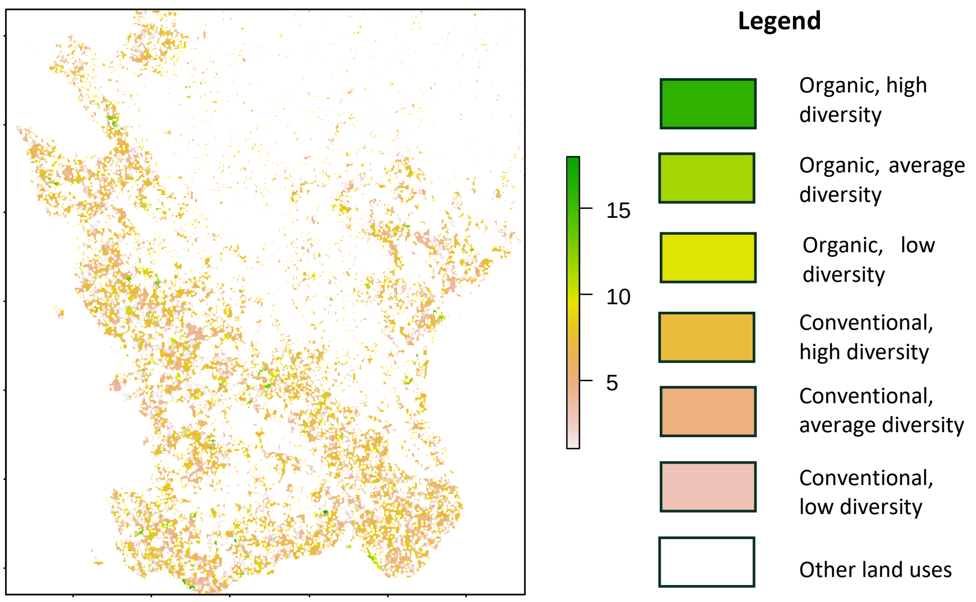


Figure 5: Agricultural area in Scania, coded (1-18) by management type, crop rotation and field size. Legend shows simplified management type and diversity. Representation: Pierre Chopin, SLU.

3.4.3. Creation of NPCP maps

The input maps were then multiplied with the expert scores from the survey. This was still done in the layered form of the maps, for each land-use type individually. This was also the first step in which differences between the insect groups came into account. Here, three maps were created simultaneously.

Then, the weighted layers were added to each other, the raster content information was summed up. The result depicts how well each spot on the map can support NE within itself. To account for the effect of the surroundings on the NPCP in each field, the distance function was added for each insect group respectively. The moving window weighs raster closest to the center stronger, resulting in a score influenced by the field itself as well as by the land-use types within the according radius.

The final step in the creation of the NPCP map was the normalization of scores within each insect group. This way, a score scale of 0 (very low NPCP) to 5 (very high NPCP) was created to allow for better comparison between the regions.

4. Results

4.1. The survey

Of the 124 experts reached out to, a total of 52 submitted a fully filled-in survey. Four experts replied by e-mail that they did not feel confident answering the questions because of a lack of expertise due to e.g. a recent shift in their professional career away from the topic.

4.1.1. Scores

Table 2 shows the expert scores connecting the land-use types to their NPCP and the respective inter-quartile range as an indicator for validity. The scores range from 3.7 to 10.6, from 2.4 to 8.8, and from 1.8 to 7.8, for 'Complete generalists', 'More specialized predators', and 'Parasitoids', respectively. The highest NPCP score was given to the organic, small scale, diverse agricultural fields, while the lowest scores were given to conventional, large scale, simple fields – for all three insect groups. The colours represent the three highest (green) and lowest (red) scores per insect group. Table 2 also shows the distances (radius) at which the three insect groups are influenced by their surroundings and the inter-quartile range. 'Parasitoids' react to their environment at the smallest scale (500m), followed by 'Complete generalists' (800m). 'More specialized predators' are influenced by their surroundings at the largest scale (900m).

Table 2: Median of expert scores (inter-quartile range (Q1-Q3)). Scale is given in m.

Land-use type	**Complete Generalists**	**More specialised predators**	**Parasitoids**
SNH herbaceous	8 (3.0)	7.5 (2.0)	7 (2.3)
SNH wooded edge	7 (2.0)	7 (2.0)	6 (3.0)
SNH wooded interior	4 (4.0)	3 (3.3)	2 (3.0)
Organic – simple –small	8.4 (6.0)	7.7 (5.5)	6.6 (5.2)
Organic – simple –medium	7.3 (4.7)	6 (4.4)	5 (5.6)
Organic – simple –large	6.3 (4.9)	4.8 (4.1)	3.9 (5.2)
Organic – medium –small	8.9 (5.8)	7.7 (5.9)	7.2 (5.9)
Organic – medium –medium	8.1 (4.3)	6.7 (4.7)	6.6 (5.7)
Organic – medium – large	6.8 (4.5)	5.6 (4.3)	5.3 (5.1)
Organic – diverse –small	10.6 (6.8)	8.8 (7.0)	7.8 (6.2)
Organic – diverse –medium	8.7 (6.2)	7.4 (5.8)	6.75 (6.3)
Organic – diverse –large	8.1 (6.8)	6.3 (4.9)	5.7 (5.6)
Conv – simple-small	6.8 (3.3)	5 (3.6)	5 (4.1)
Conv – simple - medium	4.5 (2.5)	3.6 (3.0)	3.6 (4.0)
Conv – simple-large	3.7 (2.9)	2.4 (2.7)	1.8 (4.1)
Conv – medium -small	7.5 (3.4)	6.1 (4.2)	5.5 (4.4)
Conv – medium-medium	6 (3.0)	4 (3.0)	5 (3.0)
Conv – medium -large	4.5 (2.0)	3.25 (2.3)	2.6 (3.6)
Conv – diverse-small	8.6 (4.9)	7.2 (4.3)	5.9 (5.3)
Conv – diverse-medium	6.7 (4.4)	5.4 (3.5)	5 (4.9)
Conv – diverse-large	6 (4.1)	4 (3.5)	3.3 (4.5)
Scale	800 (500)	900 (513)	500 (700)

The results of the changes in agricultural field are summarized in Table 3. The largest change is contributed to the management switch from conventional to organic (+45%), followed by a reduction in field size to below 3 ha (+39%).

Table 3: Agricultural changes sorted by: Management type, field size, crop diversity. Columns depict average expert score per category, general percentage of change from 'average', percentage of change per insect group.

Factor	Average score	General change	Complete generalists	More specialized predators	Parasitoids
Conventional	5.2				
Organic	7.3	+45%	+43%	+45%	+47%
Large fields	4.9	-25%	-19%	-27%	-29%
Medium fields	6.0				
Small fields	7.8	+39%	+39%	+40%	+39%
Simple diversity	5.4	-14%	-14%	-14%	-13%
Medium diversity	6.1				
High diversity	7.3	+26%	+29%	+25%	+23%

4.1.2. Confidence scores

The average confidence score of all questions asked lays at 2.006, indicating that out of a scale of 1 ('not confident'), 2 ('fairly confident') and 3 ('confident'), experts were overall 'fairly confident' with their response. Confidence was analyzed separately to give insight into differences between land use types, changes in agricultural fields, insect groups as well as question types (Table 4).
The confidence scores given to the different land-use types are the highest concerning herbaceous SNH, while the interior of wooded SNH received the lowest confidence. Of the changes in agricultural fields, organic management receives the highest score of confidence. Experts are more confident considering a change towards smaller fields than towards larger fields. They are the least confident about changes in the crop rotation. Comparing the three insect groups, experts were most confident about 'Complete generalists', while the other two groups show only minorly different confidence scores. The confidence scores do not vary strongly between the question types.

Table 4: Aggregated confidence scores per group of insects, land-use types, agricultural change, and question types. Farther divided into percentage of chosen answers: 'Not confident', 'Fairly confident', 'Confident'.

Compared factors	**Aggregated confidence**	**'Not confident'**	**'Fairly confident'**	**'Confident'**
Complete generalists	2.10	21%	52%	27%
More specialized predators	1.98	26%	56%	18%
Parasitoids	1.94	31%	50%	19%
SNH herbaceous	2.22	10%	55%	35%
SNH wooded edge	2.08	11%	63%	24%
SNH wooded interior	1.80	34%	52%	14%
'Average' agricultural field	2.03	14%	69%	17%
Organic	2.17	8%	65%	27%
Smaller fields	2.11	15%	58%	27%
Larger fields	1.98	19%	62%	19%
Diverse rotation	1.85	27%	59%	14%
Simple rotation	1.82	31%	55%	14%
Part 1: Direct scoring	2.03	34%	44%	32%
Part 2: percentage question	1.99	20%	60%	20%

4.1.3. Reliability

Krippendorff's Alpha was used to test the inter-rater reliability. The result is 0.759, a more detailed description can be found in the Appendix (9.2.1). The data generated through the survey can be interpreted to indicate 'substantial agreement' among the experts (Krippendorff 2018).

4.1.4. Open questions

Description of ideal landscape

Of the 52 respondents, 47 gave their answer to the first open question, describing their ideal landscape for natural enemies. In the text analysis, a total of 237 statements were analyzed, for which 21 categories were identified: 6 concerning semi-natural structures in the landscape, 13 concerning agricultural practices and two general ones (Figure 6). The percentage given in the tables and in the graphs is based on the proportion of experts who answered the question and included said category in their reply. A detailed analysis of all open questions can be found in Appendix 9.2.2.

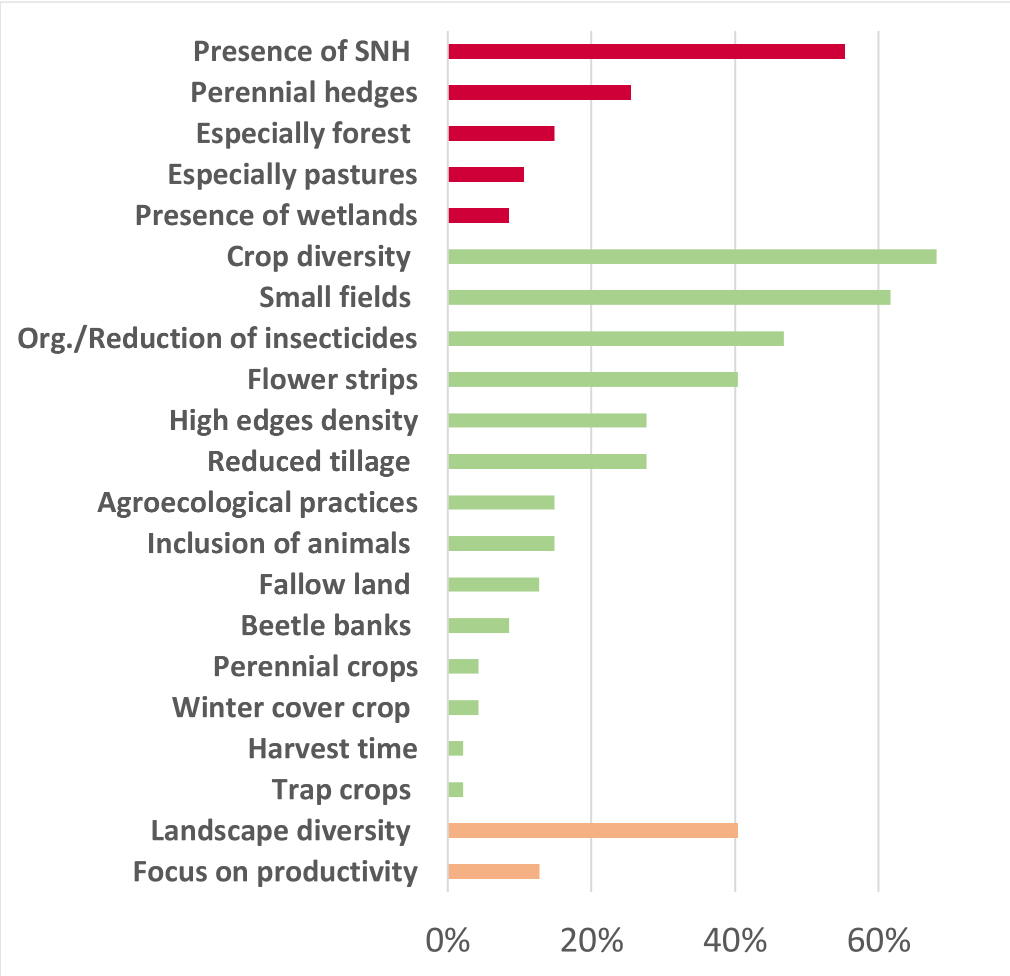


Figure 6: Distribution of categorized answers to open question: 'Description of ideal landscape. Own representation

<u>Role of pesticides in the landscape</u>

The question in which experts were asked to describe the role pesticides played in this ideal landscape was answered by 47 respondents. A total of 74 statements were categorized, and 9 categories were identified; 3 of which addressed the necessary frequency of pesticide use, 3 considered reasons for continued need, 2 include further ideas to reduce the application and one focuses on herbicides and fungicides (Figure 7).

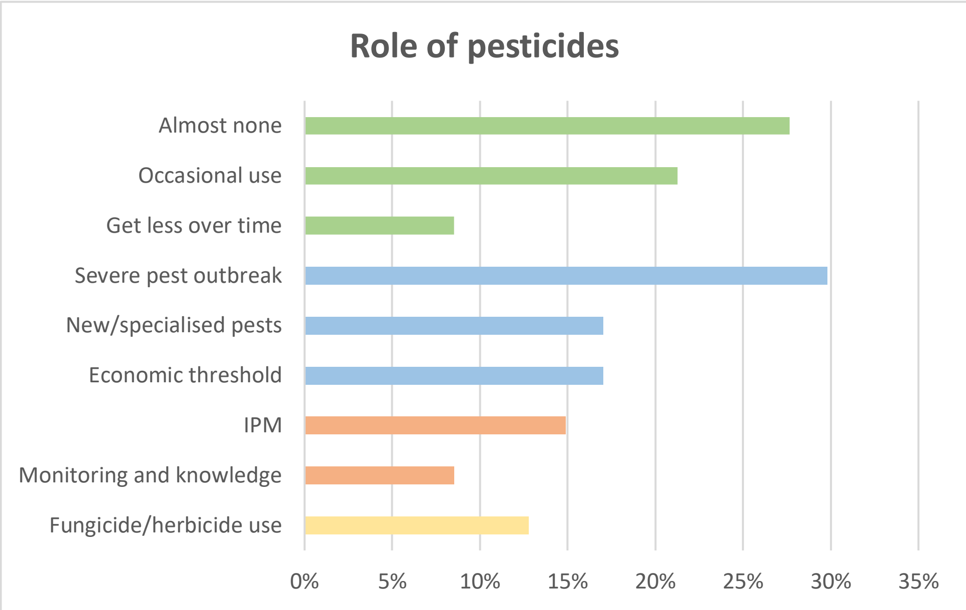


Figure 7: Distribution of categorized answers to the open question: 'Description of role of pesticides'. Own representation

<u>Further comments</u>

The possibility to give further comments was used by 18 experts, and two comments that were given during the previous open question were moved to this section because of better context fit. 9 categories were created, 4 of which include comments about answering the survey per se, 3 pick up on further discussion points concerning the topic and 2 propose solutions.

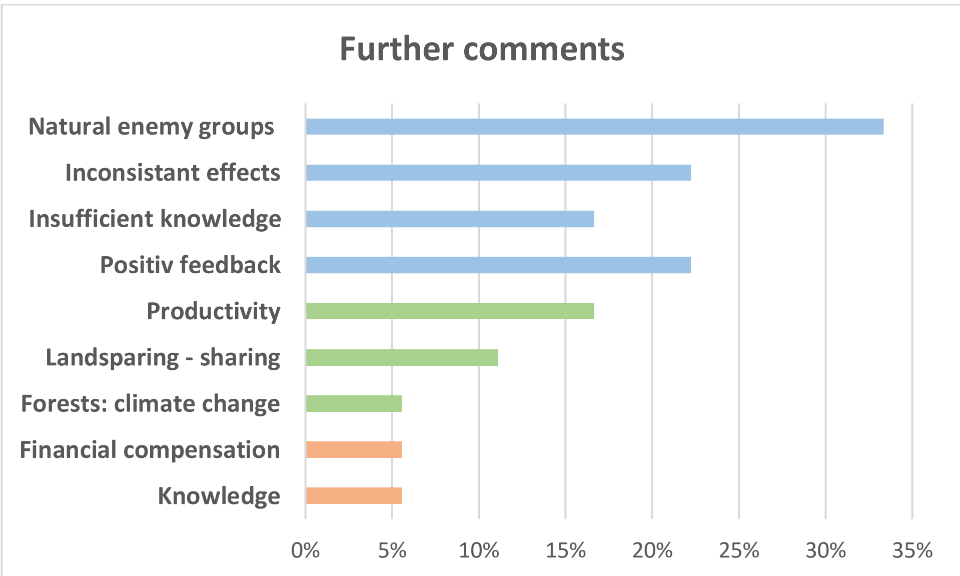


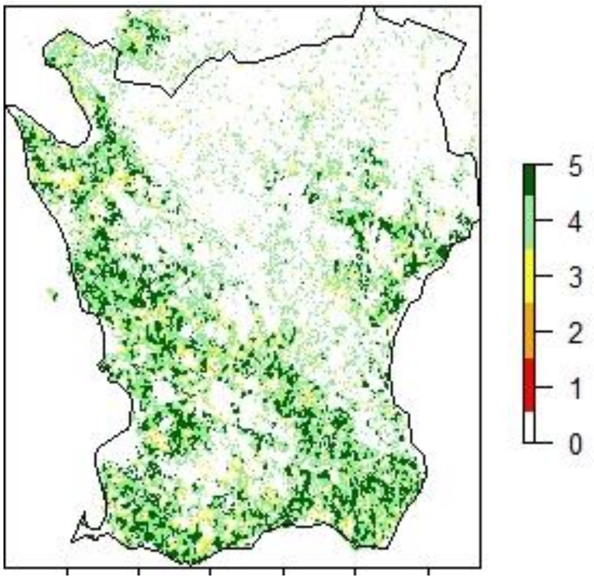
Figure 8: Distribution of categorized answers to the open question: 'Further comments'. Own representation

4.2. The NPCP maps

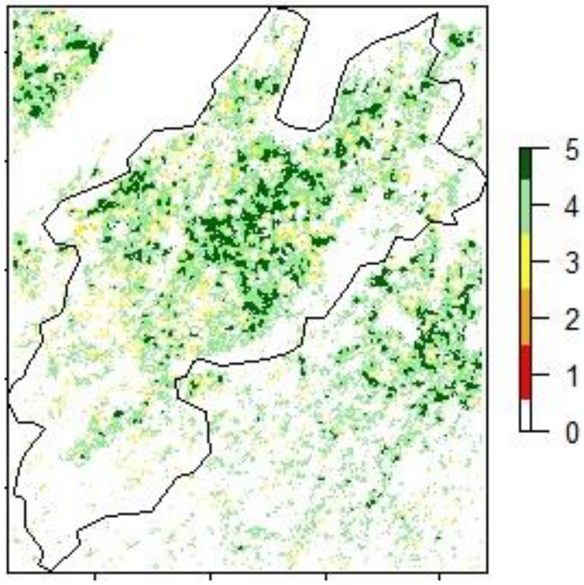
The following maps depicting the NPCP include a color scheme indicating very low potential (=0) to very high potential (=5) on a scale from 0 to 5. To compare among the regions, Figure 9 (A, B, C) shows the NPCP for 'Complete generalists' exemplarily for the three areas.

Scania has the largest amounts of areas with high NPCP, especially along the south and west coast. The more forested northern part of the region has lower scores. Dalarna consists largely of forest, which is depicted as white areas, where no NPC is needed and very little provided. The areas in Dalarna that are agriculturally used show a medium to low potential of NPC. Västra Götaland also contains large areas with low NPCP values, as well as high NPCP spots.

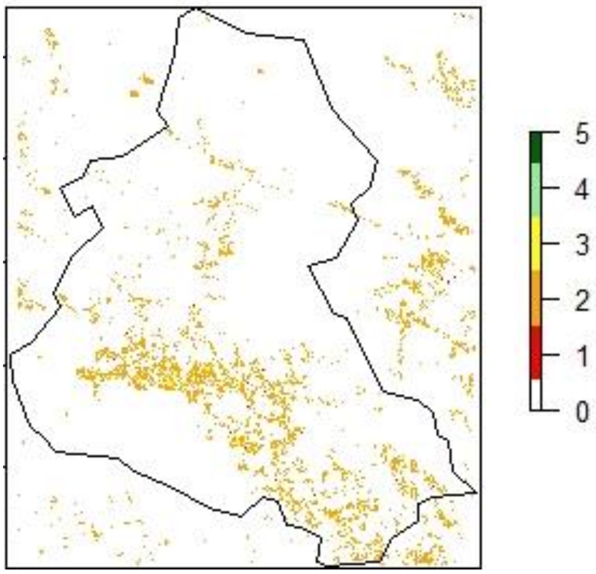
A similar trend can be seen throughout all insect groups (Appendix 9.2.4).



***A**: Scania*



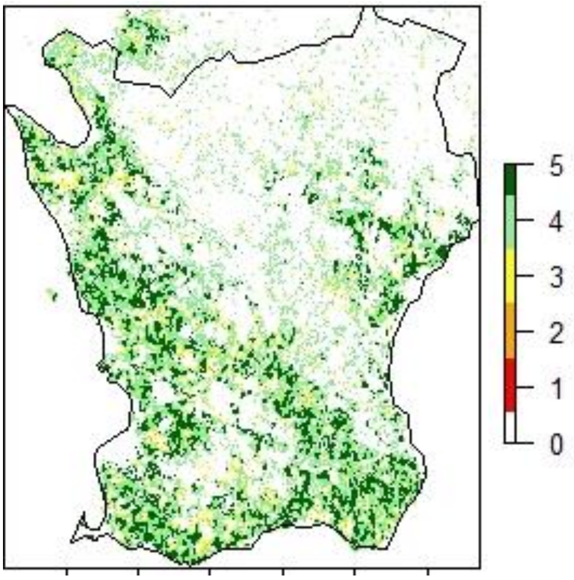
***B**: Västra Götaland*



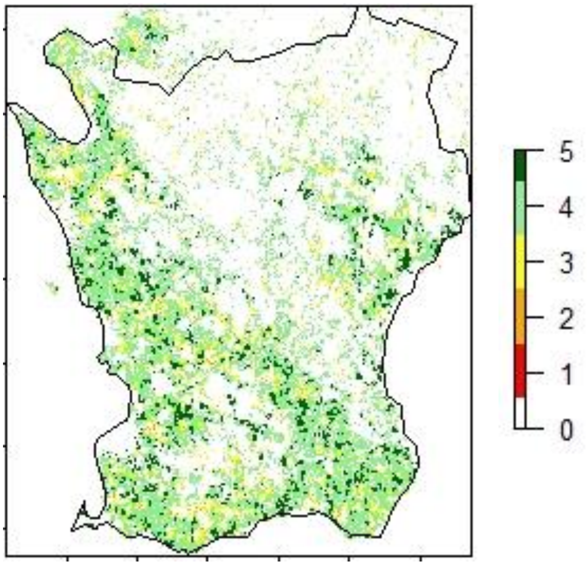
***C**: Dalarna*

Figure 9: NPCP (0-5) of complete generalists of cells (100x100m) representing agricultural fields in the regions of Scania (A), Västra Götaland (B) and Dalarna (C). Representation: Pierre Chopin, SLU.

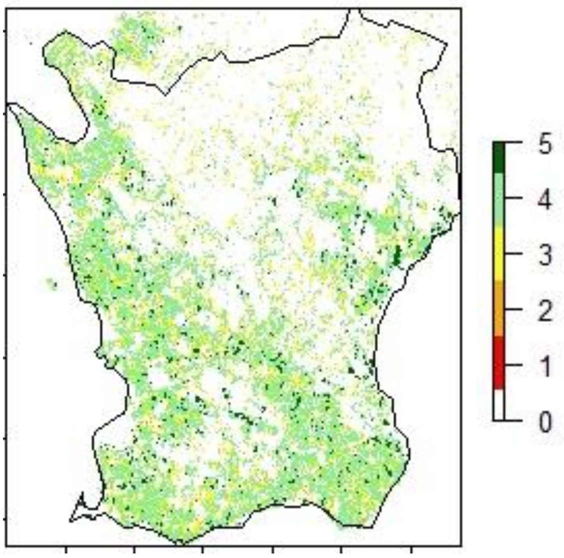
Figure 10 shows the NPCP of ‘Complete generalists’ (A), ‘More specialized predators (B) and ‘Parasitoids’ (C) in Scania. Comparing among the insect groups reveals that the abundance of ‘Parasitoids’ and therefore the NPCP connected to them is the lowest of the three groups, while that of ‘Complete generalists’ is the highest. This trend can also be seen throughout the other regions (Appendix 9.2.4).



A: *Complete generalists*



B: *More specialized predators*



C: *Parasitoids*

Figure 10: NPCP (0-5) of the three insect groups (A,B,C) in cells (100x100m) representing agricultural fields in Scania. Representation: Pierre Chopin, SLU.

5. Discussion

5.1. Discussion of scores

The generation of quantitative scores did not only allow for their application in the model, but also for an easy comparison between the different factors investigated: among the insect groups, between SNH types and between the agricultural changes.

Of the three insect groups investigated, ‘Complete generalists’ have received the highest expert scores throughout all land-use types. The average percentages of agricultural change show that they are the least affected by the aggregation to large fields, which concurs with the findings of Östman (2002), who found ground-dwelling generalist predators to cope well with disturbance such as tillage, and Hanson et al. (2017) even found higher numbers of ground and rove beetles in agricultural fields than in permanent grassland. The confidence with which experts gave these scores is also the highest for this insect group. This can be influenced by the fact that the response of generalists is documented notably more often in the literature (Chaplin-Kramer et al. 2011).

‘More specialized predators’ lay in the middle between the two other groups, both in overall scores but also in how they react to agricultural changes. All of their highest scores are agricultural fields with small sizes and organic management. This concurs with previous studies who found increased numbers of hover flies (Power et al. 2016) and *Dichochrysa* lace wings (Porcel et al. 2013) in organically managed fields, also due to the higher availability of flowers on e.g. field edges. Literature underlines the importance of flowering sources, since hover flies are carnivorous only as larvae but dependent on nectar in their adult stage (Wäckers et al. 2005). These organisms benefit especially from flower strips and flowering crops in general (van Rijn & Wäckers 2016), a measure often mentioned in the open questions.

‘Parasitoids’ have received the lowest scores in nearly all land-use types. They show the lowest reaction to changes in crop diversity, but their reaction to the change to organic management is the strongest of all insect groups. This concurs with the findings of Jonsson et al. (2012), that parasitoids are influenced especially by management changes, and rather less by crop diversity. One of the lowest scores of all was given to parasitoids in forest interiors, which corresponds with the findings of Moonen et al. (2016), who detected that parasitoids largely avoid the interior of forests. Contradicting this, Dyer and Landis (1996) have shown how the combination of the availability of nectar from flowers and the less variable microclimate in the forest can lead to high numbers of the parasitoid *Eriborus terebrans* (*Hymenoptera: Ichneumonidae*). Other than this, literature supports that parasitoids thrive best in landscapes that contain SNH and other non-crop resources (Chaplin-Kramer et al. 2011), which is reflected in high scores given to semi-natural land-use types. 'Parasitoids' received generally low scores of confidence, a reason for which can be that the broad methodological set-up of the scoring in this study is not well suited to capture the nature of specialized parasitoids. One expert phrased this issue as follows: "the more specialist the predators are, the more important it is that their key food source is available in the landscape. If this source is missing, none of the other elements can compensate for this". It is therefore imaginable that experts scored parasitoids lower because they did not know whether suitable conditions (focal crop and respective pest) were provided in the landscape, and the presence of SNH for instance was not as important.

Of the different SNH types, the experts value herbaceous SNH the highest in their ability to support NE abundance, followed by the edge of wooded SNH. This contradicts the scores used by Rega et al. (2018) who strongly value the edge of forested areas the highest. The importance of pastures, however, is well documented, for instance by Rusch et al. (2013), who used the amount of pastures as a proxy for landscape complexity and who show that it "is the main determinant of the level of natural pest control in our system" (p. 351). The ways in which SNH support NE are numerous. The low levels of disturbance associated with them, for instance, allow for good habitats for overwintering (Thomas et al. 1991). Additional food sources, such as the presence of alternative hosts or prey, can augment the abundance of NE (Östman 2004). Similarly can flowering plants that offer nectar and pollen as important alternative feed sources for both predators (Nicholls et al. 2001) and parasitoids (Costamagna & Landis 2004; Lee et al. 2004), which make species rich forests and pastures especially important.

Besides the importance of SNH in the landscape, the expert survey clearly shows that agricultural fields are vital habitats for NE, with some agricultural scores being equal or higher than those of the SNH. How the agricultural areas are managed makes a large difference, since the scores of agricultural fields include both the survey's highest and the lowest scores. Of the changes in the agricultural field, the **management** switch towards organic has received the highest percentage of positive change, supported by the highest expert confidence. Its importance is further underlined by almost half of all experts' answers in the first open question in the survey containing the reduced input of agro-chemicals. These results correspond with the combined findings of the meta-analysis conducted by Garratt et al. (2011), who show that "natural enemy numbers, impact or performance, […] was on average over 30% greater under organic treatments ." (p. 264). In the open questions of the survey, however, one expert noted "that organic pesticides can be harmful to NE as well". Neem oil for instance is an allowed substance to combat insect pests in organic farming, since it is purely plant based, degrades quickly and has a comparatively small environmental impact (Isman 2006). Still, it has been shown to have negative effects on relevant predators (Zanuncio et al. 2016). This draws attention to the fact that dividing the management into two systems is indeed a simplification and that organic practices can also be harmful to arthropods.

The change towards a smaller **field size** of below 3ha has received the second highest percentage of change, and a high confidence score. This is supported by over 60% of experts including the small field size in their ideal landscape.
A field's smaller size makes the actual biocontrol within the field more effective, because it can be penetrated easier from the outside by insects that do not have it as their permanent habitat, or those species that are dependent on external resources (Caballero-López et al. 2012). Besides this, there are also mechanisms through which smaller fields increase the abundance of NE. Configurational advantages allow for easier access to neighboring fields, and make different resources more easily accessible in a small radius (Batáry et al. 2017). Additionally, field edges oftentimes contain semi-natural structures such as hedgerows or grass strips. A landscape with smaller fields can therefore have more small scale natural habitat patches (Figure 11, A), making spillover into the field easier (Tscharntke et al. 2012). A high edge-density was considered part of their ideal landscape by almost 30% of experts, underlining their perceived importance. Finally, small fields also contribute to crop compositional diversity (Figure 11, B.). A small-mosaic landscape leads to a larger number of individual fields in a certain area, allowing for a larger diversity of crops to be present. Interestingly, the change from medium to small fields (<3ha) is deemed to have a stronger impact than from large (>7ha) to medium-sized fields. This gives insight that the effect of field size does not seem to be linear but increases with a higher edge – area ratio.
However, there are species that are hypothesized not to profit from such a landscape, namely those that require a large minimum habitat area (Batáry et al. 2017).

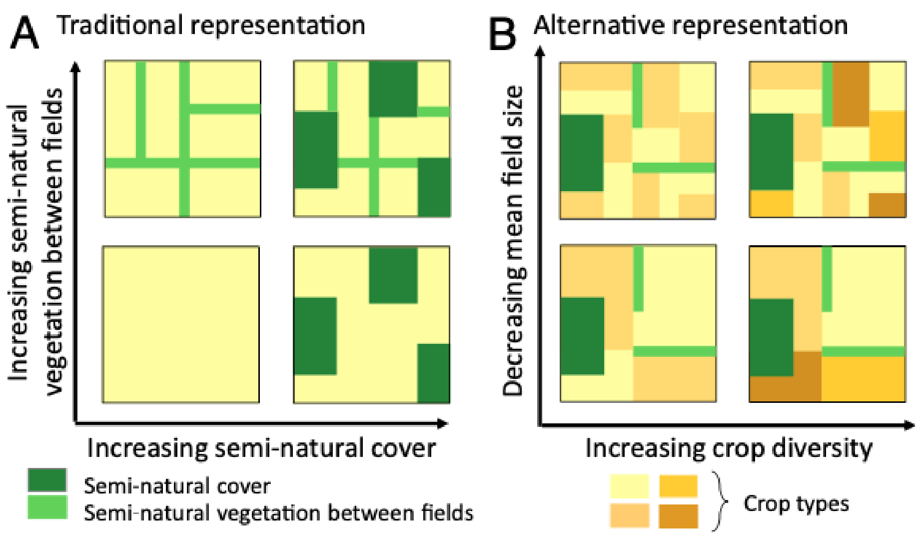


Figure 11: Effects of A.) increasing SNH in the landscape and between fields, B.) decreasing field size and increasing crop diversity. Taken from: Sirami et al. 2019

The third agricultural change, ‘diversification of the **crop rotation’** has been estimated to have the lowest impact, and experts were the least confident in scoring it. However, almost 70% of experts named crop diversity as part of their ideal landscape. The vital role of crop diversity for the abundance of natural enemies has been deeper explored in recent years by numerous studies. Redlich et al. (2018), for instance show “that crop diversity augments natural enemies and biological control.” (p. 2425). Mechanisms in which an increased crop diversity can enhance the abundance of NE are numerous. Especially the availability of a larger variety of complementary resources is important for generalist species (Palmu et al. 2014) and can provide continuous availability throughout the seasons.

The **scale** at which the insect groups are influenced by their surrounding landscape was not answered clearly in the literature and was therefore included in the expert survey as well. The results reflect this inconsistency, with high inter-quartile rates for all groups. The medians used in the model, however, concur with the dominating findings in the literature. In their comprehensive meta-analysis for instance, Chaplin-Kramer et al. (2011) found that “specialization influences the scale at which arthropods respond to landscape complexity”, with more specialized insects, such as parasitoids, reacting to their surrounding at a smaller scale.

5.2. Discussion of maps

The creation of the maps allowed to visualize the results of the survey and compare between the strongly different landscapes in the regions in Sweden.
Surprisingly, Scania has the largest amounts of very high NPCP areas of the three regions. While the more forested north-east of the region can be termed diverse, Scania’s south-west has low landscape diversity. Here, the NPCP values were expected to be lower, since intensive management, homogenization and low numbers of semi-natural structures are often connected to lower abundance of NE (Rusch et al. 2016). These numbers can partially be explained by the additive approach used to generate the agricultural scores, a means of simplification that is thought to increase the scores of multifactorial fields (e.g. organic, small, diverse rotation) artificially. However, the numbers do reflect that the high amounts of agricultural fields increase the number of those NE that thrive in this land-use type, such as certain predatory arthropods (Hanson et al. 2017). Furthermore, Scania has a high need for NPC due to the economic importance of the sectors. The large amounts of oil seed rape cultivated in Scania, for instance, and the crops dependence on pollinating insects make a reduced insecticide application especially important, underlining the value parasitoids play in this region, since they are key species in suppressing many common oil seed rape pests (Alford 2000).
Similarly high values of NPCP are shown on the map of Västra Götaland. This concurs with the input of many experts, who describe many characteristics of the more diverse region as part of their ideal landscape. It also overlaps with findings of many studies, that generally name more extensive agriculture (Garratt et al. 2011;

Puech et al. 2014), high amounts of SNH and a general structural diversity (Rusch et al. 2013) as factors increasing NPC.

The low values in Dalarna can largely be explained by the comprehensive cover of forest, which contributes very little to the NPCP score. It also underlines that large areas of infrequently disturbed, natural habitat do not per se benefit all biodiversity. Especially the NE species investigated in this report are adapted to and therefore dependent on open, agricultural landscapes (Sotherton & Self 2000). At the same time it can be assumed that the need for NPC is lower in this region, since its agricultural production is largely ley-based, a crop in which insect pests do not play a major role.

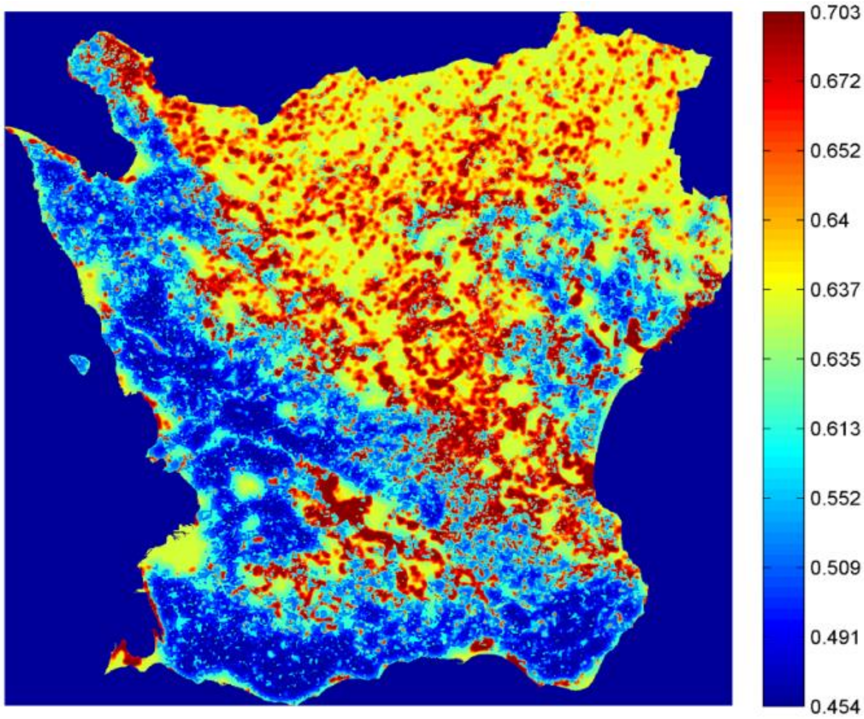


Figure 12: Natural pest control map of Scania taken from Dänhardt et al. (2016)

Comparing these maps to similar ones created in the past reveals a very stark difference. Figure 12 shows, that the map created by Dänhardt et al. (2016), based on the model by Jonsson et al. (2014), have almost inverse values to the one created in this project. The main reason for this is that agricultural fields were not included as suitable habitat in the model, and only SNH added value to a regions NPC potential. While the proportion of non-crop land is regularly used as a proxy for landscape diversity, there are studies showing that some NE do not always profit from landscape complexity (e.g. Woodcock et al. 2010; Riggi et al. 2017). A further breaking down of influencing factors can therefore increase the accuracy of maps.

While the very high scores of agricultural fields in our maps might be slightly artificially increased, attributing them no positive impact is a very strong simplification since their value as habitats has been shown by various studies (e.g. Hanson et al. 2017). Disregarding this can indeed lead to completely different

assessment of the NPCP in a certain area, which underlines the importance of the paradigm regarding which landscapes are more important for NE.
Recommendations to policy makers need to find a middle ground, understanding that despite the high scores south-west Scania is not the ideal to strive for, while promoting only SNH is also coming short.

5.3. Methodological discussion

The actual NPC service is difficult to value. Using the expert elicitation method led to a better understanding of this highly complex issue in the time frame available, promising feasible and valid results that reflect the biophysical reality (Roche & Campagne 2019). The additional analysis of the inter-rater reliability to test for the data's validity resulted in a moderate reliability, but the results are still very valuable if this is communicated transparently (Campagne & Roche 2018). The low agreement between experts is attributed mainly to the complexity of the issue with its many components. Additionally, the numerous simplifications that were necessary and that will be discussed farther below, are assumed to have added to the disagreement.
While the number of studies mapping ES in general has steadily risen over the past years, NPC is among the least visualized ones (Englund et al. 2017), making the work of this report especially important. Additionally, we have been able to address many more factors than previous models (e.g. Petz & Oudenhoven 2012; Rega et al. 2018) and thus achieved a more detailed map. However, an inherent problem of mapping is that it ignores the underlying processes and depicts solely the 'end product'. While this can help to visualize and draw connections on a larger level, it does not per se add new scientific findings about the process NPC.

The final result is the product of balancing the three steps of the report: the survey, the modelling, and the mapping. The seemingly endless possibilities of the geographical data and the equally never-ending complexity of the system of natural pest control is largely limited by what can be modelled and what factors can be quantified by experts. The final result is therefore an effort to simplify a highly complex system with innumerable interactions, aiming to find a middle-ground between questions such as 'what is relevant based on the literature?', 'what scores are possible to elicit from experts?' and 'what can be mathematically modelled and later depicted in the map?'. The major steps of simplification as well as other drawbacks are discussed here.

The **abundance** of NE is a frequently used indicator for NPC (Moonen et al. 2016; Redlich et al. 2018). However, the mechanisms underlying the process to the ES actually provided are a lot more complex, as is framed by Bianchi et al. (2006): "The benefit to the farmer of a diversified landscape […] is increased when (i) the natural enemy populations are higher and more diverse, (ii) natural enemies

substantially colonize arable fields, (iii) they significantly reduce pest densities, (iv) thereby reducing damage levels and (v) increasing yield or quality and (vi) benefits outweigh costs.” (p. 1716). This shows that there are numerous steps, at which the provision of the ES can be intersected, even in the ideal landscape for NE.
One of these tainting mechanisms is that many of the insect-friendly measures discussed above do not only enhance NE, but pests as well. SNH, for instance, can also be a source from which pests invade agricultural fields after hibernation (Denys & Tscharntke 2002). The line between the enhancing effect for NE and the facilitated entrance for pests is thin and depends on the surrounding vegetation and crop at hand (Bianchi et al. 2006; Perez-Alvarez et al. 2018). An increased crop diversity can also limit the spread of pests, by increasing the distances between host crops (Rusch et al. 2013), while a decrease in field size might facilitate the infestation between fields. Furthermore, SNH or leys can act as sinks for NE: the often suitable habitat conditions increase their number, but do not necessarily promote their migration to agricultural fields, especially if the prey availability is lower in the latter (Bommarco & Fagan 2002). Zooming in even farther, increased numbers of a species can lead to negative effects within the population, as well as between antagonistic NE taxa (Letourneau et al. 2009). Finke & Denno (2002) demonstrate, however, that the availability of patches of SNH offers microhabitats that reduce this intraguild predation.
All in all, the abundance of NE was chosen as the best proxy for NPCP, since their abundance is the main driver in the process (e.g. Chaplin-Kramer et al. 2011). Additionally, literature supports that many of the factors that benefit NE abundance also positively influence predation and parasitism rates as well as a reduction in pests in general. The overall positive effects of a diversified crop rotation for instance are demonstrated by Redlich et al. (2018): “an increase from one to three dominating crop types enhanced BCI (biological control) by up to 33%” (p.2425).

The effects of species **diversity** are neglected in this report, since its contribution to the magnitude of NPC is less straight forward (Letourneau et al. 2009). An increased complexity in the food web can even lead to different NE species feeding on each other, resulting in less predation on herbivores down the trophic cascade and eventually a reduced NPCP (Finke & Denno 2004). Species diversity, however, plays an important role in the stability of the provision of the ES (Shackelford et al. 2013; Harrison et al. 2014).

A further simplification as part of the modeling is the treating of all factors as **linear**. This is very unlikely to reflect the actual relationship between the abundance of NE and the presence of the investigated land-use factors. With a rising amount of pasture in the landscape for instance, NE abundance is more likely to reach a peak and then drop down again or level out. However, this kind of complexity (e.g. ‘How much does a 5% increase of herbaceous SNH area from 5 to 10% influence NE in the landscape compared to when it is from 55 to 60%?’) was too specific to ask experts to rate or describe.

A similar issue that would have been possible to model, but very difficult to score through an expert survey are **configurational aspects** such as shapes, patches, patterns, or combinations of the SNH investigated. The only distinction made in this report is between the edge and interior of forested areas, which automatically values free standing tree strips (score of SNH wooded edge) higher per surface area than a large, conglomerated forest. Through the collection of primary data by Moonen et al. (2016), Rega et al. (2018) were able to distinguish between areal and linear shapes of SNH and thus integrated configurational heterogeneity better in their maps. The importance of this aspect is underlined by experts describing their ideal landscape using phrases such as '[fields] separated by SNH', 'surrounded by hedgerows and small woods' or 'highly patchy'. One expert phrased this fittingly, saying that the length of fields did not matter as long as "their width [is] at a maximum 2 times the width of the machinery". The pinnacle of this issue is that **landscape diversity** per se is not counted as valuable in the model. In our results, the highest NPCP score would be given in a landscape that is completely organic, diverse, small scale, which – again – is unlikely to reflect the reality.

The shape of the **distance function** is another simplification. The bell-shape that values closer land-use types higher, has been applied in mapping approaches such as ours (Rega et al. 2018), and is suitable because it allows to combine field- as well as landscape factors in one model. However, there are studies that show that insects can react to changes farther away equally significantly (Chaplin-Kramer et al. 2011).

While the model treats the presence of different factors as simply additive, their interrelationship is more complex, and it is very likely that there are **interactions** between factors that influence the abundance of NE. The most obvious issue lies in the aggregation of the three agricultural factors, which are just 'added on top of each other' in our model. Sirami et al. (2019) for instance note that "increasing the diversity of crops available in the landscape may benefit biodiversity in a given field only if fields are small enough for adjacent fields to be reached easily" (p.16443). Similar connections are made between crop diversification and the presence of SNH, with various hypotheses existing in the literature. The 'intermediate landscape-complexity' hypothesis, for instance, describes that the effect of a positive agricultural change on biodiversity are highest neither in already diverse, nor in extremely simplified landscapes, but in intermediate ones (Tscharntke et al. 2012). Such interactions between factors are also mentioned by experts in their description of the ideal landscape. One expert's comment is in line with the hypothesis mentioned above, explaining that "in more complex landscapes (higher percentage of semi-natural/natural habitats) parameters of the arable land portion have less significance". Contrary to this, another expert argued that agricultural diversity only has a positive effect in landscapes that already include SNH ("you may have an additive or synergistic effect if you have longer and diversified rotations in landscapes that have also all the other elements described above (at least 20-30% SNH) but the effect size of this management option alone is quite low otherwise"). The fact that these interactions do not – unlike some hypotheses suggest – always seem to follow clear rules and vary between taxa and at different scales (Redlich et al. 2018) was the main reason for leaving them out of the model. They are also assumed to be hard to verbalize for experts and therefore not suitable to investigate deeper in the survey. Still, these multi-dimensional interactions are one of the main reason why causal connections are so hard to make in the system of NPC in the landscape (Fahrig et al. 2015), and need to be kept in mind when interpreting the results.

A further limitation for the sake of simplification was to **group** different insects and factors together. The division of all natural enemies into three groups is already more detailed than many other studies and was deemed the maximum in order not to overwhelm the experts in the questionnaire. Still, each category is rather heterogenous and contains sub-groups that might show very different reactions to factors, which was also mentioned repeatedly in the comment section of the survey. One expert commented on this, that "the grouping of insects is quite general while we know that species within these same groups can have distinct responses to landscape and dispersal capacities". Similarly simplifying was the grouping of the land-use types, many of which could have been divided into further sub-categories. An example for this are the different effects grassland management (e.g. mowing vs grazing) has on NE (Nagy et al. 2020), based on which herbaceous SNH could have been split into more detailed groups.

Concerning the **agricultural factors**, there is a long list of additional influences that were not included in the model, many of which were raised by the experts. Spatial diversity within the field, through intercropping or agroforestry for instance, can enhance NE abundance through a larger variety of resources (Andow 1991), as do flower strips (Tschumi et al. 2016). Reduced tillage is shown to benefit especially ground dwelling predators (Puech et al. 2014). Cover crops over the winter months can increase the diversity and number of NE in the spring by adding habitat complexity during a time in which crop habitats are low (Bowers et al. 2019). Besides this, several other agricultural practices are deemed to be beneficial (Landis et al. 2000).

5.4. Discussion in a bigger context

Connecting the results from the survey back to the ES cascade framework, they show how our shaping of the landscape – the biophysical structure – influences the provision of ES. Our land-use on the larger- as well as on the small-scale are the basis of the possible NPC in an area. The results also show the potential that lies in using the existing knowledge and implementing it to increase the abundance of NE. The open questions have revealed numerous concrete practices how farmers and practitioners can better support NE: from more diverse crop rotations, smaller field sizes and reduced insecticide applications to setting up beetle banks, flower strips and intercropping. The notion that – unlike often communicated – production surfaces do not have to be reshaped to semi-natural areas to support NE is especially promising. Crop diversification and other in-field measures are effective and applicable alternatives.

This also needs to be recognized by policy makers that have the power to set incentives and support landowners in implementing these changes. Such policies are imperative in order to shape landscapes at a larger scale. Land management strategies need to be created, verbalized, and implemented properly. Here, the maps can contribute to a better communication of how land management and farming practices can be integrated into the larger landscape, based on the respective area. In Scania, the very intensively managed fields hold the large potential of offering benefits by extensification and a decrease the field size. An increase in tree strips and other linear wooded structures would additionally benefit in controlling wind erosion. Västra Götaland already consists of large amounts of SNH and would benefit mainly from agricultural diversification measures. The large forest areas of Dalarna are an integral part of the region, making an increase in herbaceous SNH difficult. Therefore, agricultural diversification measures are integral for the region to better harness NPC.
Recommendations for further research are numerous, due to the complexity of the issue. While many projects already studied the numerous components of NPC on their own, investigations of the entire system at once including the interactions between the components still remains rare. Especially the final effect on yield - the actual 'Benefit' of the cascade – allows for deeper research. Furthermore, the integration of NPC-promoting practices with other ES as well as other overall goals would be interesting. This has been done for NPC and pollination, showing that these particular ES can well be pursued at once, as they are both insect driven (Shackelford et al. 2013). A similar comparison with e.g. herbicide reduction or time-efficient production, might result in potential trade-offs, the discussion of which can help practitioners form a clearer strategy in balancing priorities.

All in all, the harnessing of NPC can contribute substantially to reduce crop damage by pests (Jonsson et al. 2014). This is vital on the one hand to sustain high yields needed to feed a growing population, and on the other hand offers an important puzzle piece towards ecological intensification. Experts perceive NPC as a very promising solution to reduce the application of pesticides, which can have many positive effects, such as environmental benefits through a reduced pollution of surrounding ecosystems by agro-chemicals. Besides this, a stable NPC helps break the cycle of dependence, in which an initial disruption of the system makes use of pesticides necessary and vice versa the use of pesticides disrupts the provision of NPC. This way, the agricultural system can become more resilient to future challenges and more agroecological in moving away from constant intervention to an ecological balance.

6. Conclusion

In this study, the connection between land-use types and the NPC provided by NE was investigated. Scores quantifying this relationship and were generated through an expert survey, and in order to upscale and visualize these findings, NPCP was modelled and mapped for three Swedish regions exemplarily.

The results show that semi-natural areas such as forest patches, pastures and permanent leys are valuable habitats for insect predators and parasitoids by offering food resources and refuge. Additionally, despite the frequent disturbance, agriculturally cultivated areas also contribute immensely to the NPC provided in a region. The stark differences to similar maps created in the past can contribute to fueling the scientific discussion and eventually lead to a paradigm shift and a more holistic approach of how to account for NPC.

How we farm makes a large difference in how insect-friendly a field is. The reduced application of pesticides, a reduction in tillage, more diverse crop rotations and smaller fields are only a few of the practices identified in this report that can contribute to a more abundant NE community. Contradicting the persisting notion that only semi-natural, but not agriculturally used areas, are valuable habitats for insects, the findings of this report offer insights that production and insect support can indeed go hand in hand. This is especially promising for farmers, as well as policy makers to be included in funding and shaping the agricultural sector.

Here, the creation of the maps can contribute to a better communication with stakeholders and help bridge science and applied, in-field solutions. The maps show that the potential of the investigated regions in Sweden in harnessing the provision of NPC is large, by increasing the diversity of semi-natural structures or applying even a few of the agricultural changes discussed. It holds the possibility to significantly diminish the levels of pests, thus reduce the dependence on insecticides and (together with the integration of other ecological principles in the agricultural production) offers an important puzzle piece of the ecological intensification. Simultaneously, it brings up the question of multifunctionality in our landscapes and how productive and ecological values, but also recreational and cultural ones can and need to be balanced. We need to shape landscapes that fulfill multiple services, that are versatile and resilient, and include all land-users.

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Finally, I want to thank my family for their constant encouragement and making my education possible in the first place. You are awesome and your support throughout my sometimes not very straight-forward life choices means the world to me.

9. Appendix

9.1. Additional background to Methods

9.1.1. Expert elicitation background

Figure 12 shows various options of how the in the thesis required knowledge could be generated, depending on the data available and the precision needed in the outcome. Since the model does not include details about the underlying process and the map aims to give a rough overview rather than an exact amount of natural pest control in the landscape, tier 1 was deemed precise enough. Therefore, the method of expert elicitation was chosen.

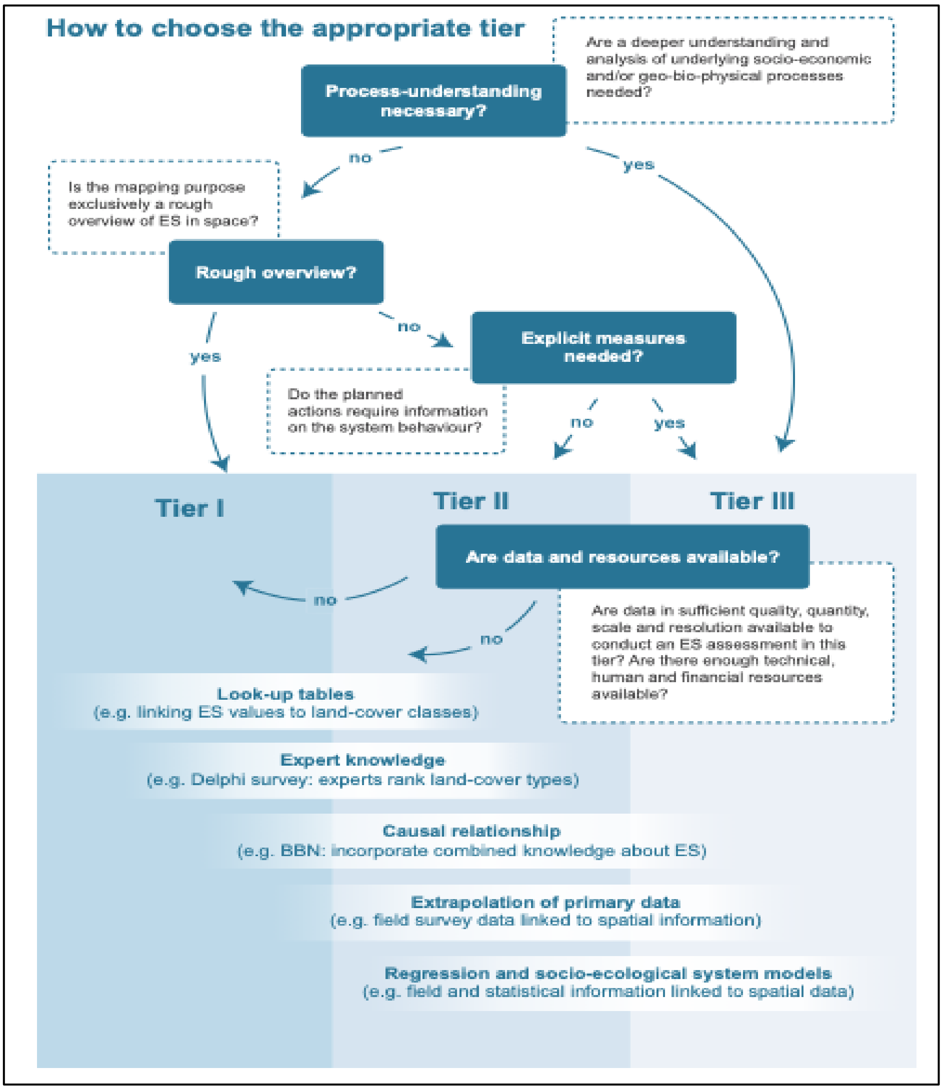

Figure 13: Decision tree on tiered methods for ES mapping. Taken from: Burkhard and Maes (2017)

9.1.2. Expert elicitation survey

What we do:

The map is created by using an enhanced version of the spatially explicit model applied by Rega et al. (2018), which uses the abundance of natural enemies as an indicator for the ecosystem service Natural Pest Control and acknowledges that different landscape factors have a different influence on natural enemies. In this project we developed this model further by recognizing the impact of various agricultural factors as well as the differences in the response of a wider array of insect groups. Interactions between factors (e.g. between the amount of semi-natural habitat and crop diversity in the landscape) are not accounted for. In the model, natural pest control is considered as an additive effect of each field and landscape factor. The factors are linear and their influence in space is greater when their distance is closer to the field of interest.

Method:

Through an extensive literature review, a strong variety between factors was identified. In this survey you will be asked to rate the capacity of different influencing landscape factors to support the three main natural enemy groups.
The following section describes the six investigated factors in more detail, three of which are categorized again by their intensity (e.g. crop rotation). This is followed by more precise scoring instructions including examples.

Definition of influencing factors (fixed variable):

Table 5: Definitions of influencing factors

Factors	**Definition**
Semi-natural habitat herbaceous	- Less than 30% of canopy cover wooded - Minimum of 5 years not ploughed - Can be mowed or grazed -Includes: permanent and semi-natural pastures, field margins, riparian buffers, permanent ley…
Semi-natural habitat wooded	- More than 30% of canopy cover wooded - Any perennial plant >1m height counts as wooded (trees, shrubs…) - Divided into: - **edge**: exterior 10m of forest - **interior**: farther than 10m into the forest

Organic management	- used as an indicator for a less intensive management style - based on EU standards - main focus on a <u>reduced use of chemical plant protection agents</u> and synthetic fertilizer
Conventional management	- used as an indicator for a more intensive management style - availability of chemical plant protection agents and synthetic fertilizer
Crop rotation	- Indicator for temporal crop diversity as well as for spatial crop diversity (in combination with field size) - Division into functional groups rather than individual crop species. **Legumes**: Field beans, peas, lentils… **Cereal**: Wheat, rye, barley, oat… (spring and fall sown) **Corn**: Corn crops **Grass**: For seed production (e.g., clover), harvested only once **Ley:** For production of silage and hey, also fodder crop mixes: Cut several times per year, usually occupies min. one winter **Flowering crops**: Oilseed rape, sunflowers (non-legume and non-ley) **Roots**: Sugar beet, potatoes, fodder beet… **Vegetables**: Horticultural crops (e.g. spinach, cabbage...) **Others** **Categories:** The basic crop rotation is defined by 3 functional groups, while a simple one contains only 2. A diverse crop rotation contains 4 functional groups AND/OR **lay**.
Field size	- Overall area of one agricultural field - Sometimes divided by a machine track or grassy borders - Shape is neglected **Categories**: - Medium: 3-7 ha (based on the Swedish average in the different regions), - Small fields: below 3 ha - Large fields: above 7ha.

<u>Definition of insect groups (effect variable):</u>

The insects relevant for natural pest control are divided into three different groups. The rating of the influence of specific landscape factors on the insect groups focuses on the abundance of the certain insects in the <u>overall landscape</u>. This is especially important when considering parasitoids, who technically mostly occur in their focal crops. In this scenario the abundance is rated independently of the crops present in the area.

Table 6: Division into insect groups and examples

Insect group	Definition
Complete generalists	- Wide preference in prey - Includes: spiders, ground beetles (Coleoptera, Carabidae), Rove beetles (Staphylinidae)…
More specialized predators	- Includes: coccinellids (Coleoptera, Coccinellidae), lacewings (Neuroptera, Chrysopidae), hoverflies (Diptera, Syrphidae)…
Parasitoids	- Reduction of pest population through parasitism - Includes: parasitic wasps, (Hymenoptera: Braconidae, Aphidiinae)…

Figure 14: Example of average Swedish landscape (Google Earth). While the wooded semi-natural habitats are easily spotted, the herbaceous ones were circled in orange.

The scoring scenario:

The scoring in this survey is conducted in a hypothetical area. We imagine an **average Swedish landscape** similar to the region south of Lake Vänern (example: Figure 1), which is dominated by conventional, cereal-based agriculture and contains low levels of semi-natural habitats. The precise area, shape and distance of these landscape elements is irrelevant. In this base scenario all characteristics of the agricultural fields are also the Swedish average: conventionally managed with a size between 3 ha and 7 ha and a crop rotation consisting of 3 functional groups (e.g., cereal, root crops, oilseed rape). It is a regular day, where the season and the weather conditions do not influence the presence or absence of the natural enemies.

Instructions:

In **part 1** you are asked some questions about your experience in the work field.

In **part 2** you are asked to rate the capacity of one specific landscape factor present in our hypothetical landscape to support the abundance of each of the three natural enemy groups in the overall landscape. Here, it is important that imagined proportion, shape of habitat patch and configuration in the landscape of the factor in focus do not influence the scoring, only the landscape 'type' is of importance.
We use a scale from 0 to 10, where for instance an answer of 8 indicates it is twice as 'good' as 4. The numbers do not represent absolute values but rather depict the relative potential across the different factors. Furthermore, we do not have the aspiration for a perfectly precise result, but rather want your perception.
Additional to each question, you will be also asked to state your confidence (scale 1-3) on the score you have given.
The following example is meant to double-check your understanding of the question type, not your knowledge.

Example:

You have just recently read (or even published) a paper in the journal 'Bird Studies' on how leaving small patches non-seeded ('lärkrutor') within your agricultural fields can create valuable breeding spots for the *Eurasian Skylark* (*Alauda arvensis*), a bird species dependent on agricultural fields whose dropping numbers are largely connected to an intensification of agricultural production. Other bird species in agricultural regions do not profit from these conservation measures quite as much.

How do you estimate the capacity of non-seeded patches within cultivated fields to support the following bird species?		
Eurasian Skylark *(Alauda arvensis)*	**Whinchat** *(Saxicola rubetra)*	**Eurasian Curlew** *(Numenius arquata)*
☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”

In **part 3**, you are presented with a change in the hypothetical landscape that differs from the base case in one specific factor (e.g. the management type of the agricultural fields). Other than this, all characteristics stay the same. Here, you will be asked to choose one category by which the new scenario is better or worse in achieving a certain goal. As an example, + 100% would indicate that the new scenario is two times as good as the base scenario, while -50% would be a reduced potential by half.

<u>Example:</u>

<table>
<tr><td colspan="3">How much better/worse does a field (5ha) with four non-seeded buffer strips (4m²) support the Eurasian Skylark than with two strips (4m²) as described in the base scenario. Choose a category of percentage of improvement (+)/worsening (-).</td></tr>
<tr><td>Eurasian Skylark (Alauda arvensis)</td><td>Whinchat (Saxicola rubetra)</td><td>Eurasian Curlew (Numenius arquata)</td></tr>
<tr><td>☐- 50 to - 100% = considerably worse
☐-20 to -50%= notably better
☐-1 to -20% = slightly worse
☐0 = no change
☐+1 to 20% = slightly better
☐+20 to 50%= notably better
☐+ 50 to 100%= considerably better
☐+100 to 200% = extremely better
☐X = I don’t know</td><td>☐- 50 to - 100% = considerably worse
☐-20 to -50%= notably better
☐-1 to -20% = slightly worse
☐0 = no change
☐+1 to 20% = slightly better
☐+20 to 50%= notably better
☐+ 50 to 100%= considerably better
☐+100 to 200% = extremely better
☐X = I don’t know</td><td>☐- 50 to - 100% = considerably worse
☐-20 to -50%= notably better
☐-1 to -20% = slightly worse
☐0 = no change
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☐+20 to 50%= notably better
☐+ 50 to 100%= considerably better
☐+100 to 200% = extremely better
☐X = I don’t know</td></tr>
<tr><td>How confident are you with this score?</td><td>How confident are you with this score?</td><td>How confident are you with this score?</td></tr>
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☐2 = “I feel fairly confident with my score”
☐3 = “I feel confident with my score”</td><td>☐1 = “I don’t feel confident with my score”
☐2 = “I feel fairly confident with my score”
☐3 = “I feel confident with my score”</td><td>☐1 = “I don’t feel confident with my score”
☐2 = “I feel fairly confident with my score”
☐3 = “I feel confident with my score”</td></tr>
</table>

Finally, in **part 4** you will be asked a general question about the three natural enemy groups as well as two open questions about natural pest management in general. Here, you also have the opportunity for further comments.

Survey

Introduction questions:

How many year of experience do you have in the field (natural enemies in a landscape ecology context)?

I am working in the following field:

- Academia
- NGO
- Governmental organization
- Others:

Direct scoring questions:

How do you estimate the capacity of the *herbaceous semi-natural habitat* to support the abundance of the following insect groups in the landscape:		
‘complete generalists’?	**‘specialized predators’?**	**‘parasitoids’?**
☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don’t know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”

The second semi-natural habitat type – **wooded** - is divided into its edge and its interior. The *edge* is defined as the 10 meters of the forrested area directly adjacent to another habitat type (e.g. pasture, agricultural field). The *interior* is everything farther than 10 meters inside the forested area.

How do you estimate the capacity of the *edge* of *wooded semi-natural habitat* to support the abundance of the following insect groups in the landscape:		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

How do you estimate the capacity of the *interior of wooded semi-natural habitat* to support the following insect groups in the landscape:		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

How do you estimate the capacity of the *agricultural fields* (conventional, average size: 5 ha, crop rotation with 3 functional groups) to support the following insect groups in the landscape:		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know	☐0=no relevant capacity ☐1 ☐2= low relevant capacity ☐3 ☐4 = relevant capacity ☐5 ☐6= moderate relevant capacity ☐7 ☐8=high relevant capacity ☐9 ☐10= very high relevant capacity ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

Percentage questions:

How much better/worse would the agricultural fields in the landscape support natural enemies if they were managed completely ***organically***? Other than this change, all characteristics stay the same as in the base scenario. Give a number indicating the percentage of improvement(+)/worsening(-).		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably worse ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably worse ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably worse ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

How much better/worse would the agricultural fields support natural enemies in the landscape if they were divided into *more, small field (below 3 ha)* (surface area stays the same)? Other than this change, all characteristics stay the same as in the base scenario. Give a number indicating the percentage of improvement/worsening.		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
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How much better/worse would the agricultural fields support natural enemies in the landscape if they were aggregated into <u>fewer, *larger fields (above 7 ha)*</u> (surface area stays the same)? Other than this change, all characteristics stay the same as in the base scenario. Give a number indicating the percentage of improvement/worsening.		
‘complete generalists’?	**‘specialized predators’?**	**‘parasitoids’?**
☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don’t know	☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don’t know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don’t know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”

How much better/worse would the agricultural fields support natural enemies in the landscape if they all had a *<u>diverse crop rotation (min. 4</u> functional groups/includes lay)*? Other than this change, all characteristics stay the same as in the base scenario. Give a number indicating the percentage of improvement/worsening.		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

How much better/worse would the agricultural fields support natural enemies in the landscape if they all had a ***simple crop rotation (max. 2** functional groups*)? Other than this change, all characteristics stay the same as in the base scenario. Give a number indicating the percentage of improvement/worsening.		
'complete generalists'?	**'specialized predators'?**	**'parasitoids'?**
☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐-50 to -100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know	☐- 50 to - 100% = considerably worse ☐-20 to -50%= notably better ☐-1 to -20% = slightly worse ☐0 = no change ☐+1 to 20% = slightly better ☐+20 to 50%= notably better ☐+ 50 to 100%= considerably better ☐+100 to 200% = extremely better ☐X = I don't know
How confident are you with this score?	**How confident are you with this score?**	**How confident are you with this score?**
☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"	☐1 = "I don't feel confident with my score" ☐2 = "I feel fairly confident with my score" ☐3 = "I feel confident with my score"

Further questions:

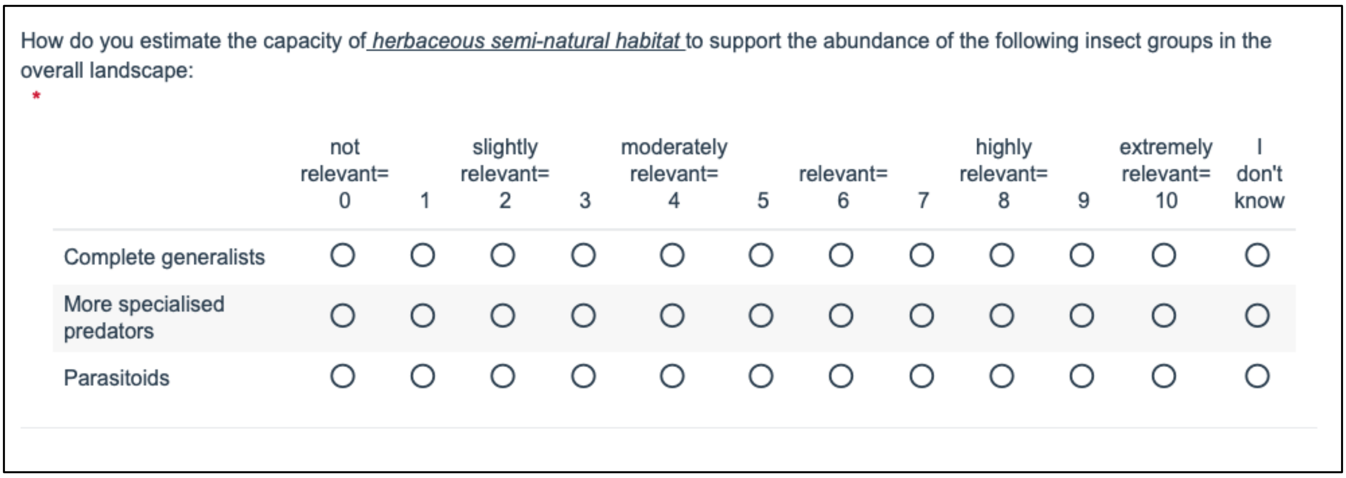
At which spatial scale are the three insect groups influenced by their surrounding landscape? Give a number between 0 and 2000 meters.		
‘complete generalists’?	**‘specialized predators’?**	**‘parasitoids’?**
Distance =	Distance =	Distance =
How confident are you with this number?	**How confident are you with this number?**	**How confident are you with this number?**
☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”	☐1 = “I don’t feel confident with my score” ☐2 = “I feel fairly confident with my score” ☐3 = “I feel confident with my score”

Open questions:

- In a few sentences, describe your ideal agricultural landscape in which (all) natural enemies can thrive best. This can include a combination of the elements discussed in this survey as well as additional agricultural and landscape factors.
- Describe the role of pesticides used in this perfect landscape:
- If you have any additional comments, you can tell us here:

Thank you very much for your participation!

9.1.3. Extracts from the online survey



How do you estimate the capacity of _herbaceous semi-natural habitat_ to support the abundance of the following insect groups in the overall landscape:
*

	not relevant= 0	1	slightly relevant= 2	3	moderately relevant= 4	5	relevant= 6	7	highly relevant= 8	9	extremely relevant= 10	I don't know
Complete generalists	○	○	○	○	○	○	○	○	○	○	○	○
More specialised predators	○	○	○	○	○	○	○	○	○	○	○	○
Parasitoids	○	○	○	○	○	○	○	○	○	○	○	○

Figure 15: Example of direct scoring question in the online survey (Alchemer)

How confident are you with the scores you just gave? *

	"I don't feel confident with my score"= 1	"I feel fairly confident with my score"= 2	"I feel confident with my score"= 3
Complete generalists	○	○	○
More specialised predators	○	○	○
Parasitoids	○	○	○

Figure 16: Example of confidence score question in the online survey (Alchemer)

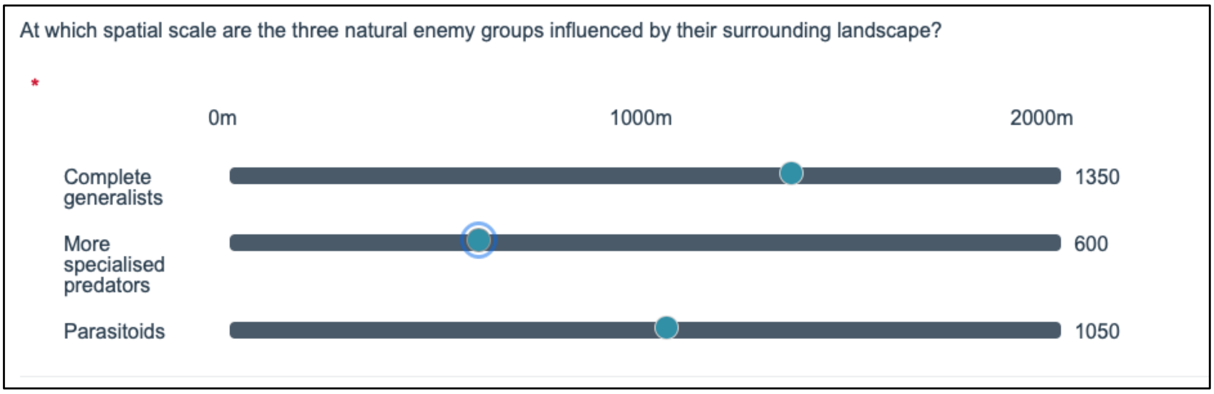


Figure 17: Distance question with sliders in the online survey (Alchemer)

9.2. Additional results

9.2.1. Inter-rater reliability

Krippendorff's alpha

Charlotte Peitz

6/6/2021

```
library(readxl)
```

```
library(lpSolve)
library(irr)
```

Krippendorff's alpha

```
kripp_matrix <- as.matrix(kripp)
```

```
kripp.alpha(kripp_matrix, method = "ordinal")
```

```
##  Krippendorff's alpha
##
##  Subjects = 27
##    Raters = 52
##     alpha = 0.759
```

Figure 18: R output for Krippendorff's Alpha

9.2.2. Open questions

Table 7: Categorized answers to the open question: 'Description of ideal landscape.'

Category	**Examples**	**Number of times stated**	**Percentage**	**Explanatory comments**
Presence/proximity of SNH	"ca. 30% semi-natural habitats" "areas of semi natural habitat in proximity to crops"	26	55.3%	11 answers included a concrete surface amount of SNH, ranging from 10% to 40%
Perennial hedges	"hedgerows" "tussock grasses"	12	25.5%	
Forested area especially important	"forest patches" "woody elements"	7	14.9%	
Herbaceous/Pasture area especially important	"grasslands" "herbaceous elements"	5	10.6%	

Presence wetlands	"includes water" "restoration of wetlands"	4	8.5%	
Crop diversity	"both flowering and non-flowering crops" "spatial/temporal crop diversity" "crop rotation of a minimum of X years"	32	68.1%	
Small field size	"small scale fields" "fields below X ha" "their width at a maximum 2 times the width of the machinery"	29	61.7%	
Organic management / reduction of chemicals	"rigorous reduction of insecticide use" "limited chemical inputs" "organic fields"	22	46.8%	"organic pesticides can be harmful as well to NE"
Flower strips	"tussock grasses" "flowering resources next to fields" "flowering habitat"	19	40.4%	
High edge density	"field margins" "non-crop edges"	13	27.7%	
Reduced tillage	"low or no-tillage" "extensive soil management"	13	27.7%	- "Soil management can effect a lot of overwintering generalist predators and parasitoids"
Agroecological practices	"under sowing" "companion cropping" "permaculture or agroforestry aspects"	7	14.9%	
Inclusion of animals in system	"animals/grazing" "mixed farming (crops + animals)"	7	14.9%	
Fallow land	"rotation including 1 or 2 year fallow" "fallow strips" "open soil for nesting"	6	12.8%	
Beetle banks	"beetle banks within fields"	4	8.5%	
Perennial crops	"annual and perennial crops"	2	4.3%	
Cover crops over winter	"cover all year long" "avoid bare soils"	2	4.3%	
Adapted harvest times	"time-delayed harvesting between fields"	1	2.1%	"time-delayed harvesting between fields could provide

				refuges and alternate habitats that buffer the effects of disturbance through agricultural management practices”
Trap crops	“trap crops to attract pests to particular areas of the field”	1	2.1%	
General landscape diversity	“mixed landscape with… “ “high land-use diversity” “heterogenous landscape”	19	40.4%	
Focus on productivity	“mix of intensive and extensive management” “importance of the crop yield” “ small and large scale agriculture”	6	12.8%	“In this evaluation, however, the importance of the crop yield is not being considered and therefore it is difficult to say how realistic those expert opinions could be.”

Table 8: Categorized answers to the open question: 'Description of role of pesticides'

Category	**Examples**	**Number of times chosen**	**Percentage**	**Explanatory comments**
Almost no need anymore	“shouldn’t require a lot of pesticides” “no more pesticides are required”	13	27,7%	“you might be able to use no insecticide for common regular pest found in Sweden”
Occasional need	“probably still needed but perhaps only occasionally” “used as a last resort”	10	21,3%	“for rapeseeds, maybe one/two insecticides would be necessary to control their pests”
Will get less over time	“in the long term…” “after an initial buffer period	0	8,5%	

	"(…) the system will find a balance"			
Severe pest outbreak	"unexpected high infestation rates" "inter-annual changes" "localized pest outbreaks"	14	29,8%	
New/specialized pests	"in case of climate change" "specific weather conditions" "migratory species"	8	17,0%	
Economic threshold	"populations surpass economic threshold" "depends on economic value of crop"	8	17,0%	
Integrate pest control measures	"pheromones, attractants…" "resistant varieties" " biocontrol (…) only if nontoxic to non-target species"	7	14,9%	
Monitoring and clear decision rules	"decision rules" "ecological knowledge" "continuous monitoring"	4	8,5%	"consumption should decline proportionally to the development of ecological knowledge, which unfortunately is not the case"
Herbicide and fungicide use	"need for herbicide and fungicide" "herbicides necessary in no-till farming" "herbicides may be needed to deal with weeds resulting	6	12,8%	"Need for herbicide and fungicide use might even increase due to more crop--non-crop interfaces, intermediate hosts and shading of woody elements."

	from in-field/field margin approaches”			

Table 9: Categorized answers to the open question: 'Further comments'

Category	**Examples**	**Number of times chosen**	**Percentage**	**Explanatory comments**
Natural enemy groups too heterogenous	“they contain different groups that sometimes could respond differently” “effects (…) are species specific”	6	33,3%	
Effects too complex	“effects (…) are not necessarily consistent” “it may depend on the identity of organisms and on the identity of crops concerned”	4	22,2%	
Not sufficient knowledge (about a certain aspect)	“I have worked only with carabid beetles. For other groups, my answers are more guestimates.” “I have not worked on the simplification of landscapes”	3	16,7%	
General positive feedback	“Very nice questionnaire” “Good luck and looking forward to the results!” “it was fun :-)”	5	22,2%	
Focus on productivity	“these landscape may produce less food” “tradeoff between production vs the	3	16,7%	

	land that can be set aside to support natural pest control”			
Land sparing/ sharing debate	“overall extensification better than sparing” “made me think about the land sharing vs sparing debate”	2	11,1%	
Forests vital against climate change	“In these warmer future landscape, forests as well as hedges may play a bigger role than we attribute to them today”	1	5,6%	
Financial compensation	“need to be financially compensated by the civil society in a system of global markets”	1	5,6%	
Knowledge on IPM	“knowledge of phenology and population dynamics of pests and their natural enemies” “Preventive and cultural control /pest management in IPM	1	5,6%	

9.2.3. Agricultural types in the regions

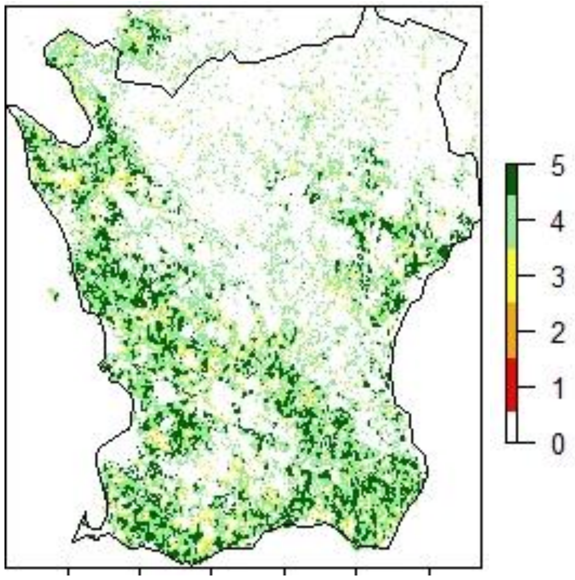
Table 10: Codes of the 18 combinations of the three agricultural factors. Management system: Organic or conventional. Crop diversity: Low, Average or High. Field size: Small, Medium or Big

Management	C	C	C	C	C	C	C	C	C	O	O	O	O	O	O	O	O	O
Diversity	L	L	L	A	A	A	H	H	H	L	L	L	A	A	A	H	H	H
Size	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

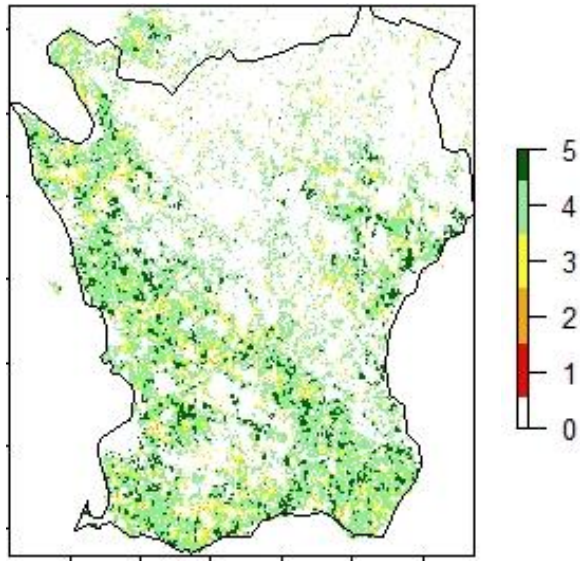
Table 11: Agricultural land in Scania, Västra Götaland and Dalarna (in ha) belonging to each agricultural factor combination (Table 10)

CODE	SCANIA	VÄSTRA GÖTALAND	DALARNA
1	97966	48760	11733
2	15547	8284	1827
3	4886	2430	552
4	90954	42458	10564
5	19225	9034	2249
6	8492	4047	796
7	132860	69325	14340
8	30981	17610	3359
9	21009	10955	2400
10	7531	5057	1543
11	1289	1152	227
12	366	298	63
13	2458	1602	538
14	742	426	185
15	509	235	29
16	210	472	52
17	96	151	26
18	128	116	15

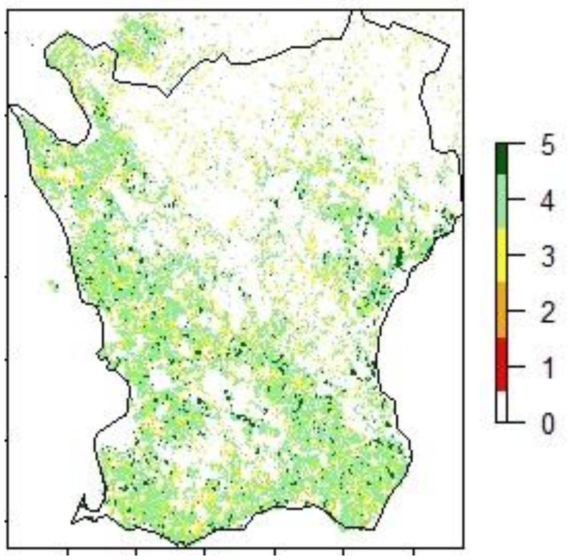
9.2.4. NPCP of the three regions



***A:** Complete generalists*

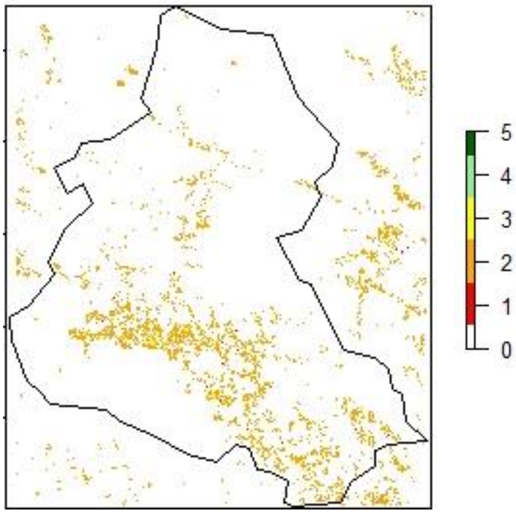


***B:** More specialized predators*

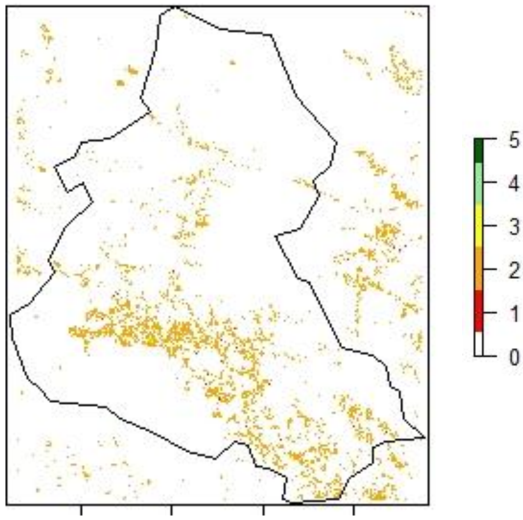


***C:** Parasitoids*

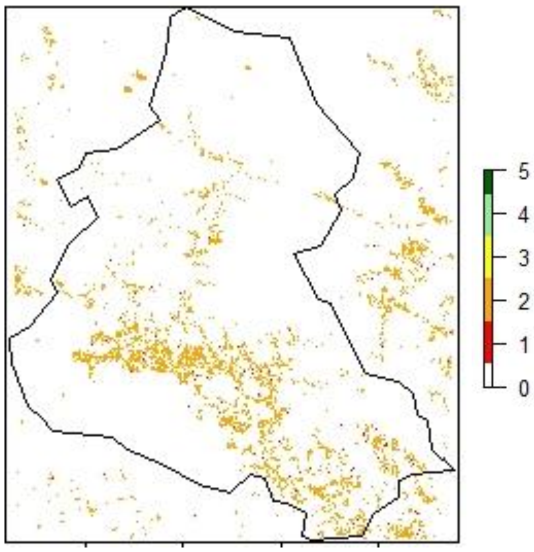
Figure 19: NPCP (0-5) of the three insect groups in cells (100x100m) representing agricultural fields in Scania. Representation: Pierre Chopin, SLU.



A: *‘Complete generalists’*

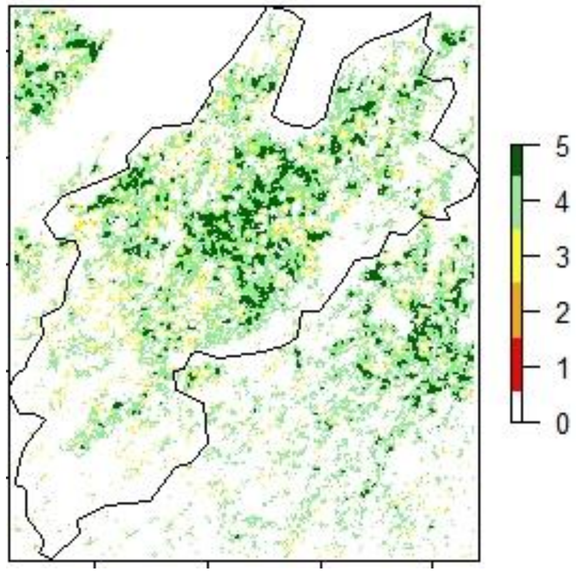


B: *‘More specialized predators’*

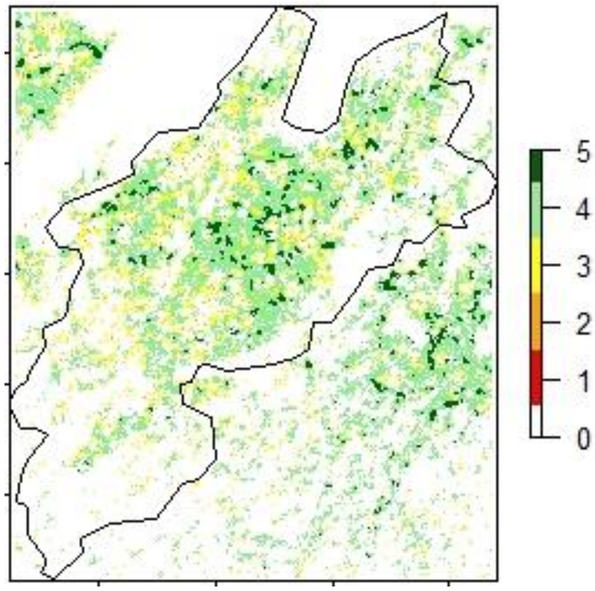


C*: ‘Parasitoids’*

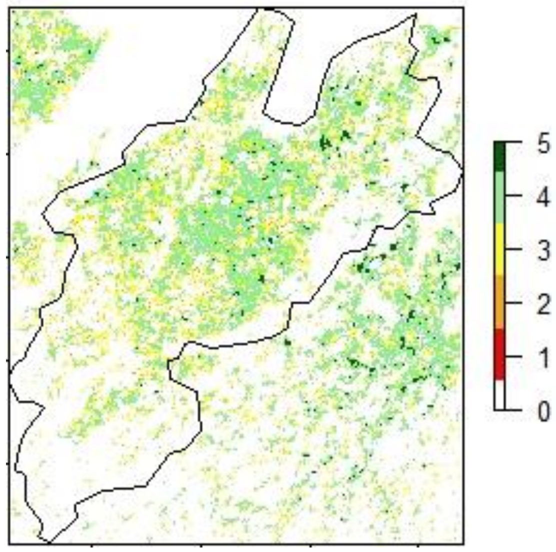
Figure 20: NPCP (0-5) of the three insect groups in cells (100x100m) representing agricultural fields in ***Dalarna****. Representation: Pierre Chopin, SLU.*



A***: 'Complete generalists'***



B: *'More specialized predators'*



C: *'Parasitoids'*

Figure 21: NPCP (0-5) of the three insect groups in cells (100x100m) representing agricultural fields in ***Västra Götaland****. Representation: Pierre Chopin, SLU***.**

Harnessing the powers of natural enemies

Semi-natural structures and concrete farming practices for natural pest control

Fact sheet for farmers

Insects are vital actors in our ecosystems. Besides the well know pollinators, **natural enemies** are essential for the functioning of the agricultural sector: they suppress pests, thus reducing the crop damage and the dependence on pesticides. Some examples of different natural enemies are:

- Complete generalists: spiders, carabids…
- More specialized predators: lace wings, lady bugs…
- Parasitic wasps

You can support insects while keeping the land productive!

These natural enemy groups have different preferences in pray and react differently to changes in their environment. However, there are certain **measures** that land managers can take that are generally beneficial for all of them.

Concrete farming practices:

- Reduction of agro-chemicals
- Reduction of tillage
- Smaller fields
- Larger crop diversity
- Agroecological practices (Intercropping, flower strips…)

Semi-natural structures:

- Presence of forests and wooded structures (hedges)
- Integrating pastures and meadows
- Preserving and creating wetlands

+

Results:

By improving the habitat structure in a certain area, the overall insect abundance and diversity can be improved, which can loop back and hold real advantages for natural pest control in your fields!

A concrete example for **barley** farmers: **ground-dwelling predators** have been found to **reduce the damage** done to crops by aphids by **40 € per ha**[1]. Creating an insect-friendly environment can help attract even more natural enemies and increase this number for numerous other crops as well.

Based on the Master thesis: "The natural pest control potential of different landscapes – Mapping the Ecosystem Service in three regions in Sweden" (Charlotte Peitz, 2021), SLU

[1] Östman, Ö., Ekbom, B. & Bengtsson, J. (2003). Yield increase attributable to aphid predation by ground-living polyphagous natural enemies in spring barley in Sweden. https://doi.org/10.1016/S0921-8009(03)00007-7