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NINA Report

Assessing Norwegian pollination deficits

Capacity building towards IPBES, with implementation and methodological evaluation of the “Protocol to Detect and Assess Pollination Deficits in crops”.

Jens Åström, Wenche Dramstad, Misganu Debella-Gilo, Knut Anders Hovstad, Sandra Åström, Graciela M. Rusch

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COVER PICTURE
Aroma apple ready for harvest in Telemark county, Norway. © Jens Åström, NINA

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Abstract

Åström, J., Dramstad, W., Debella-Gilo, M., Hovstad, K. A., Åström, S. & Rusch, G. M. 2014. Assessing Norwegian pollination deficits. Capacity building towards IPBES, with implementation and methodological evaluation of the “Protocol to Detect and Assess Pollination Deficits in crops”. - NINA Report 1101. 51 pp.

In 2012, the Norwegian Environmental Agency funded an extension to the Global Pollination Project, coordinated by the FAO (Food and Agriculture Organization of the United Nations) to expand the number of connected countries from 7 fully participating to in total 13 countries. This international effort seeks to build capacity for pollination studies and add to the knowledge base for the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES). IPBES is currently conducting its first fast track case study on pollination. Specifically, the Global Pollination Project implements the “Protocol to detect and assess pollination deficits in crops: a handbook for its use” (Vaissière et al. 2011), developed through the FAO. The protocol outlines a unified method to investigate pollination and measure pollination deficits in various agricultural systems around the world. NINA (the Norwegian Institute for Nature Research) was tasked with setting up a Norwegian collaboration to implement the protocol in Norway, to analyse its applicability to Nordic conditions and evaluate its strength in relation to alternative research strategies. The present report is the result of this effort.

This report does not communicate the final results of the analyses, as they will be conducted in the two larger “host-projects” that made the implementation of the protocol possible. Instead, it outlines the rationale of the protocol, and evaluates its potential for providing management relevant information on pollination deficits, with particular emphasis on Norway. We discuss the state and trends of pollination dependent crops in Norway, as a background for the need for pollination in Norwegian Agriculture.

The protocol is general enough to be applied to a wide variety of settings, and we did not experience any fundamental problems of implementing it in a Nordic setting. We did however notice challenges to an effective implementation, which might be especially pronounced in a Norwegian or Scandinavian setting. First, it can be difficult to find a wide enough range of factors that influence pollinators to efficiently analyse the importance of pollination without resorting to manipulative treatments. For example, the amount of flower resources and fragmentation of habitat are factors known to influence pollinators. But many crops are spatially aggregated to relatively narrow valleys and therefore experience similar surroundings. Secondly, it can be challenging to find enough replicate farms since Norway is a relatively small agricultural nation. Thirdly, pollinators in Norway (as in many other parts of the world) are intractably linked to agricultural and animal husbandry practices that provide a diversity of flowering resources necessary for pollinating insects, yet these practices and resulting resources in the surrounding landscape is not sufficiently captured by the survey protocol.

The protocol is designed to estimate differences in yield given differences in pollination, and various methods are available to approach optimal pollination, that acts as benchmark. Estimating the effect of pollination on yield is the foundation to understanding the status of pollination deficits for any crop. The protocol appears to be a successful effort to create a unified standard of measuring pollination and pollination deficits by this definition. It thus marks a great improvement for pollination research in agriculture internationally.

However, we argue that additional knowledge is needed for a successful management of pollinators in agriculture. Firstly, we need to have an understanding of the relationship between pollination and yield throughout a wide range of pollination levels, beyond what is typically achieved from a single study that implements the protocol. Here, the unified standard of the protocol has great potential since it facilitates comparisons and joint analyses of data sets from different regions. It could be difficult to precisely estimate pollination deficits and to correctly

interpret the results, just by employing the protocol in one individual study. Therefore, much of the protocol's strength seems to rely on combining datasets and meta-analyses. Secondly, it is important to be able to put the measured levels of pollination in context with what is reasonably achievable in a particular region, either through management of natural resources or adding of domesticated pollinators. An understanding of the factors that influence pollinator levels is here crucial in order to successfully design effective policy instruments. The protocol itself is not designed to provide detailed information about these mechanisms, so additional studies are recommended. Lastly, we point to the need to review the trends of the factors that influence pollinators in a historical and societal context. When we have 1) established that there is a potential for increased yield by increasing pollinators (by employing the protocol), we need to know 2) what governs the levels of pollination in a particular region, and 3) what levels could we reasonably achieve given the available management actions and policy responses.

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Sammendrag

Åström, J., Dramstad, W., Debella-Gilo, M., Hovstad, K. A., Åström, S. & Rusch, G. M. 2014. Vurdering av pollineringsunderskudd i Norge. Kapasitetsbygging mot IPBES, med implementering og metodisk evaluering av FAOs protokoll for å oppdage og vurdere pollineringsunderskudd i avlinger.- NINA Rapport 1101. 51 s.

I 2012 finansierte Miljødirektoratet en tilleggsmodul til "The Global Pollination Project" som koordineres av FAO (Food and Agriculture Organization of the United Nations). Målsetningen med denne tilleggsmodulen var å utvide antall land som gjennomførte undersøkelser i henhold til den protokollen som er utviklet i det internasjonale prosjektet fra 7 til 13. Dette internasjonale arbeidet søker å bygge kapasitet for pollineringsstudier og utøke kunnskapsgrunnlaget for FNs plattform for biologisk mangfold og økosystemtjenester (IPBES), som for tiden gjennomfører sin første case study på pollinering. Spesielt implementerer prosjektet protokollen som er utviklet gjennom FAO for å måle pollineringsunderskudd (Vaissière et al. 2011). Protokollen skisserer en enhetlig metode for å undersøke pollinering og måle pollineringsunderskudd i ulike jordbrukssystemer rundt om i verden. NINA (Norsk institutt for naturforskning) fikk samme år i oppgave å sette opp et norsk samarbeid for å implementere protokollen i Norge, analysere dens anvendbarhet under nordiske forhold og vurdere protokollens styrke i forhold til alternative forskningsstrategier. Denne rapporten er et resultat av dette arbeidet.

Denne rapporten kommuniserer ikke de endelige resultatene av analysene, ettersom de vil bli gjennomført i de to større "vert-prosjektene", som gjorde gjennomføringen av protokollen mulig. I stedet, skisserer denne rapporten begrunnelsen for protokollen, og evaluerer dens potensiale for å levere relevant informasjon om pollineringsunderskudd til forvaltningen, med særlig vekt på Norge. Også tilstanden og utviklingen av pollineringsavhengige avlinger i Norge diskuteres, som en bakgrunn for behovet for pollinering i norsk landbruk.

Protokollen er generell nok til å brukes i en rekke forskjellige omgivelser, og vi opplever ikke noen fundamentale problemer med å implementere den i en nordisk setting. Vi registrerte imidlertid noen utfordringer knyttet til mulighetene for å oppnå en effektiv gjennomføring, utfordringer som kan være spesielt uttalte under norske eller skandinaviske forhold. For det første kan det være vanskelig å finne egnede studieområder der en rekke faktorer som påvirker pollinatorer har stor nok variasjon til å kunne analysere betydningen av bestøvning uten å ty til manipulerende behandlinger. Mange avlinger er geografisk samlet, for eksempel i relativt trange dalfører og ligger derfor i lignende omgivelser. For det andre, kan det være utfordrende å finne et stort nok antall gårder, siden enkelte av de interessante vekstene har begrenset utbredelse i Norge.

Protokollen er utformet for å beregne forskjeller i avlinger gitt forskjeller i pollinering, og ulike fremgangsmåter er tilgjengelige for å nærme seg "optimal pollinering", som er det foretrukne referansepunktet. Den estimerte effekten av pollinering på avlingene er grunnlaget for å forstå statusen på pollineringsunderskuddet. Protokollen ser ut til å være et vellykket forsøk på å skape en enhetlig standard for måling av pollinering og pollineringsunderskudd etter denne definisjonen. Dette markerer dermed en stor forbedring for pollineringsforskning internasjonalt.

Imidlertid hevder vi at ytterligere kunnskap er nødvendig for en vellykket forvaltning av pollinatorer i landbruket. For det første må vi ha en forståelse av forholdet mellom pollinering og avling gjennom et bredt spektrum av pollineringsnivåer, utover det som normalt oppnås i en enkelt studie som implementerer protokollen. Den enhetlige standarden protokollen representerer har stort potensiale siden det blir lettere å utføre sammenligninger og felles analyser av datasett fra forskjellige regioner. Det kan være vanskelig å anslå presist pollineringsunderskudd og tolke resultatene bare ved å bruke protokollen i en enkelt studie. Mye av protokollens styrke synes å bygge på å kombinere datasett og lage meta-analyser. For det andre er det viktig å være i stand til å sette et erfart nivå av bestøvning i sammenheng med et bestemt område. En

forståelse av de faktorene som styrer nivåer av pollinatorer er avgjørende for å kunne designe vellykkede virkemidler. Selve protokollen er ikke utformet for å gi detaljert informasjon om disse forhold, så ytterligere studier anbefales. Til slutt peker vi på behovet for å gå gjennom trender av hvilke faktorer som påvirker pollinatorer i en historisk og samfunnsmessig sammenheng. Når vi har 1) fastslått at det er et potensial for økt avling ved å øke tetthet og / eller diversitet av pollinatorer (ved å bruke protokollen), må vi vite 2) hva som regulerer nivåene av pollinering i en bestemt region, og 3) hvilke nivåer vi rimelig kan oppnå gitt de tilgjengelige skjøtselstiltakene og politiske tiltakene.

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Foreword

Pollination is currently receiving attention from policy makers, scientists and conservationists, news media and the public. We as a society are starting to appreciate the great value of pollination, not only as an important interaction between species, but as an invaluable service to the global human population. This attention is brought on by a concern for the recent development in pollination, showing signs of declining pollinator populations and intensification of the pressures on pollinators as well as emergence of new threats. The situation is serious, and we need determined action to adequately investigate the situation and deploy actions to secure the future health of wild pollinators. This will require not only increased scientific knowledge and methodological development, but also considerable political will. Frankly, it will not be easy to revert the many detrimental changes to pollinators within the agricultural landscape, which are the result of many processes and decisions that all individually can seem rational in an era of increased efficiency and mechanization. On the science and science-policy side, this report plays a part in implementing and evaluating a promising methodology to measure the international state and need for pollination in a unified way.

Registering pollinating insects, apples and red clover requires many eyes, hands and brains and this project has had help from many. I would like to thank Nadine Azu, Emma Bengtsson, Riccardo Bommarco, Inga Bruteig, Luisa Carvalheiro, Ed Connors, Sondre Dahle, Lucas Garibaldi, Jan Ove Gjershaug, Oddvar Hansen, Barbara Herren, Eveliina Kallioniemi, Ingvil Kålås, Helene Müller, Heidi Myklebust, Hien Ngo, Maj Rundlöf, Antonio Mauro Saraiva , Stine Skjellevik, Erik Stange, Arnstein Staverløkk, Bernard Vaissière, and Ruan Veldtman for practical help with recordings, organizing workshops and giving appreciated input.

I also would like to thank all the co-authors for their collaborative effort in producing this report and laying the foundation for future collaboration.

We especially want to thank Tone Gislerud for her insights into apple production, much appreciated help related to the apple harvests and her passion for pollinator friendly landscapes, and John Ingar Overland for his continuous help with red clover seed farms and farmers, careful sowing of flower strips and his commitment to bumblebees.

Funding for the project was received from the Norwegian Environmental Agency, and we thank them for taking this initiative.

15 December, 2014.
Jens Åström

1 Introduction

In 2012, the Norwegian environmental agency funded an extension to the Global Pollination Project, coordinated by the Food and Agriculture Organization of the United Nations (FAO) to expand the number of participating countries from 7 to 13. This international project seeks to build capacity for pollination studies internationally, and adds to the knowledge base for the International Panel for Biodiversity and Ecosystem Services IPBES, currently conducting its first fast track case study on pollination. Specifically, the project implements the Pollination deficit protocol (Vaissière et al. 2011), which outlines a unified method to investigate pollination and measure pollination deficits in various agricultural systems around the world. The current project was tasked with implementing the protocol in Norway, analysing its applicability to Nordic conditions and evaluate its strength in relation to alternative research strategies.

The project was able to latch on to and extend two already running projects in Norway, targeting pollination in commercial apple orchards and red clover seed production, respectively. The project relating to apple is part of an internal strategic research program at the Norwegian Institute for Nature Research (NINA) focusing on landscape ecology, funded by The Research Council of Norway. The project related to red clover seed production is the PolliClover project, led by Bioforsk, with funding from the research fund “Fondet for forskningsavgift på landbruksprodukter”, and the commercial partners Norsk frøavlerlag, Graminor, Felleskjøpet Agri and Strand Unikorn. As a result of the collaboration with these two “host” projects, NINA together with Norwegian Institute for Agricultural and Environmental Research and the Norwegian Forest and Landscape Institute has performed pollination deficits measurements in two crops for two seasons. This report is a summary of the experiences of working with the pollination deficit protocol in Norway. Detailed analyses of the collected data will be conducted within the two host projects and reported in later publications.

2 Project summary

2.1 Timeline and international partnerships

This project has committed Norway to the international pollination project lead by FAO and GEF (Global Environment Facility), which implements the pollination deficit protocol and summarizes the findings in an international meta-analysis spanning 13 countries on four continents. Through the management of Barbara Herren and Nadine Azzu (FAO), the project connects a global network of researchers throughout the world, working locally with a broad array of crops. Funding was received from the Norwegian environmental agency in December 2012.

Bernard Vaissière from INRA (The French National Institute for Agricultural Research), and lead author of the pollination deficit protocol, hosted an introductory workshop on the experimental set-up and implementation of the protocol in Avignon, France in the spring of 2013. Participating from the project was Jens Åström, together with Lucas Garibaldi (Universidad Nacional de Río Negro, Argentina), and Hien Ngo (York university, Canada, and IPBES, Bonn, Germany), who extended the protocol in South America and Asia, respectively. Details of the practical implementation of the protocol in the field have been discussed within this group throughout the project. Lucas Garibaldi also manages the international meta-analysis together with Luisa Carvalheiro (University of Leeds).

The first field measurements were performed in apple orchards in May of 2013, sampling the pollinator communities in commercial apple orchards in the counties Telemark and Buskerud of Norway. At the same time, transects were placed and checked for pollinators and flower resources in landscapes encircling apple, red clover seed fields, and controls without pollinator dependent crops (details below).

Red clover seed fields were first visited during July 2013, recording their pollinator fauna in line with the protocol. These were revisited in August to collect pest samples and record yield. Apple orchards were revisited in late September to measure yield.

Jens Åström also participated in a meta-analysis workshop hosted by Antonio Mauro Saraiva (Universidade de São Paulo), in São Paulo in the summer of 2013. The workshop brought together participating researchers from the respective countries and discussed analyses, streamlining of data, surveying methods, and international databases.

Inga Bruteig (NINA) participated in a workshop on science-policy interface in Nairobi, Kenya in the fall of 2013. Through the host project PolliClover, the project has also collaborated with Swedish pollination researchers Riccardo Bommarco (Swedish university of agricultural reseach) and Maj Rundlöf (Lund University).

The second field season in 2014 continued with similar schedule as in 2013, visiting apple orchards blooming in May, Red clover fields in July, returning to harvest Red clover in August and apples in September.

2.2 National project partnerships

This project has brought together expertise from three national research institutes, combining experiences from conservation ecology, entomology, plant ecology, and landscape ecology. The Norwegian Institute for Nature Research (NINA) has a long record of pollinator identification, surveying and conservation, and holds a large collection of reference samples of Norwegian pollinators. This project has expanded the institute’s competence in the field of ecosystem services provided by pollinating insects, building a bridge between ecological and agronomical research. The Norwegian Institute for Agricultural and Environmental Research (Bioforsk) is a major Norwegian research body in for example agriculture, plant science, and natural resource management. The Norwegian Forest and Landscape Institute has broad expertise in landscape ecology and conducts extensive mappings of natural resources and holds nation-wide records related to agricultural production. The combination of these competences and qualities is conducive to understand and assess the processes that govern crop pollination in Norwegian agriculture. Using this report as a starting point, the three institutes will proceed with the analysis and communication of the state of pollination in Norway through scientific publications.

The project has through its two “host projects” also collaborated with the Norwegian Agricultural Information Service (Norsk Landbruksrådgiving), which holds in-depth knowledge of agricultural production systems and has provided crucial information and assistance both linked to apple production and red clover seed production.

2.3 Relevance of the project

This project has applied and tested the applicability of the pollination deficit protocol to Norwegian conditions, for two different agricultural plants through two seasons. In addition, we have analysed the strengths and limitations of the approach, and made some general statements of what the protocol can produce given the preliminary analysis of the data so far, and sketched suggestions for approaches that could complement and improve the current protocol. We have also visualised the geography of certain groups of pollination dependent productions in Norway, and assessed the development in area used for production of these crops since circa year 2000.

The findings should help guide in future studies of agricultural pollination and pollination deficits in Norway, giving insight into its possibilities and pitfalls. It should also help managers and policy makers, by identifying broadly what types of results and answers similar studies can produce, and discuss roads to additional information of value to policy makers. We discuss the need for a common understanding of what the term “pollination deficit” means for a particular setting, and give examples of different ways of operationalizing it. Lastly, we provide a sketch of a combined approach to acquire the required parts to build an informed and effective management strategy.

Policies and management decisions and the pressures that affect pollinators act on multiple scales; from individual farmers and land owners, to county and national policy documents, regional advisory boards, and local and international markets. A dialog between managerial levels and governmental sectors is thus important for successful conservation of wild pollinators and increased pollination. A common understanding of terms, states and processes is also central, and we hope this report will contribute to such an understanding.

3 Pollination – an essential ecosystem service

3.1 Pollination

Although many plants are capable of vegetative reproduction, most flowering plants depend on sexual reproduction in order to produce seeds. This involves the transfer of pollen from the anthers to the stigma (pollination in the strict sense), followed by the growth of a pollen tube connecting the male and female gametes in the ovary, where they fuse to form a viable seed (see e.g. Richards 1997 for a thorough treatment). However, pollination is also used more specifically to refer to the active pollen transfer by animals. In the international pollination deficit project and in this report, pollination is further restricted to mean insect mediated transfer of pollen from the anthers to the stigma, resulting in viable seeds. Self-dispersed (e.g. between male and female parts inside the same flower), or wind-dispersed pollen is arguably little affected by human management practices and so is rarely of concern in discussions of pollination of agricultural crops. Furthermore, insects are the dominating group of animal vectors for pollen transfer, especially in agriculture, so insect pollination is generally the process of interest regarding pollination of agricultural crops.

Insect pollination is the result of a co-evolution of plants and insects, spanning millions of years and resulting in a myriad of plant and insect diversity. It is so ubiquitous that it is hard to overvalue its importance. It has been estimated that approximately 85% of all European plant species (Williams 1994) and roughly 90% of the world’s flowering species depend on pollination for reproduction (Costanza et al. 1997), resulting in about 35% of the global food production (Klein et al. 2007, Ollerton et al. 2011). Economic evaluation for pollination framed as an ecosystem service can be difficult, and there often are no alternative goods on the market that can fully replace a pollination dependent crop. Nevertheless, the global monitory value of pollination has been estimated to 190.5 billion US$/year globally (Gallai et al. 2009). It is only natural then, that pollination is receiving increased attention internationally, given the vast importance of pollination and the recent worrisome trends of pollinators.

Pollination can be performed by many groups of insects that may visit flowers for different reasons. The most specialized pollinator group is bees, which has pollen and nectar as their main or only food source. Nectar contains sugar and make up their main energy source, and pollen contains proteins, that are the building blocks of the larva that later metamorphoses into new adult individuals. Bees´ dependence on nectar and pollen make them dedicated flower visitors that often can fly distances of several kilometres to forage. Many bees are social, with separate castes of individuals, where a queen forms a colony of female worker bees, and males and new queens are produced for reproduction at the end of the lifespan of the colony. Social bees are represented in Norway by bumblebees (*Bombus* spp. with 35 species of which 28 are social) and by the domesticated honeybee *Apis mellifera*. Although they can have preferences for particular species of flowers, they generally forage on a range of species, and require access to pollen and nectar throughout the entire active period of the colony, spanning most of the summer. Solitary bees in contrast, do not build colonies. Here, the females typically lay a more limited amount of eggs which she provides food for by herself, and larvae are not further reared. They generally have a shorter life span than social bees and can be more specialized to certain flowers, which results in a more limited period of active foraging. A total of 171 solitary bee species has been found in Norway.

The order Hymenoptera, where bees reside, contains many other groups that may also act as pollinators. Various species of wasps can be frequent flower visitors where they typically feed on nectar. But they lack hairs to collect pollen and generally have other sources of protein from predating or parasitizing on other insects, and are thus generally less efficient pollinators.

Flies (Diptera) can also be dedicated flower visitors, represented by several families, but perhaps syrphid flies are the most relevant group of flies for pollination of crops in Norway. For a more complete discussion of pollinators and pollination of wild flora in Norway, see Totland et al. (2013).

3.2 Pollinator communities in changing landscapes

The extraordinary increase in agricultural output in the past half century has been a cornerstone in the feeding of a growing global human population and the increased standard of living of the western world and many developing countries. Parts of this development can be attributed to plant breeding programs leading to higher yielding crop varieties. But much of this development is due to the increased mechanisation of agriculture, made possible by cheap fossil fuels, and the invention and increased use of various industrially produced fertilizers. This has led to an increased “rationalization” of agricultural practices, with larger fields, and fewer and smaller field edges, containing only a small number of plant species. There are now less semi-natural grasslands and flowering meadows than before, and less crop rotation and leys. Living in the days of rapid development and frequent change, it is easy to miss that this development has been abrupt in evolutionary and even ecological timescales, transforming vast areas of agricultural land, which is the main habitat for a high number of co-evolved species. This development has led to less and more fragmented resources for pollinating insects in terms of flowering plants and nesting sites.

The agricultural landscape in Norway has been subject to a number of changes the last 50-100 years. These changes can potentially have significant impacts on populations of pollinating insects. The main theory of the reason behind the decline of many species of pollinating insects is that the landscape no longer offers the total amount of resources (e.g. early flowering species, nest sites) needed by the different species. Semi-natural grasslands providing important habitats for pollinating insects have decreased in area and the remaining patches are small and scattered (Norderhaug & Johansen 2011). This is likely to influence the availability of feeding resources, but also other resources like nesting sites, for several groups of pollinating insects. Studies conducted in Scandinavia has shown that distance to semi-natural grasslands can influence the quantity and quality of seed set in both wild plants (Jakobsson & Ågren 2014) and agricultural crops (Bommarco et al. 2012 b). The importance of semi-natural habitats is larger in landscapes with intensive farming and a high proportion of arable land as compared to landscapes with less intensive farming practices (Rundlöf et al. 2008; Jakobsson & Ågren 2014; Tuck et al. 2014). Intensively farmed landscapes can have large and easily available feeding resources for pollinating insects, at least for shorter periods, but can lack suitable nesting and hibernating sites (Svensson et al. 2000; Kells & Goulson 2003). Limited availability of sites for nesting and hibernating can also influence pollination of agricultural crops (Ricketts et al. 2006).

The management of arable land and productive grasslands can also have important impacts on populations of pollinating insects (Schneider et al. 2014). In particular, the potential for comparing organic and conventional farming systems have attracted large attention from the research community (see e.g. Rundlöf et al. 2008; Tuck et al. 2014). The changes in management of arable land and productive grasslands in Norway since the 1950s are however complex and multifaceted. In the 1970s, 80s, and 90s, the management of grasslands was striving towards high productive grasslands by using fertilizer and trying to keep weeds down by herbicides and other measures. It is likely that these actions reduced the resources available for pollinating insects and had a negative effect on their populations. Today the management strategies are more diverse with both intensively managed grasslands with few plant species and extensively managed grasslands often with relatively high proportions of dicotyledonous weeds and sometimes also legumes. It can be expected that the areas with less intensive management have positive effects on at least some groups of pollinators (see Schneider et al. 2014, which also included results from Norway).

Important resources for pollinating insects are also offered by different non-crop areas, e.g. rocky outcrops, grassy banks, and hedgerows, but in many landscapes such non-crop areas have been lost or their quality as a resource for many pollinating insects have diminished as a result of a simplification of the landscape (see Figure 1). Pollinating insects require feeding resources throughout spring, summer, and early autumn and often need access to a diversity of different plant species that flower sequentially. The tree *Salix caprea* often occurs in hedgerows and field margins, and this species is an important forage resource for many pollinating insects in early spring. To our knowledge, there are no data on trends in occurrence of *S. caprea* in Norway but it is likely that that the species has declined in abundance in agricultural regions where hedgerows and field margins have been removed or reduced.

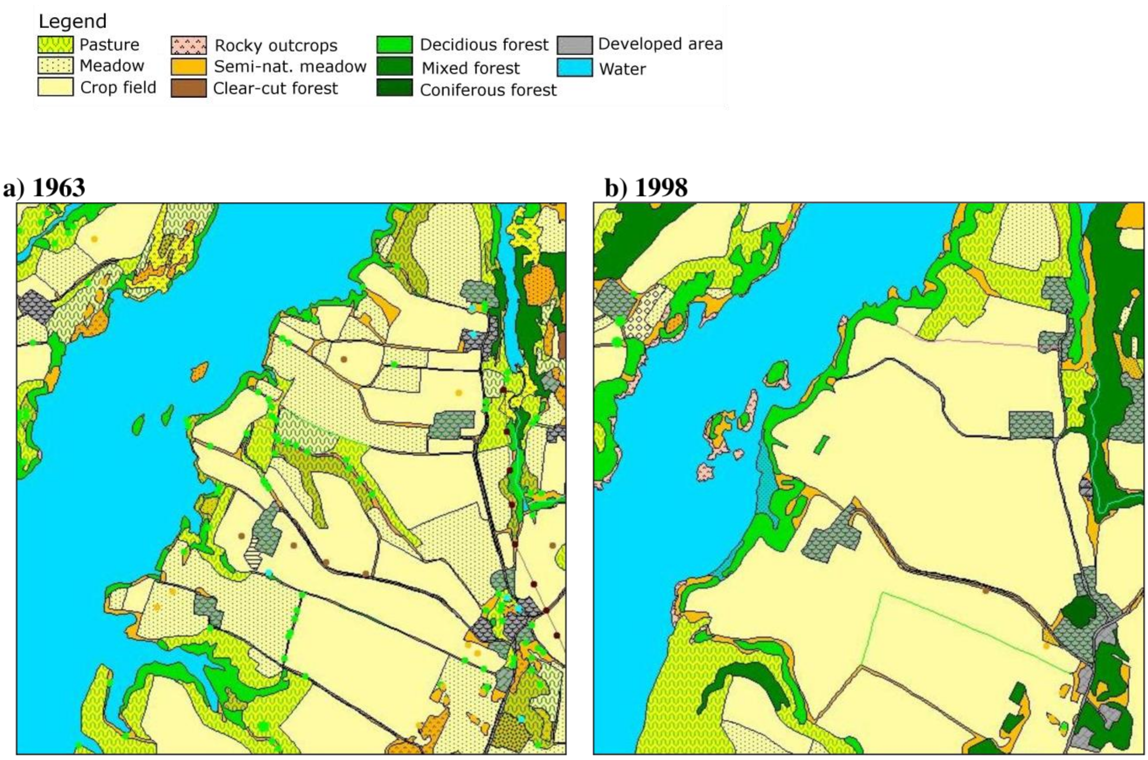

Figure 1. *Comparisons of historical aerial photos with modern surveys can be used for analysis of landscape transformation. Here we see a representative example of the extensive simplification of an agricultural landscape located in South-eastern Norway between the years 1963 and 1998. Data from the Norwegian monitoring program for agricultural landscapes. © Skog og landskap.*

In addition to this decreased amount and changed configuration of habitat, pollinating insects also face more direct threats in the agricultural landscapes. Highly productive agriculture has made extensive use of different herbicides and pesticides, often targeting the food resources of pollinators directly.The use of pesticides within crop production potentially influence the pollinator communities in multiple ways. Insecticides can have direct negative effects on pollinating insects, although legal regulations have been implemented to reduce this, e.g. by prohibiting use of certain insecticides during daytime when bees and bumblebees have their forage search.

Pesticides have been demonstrated to have detrimental effect on pollinator populations (Henry et al. 2012; Whitehorn et al. 2012) and it is likely that the use of pesticides are part of the explanation for the observed decline in pollinators in Norway as well as other part of Europe (Potts et al. 2010). It has also been documented that some pesticides have important detrimental effects on the behavior of social insects which in turn have negative effects on their populations (Gill et al. 2012; Feltham et al. 2014).

Recently, much attention has been put on a new family of pesticides, the neonicotinoid family. These compounds are similar to the chemical nicotine, which certain plants produce as a natural pesticide, and acts as a toxin that binds permanently to receptors in the nervous system of insects. The high toxicity of these compounds is both a selling argument and a cause for concern. High and specific toxicity enables the farmers to spray a small quantity of the chemicals that will only affect insects. At the same time, neonicotinoids present in pollinator attractive crops, or lingering in the ecosystem, can have toxic or sub-lethal effects from exposures as low as a few nanograms per insect. This knowledge lead the EU, including Norway through EEA, to implement stricter regulations on the use of neonicotinoids in 2011/2012 (European Commission Directive 2011/69/EU). There is, however, a paucity of studies from Norway on effects of pesticides on pollinating insects and plant-pollinator interactions. Although evidence is mounting against the use of neonicotinoids in agriculture on open land, their use is still very much under debate, to a large extent because of trade-offs and the large immediate economic benefits in play.

Farming practice and landscape structure can also influence parasitic organisms targeting pollinating insects, which in turn can have important implications for the population dynamics and availability of pollinators in the landscape (Andersson et al. 2013). It should also be mentioned that introduced organisms, both plants and invertebrates, can alter ecological interactions important to sustain populations of pollinators and pollination of both crops and wild plants. Another possible threat is the increased amount of traffic, which can be a collision hazard for insects that aggregate to road verges to forage.

These challenges affect both wild pollinators and domesticated bees, but domesticated bees are somewhat protected since they are continually reared and are supplied with sugar as an additional source of subsistence. They are also often moved considerable distances and could thereby have a larger effective resource base than wild bees. But domesticated honey bees also have their unique problems. One has appeared particularly in North America, manifesting itself as sudden disappearance of bees. “Colony Collapse Disorder” or CCD, is now affecting a significant portion of the managed honey bee hives in North America. Since vast stretches of agricultural land in North America depends on ambulating honey bee keepers that travel with their hives to where the flowering crops are located, CCD has caused wide spread concern for the future of pollination in these areas. There are several candidate explanations for the cause of CCD, including pesticides, but increased spread of and susceptibility to disease caused by industrialized bee keeping practices appears to be at least part of the explanation. Honey bees have many pathogens, with which they probably have co-evolved for a long time. However, modern honey bee keeping, especially in North America, involves moving very dense collections of bee hives around, often containing very little genetic diversity, which tilts the balance in favour of the pathogens, increasing their prevalence in the population. Not all of these diseases are bound to specific species, and domesticated honeybees can act as contagions to the surrounding wild bee fauna, transmitting pathogens different species visit the same flower (Fürst et al. 2014).

Bumblebees also have their unique problems, although it is unknown to what extent it affects other groups of pollinators. In the past decades, there has been an increased use of reared bumblebees for pollination, especially in vegetable production in greenhouses. The species used is exclusively *Bombus terrestris*, a highly competitive generalist bumblebee. There are numerous records of this practice facilitating the spread of *B. terrestris* by individuals escaping from greenhouses to habitats where it does not appear natively, with the result of outcompeted native species (Gjershaug & Ødegaard 2012). This practice could even help the spread of *B. terrestris* in countries where it does also appear naturally, bolstering the natural populations and extending its range. It is documented that the trade with reared *B. terrestris* also can spread disease, which could potentially affect native wild pollinators (Whitehorn et al. 2013).

It is not easy, and maybe not even possible, to say which aspect of change in environment or agricultural management that have had the largest impact on availability of pollinating insects, but loss and degradation of semi-natural habitats is without doubt among the most important factors explaining the changes in populations of pollinating insects (Potts et al. 2010; Totland et al. 2013).

In the light of these pressures on wild and domesticated pollinators, it is perhaps not surprising that declines in the number of pollinators have been recorded in many parts of the world (Potts et al. 2010). Wild pollinators have been recorded to decline in England and Holland (Williams 1986; Biesmeijer et al. 2006), North America (National Research Council 2007), Sweden (Bommarco et al. 2012), and in Europe as a whole (i.e. the European Grassland Butterfly Indicator , Van Swaay et al. 2013). Despite studies like these, we have only fragmentary knowledge on the status and trends of pollinators world-wide. Even in the western world, with an extensive tradition in natural history, there exist few historical records to compare with current populations and long-time monitoring programs are few and far between. This means that a further negative trend could been underreported.

4 Pollination dependent crops in Norway

4.1 Background

There are currently approximately 44 000 active farms in Norway (data from 2014). These together manage approximately 10 000 km^2 of agricultural land. Given the climatic conditions, geography and soil and bedrock conditions, there are significant limitations on what can be produced where in Norway. For example, only approximately 1% of the total agricultural area can be used for grain production for human consumption. As a result, certain productions have a fairly restricted geographic distribution. The many hours of daylight during summer have positive effects on the quality of certain crops, however, making some pollination dependent crops such as strawberries a highly rewarding and widely distributed crop in Norway.

The importance of ensuring a continued production of ecosystem services, including pollination, has received some attention in Norway (see e.g. NoU 2013-10). To our knowledge, the geographical distribution of crops in need of this ecosystem service has not received much attention hitherto, however. The same applies to the connection between the wider landscape structure, occurrence of non-crop areas in the agricultural landscape and production of these crops.

4.2 Data compilation of pollination dependent crops in Norway

A wide range of agricultural support mechanisms exists within Norwegian agriculture. Some of these are so-called agro-environmental measures, directed towards managing e.g. non-crop habitat and remains of cultural heritage within the agricultural landscape. The larger group of subsidies, however, in economic terms as well as in number of farms, is the production-related subsidies.

To claim these subsidies, the farmers have to provide fairly detailed information on their production. This includes, for example, information on area and type of field based crops, fruits and berries (for details see www.slf.dep.no). The database containing production subsidy claims for all Norwegian active farmers are a key dataset used in the analysis reported here. This database contains every claim made by all active farmers for their total production each year between 1999 and 2013. This makes it possible also to analyze changes in crops since 1999.

We here exemplify how this information can be used to improve the understanding of the geographic variation and temporal changes of pollination-dependent crops in Norway. Data and spatial location of the farms have been retrieved from the Norwegian database of crop production. The unit of production quantity varies in the database depending on the type of crop. Most crops are reported in terms of the land area used for their production. The pollination-dependent crops are also reported in terms of area, specifically in units of 1000 m^2 (dekar, 1/10 of a hectare).

We selected 10 annual and perennial pollination-dependent types of crops that are identifiable from the national database (Table 1). The data spans a 15 year period with geographic coverage of the entire Norway but a few crops lack consistent record over the entire 15 year period. In addition, some of the crops are related in terms of their geographic location, seasonality, etc. Thus, exploratory correlation analysis between the different crops showed that the crops are more practically pooled into four groups: legumes (beans and peas), oil seeds (rape of different seasons), fruits (apples, pears, plums, cherries and other fruits) and berries (strawberries and other berries. These groups are then further analyzed with respect to their geographic variation and temporal changes. Red clover seed production is not readily distinguishable in the database as it sorts under seed production, dominated by grasses and other plants that do not depend on insect pollination. Red clover is therefore not included in the analysis. However, we were able to map this production using records of farmers obtained from the seed production companies (see chapter 7).

Table 1. Total production areas of pollination-dependent crop types and groups in 2013. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)

Crop Group	Dekar (1000 m^2)	Contributing crops	Dekar (1000 m^2)	Share of the crop type in group (%)
Fruits	**20 615**	Apples	13 803	**67**
		Cherries	1 906	**9**
		Pears	638	**3**
		Plums	4 208	**20**
		other fruits	60	**<1**
Oil seeds	**34 623**	Oil seeds	34 623	**100**
		Oil seeds (autumn sown)	0	**0**
Berries	**15 261**	Strawberries	15 261	**100**
		other berries	0	**0**
Legumes	**16 244**	Peas, beans & others for ripening	10 169	**63**
		Peas and beans for preservation	6 075	**37**

The data are geo-referenced with the point location of the producing farms. Although farmers increasingly rent or let their fields to other active farmers, this “trade” in agricultural land is usually limited geographically due to logistical constraints. Therefore the choice of the location is assumed to be a good representation for the production areas. For the purposes of this analysis and to give a geographic areal ‘support’ to the points, the 5x5 km SSB (Statistics Norway) grid is used. The points that are contained within each 25 km^2 grid square are aggregated by summing up the area of the specific crop type under consideration or the entire pollination-dependent crops depending on the purpose. Exploratory analysis of the geographic distribution and the temporal changes of the crops are carried out based on these aggregated data.

4.3 Distribution of pollination dependent crop groups

According to the production subsidy data of 2013, approximately 87 km^2 (8700 ha) of agricultural land is used for the production of the identified pollination-dependent crops in Norway. Figure 2 shows the total area used by each of the crop groups in 2013. About 40% of the total area occupied by pollination-dependent crops are actually used by oil seed crops followed by fruits (near 25%); whereas legumes and berries occupy just under 20% each. Legumes are generally attractive to bumblebees and were historically a stable crop in traditional crop rotation systems.

Figure 3 presents the geographic distribution of the sum of all the pollination dependent-crops in the year 2013, displaying the aggregated production areas in each 25 km^2 grid with quartiles of the data distribution in brackets. For example, grids with values less than 7000 m^2 per 25 km^2 (0-7 in the figure) are below 25% of the total number of grids with production, i.e. the 1-quartile. The studied crops are mostly concentrated in the coastal areas of Norway with the counties in the south-east (Østfold, Akershus, Vestfold) being the major geographic centers of agricultural production.

Figure 4 breaks this information into the above-mentioned four major production groups. Both oil seeds and legumes (beans and peas) are concentrated in the south-eastern part of the country in addition to a small number of scattered occurrences in the Trøndelag region, in central Norway. Fruits are mainly produced in the coastal areas in the south (south-east and south-west with some areas in the South-Trøndelag region). It is only the berries that are relatively widely distributed throughout the country and as far north as the Finnmark county. While the south-east is the hotspot for all the pollination-dependent crops, the north and the center of the country are almost devoid of these crops. This is the general picture for the year 2013. However, the data shows somewhat wider spread of production areas for some of the crops in previous years as can be observed from the changes of the oil seed production from 2003 to 2013 in figure 6.

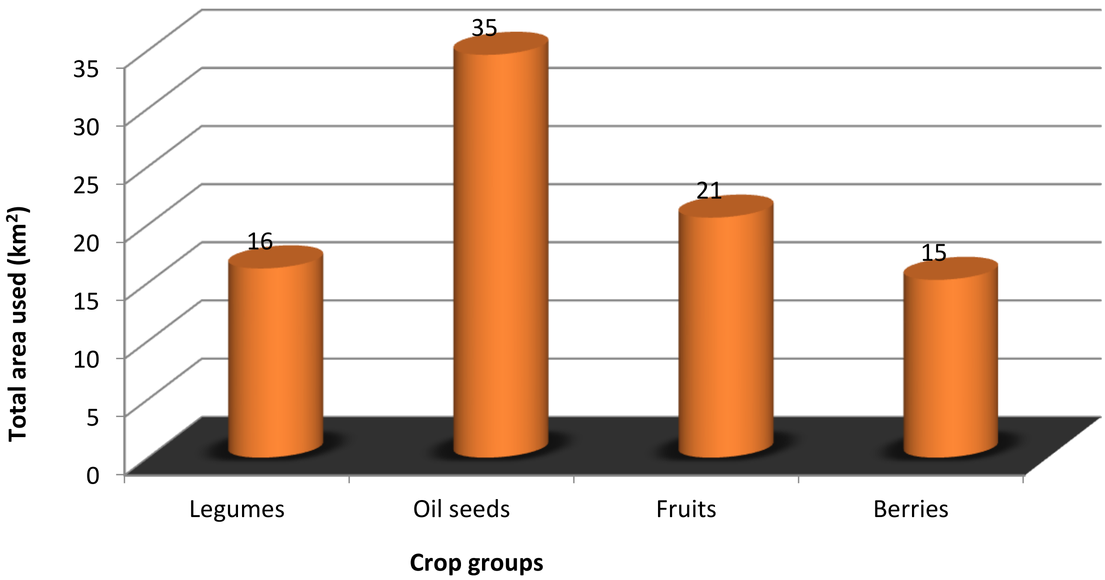

Figure 2. *Area occupied by each group of pollination dependent crops in 2013. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

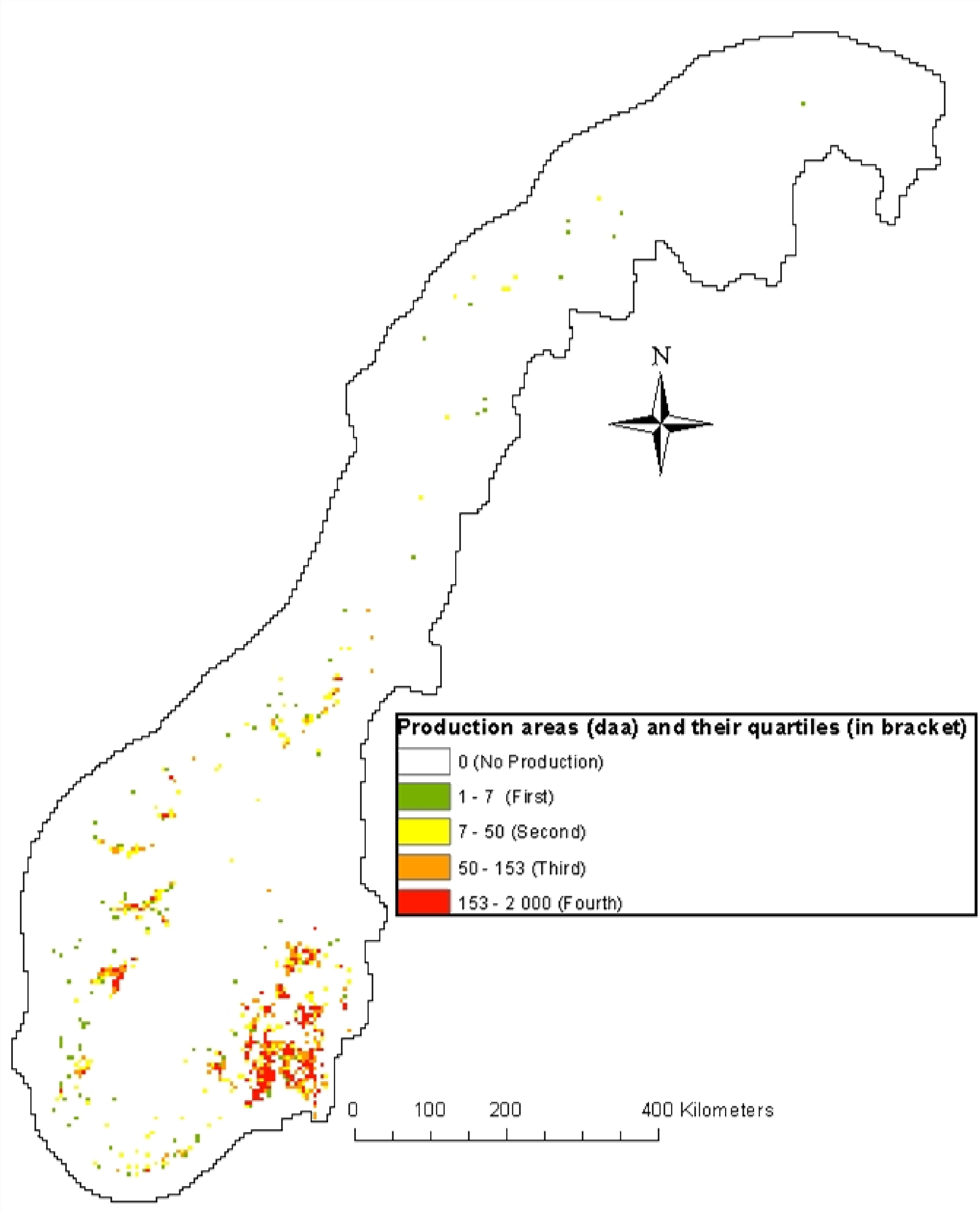

Figure 3. *Geographic distribution of all the pollination-dependent crops in 2013 measured as the number of dekars (1000 m^2) of agricultural land per each 25 km^2 grid (red indicates large agricultural activity). The ordinal names in the brackets show the quartiles of the data. The first quartile shows the range of values for the lowest 25% of the data; the second quartile is the median; the third is at the middle of the median and the value of the upper 25% of the data. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

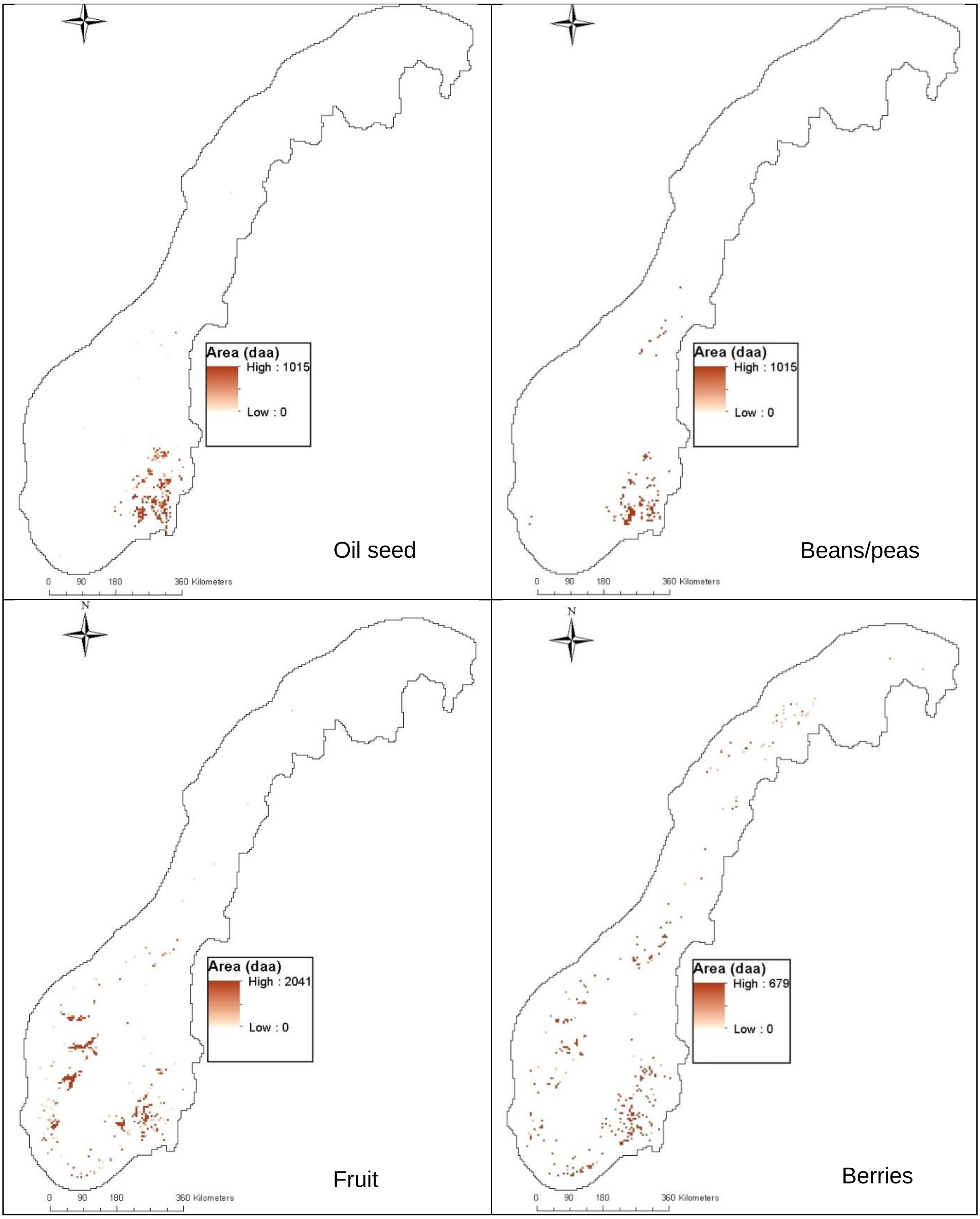

Figure 4. *Geographic distribution of the four pollination dependent crop groups in 2013: upper left (oil seeds), upper right (beans and peas), lower left (fruits) and lower right (berries). (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

The line graphs in Figure 5 present the total production areas of the four crop groups and their total sum between 1999 and 2013. The figure shows that the year 2013 is not a representative of the past 15 years as there was a pronounced decline in production areas in 2013. The total area presented above for 2013 (87 km^2) is only almost half (48%) of the total production area of the peak year of production (2002) when the total area of production for pollination-dependent crops was over 167 km^2. The overall trend over the 15 year period is a consistent decline with the production of oil seed crops declining the most. The fruits and berries changed much less as could be expected given that most of them are perennial crops and their production cycles are relatively longer. They still show a decline, however. If we take the peak year of 2002 as a reference and compare it to the year 2013, the production areas have decreased by 68%, 16% and 34% for the oil seeds, fruits and berries, respectively. This is in contrast to the production of legumes, which increased by 67% during the same time period.

The oil seeds, representing 40% of the total production areas of the pollination-dependent crops, are the most variable during the last 15 years, thus dictating the temporal behavior of the total production areas. The changes in the production areas of oil seeds between 2003 and 2013, i.e. ten years interval, is presented in Figure 6. The negative values (green) indicate that the production areas decline, while the positive values (red) indicate increase in production areas. Only a few grid cells show increased oil seed production area over the ten years period. The result of the change is a concentration of the oil seed production only in the south-eastern part of the country. The driving factors behind the geographic variation and temporal changes require a more detailed investigation.

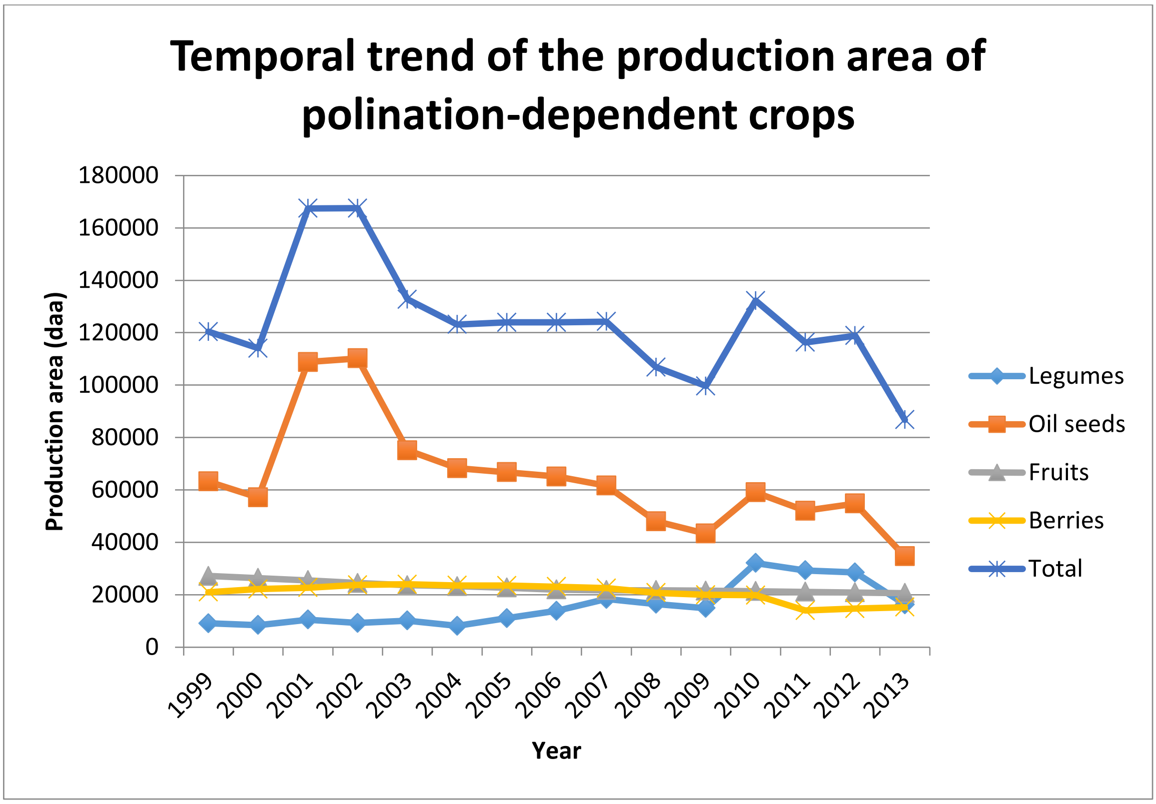

Figure 5. *The temporal variation of the total production areas of the four pollination-dependent crop groups. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

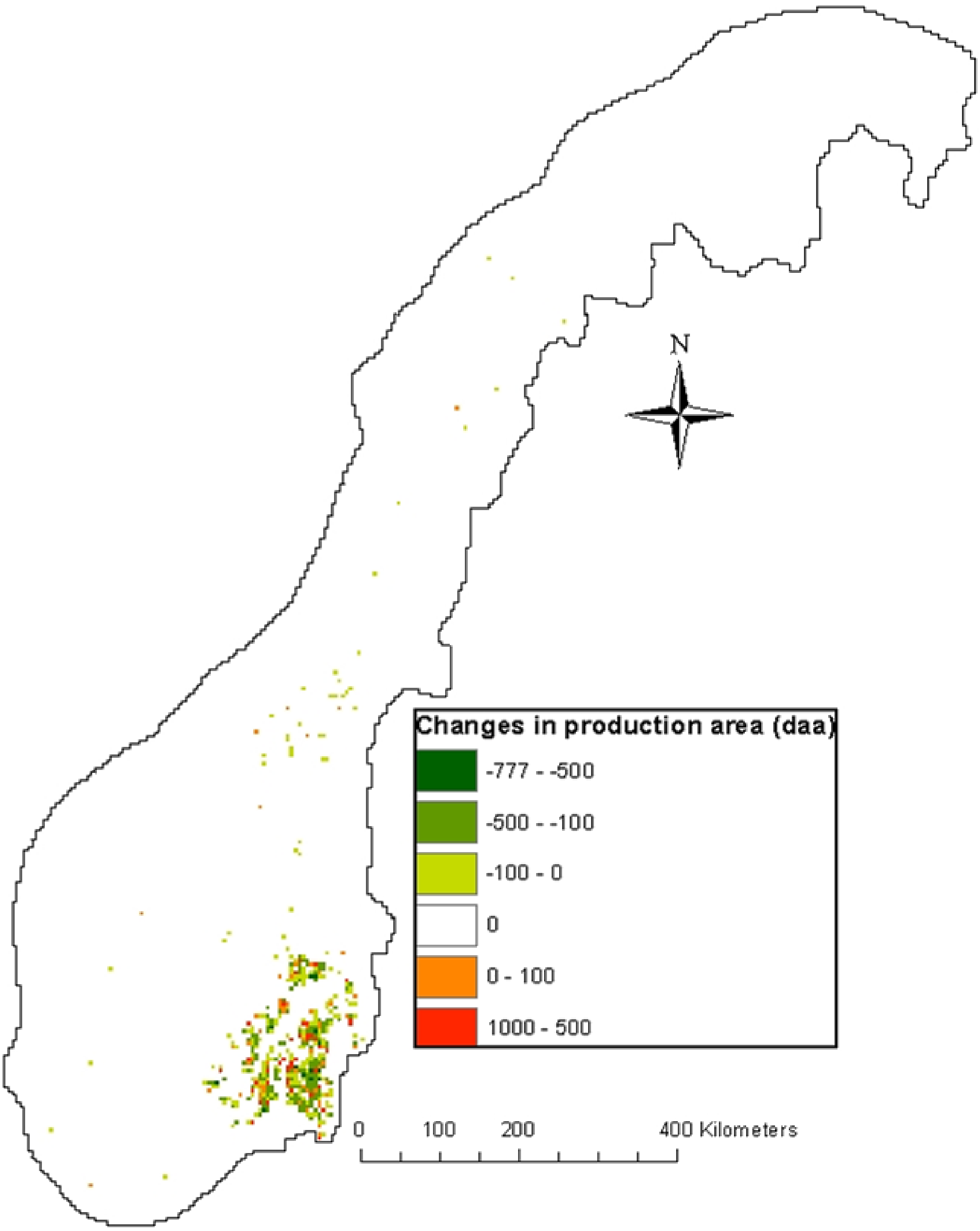

Figure 6. *Changes in the production areas of the oil seeds between 2003 and 2013 in number of dekars (1000 m^2) per 25 km^2 grid. Negative values indicate a decline, positive values indicate an increase in area. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

5 Ecosystem services and the science-policy interface

The concept of Ecosystem Services (ES) was coined in the late 80:ies and reached the scientific mainstream in the 90:ies (Erlich and Erlich 1981, Daily 1997) as a response to the large impacts on the environment and life systems (biodiversity) from human activities observed in the second half of the 20th century. The Millennium Ecosystem Assessment (MA 2005) further developed the concept into a framework that makes explicit the dependence of human society on nature with the aim to draw attention on the intrinsic linkages between ecosystem functioning and long-term societal development. In the past decade, a substantial body of research has developed the science around ESs with many commonalities with sustainability science. Central questions in ES science are issues about the assessment of the capacity of ecological systems to maintain functions on which society relies, how they are impacted by decision-making, and which are the drivers behind these decisions. This involves many aspects; such as economic profit, non-economic values and rules of use, and have been the focus of much ESs research in recent years (Gómez-Baggethun & Barton 2013). ES science explores the interface between nature and society, including practical implementations of ecosystem management and governance at multiple levels. These aspects of the ES research provides many opportunities to nurture the science-policy exchange, as reflected in the great interest to promote science-policy communication at European and global level (e.g. TEEB, CBD, IPBES).

One of the cornerstones of the ES framework is that it acknowledges that the benefits provided by nature to society are multiple and covering various dimensions (MA 2005), which opens, at the same time, to the analysis of trade-offs between different kinds of benefits and beneficiaries (Schröter et al. 2014). This kind of analysis is central to decision-making.

5.1 Knowledge base for ecosystem services management

One particular challenge about ES management is that the underlying ecological functions that provide the services take place at different spatial scales, typically at the local (e.g. species interactions) and landscape (e.g. dispersal, migration processes) levels. As a consequence, benefits and costs associated with ES provision vary across scales and entail multiple levels of decision-making, for instance by consumers of ES-based products, land-owners, and policy makers.

ES management often deals with complex systems, and knowledge of the multiple interactions and processes operating at various temporal and spatial scales is the fundament on which a successful management must be based. There is a strong emphasis in the field on the importance of knowledge to support policy design. ES management decisions should be based on the best available scientific evidence together with other forms of knowledge (Sutherland 2003, Sutherland et al. 2006). However, the available scientific knowledge is typically incomplete and decisions on management of ES often need be made in the face of considerable degrees of uncertainty. It has been proposed that there is a relationship between the accuracy and reliability of the data required for ES planning, the spatial level of implementation, and the particular governance/decision-making context. For instance, higher level of accuracy is required in the case of policy design (setting incentive levels to land-owners to change practices and targeting user groups) compared to the information required for awareness raising (Gómez-Baggethun & Barton 2013). Similarly, different levels of quality and accuracy in the ecological data are required to manage ESs (Fig. 7).

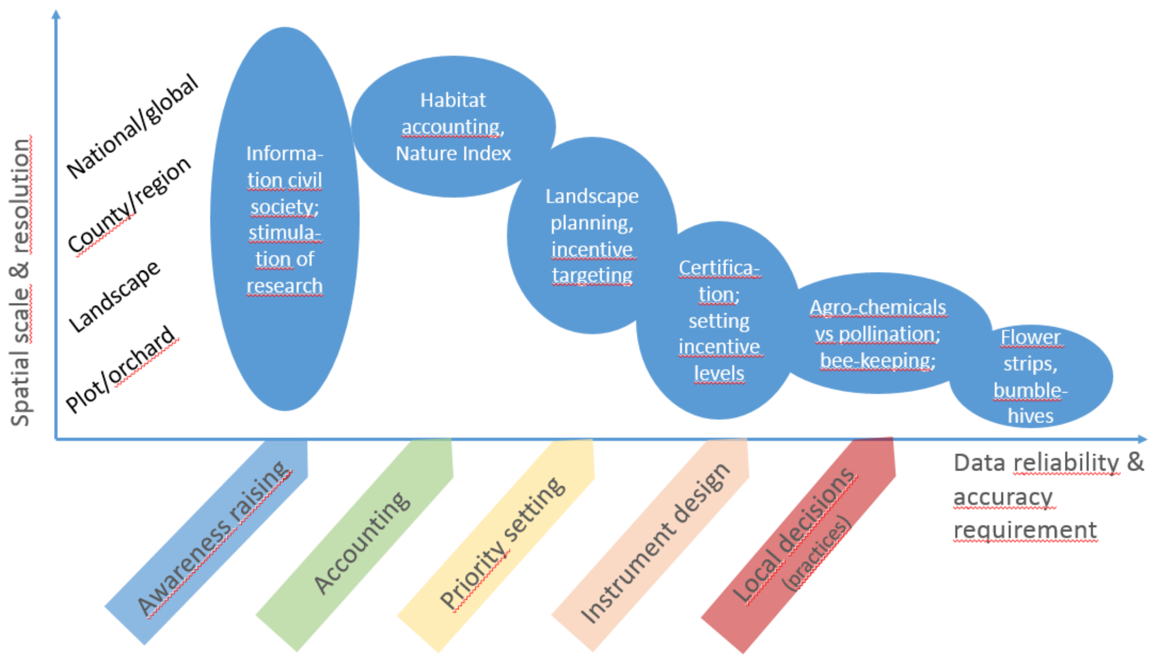

Figure 7. *Examples of instruments for conservation and sustainable use of pollination services in relation to spatial scale /level of governance and requirements on data reliability and accuracy. Based on Gómez-Baggethun & Barton (2013).*

5.2 Science – policy interface

Pollination is one of the most researched ecological functions in the field of ESs (Fig. 8), which reflects, in part, the importance of this function for food security and for the economy in the agricultural sector. Studies have addressed questions about pollination services at various spatial scales, explored different indicators of pollination service provision and evaluated the actual pollination function and its outcomes with different degree of specificity. We illustrate with some examples from the literature how the different levels of accuracy and detail of ecological information can be suitable in different decision-making contexts as a backdrop to pollination deficit studies in this report (Fig. 7).

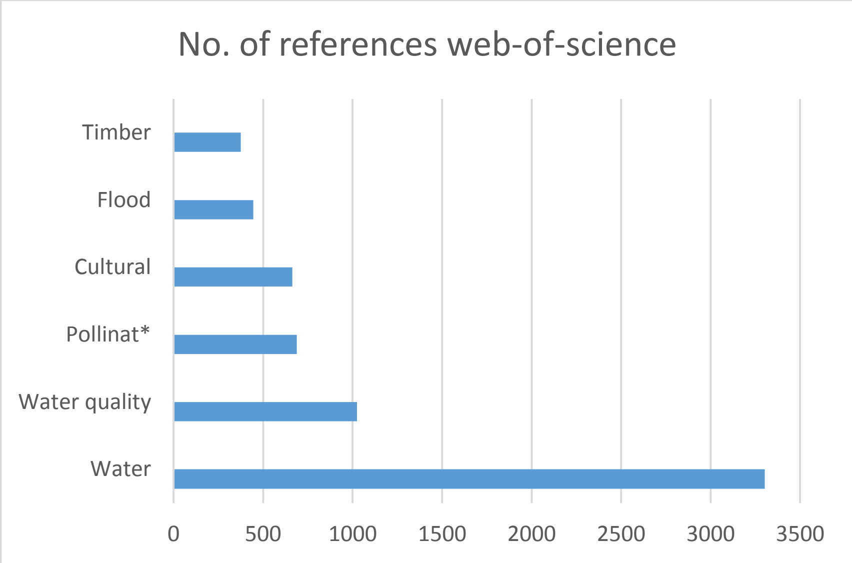

Figure 8: Number of hits in the web-of-science database using the string "ecosystem service*" in combination with the search strings indicated by each bar. Total number of hits of the string "ecosystem service*" was 15 002.

Costanza's et al. (1997) seminal paper on a global valuation of ecosystem services, explicitly acknowledged the question of uncertainty and coarse scale approximations used in the study. It states that "*the valuation approach assumes that there are no sharp thresholds, discontinuities or irreversibilities in the ecosystem response functions. This is almost certainly not the case. Therefore this valuation yields an underestimate of the total value*". This study has played a critical role in raising awareness on the magnitude of the importance of pollination for agriculture and stimulated research. Also at the global scale, several studies contribute to support awareness about the importance of pollination for food security (Eilers et al. 2011) and the economy (Klein et al. 2007). Recent studies highlight the role of pollinator diversity (Brittain et al. 2013; Frund et al. 2013) and coarse-scale drivers of pollination services change (Winfree et al. 2009; Potts et al. 2010 & 2011; Sodhi et al. 2010; González-Varo et al. 2013).

A substantial body of research has addressed questions about landscape quality (provision of nesting sites and flower resources) on pollinator diversity and on the impact landscape configuration on the potential for the provision of pollination services (e.g. Steffan-Dewenter & Tscharntke 1999; Steffan-Dewenter et al. 2002; Tscharntke et al. 2002; Tscharntke et al. 2005; Rundlöf et al. 2008; Batáry et al. 2011; Schleuning et al. 2011). Historical data provide insights on the magnitude of changes in response to land-use drivers (Bommarco et al. 2012a). This evidence can support policy decisions on for instance landscape planning and targeted measures to protect habitats that are important to maintain pollinator diversity.

More detailed and accurate information is required to design practices at the farm and/or plot level, e.g. the cultivation of additional food resources near target crops. Also, to resolve possible farm-level production trade-offs, such as between honeybee keeping and seed production of certain crops, or between the use of agro-chemicals for crop protection and pollination. This information can also be useful to define certification schemes for food products and levels of incentives to land-owners to adopt certain management practices.

However, detecting pollinator declines is not a trivial matter. Pollinator populations are often highly variable, both spatially and temporally and inferring statistically robust declines require extensive sampling. Lebuhn and colleagues (2012) estimated that you would need to sample between 200 and 250 sites over 5 years to have an adequate chance to detect a change, given a yearly population decrease of 2-5%. Annual declines of 5% level are dramatic, with projected halving of the populations in just 14 years. Smaller declines of 1% yearly decrease would require more than 300 sites with scheduled follow up recordings, which means that it is very difficult for ad-hoc point samples to detect these changes. As a result, in order to be able to detect declines in pollinators, we need continuously running monitoring programs, and the Global Pollination Project has worked to develop such programs in several countries. Also, since 2009, yearly recordings are being conducted in three regions of Norway, monitoring bumblebees and butterflies in open lowland habitats (Åström et al. 2013).

The pollination deficit protocol tested here could be implemented with relevant management schemes to experimentally manipulate pollinators, and could thus help provide information at this local level. However, this generally limits the potential to investigate landscape level effects as similar study sites often needs to be used in order to limit the level of confounding variation.
Conversely, the protocol could be used to investigate differences in pollination between landscapes of differing composition, providing more general information spanning larger regional scales. It is difficult, however, for any study to combine high level of detail with large spatial extent, and this also applies to the pollination deficit protocol.

6 The Pollination deficit protocol

6.1 Genesis

Answering to the rising awareness of the dependence on pollination for food production and to signs of a precarious development of crop pollination in parts of the world, the Global Pollination Project was launched in 2009 by the Food and Agricultural Organization of the United Nations (FAO) with support from the United Nations Environmental Program (UNEP). The project seeks to identify practices and build capacity in management of pollination services, adopting an ecosystem approach to harness the pollination services of wild biodiversity. Seven countries (Brazil, Ghana, India, Kenya, Pakistan, Nepal and South Africa) participated in a full sized GEF/UNEP/FAO project from 2009 to 2013, adopting a unified method in measuring pollinator activity. The methodology is presented in the "Protocol to Detect and Assess Pollination Deficits in Agrocultural Crops" (Vaissière et al. 2011), which specifies in detail experimental designs, surveying methods and support mechanisms to measure what is termed "pollination deficits" in a robust way.

Leading up to the formation of IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services), which is the biological counterpart of the IPCC (Intergovernmental Panel on Climate Change), the Government of Norway provided additional support to extend these studies to six new countries (Argentina, China, Colombia, Indonesia, Norway, and Zimbabwe) with the intent to build enough case studies for an international meta-analysis spanning different crops and geographic regions.

6.2 What is a pollination deficit?

The protocol and international partnership adopts the term pollination deficit, which has a longer history in ecology and is connected with pollen limitation (see e.g. Thomson 2011). "Deficit" in general is defined as the difference between a lower observed amount of pollination and a higher reference amount, and "pollination deficit" thus means the difference between the actual pollination and some higher reference point. Thus, a pollination deficit is quite different from an economic deficit, which means an excess amount of expenditure or cash outflow to the amount of revenue or cash inflow, and common wisdom related to economic deficits may not apply to pollination deficits. However, the differences in pollination deficit could in principle be translated into a magnitude of crop productive loss, and economic values could thereby be assigned pollination deficits. Nevertheless, the linkage between the level of flower pollination and crop yield is difficult to establish a priori because fruit and seed production involve resource allocation trade-offs within the plant.

The reference point to which pollination deficits is compared is generally defined as full pollination, meaning the level of pollen transfer where seed set is the highest. This however, may not be the same as optimal pollination or the pollination level giving the highest yield. Some plants are known to vary their growth and seed set depending on the seed set of past seasons. For example Ehrlén and Eriksson (1995) found that individuals of the wild legume *Lathurys vernus* that where hand pollinated could later shrink in size and more often enter dormancy than would individuals experiencing "normal" levels of pollination. Further, Vaissière (2011) cites observations of cocoa plants, that after having been hand pollinated to saturate seed set, produced massive amounts of fruits only to die afterwards, likely resulting in a lower total yield over the life span of the plant. In addition, thinning is a common practice in commercial apple orchards, where an excess of fruit can lead to smaller fruit size and lower quality, or even according to some growers, lower total yield (personal communication). In these cases, increased pollination is not necessarily advantageous. On the one hand, high fruit set gives the farmers more choice in what fruits to keep for maturation as the placement on the trees and individual branches affect their size and quality. On the other hand, increased fruit set may mean an increased cost of thinning, which in Norway often is carried out by hand.

Therefore, at least for perennial plants, the term pollination deficit needs to be clarified, and the protocol further defines that pollination deficits in agricultural settings refers to the total yield measured throughout the entire life span of the plant. This of course puts additional requirements on pollination deficit studies of perennial plants, such as apple.

In practice however, determining an optimal pollination is not straightforward. For wild plants, there are several hypotheses of how wide-spread pollination deficits should be under “equilibrium conditions” given life-history trade-offs and plant-insect mutualism, developed under evolutionary timescales (Thomson 2011). Given the controversy and lack of definitive evidence, one can at least say that pollination deficit (limitation) is not an uncommon natural phenomenon. For agricultural crops, the situation is a slightly different since the flower morphology and other properties of the plant are to a large degree the result of selective breeding. For example, several modern red clover seed varieties are tetraploid varieties bred from traditional diploid varieties. When selecting for beneficial traits for fodder production, such as increased biomass and hardiness, an unintended consequence is often an extension of the floral tube, or corolla, making retrieval of nectar and successful pollination more difficult. It is hypothesised that breeding has made it more difficult for bees with shorter tongue to effectively pollinate these varieties. In such circumstances, while it may be true that higher pollinator densities increases yield due to more effective pollination, perhaps it is more appropriate to blame an unfortunate plant selection for the pollination deficits.

A traditional way to achieve full pollination is to hand pollinate, often with a small paint brush. This can be an effective way to saturate the stigma with appropriate pollen, but may not always mimic naturally achievable conditions. Hand pollination typically is performed with pure pollen sources from a compatible individual, with pollen capable of successfully fertilizing the ovum of the female flower. Under natural conditions, however, pollinators will deposit a mix of pollen from various sources, including the same individual or other individuals of the same variety (Thomson 2001). Therefore, hand pollination may represent an unattainable goal under natural conditions, leading to estimates of pollen deficits that are not relevant for nature management or economic crop production. In conclusion, care must be taken to establish a relevant reference point for optimal pollination, and interpretations of reported pollination deficits must take this issue into account.

6.3 Methodology

The basic method of the protocol is to compare agricultural yield under differing amounts of pollination, and the protocol allows for both experimental manipulation and utilization of natural variation in pollination pressure among replicate farms. Experimental manipulation of pollination can often produce larger and more exact differences in pollination between fields, but is not always logistically possible, and does not necessarily reflect realistic management efforts for the growing system in question. Theoretically, it might be possible, for example, to add domesticated bees to many production systems to increase yield, but such analyses would have to consider the feasibility of such management actions on large scales. As a result, and in line with the aim of the Global Pollination Project, the protocol mainly targets differences in wild pollinators. Examples of experimental manipulations that are feasible on large scales are sowing of flower strips and management of semi-natural grasslands to attracting wild pollinators, which also can be used in agricultural management schemes.

Agricultural yield is notoriously variable between fields and thus requires adequate replication in order to establish statistically reliable differences between fields. The protocol suggests a minimum of 5 replicate fields with treatment and 5 control fields, which should be located with enough distance between each other that the pollinator communities visiting them are independent. This naturally varies with production system and region, but a common assumption in similar studies is that pollinators rarely forage over more than 2 km distance which is stated as the suggested minimum distance between replicate fields (although we interpreted this as a minimum of 4 km distance). The protocol further suggests controlling for confounding factors in the selection of replicate fields but does not specify how to allocate other possibly interesting strata, such as field size and landscape composition, since this is contingent on the specific situation at hand. As in many other ecological studies, the range of variation among replicates is important to determine a suitable sample size to produces statistically robust inferences, but this variation may be difficult to establish before the fields are identified and the measurements are made. Here, experiences from already performed field studies could give information on suitable experimental designs which could be used to update the recommendations. Lastly, the protocol allows for within field differentiation of treatment if the fields are large enough, exploring natural or manipulated pollinator gradients.

6.4 Analysis

The protocol only makes general suggestions for statistical analyses, listing traditional ANOVA of regression techniques as viable choices. It does not, however, provide detailed guidance on how to interpret possible statistically significant findings. For example, the relevance of an estimated pollination deficit using a specific reference point relies on the relevance of that reference point for a particular management perspective.

This work is currently under development within the international meta-analysis. In light of the discussion above, we highly recommend attempting to establish pollination-yield curves using data from multiple sites, which would help put individual sites and countries' results into context.

7 Norwegian implementation

7.1 The study crops

To be able to achieve adequate sampling sizes, the project collaborated with two host projects, mentioned above. The internal strategic project within NINA conducted a case study on pollination with specific focus on the quality and composition of the resources on a landscape scale. Apples where chosen as study crop for its clear dependence on pollination, but relatively unknown influence of wild pollinators. Apples also have a concentrated blooming period of approximately two weeks in spring, when pollinator activity still can be low and variable due to weather conditions. Figure 9 shows a temporal trend in the total production area of fruits and apples. There has been a steady decline in the total area used for apple farming during the last decade but it is unknown to what extent this could be influenced by a lack of pollinators. Apples also represent a potentially important early food resource for wild pollinators and could potentially boost early colony development of bumblebees.

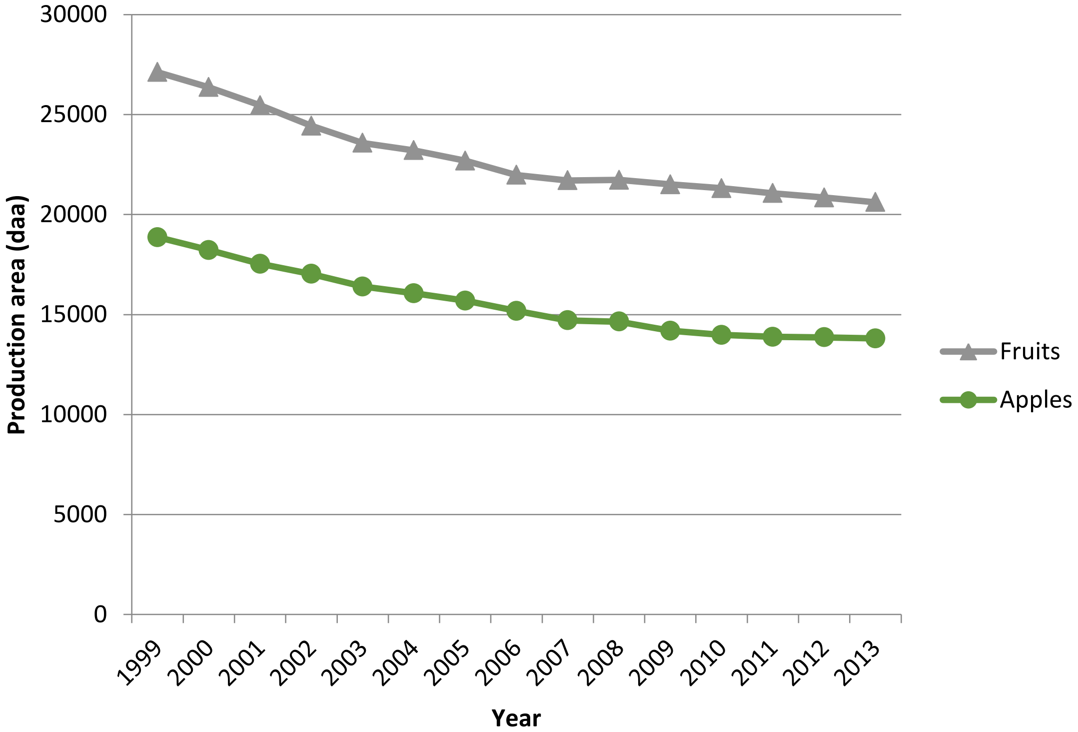

Figure 9. *Temporal trend of the production area of fruits and apples in Norway. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

Understanding and enhancing the pollination in red clover seed production is the main objective for the project PolliClover. There has been concern for the future of Norwegian production of red clover seed following a worrisome trend in yield during the past decade (Fig. 10). Lack of pollination has been put forward as a main hypothesis for the decline. Red clover seed is an important crop for the national agriculture as a whole. Organic farming relies on red clover for soil fertilization in crop rotation systems where red clover is used for its nitrogen fixating abilities. Red clover is also a major part of grass-mixtures grown for fodder. In the years before the start of the PolliClover project, Norway produced only about half of its demand for red clover seed.

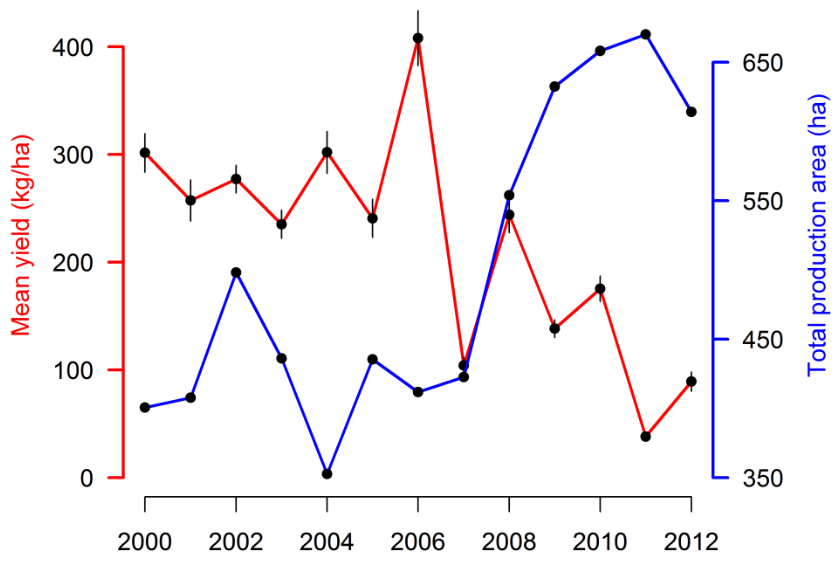

Figure 10. *Time trend of red clover harvest in Norway. Red line (left axis) shows mean yield per hectare, blue line shows the total production area of red clover seeds in hectares. The figure is based on the complete harvest records for Norway, curtesy of the seed companies Felleskjøpet Agri and Strand Unikorn.*

7.2 Distribution of apple and red clover farms in Norway

In the same way as legumes and oil seed were shown to be concentrated in the south-eastern part of the country (Fig. 4), both apple and red clover farms show the same pattern (Fig. 11, 12, 14). However, apple farms are also common in the south-west part of Norway (Fig. 11, 13), where it is especially concentrated around a few narrow fjords with favorable climatic conditions.

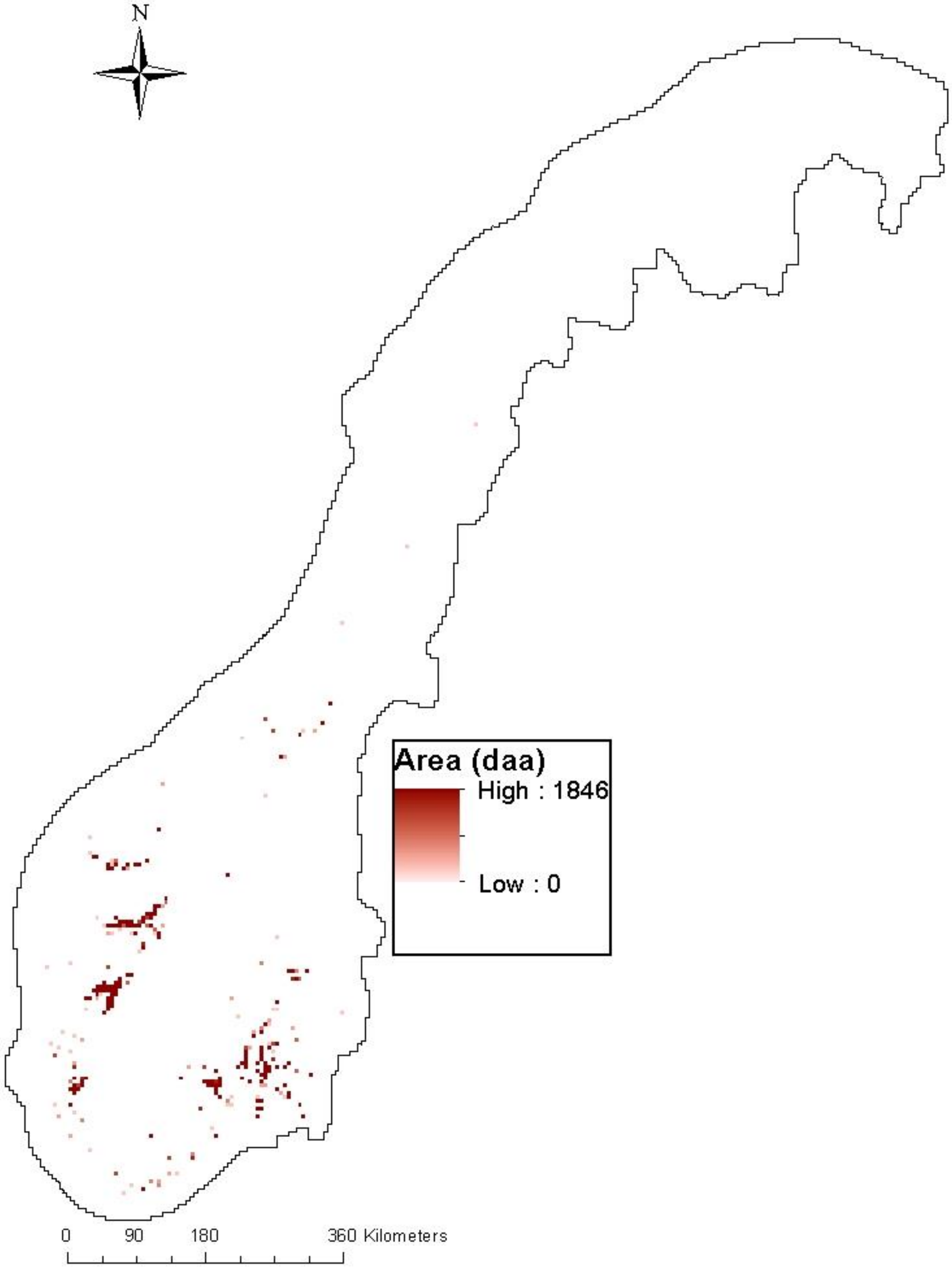

Figure 11. *Geographic distribution of apple farmers in Norway. Grid size is 25 km^2. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

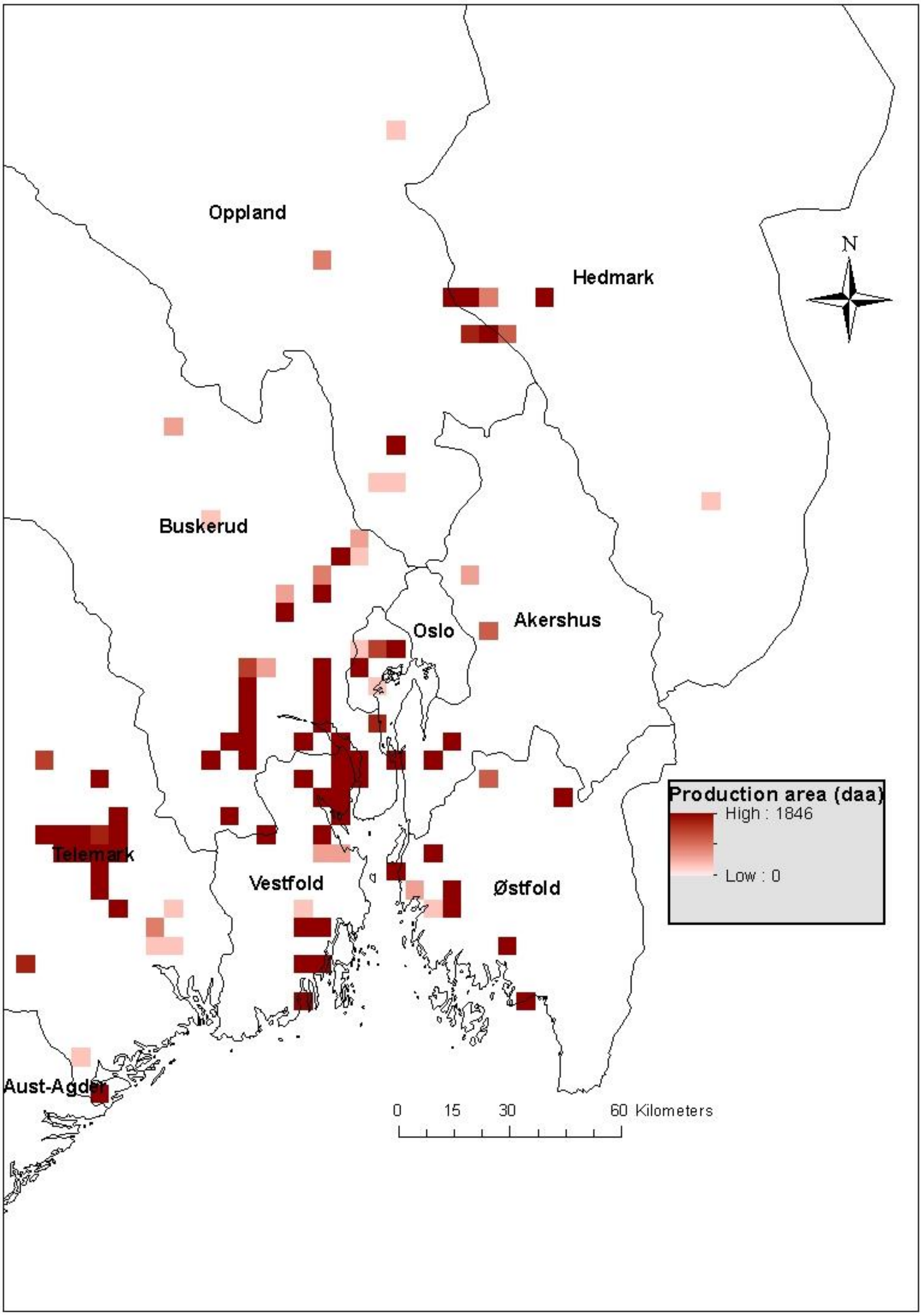

Figure 12. *Geographic distribution of apple farmers in the south-eastern region of Norway. Grid size is 25 km^2. (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

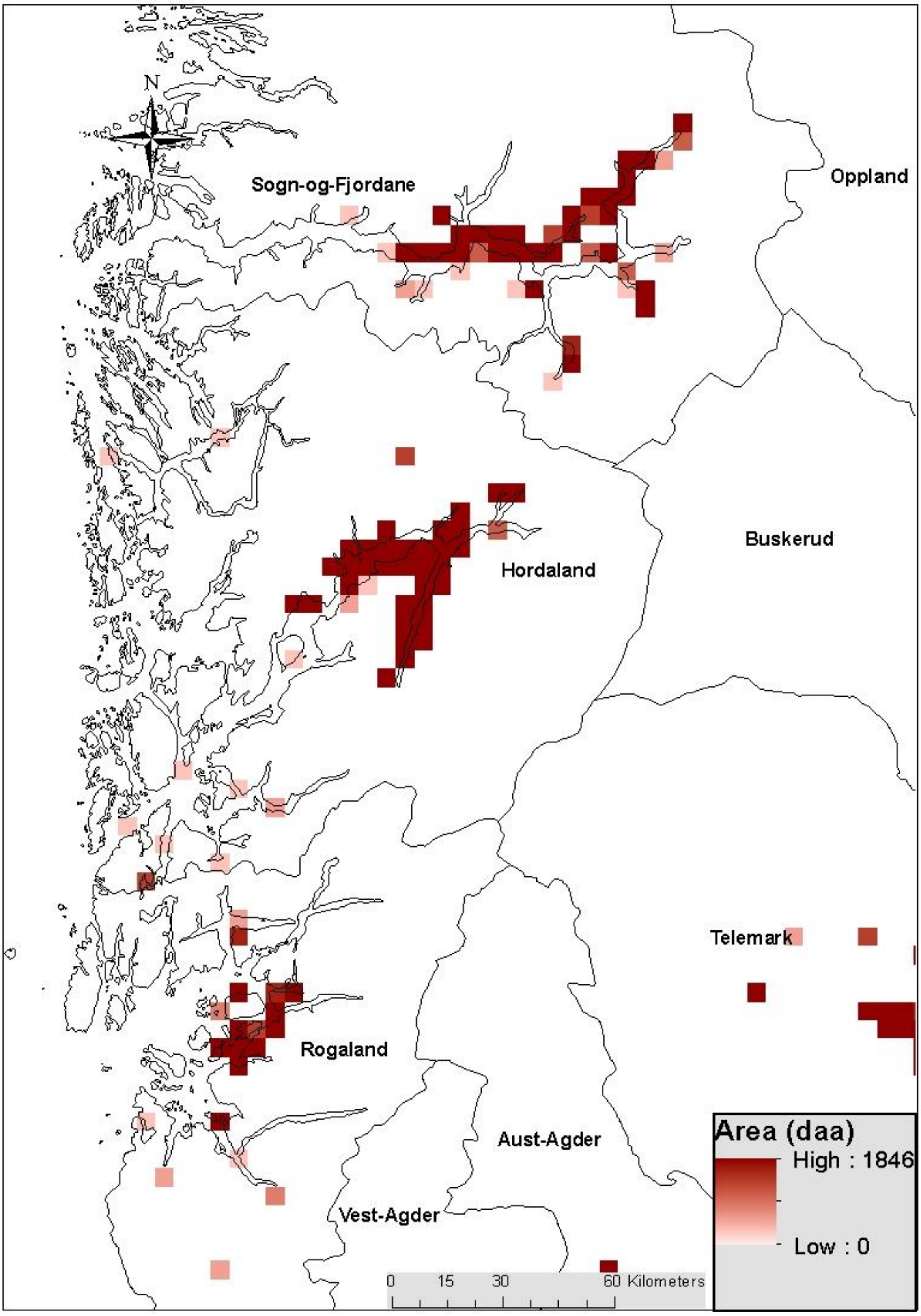

Figure 13. *Geographic distribution of apple farmers in the south-western region of Norway. Grid size is 25 km². (Source: Direct Payment Register, Norwegian Agricultural Authority, 2013)*

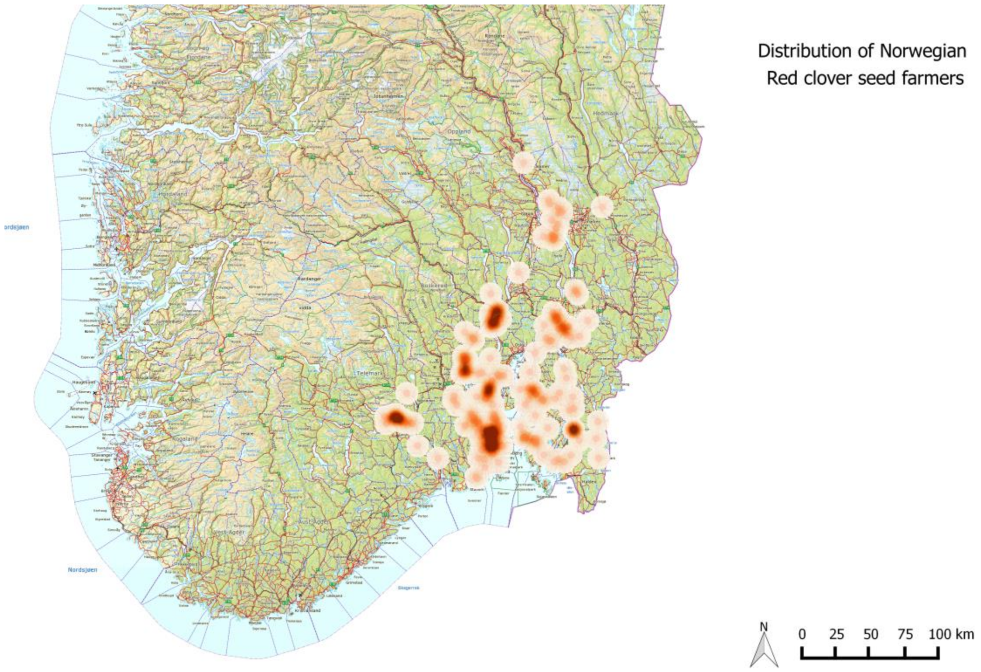

Figure 14. *Geographic distribution of red clover seed farmers in Norway. Data from the seed companies Felleskjøpet and Strand Unikorn containing complete records from 2000-2012.*

7.3 Field studies

The data from 2014 is currently being processed and will be analysed together with the data from 2013 within the planned progress of the two host projects and reported later on in peer-reviewed journals. It is not within the scope of this report to communicate detailed results, but we will outline some general findings and discuss the potential for various analyses.

7.3.1 Apple

In the first field season in 2013, we surveyed 13 apple orchards in accordance with the protocol, noting the diversity and density of the visiting pollinators and measuring the yield, by performing complete harvests of 8 trees per replicate field. Replicate fields were chosen within the same general geographical region that grow the same variety (Aroma) and are located at least 4 kilometres apart, to ensure independence of the visiting pollinator fauna. This study uses the natural variability in pollinators between fields as a natural experiment, and thus does not contain experimental manipulations. Figure 15 displays the major pollinator groups that visited the apple flowers in 2013. Figure 16 shows the pollination visitation levels of honey bees, bumble bees and hoverflies together with the apple yield in the different fields under study in 2013.

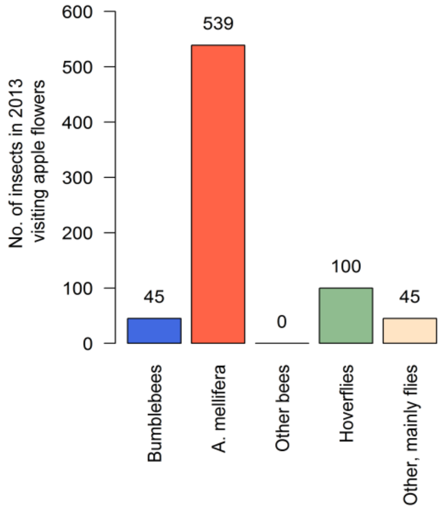

Figure 15. *Major pollinator groups visiting the 13 surveyed apple orchards in 2013.*

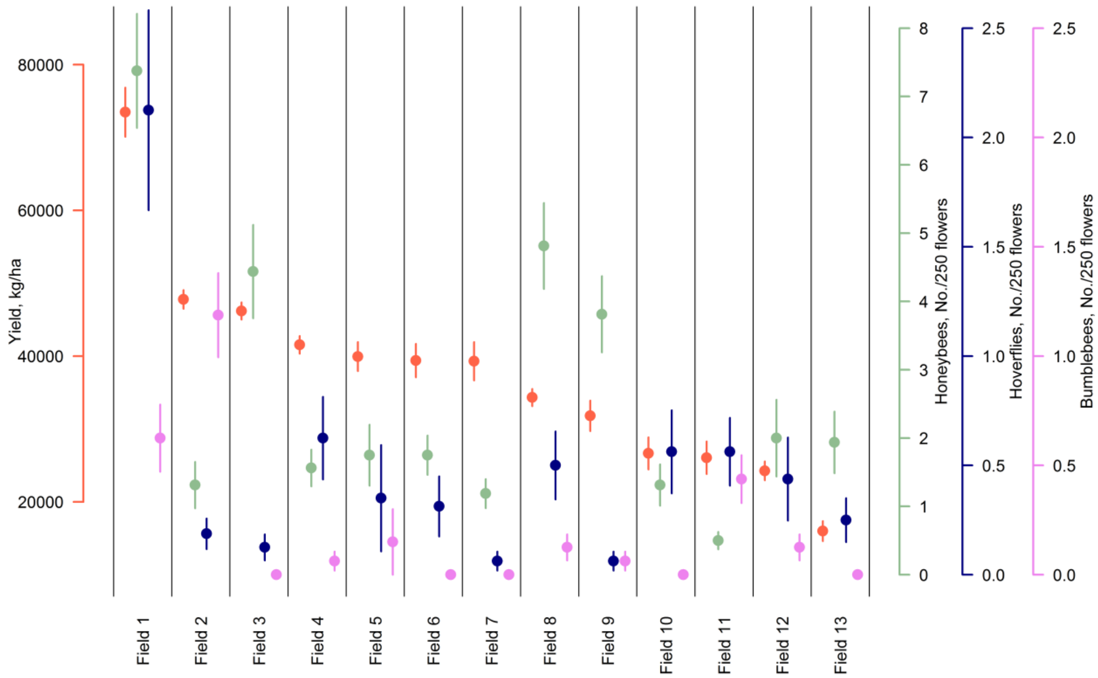

Figure 16. *Pollination visitation levels (right axis) and fruit yield (left axis) in 13 different apple orchards in 2013. Preliminary analysis indicates that honey bee occurrence (Apis mellifera) is correlated with higher yields. However, further analyses are needed to disentangle the effect of other correlated pollinator groups and covariates.*

In 2014, we revisited the same apple orchards as in 2013 with the exception of two, resulting in 11 resurveyed fields. Combining data from a second field season strengthens the analysis in several ways. First, it is a practical way to extend the number of replicates, with limited candidate fields and ability to survey many farms in one season. Second, by re-visiting the same field, one can better control for the differences between farms by focusing on how the between-year differences in yield relates to the between-year differences in pollination. Third, for perennial crops, it is possible to analyse the dependence of yield on earlier seasons. This is a potential important factor for apple, since the unusually high yield of 2013 was followed by a substantially lower yield of 2014. Statistical analysis is pending, but the difference in yield between years does not appear to be explained by differences in pollination, indicating compensatory yield decreases in apples following a particularly good year. This is indicated by the growers themselves (personal communication) and accentuates the distinction between optimal pollination in short terms and optimal pollination throughout the plant's entire life span (see section 6.2).

7.3.2 Red clover seed

In the first field season in 2013, we selected 10 fields producing red clover seeds of the same variety (Lea), placed more than 4 kilometres apart. Like apple farming, the distribution of red clover seed production is rather small, so fields are located within relatively similar conditions (Fig. 14). This study has as its main aim to improve pollination in red clover, and experimental manipulation forms a key part. We administered two manipulative treatments in half of the fields. First, flower strips of *Phacelia tanacetifolia,* a highly attractive plant for bees, where sowed. These strips flower before the red clover and draw pollinators to the fields from the surrounding landscape. In addition, we placed reared bumblebee colonies of *Bombus pascuorum* in the field edges, a long-tongued bumblebee thought to be a well suited pollinator for red clover. Rearing of *B. pascuorum* is pioneering work as they rarely are reared even internationally, and the logistics of a full scale operation is very challenging. This resulted in few successful colonies and a weak treatment overall. In addition, there were troubles with the sowing of the flower strips. *P. tanacetifolia* requires about 8 weeks from sowing to onset of bloom, and the late spring of 2013 resulted in overall poor condition of the flower strips. In summary, the manipulations were less than optimal in 2013, and the treatment effects are not further discussed here. However, both the bumblebee and flower resource additions trials have provided valuable insights about the feasibility of the implementation of these management practices.

Figure 17 shows the abundance of honeybees and bumblebees in the fields, and two measures of yield; the mean of the four 1m^2 experimental plots and the official yield from the seed companies. Mean densities were similar for honeybees and bumblebees, which were highly dominated by members of the species-complex *Bombus lucorum*, *B. magnus*, and *B. cryptarum*, together with *Bombus terrestris.*

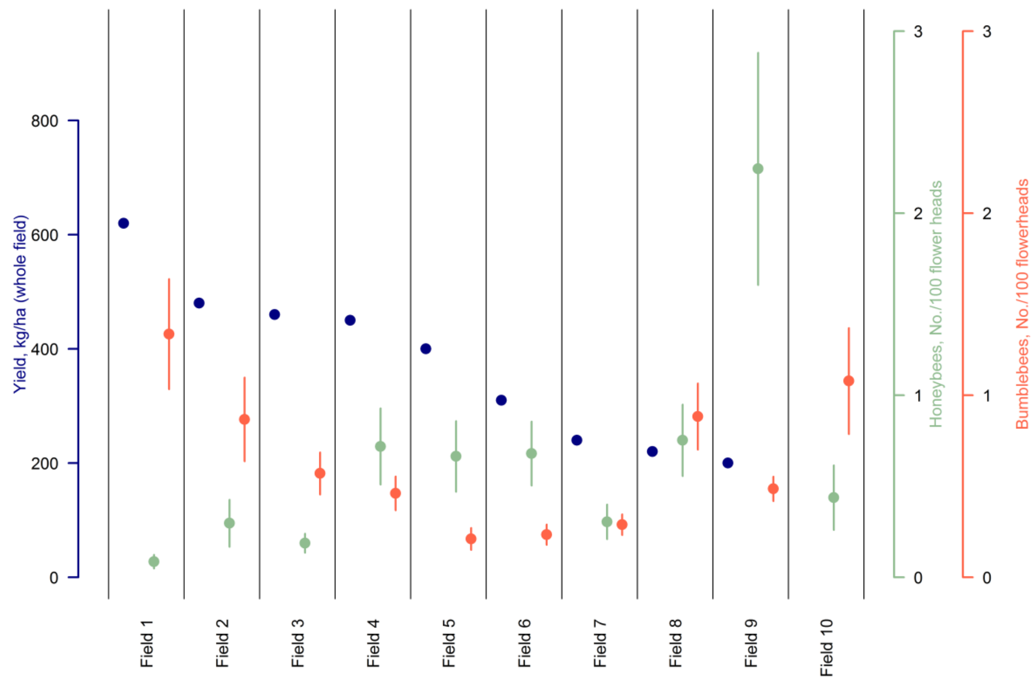

Figure 17. *Abundance of honeybees and bumblebees in the red clover fields (right axis) and the official yield provided by the seed companies (left axis, blue).*

The 2014 field season expanded the study to 20 fields, revisiting most farmers that participated in 2013. Also this year, the rearing of *B. pascuorum* was wrought with problems, practically resulting in a non-existing treatment. The flower strips however, were generally of better quality than the year before and preliminary analyses indicate improved yields in treatment fields. If these results hold, they represent a feasible management action for red clover seed farmers. A further full field season is planned for 2015.

7.4 Applicability of protocol to Norway

The protocol itself appears to be readily applicable to Norwegian settings. The protocol is general enough to be applied to a wide variety of crop types and specific specific survey methods are described for most conceivable types of agricultural crops. We have not identified any particular properties of Norwegian or Scandinavian weather, crop types, or agricultural practices that would hinder or invalidate the use of the protocol for assessment in the Scandinavian context.

Even so, we have identified challenges that might be especially pronounced for Norway and similar regions. The first is related to the amount of natural variation of factors that may influence pollinators. The production of most pollinator dependent crops in Norway is concentrated to a distinct region or to a few similar regions, where they are best suited based on soil properties, climate, geography, or located based on cultural and historical reasons (see chapter 4). Most crops grown today have a long agricultural history in Norway, and establishment of new agricultural land through land transformation is rare, meaning that farmers have had ample time to locate the most suitable regions for a particular crop and rarely establish new and potentially different agricultural lands. Crops of a specific type therefore often have similar surroundings, limiting the possibility of analysing the importance of landscape characteristics for the pollination.

Farmers in Norway are also generally well organized as a group, often following similar management practices, guided by central agricultural information agencies. For example, apple production in Norway is centred on a few locations, where most farmers run rather similar operations. Red clover seed production is also well organized and mostly located within a well-defined region. This is likely advantageous for the farmers and for the country as a whole, benefitting from the probable increased yields of such a well-managed production system. But it makes it challenging to find natural differences in management that may affect pollinator communities with potential consequences for yields. The alternative route, also indicated in the protocol, is experimental manipulation of factors that potentially affect pollinators. However, this approach also presents challenges. For example in the case of apple production, it was not deemed feasible to alter the pollinator densities on the orchards in this study. Most apple farmers themselves take measures to increase pollination, by either keeping bee hives themselves or borrowing hives from local bee keepers during the blooming period. Manipulating these set-ups was beyond the scope of this study, but it would in principle be possible to experimentally increase pollination levels by further addition of honey bee or bumble bee hives.

Secondly, the relatively small group of farmers that grow the same crop makes it difficult to find enough replicate fields to implement the protocol effectively, especially when considering the variety of crops, and the distance between fields. Our survey of 13 apple orchards is probably close to the maximal possible amount for southern Norway, given that our selection was based on a near complete record of professional apple farmers and that we selected the most commonly grown variety. Extending the study to include also the south-western apple growing regions would increase the number of replicates, but was not practically feasible for this study, and would have demanded considerable additional resources (staff capacity and funding). Similarly, the 20 fields chosen for the red clover seed study was close to the maximum possible number, even though we here had complete records of farmers and we again targeted the most commonly grown variety. Still, here we were lucky to be able to implement two manipulative treatments through the collaborative project PolliClover.

Thirdly, in Norway as in most parts of Europe, much of the pollinator fauna is the result of an active land management through agriculture and husbandry, spanning hundreds if not thousands of years. Through these practices, the lands are kept open (without tree cover) with various amounts of habitats with flowering herbs and crops that provide the food resource for the majority of bee species. It is the decrease and change of these agro-pastural practices, and other human interventions, which has been identified as the primary reason for the decline of pollinator communities throughout much of Europe. This situation could be different to e.g. countries in tropical or temperate regions, where wild pollinators could originate from, and to a higher degree depend on, natural resources untouched by human hands. This is exemplified in the protocol, which emphasizes factors such as distance to natural habitat. For example in huge canola fields in Brazil, “natural habitat” can form a very small portion of the landscape, while still being the hypothesised important factor for wild pollinator occurrences. In a northern European setting, especially in Norway, “natural habitat” is boreal forest, which is never far away and often constitutes a significant portion even of agricultural landscapes. Even so, it is not generally thought that the amount of forest mostly determine which pollinators are present, but rather what goes on in and between the agricultural fields and pastures. The protocol itself does not record these qualities, although they could form the basis for contrasting selection of replicate landscapes.

7.5 Applicability of finding to other localities/regions

The findings and reasoning in this report are not necessarily limited to the local or national settings of the study sites. The general reasoning should apply to other regions, but there are particular characteristics of the study sites one should keep in mind when generalizing to other areas. Norwegian landscapes differ to most of the other study locations participating in the international project, in that they often hold many of the qualities that are identified as positive for pollinators. The agricultural landscapes have relatively small fields, interspersed with natural habitat that are largely unaffected by management practices that would decrease their ability to provide habitat for wild pollinators. Distance to natural habitat is seldom more than a few hundred meters and there are significant portions of forest in all studied landscapes. This is often the result of the natural geography limiting the amount of homogenization of agricultural fields possible. Even in a Nordic comparison, most of the Norwegian agricultural landscape consists of relatively small fields interspersed with much natural habitat. In other words, these sites probably occupy one extreme in the spectrum of landscape configuration within the international study.

On the other hand, Norway, as other parts of Northern Europe, differs in comparison to many temperate and tropical regions in where the important habitat for wild pollinators is located. Much of the relevant wild pollinators in Northern Europe are present as a result of a traditional agricultural management spanning several hundred or perhaps thousands of years. It is thought that many herb species originate from more limited areas of natural grassland in central or southern Europe, that when spread through agriculture brought with them their associated insect species (Hejcman et al. 2013). Many wild bees in Northern Europe rely on flower resources that would disappear if active agriculture where to seize and the pastures and fields were allowed to regrow with forest. Diversity of pollinators is not maintained despite agriculture and animal husbandry, but because of the right sort of agriculture and human management of the land. Therefore, a lack of natural habitat is probably not the most crucial factor in landscape analyses for pollinators in Northern Europe, but rather the landscape management practices throughout the landscape. The pollination deficit protocol emphasizes distances to natural habitat, but lacks a methodology to collect and summarize information on pollinator friendly practices in the surrounding landscape. This probably makes it less sensitive to the factors affecting pollinator communities in Norway and similar regions. Alternative methods and landscape studies of such factors are discussed in chapter 8.

8 Additional and alternative approaches

8.1 Pollination-yield relationships

Pollination dependent crops should by definition increase their yield with increased pollination from an already low level. But this pollination-yield relationship is likely non-linear. Pollination dependent crops should typically show an initial increase in yield, followed by an asymptotic levelling off as pollination continues to increase. As the stigma of a flower becomes saturated with compatible pollen, additional visits by pollinators should give no increased seed set. But pollination dependent plants also likely differ in the shape of their pollinator-yield relationships, some with only minimal dependence on pollination, and others with high dependence. Some are self-compatible and able to set seeds even without transfer of pollen between flowers of different plants; others are self-incompatible, requiring outcrossing between plants. Self-compatible plants can still benefit from visitation by pollinators, however. For example canola (*Brassica napus*), is self-compatible but is known to both outcross with other varieties (Becker et al. 1992) and benefit from insect pollination in terms of quantity and quality of yield (Bommarco et al. 2012). Self-incompatible plants include most apple varieties, which not only require pollen from a different plant, but from a different variety or cultivar, since plants of the same cultivar are genetic clones. As a result, apple is heavily dependent on pollination and pollinator exclusion experiments usually demonstrate very small yields.

Figure 18 sketches four of several possible types of pollinator-yield relationships. Quantifying the shape of this relationship is the basis for evaluating pollination deficits, and the basic principle of the protocol is to compare at least two points on these curves. If we had a perfect understanding of the pollination-yield relationship, we would in theory be able to draw conclusions about the level of pollination deficit after observing just one pollination level. However, investigating the shape of these relationships is a challenging task and so basic linear models are usually adopted. For example, a simple one-level manipulation of pollinator densities would measure two points on such a curve, drawing a straight line between the points.

However, there are important drawbacks in simplifying this relationship into a straight line. For instance, if we happen to compare yield at pollination levels A and B of figure 18, the estimated pollination deficit would be roughly equal for plant species 1 and 2 (green and blue), although plant species 1 is well below its optimal pollination level and species 2 has reached its peak. In addition, species 3 and 4 (red and yellow) would both exhibit no pollination deficit, although both pollination levels would be sub-optimal for species 4. Such a situation is possible if pollen deposition would saturate after relatively few pollinator visits, and additional visits would remove deposited pollen. Bees collect pollen as a food source for their offspring and there is no immediate incentive for bees to leave pollen on another flower even if it would benefit the plant. Another possible mechanism could be if increased levels of pollination where coupled with increased levels of nectar robbers, damaging the flower with lowered seed set as a result. Now consider what would happen if we compared pollination levels B and C. In this case, it is likely we would not discern any effect of pollination on yield and conclude that pollination is unimportant for these plants, while this would only be true for species 3 (red). Whatever the actual mechanism may be for a particular crop, one would expect different crops to respond differently, and in that sense it is a challenge how to define an overall level of pollination deficit for several plant species (Lonsdorf et al. 2009).

A perfect understanding of these relationships is of course impossible to achieve, since the exact shape of the curve could differ depending on the crop variety, the regional pollinator fauna, cultivation practices, and other contingencies. Still, having a general understanding of the shape of the pollination-yield relationship seems crucial for a correct assessment of pollination deficits, and to be able to put this deficit into a management perspective. Not only would it inform researchers where their study system broadly is located on the relevant pollinator spectrum. It would also help to determine whether a lack of estimated pollination deficit is due to a true lack of deficit, or due to an inadequate study design leading to low statistical power. Generally, data sets based on observational studies have large sources of unexplained variation and are laden with confounding factors. A real challenge for studies of this kind is to achieve enough statistical power to make robust inferences of the study system. Establishing at least a general understanding of the shape of the pollination-yield relationship would greatly improve researchers' ability to correctly interpret their observed data.

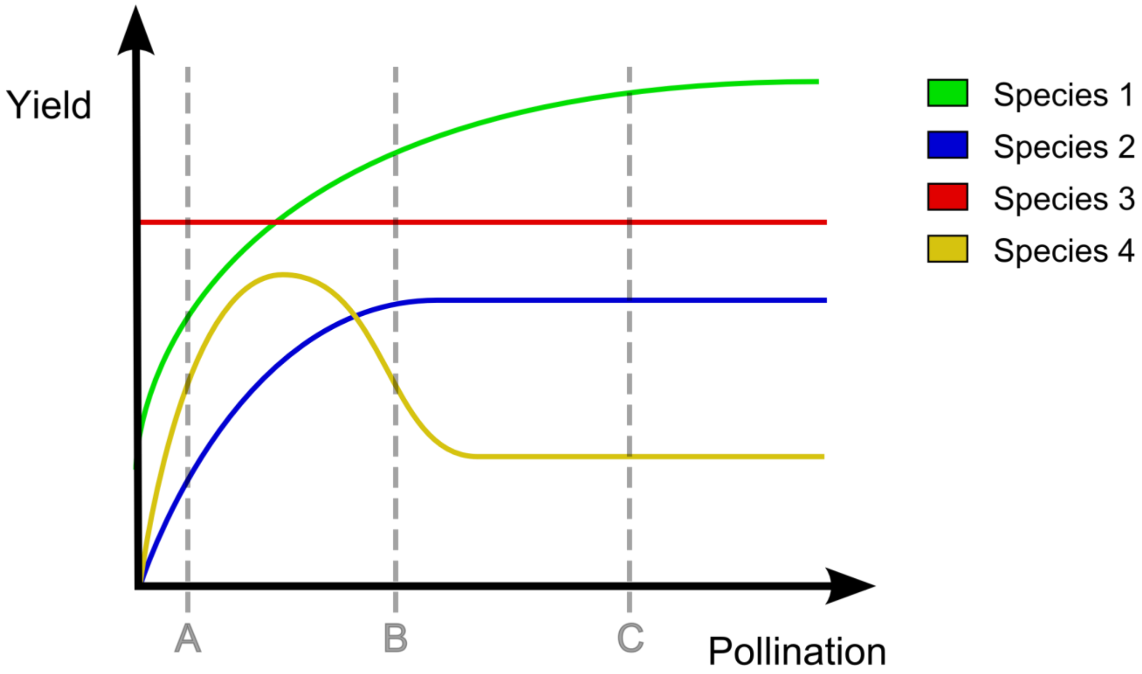

Figure 18. *Four possible types of pollinator-yield relationships representing different plant species. Species 1 (green) and species 2 (blue) increase their yield with increasing pollination, but reaches an asymptote at different levels of pollination. The yield of species 3 is unaffected by pollination. Species 4 has a hump-shaped response to pollination with maximum yield at an intermediate level of pollination. A, B, and C refers to different pollination levels, discussed further in the text in the context of different pollinator-yield relationships.*

8.2 Estimation of pollinator-yield relationships

Mapping the full pollination-yield relationship for a particular crop requires measuring yields under pollination densities ranging from zero to full pollination. Zero pollination can in most cases be achieved by pollinator exclusion, hindering pollinators to visit the flowers (e.g. Garratt 2014 for a recent example in apple). Various levels of degraded pollination could be mimicked by different types of exclusion practices, typically using different forms of mesh bags or cages to enclose the flowers or whole plant, or administrating the bags or cages during different amounts of time.

Achieving full pollination may be more challenging. Manipulating pollinator densities can be practically challenging, whether you do it indirectly through management actions that improves conditions for wild pollinators, or directly by placing captured or reared pollinators in the field. Improving conditions for wild pollinators has the added benefit of evaluating the potential and practicality of various conservation and management actions. The drawback is that it can be labour intensive and costly, and that it is difficult to reach the absolute maximum level of pollination.

A traditional approach is to artificially pollinate the flowers by hand to saturate the pollen deposit on the stigma (used e.g. in Garratt 2014). While this probably can capture the theoretical full level of pollination, it is unclear to what extent this pollination level realistically could be achieved for real pollinators. As discussed above, natural pollinators deposit a combination of suitable and unsuitable pollen on the stigma. In addition, bees are efficient collectors of pollen as a protein source and it is possible that the pollen resources are depleted before full pollination has been achieved (Thomson and Thomson 1992, Wilson and Thomson 1991)

Conversely, pollinating by hand usually involves using pure samples of suitable pollen that is generously dosed on the receiving flower. This method thus represents a benchmark of uncertain relevance to practically achievable conditions, and may not be straight forward to interpret. On the other hand, it does increase the chance of observing full pollination and thereby estimating a statistically robust relationship between pollination and production. When using artificial enhancements of pollination, it would also be advisable to consider a potential backlash in subsequent years, as it is possible to achieve levels of pollination that the plant never has experienced in its evolutionary history.

Regardless of which method you adopt, it would be a significant effort to adequately model the pollinator-yield relationship for most crops within a single study. As it stands, operationalizing the provision of pollination as an ecosystem service by use of indicators remains challenging. Therefore, cooperation between studies, with varying pollinator occurrences and other co-variables, may be a valuable approach. This seems like a task well suited for the international meta-analysis and we strongly suggest that an output of the Global Pollination Project and the work linked to IPBES is to estimate the shape of the pollination-yield relationships where the number of replicates allows.

8.3 Modelling determining factors for pollination

The causal chain linking management of pollinators to agricultural yield can be separated into distinct parts. A full understanding of the system requires understanding of all parts, which may require different types of experiments and observation.

One part of this question is what determines the regional pool of potential pollinators for a particular crop. Although the very basic characteristics of the regional pollinator fauna will be determined by evolutionary, climatic, and historical events which we cannot change, pollinator management is often aimed at the regional level. Because of the high mobility of pollinators, they are often affected by the quality of a relatively large landscape and explanatory factors are often summarized on a landscape level. For example; the amount of deforestation, trimming of road verges, management of pastures and lays e.g. within an area of several kilometres can have broad implications for the regional pollination fauna from which pollinators will be drawn. Forming a general understanding of these processes is a primary task for managers of larger regions. Analysis of pollinator resources on a landscape scale is a main source of information for these studies (Fig. 19).

Second is the question what determines which pollinators from the regional pool that visit a particular agricultural unit. Many pollinators forage over large distances and selectively choose which resources within the landscape to visit. Understanding and manipulating these factors can form a feasible management solution for the local farmer but does not necessarily increase the overall amounts of pollinators in the landscape. Some management actions could influence both aspects. For instance, flower strips can be a strong attractant for pollinators to a field and thus concentrate pollinators to a specific place, but may also boost populations at regional levels if it for example increases overall fecundity.

Lastly is the question what effect the local occurrences of pollinators have on agricultural yield. This is of course a crucial bit of information both for farmers and management and it is primarily this question that the protocol targets with obvious management interest. However, it alone does not capture all relevant questions for management.

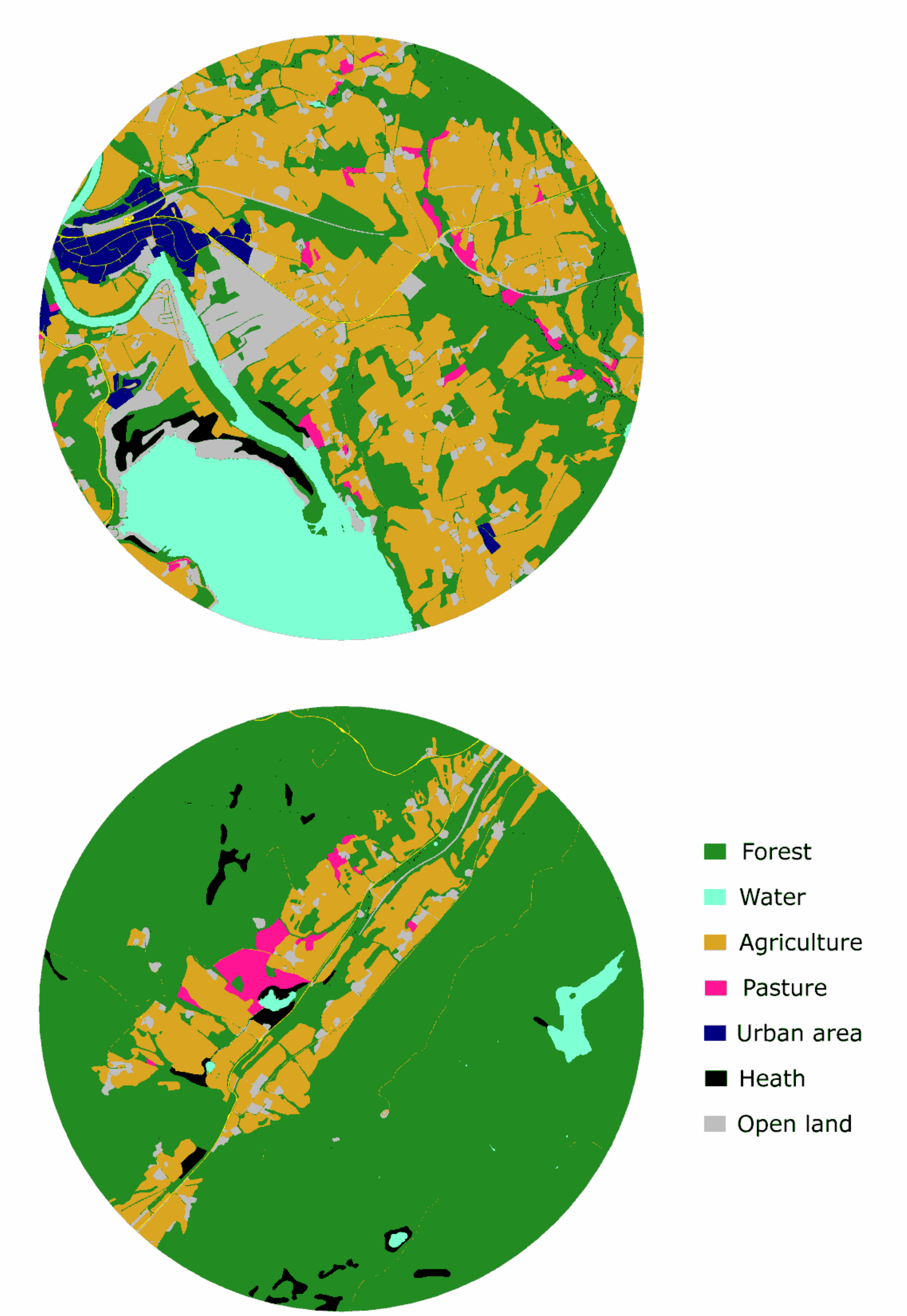

Figure 19. *Landscape surveys and GIS can form the basis for understanding the regional pollinator fauna. Here, two landscapes of 2 km radius show the extreme end points in total amount of forest. Note that the most developed agricultural landscape still contains plenty of forests within flying distance of bees.*

8.4 Establishing a reference point

In section 8.1, we discussed the importance of developing an understanding of the shape of the pollinator-yield relationships in order to understand the relevance of pollinators to yield, and to put a particular pollinator density and estimated deficit into context.

In section 8.3, we discussed the value of understanding the separate mechanisms that affect the regional and local pollinator fauna, and ultimately yield. In section 3.2, we discussed the importance of understanding the history and trends of the factors that influence abundance and species composition of pollinators.

We argue that all these components are necessary to provide sufficient information to policy makers on the management of pollinators. This is because it is important to understand which level of pollination is a realistic target for a particular crop in a particular region, and thereby to be able to put a reported theoretical pollination deficit into context. For example, how many pollinator species and how high abundances could we reasonably expect, given a scenario where landscape management follows the best practises as guided by for instance, by biodiversity conservation planning? Further, it is necessary to consider if there are potential drawbacks with some measures introduced to increase pollination. Domesticated honeybees or reared bumblebees could potentially outcompete and displace wild pollinator fauna.

8.5 A sketch of an analysis

We can draw from the parts discussed above to build a set of measurements and analyses that as a whole will give a fuller picture of the pollination deficit than what just the analyses suggested in the protocol would produce. We do not propose this would form a unique gold standard, but we argue it would provide a deeper understanding of the context of the measurements and findings, and their use for territorial planning and policy formulation.

The first step is to form a basic understanding for the study system, by providing the best possible estimation of the pollinator-yield relationship, including the full range of conditions, from no pollination to full pollination. The “no pollination” situation can be achieved for example through exclusion experiments, and full pollination could be achieved for example by hand pollination or adding artificially high levels of pollinators. The intermediate pollination levels could be achieved either through the use of natural variation or different experimental set-ups either of adding pollinators directly or indirectly through pollinator friendly management schemes. These relationships could also be found through pooling together data sets from different regions, and we suggest that this will be a key product from the international meta-analysis.

The second step is to relate the observed rates of pollination to potential explanatory factors, in order to understand what govern the pollination communities. This involves both what determines pollinators locally as well as regionally.

The third step is to analyse to what extent we can influence the factors that govern pollinator occurrences in land management.

Together, these steps would give an understanding of what levels of pollination are reasonably achievable in a specific location, given the changes in practice needed to produce them, and what the different levels of pollination could be expected to render in terms of agricultural yield.

9 Future work

The next phase in this project is to analyse the collected data in detail. This will include pollinator-yield relationships at the sampled sites, the role of the resources within the surrounding landscape for determining the regional pollinator fauna, what determines local aggregation of pollinators on a given location. These analyses will be conducted within the two host projects and reported later on. The combination of surveys in early and late crops, with continuous landscape surveys provides a fruitful combination of data to investigate several scientifically interesting mechanisms. An analysis of historical yield records and climate data is also planned for red clover seed production.

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