An evaluation of analyses and data collection of winter loss in honey bees in Sweden

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Background to this report

Swedish beekeeping rely on the health of honey bee *Apis mellifera.* Loss of colonies during winter (winter losses) is an indicator of poor honey bee health. Winter is a critical period for honey bee fitness. A large number of colonies lost during winter has a direct negative impact on both domestic honey production and the size of the bee stock which pollinate important crops. Keeping winter loss at a biological feasible and economically acceptable level is a requirement to ensure profitability in beekeeping and sustainable crop pollination by honey bees. There are several factors behind winter loss in honey bees and sometimes the beekeepers themselves could have done more to prevent unwanted loss.

Winter loss varies between years and regions. Some of this variation is the result of natural variability as honey bee colonies are biological systems in a natural varying environment. Another part of the variation in winter loss is due to temporal and spatial variation in risk factors influencing the health of managed honey bee colonies, including differences in beekeeping practices between beekeepers. A third cause for apparent differences in winter loss is due to how it is measured and described.

Prioritisation of management actions to reduce winter loss can be made by identifying the most important risk factors affecting winter loss and target these. Since the importance of different factors may vary between regions, landscapes and individual beekeepers, the action taken must be adaptive. The importance of factors can also change over time: in the 1970s American foulbrood was a major cause for winter loss, whereas in the 2000's *Varroa* has spread over a large part of Sweden.

A systematic approach to reduce winter loss to acceptable levels need reliable estimates of winter loss as well as a better understanding of the impact from management in combination with other factors putting bee health at risk. This is possible with good data and analysis. This report evaluates current data collection of winter loss in Sweden with the purpose to give recommendations for future improvements. What constitute improvements depends on the goal of data collection and analysis.

The report has been commissioned by the Swedish Commercial Beekeping Association.

Svensk sammanfattning

Syftet med detta uppdrag har varit att utvärdera hur data på vinterförluster hos honungsbin i Sverige samlas in och analyseras, samt ge förslag på förbättringar av övervakning och analys.

Denna rapport innehåller

- En sammanställning av faktorer som kan påverka vinterförluster hos honungsbin under svenska förhållanden
- En beskrivning av nuvarande sätt att rapportera och analysera vinterförluster i Sverige
- En utvärdering av nuvarande sätt att rapportera vinterförluster i Sverige
- Förslag på åtgärder för att förbättra övervakning av vinterförluster i Sverige med syfte att a) bedöma status, b) bedöma trender och c) göra prognoser av vinterförluster.

Vinterförluster brukar beskrivas som totala förluster och genomsnittliga förluster. Totala förluster är proportionen förlorade samhällen bland alla som har invintrats i en region ett visst år. Genomsnittliga förluster mäter hur stora förluster en viss typ av biodlare har i snitt i en viss region och år.

I Sverige genomförs varje år två stora undersökningar som samlar data på vinterförluster. Varje biodlare har sedan tio år tillbaka bjudits in att frivilligt svara på COLOSS-undersökningen under maj månad. COLOSS frågar bland annat efter information om antal kolonier som har invintrats, antal förluster, möjliga orsaker till förluster samt var huvudparten av biodlarens bigårdar finns uppställda. COLOSS-undersökningen är en del av ett internationellt nätverk som genomför liknande undersökningar i flera länder, både i och utanför Europa.

Den andra datainsamlingen som berör vinterförluster är Sveriges biodlares (SBR) medlemsundersökning. Den går ut till drygt 12000 medlemmar i Sverige och besvaras av cirka 6000 biodlare över hela landet. SBR-undersökningen samlar in totala förluster för vart och ett av 25 distrikt i Sverige. Data från enskilda biodlare förstörs efter att ha räknats ihop på distriktsnivå. Därmed försvinner en möjlighet att använda SBR-data för att undersöka betydelse av de många faktorer som kan tänkas påverka vinterförluster.

Data på vinterförluster på biodlarnivå, såsom den som samlas in i COLOSS-undersökningen, öppnar upp för att övervaka förluster för små och stora biodlare.

Det är också möjligt att använda flera indikatorer för vinterförluster. Spridningen i vinterförluster för biodlare i samma region ger mer information genom att exempelvis ange hur stor andel av biodlarna som har inga vinterförluster alls eller hur många som har oacceptabelt stora vinterförluster.

Förutsättningar för biodling varierar inom Sverige beroende på klimat och andra miljövariabler. Biodling bygger på hantering av biologiskt material och därför är en viss vinterförlust något man får räkna med. Vad som är en acceptabel vinterförlust kan variera från biodlare till biodlare. Det är relevant att fråga efter biodlares uppfattning om vad som är en rimlig förlustnivå.

Biologiska stressfaktorer såsom sjukdomar och parasiter bidrar till vinterförluster. Skillnader i vinterförluster förklaras bäst genom att bedöma kombinationer av flera faktorer. En del biodlare har låga förluster trots att det finns Varroa medan andra har högra förluster där det inte finns Varroa. Det finns enkla rekommendationer att följa för att hantera en del faktorer, men inte alla. Exempelvis uppmanas biodlare att bekämpa Varroa under säsong och inte invintra samhällen med tecken på sjuka bin. Svåra faktorer är sådant som ligger utanför biodlarens handlingsram. Exponering för bekämpningsmedel, extremt väder samt brist på födoresurser är stressfaktorer som kan vara svårare att hantera för en biodlare under säsong. En systematisk undersökning av riskfaktorer för svenska förhållanden kan ge värdefull kunskap om hur biodlare kan hantera och planera för vinterförluster.

Information eller bra skattningar på antal och fördelning av samhällen och biodlare i Sverige bidrar till att skapa en bättre uppfattning om hur representativt insamlade data är. Vi lyfter fram att bra skattningar på mängd och fördelning av honungsbin är nödvändigt för att kunna bedöma hur mycket pollineringstjänster honungsbin bidrar med. Sverige har jämfört med en del andra länder relativt dålig kunskap om antal och geografisk spridning av dess biodlare.

Rapporten avslutas med rekommendationer gällande analys och insamling av data på vinterförluster i Sverige. Dessa är att

- Skapa en nationell samverkan för bihälsa och biodling i Sverige med syfte att formulera mål för hantering av vinterförluster i Sverige och säkra att det sker insamling av data och analys för att ge mer kunskap och följa upp dessa mål. Denna organisation ska minst bestå av båda biodlarorganisationerna för att se till att merparten av professionella biodlare och hobbybiodlare är representerade och representanter från länsstyrelser, bihälsokonsulenter (vi har just nu bara en i Sverige) samt Jordbruksverket.

- Skapa en hemsida där man publicerar årliga rapporter på vinterförluster, information om undersökningar och råd gällande hantering av vinterförluster. Idag finns informationen i biodlarorganisationernas tidningar vilket inte är tillgängligt för alla eller lätt att få tag på i efterhand.
- Bilda en expertgrupp för analys av vinterförluster i Sverige.
- Uppmuntra COLOSS att publicera statistiska analyser på COLOSS-data med temporala trender och geografisk variation in vinterförluster, helst med fokus på Sverige. Just nu publiceras en rapport för varje år som data samlas in.
- Öka mängd svar från kommersiella biodlare (biodlare med fler än 50 samhällen) och framförallt stora biodlare (med över 150 samhällen) i COLOSS-undersökningen.
- Undersök orsaker till att så få kommersiella biodlare svarar på COLOSS-undersökningen. Biodlingsföretagarna uppmuntras att göra en undersökning bland sina medlemmar om vad de ser för behov kring vinterförluster och om det finns några problem med att svara på COLOSS-undersökningen.
- Undersök möjlighet att spara data på vinterförslutser i SBRs medlemsundersökning på en lägre nivå än distriktsnivå, till exempel på nivån av lokala föreningar eller biodlarnivå. En fördel är att undersökningen kan göras via nätet och att data kan användas till flera indikatorer på vinterförluster.
- Samla in data på överlapp mellan SBR och COLOSS-undersökningarna. Skapa system som gör det enkelt att koppla ihop dessa två undersökningar.
- Undersök möjlighet att skapa en gemensam undersökning av SBR och COLOSS-undersökningarna för att underlätta för biodlare och öka svarsfrekvenser.
- Undersök möjlighet att kunna svara på COLOSS-undersökningen på bigårdsnivå istället för på biodlarnivå.
- Undersök möjlighet att synkronisera rapportering av placering av bigårdar och primärproduktion till länsstyrelsen med rapportering av vinterförluster.
- Skapa en referens för vinterförluster, honungsproduktion samt antal och spridning av biodlare av olika typer i Sverige. Detta kan ske genom att ha en period med intensiv datainsamling (svarsfrekvens nära 100%).
- Komplettera rapportering av totala och genomsnittliga förluster med andra indikatorer av vinterförluster.
- Komplettera övervakning och analys av vinterförluster med systematiska utvärderingar av biskötsel i kombination med riskfaktorer.

English summary

This report evaluates current collection and use of data on winter loss in honey bees in Sweden and is a commission from the Swedish Professional Beekepers Association. It includes an overview of factors which may influence winter loss in honey bees in Sweden. In Sweden, data on winter loss is collected by two instances, the COLOSS survey and the Swedish Beekeepers Association (SBR). We identify several ways to improve his data collection and make it more cost efficient. Several recommendations are provided such as creating a Swedish partnership for bee health which can specify shared goals for winter loss management and identify needs for data and analyses.

ACKNOWLEDGEMENTS

We are grateful to Preben Kristiansen, bee health officer at the Swedish Board of Agriculture (2018) former bee health officer at the Swedish Beekeeping Association (SBR), for letting us use a selection of COLOSS survey data to support the evaluation of data collection and analysis in Sweden and his insights into Swedish winter loss data collection and analyses. This work has also been informed by interviews with representatives from the Swedish Beekeepers' Association (SBR) and the Swedish Commercial Beekeeping Association (Biodlingsföretagarna, BF), and Magnus Gröntoft on the Swedish Board of Agriculture. We are thankful for comments and input provided by individual beekeepers. Johan Lindström at the Department of Mathematical Statistics at Lund University provided advice on the analysis of data. The report has been reviewed by Henrik G. Smith Lund University, Preben Kristiansen and Jonny Ulvtorp (BF).

What is winter loss and why is it relevant?

WINTER LOSS OF MANAGED HONEY BEES

Honey bees are both a source of income for commercial beekeepers, and provide important services in the form of pollination. In Sweden there are hundreds of commercial beekeepers, which earn part of their income from honey bees and a large number of non-commercial beekeepers for which beekeeping is socially important. For these, winter loss can have tremendous consequences, which may even discourage them from beekeeping or make the scale down their efforts. Honey is also an appreciated commodity, where Swedish beekeepers have problems meeting the demands on the market. Honey bee, together with wild pollinators (bumble bees, solitary bees and hover flies), are important for the pollination of agricultural crops, fruits and wild flowers (Garibaldi et al. 2013; Potts et al. 2016), also in Sweden (Rahbeck Pedersen et al. 2009; Jacques et al. 2016).

In Sweden, the majority of honey bee colonies that die, do so during winter (Rahbeck Pedersen et al. 2009). Although, high winter losses occur naturally, there is a possibility to reduce the total colonies lost by reducing stressors and making the correct management decisions. However, this requires a proper understanding what causes variation in winter losses and how to best avoid it. The number of honey bees have been declining in Europe (Potts et al. 2010), but this can be an effect of changes in the number of beekeepers or the type of beekeepers as high winter loss is not necessarily the same as declining honey bee stocks (Moritz and Erler 2016).

To determine the importance of different stressors and management regimes, reliable estimates of winter losses are necessary. However, winter losses may be simultaneously affected by multiple stressors and management decisions (Potts et al. 2010; van der Zee et al. 2015b). Hence, it is necessary to jointly collect data on winter losses, potential stressors and management in order to understand which stressor (or stressors) to deal with first and which management to promote. A pan-European study of national bee surveillance programs shows that there is a lack of consistency between programs, a variability in the definition of winter loss, different quality in data collected and that data is rarely collected in a way to enable comparison of indicators for winter loss and stressors and factors thereof (Hendrikx et al. 2009).

The purpose of this report is to evaluate current goals and ways of collecting data on honey bee winter loss in Sweden. We do this by giving a background to why more knowledge of winter loss is important and then look at the way data on winter loss is currently collected in Sweden and the possibility for analysis.

DEFINITION OF WINTER LOSS

Winter loss is defined as the death of the colony during hibernation, i.e. the resting period of the colony (Barron 2015). This excludes colony loss immediately related to e.g. Varroa treatment and the merging of colonies, as well as losses after hibernation, i.e. food shortage in early spring or the loss of queens due to active management are not included. Losses due to active management during hibernation, such as Varroa treatment and control of colony status during winter, are not included. More specifically, winter is here defined as the period between the moment that a beekeeper finished pre-winter preparations for his/her honey bee colonies and the start of the new foraging season (van der Zee et al. 2013). A general rule of thumb is that winter loss is the difference between colonies before and after the winter and no distinction is made when during a winter a colony is lost.

Winter loss can be described in two ways:

A) Total number of colonies lost
   - a) Observed total number of colonies lost
   - b) Actual number of colonies lost

B) Loss rate
   - a) Average loss rate
   - b) Overall loss rate (the proportion of colonies lost)

The total number of colonies lost is possible to observe directly. Total number of colonies lost depends of the number of colonies before the winter. Just looking at total numbers of colonies lost can be misleading. A zero can be a zero because there were no or very few colonies before the winter. A large number of colonies lost is an indication of a high winter loss only in relation to the number of colonies before the winter. The number of colonies before winter should be communicated no matter which measures of winter loss that is used.

Numbers of colonies lost should also be evaluated in relation to how representative these are for the total beekeeping in the region. Numbers based on those beekeepers responding to a survey is only a fraction of the actual number, which is unknown. The latter is obviously the largest and depend on the actual total number of colonies to begin with. The actual number of colonies is relevant for managers who wants to estimate pollination services, make forecasts of honey production or the cost associated to winter loss. Information of the total number and distribution of beekeepers and their colonies is a valuable reference for any type of monitoring of winter loss or changes in bee stocks.

Winter loss characterised by a loss rate allows for comparison of winter loss with different number of beekeepers and colonies. It is possible to view loss rate as a property of a specific type of colony. If so, loss rate is interpreted as the probability of an individual colony with certain characteristics to die during winter. We refer to this as loss rate at colony level.

Another way is to interpret loss rate as the proportion of colonies lost. By doing that, one assumes that loss rate is not colony specific, but a property of a (statistical) population of colonies, e.g. colonies in a region. We refer to this as overall loss rate. The overall loss rate can be derived at different scales.

As a comparison, one can think of the number of patients that die in a population during a month to the probability that a specific patient will die during the coming month. The first is the overall loss rate whereas the second is a specific loss rate.

Loss rates can be derived at one scale (e.g. apiary level) but then compared across a larger scale (e.g. regional level). Overall loss rate is the numbers aggregated up to the larger scale, whereas average loss rate is the average of a population of loss rates on the lower scale.

Total number of colonies lost and loss rate can be derived from each other and they complement each other in an analysis. Loss rate allows a comparison of winter mortality between regions and years on the same scale, with varying total number of colonies. The total number of colonies indicates the impact of winter loss in economic terms and performance of an ecosystem service such that every lost colony can be associated to a certain loss in honey production and crop pollination by honey bees.

Management goals can be specified with respect to total numbers or loss rates. Total number refers to the honey production and crop pollination by honey bees. The latter is related to making sure that the endpoint is above a certain level and is resilient and sustainable. In regions where there are few honey bees it is relevant to increase the total number of colonies, which can be obtained by reducing winter loss and increasing the number of beekeepers or colonies. Loss rate is other hand about the health status of honey bee colonies. High loss rates compared to a reference is an indication of a change or anomaly in bee health.

WHO CAN BENEFIT FROM RELIABLE ESTIMATES OF HONEY BEE WINTER LOSSES?

There are several organisations and business which could benefit from reliable estimates of winter loss in honey bees.

BEEKEEPERS

Swedish beekeepers consist of a large number of hobby beekeepers and beekeeping enterprises, which can be full or part time business. Most Swedish beekeepers are members in one or both of the two beekeeping associations. The commercial beekeeping organisation (Biodlingsföretagarna, BF) had 370 members during 2017. The Swedish Beekeeping Association (Sveriges Biodlares Riksförbund, SBR) had 12 782 members.

Reliable estimates of winter loss are useful information in local, regional and national actions to support a sustainable and profitable honey bee keeping in Sweden. This can be done by identifying what the most likely problems are in areas with high winter losses. Reliable information on winter loss can, in combination with other data, be used to derive specific assessments of the effect of beekeeping management practices under different environmental conditions. Since winter loss is affected by many causes, it requires a lot of samples to be able to say something about an effect of management.

REGULATORS

The ***Swedish Board of Agriculture*** (SBA) seeks to stimulate Swedish agricultural production, which includes action to promote beekeeping. The regulation of diseases (Bisjukdomsförordningen 1974:212) gives SBA the mission to reduce spread of diseases in honey bees. Winter loss can be used as an indicator to monitor impacts on bee health.

Together with beekeeping organisations the national honey program (Det nationella honungsprogrammet) has been developed, with the purpose to improve conditions for production and sales of honeybee products in Sweden (REF). Products from honeybees include honey, wax, propolis, royal jelly and pollen. The main aim of the program is to promote good bee health. Other aims are to ensure growth and consolidation, access to information and course material on beekeeping, and ensure a supply of pollen and nectar.

The SBA is also working together with industry in promoting biodiversity in the Rural Development Program. The program Mångfald på slätten support projects e.g. aiming to increase food resources for pollinators and enhance pollination in agricultural landscapes (SBA. 2013).

The 21 ***County Administrative Boards*** are responsible for environmental monitoring. The CAB manages the reporting of the spatial allocation of honey bee apiaries according to the Swedish regulation on treating bee diseases (Bisjukdomsförordningen 1974:212).

The ***European Union*** monitors and maintains healthy bee stocks and puts efforts on bee health targets beekeeping and agriculture, environment, research, pesticides, veterinary issues and surveillance measures (https://ec.europa.eu/food/animals/live_animals/bees/health_en). The ***European Food Safety Authority*** (EFSA) is responsible for risk assessment, developing risk assessment protocols and the harmonisation of monitoring of bee health across Europe.

INDUSTRY

Crop growers of pollination dependent crops and seed producers rely on pollination by honey bees and other insects. Pollination services can be boosted by providing more habitats for wild pollinators or by increasing the supply of managed bees which can be placed in the vicinity of the fields in need of pollination services. Managed bees are an important source to meet the demand for pollination of particular crops, both in fields and in greenhouses. The dominating managed pollinator is honey bees, but also imported bumble bee colonies are used for pollination services. The number of honey bee colonies specifically used for pollination services is unknown, but is likely less than the demand, especially in certain areas (Breeze et al. 2011). The supply of pollination services is sensitive to large winter losses. Thus, reduced winter loss is not only desirable for beekeepers but also for pollination dependent crop producers.

RESEARCH

High quality surveillance data on winter loss can contribute to research on bee health and pollination. Studies on the effect of management and other factors on winter loss is based on estimates of winter loss at different scales:

- Data or estimates of winter loss on local scale (colony or apiary) is necessary to be able to assess the effect of stressors and beekeeping management practices. The recommendations in the harmonisation of data collection for honey bee health by the European Food Safety Authority EFSA is to collect data on colony level since the stressors can differ between colonies within an apiary (EFSA 2016). This takes a lot of resources, and for practical reasons data is more often collected on apiary levels e.g. as done in the COLOSS survey (van der Zee et al. 2013).
- Estimates of winter loss on landscape to regional scales are useful to assess changes in the total stock of honey bees, honey bee density, honey production and their pollination services (Odoux et al. 2014).
- Estimates of winter loss on regional to national scales are needed to evaluate trends and anomalies in honey bee health from regional to national and global scales.

It is straightforward to scale up data from lower to larger scales using different methods for aggregation. Scaling down from larger to lower scales is highly difficult, close to impossible, without any other information, e.g. sizes and positions of apiaries for each beekeeper.

INSURANCE COMPANIES

Reliable estimates of winter loss including variability therein is useful information to design insurance policy for honey beekeepers, but also for the risk of losses in the production of crops that are linked to pollination services. The risk of losses in crop production is so far dedicated to weather conditions, in particular to extreme weather events. Rapid declines in honey bees and other pollinators might make it necessary to expand such risks to the lack of pollination services in the future.

An overview of factors that potentially can influence winter loss in honey bees in Sweden

A CONCEPTUAL RISK MODEL FOR WINTER LOSS

Various studies focus on single or multiple drivers of winter losses within a single country or across different countries as well as across different time periods. As a common agreement, drivers of honey bee winter losses are multifactorial but the impact of different factors or their interactions is case-dependent and/or can vary between regions/countries and years (Genersch et al. 2010; Ratnieks and Carreck 2010; Jacques et al. 2016; Steinhauer et al. 2018). There are several reviews of factors behind winter loss in managed honey bees (Steinhauer et al. 2018; vanEngelsdorp and Meixner 2010).

Here, we list different categories that increase or mitigate winter losses and give examples for each category. Altogether, we identified four main categories: ***BIOLOGICAL STRESSORS***, ***CHEMICAL STRESSORS***, ***BEEKEEPING MANAGEMENT*** as well as ***CLIMATE*** and ***ENVIRONMENTAL FACTORS*** at different scales (Figure 1). Chemical and biological stressors and interactions between stressors and other factors are of increasing importance for honey bee health. This is acknowledged by adding ***INTERACTIONS*** between distinct characteristics of some categories.

This conceptual risk model is similar to that in Hendrikx et al. (2009), which share properties with the holistic risk framework for health in honey bees by the EFSA (2016). EFSA's framework aim to identify measures of honey bee health and distinguishes between measures made on colony attributes and external drivers. External drivers are divided into a resource providing unit, environmental drivers and beekeeping management practices. Here, since the resource providing unit is closely related to environmental factors, it was turned into a new category dealing with spatial environmental factors at different scales. Factors can include stressors, drivers or just covariates of health. For clarification, climate is seen as a separate category.

In general, honey bee winter losses are strongly connected to factors limiting the ability of honey bees to build a strong colony before winter (van der Zee et al. 2015a; Steinhauer et al. 2018). Although some studies cover various factors, they do not (cannot) test all factors together and thus interactions between factors, but also site factors that explain winter losses might be overlooked (van der Zee et al. 2015a) and thus also, a holistic approach is still missing.

The variability in winter loss is often high at very small spatial scales. While a larger variability is expected at smaller scales because stochastic variation will play a larger role, this could also mean that in-hive or local conditions have a large impact on winter loss.

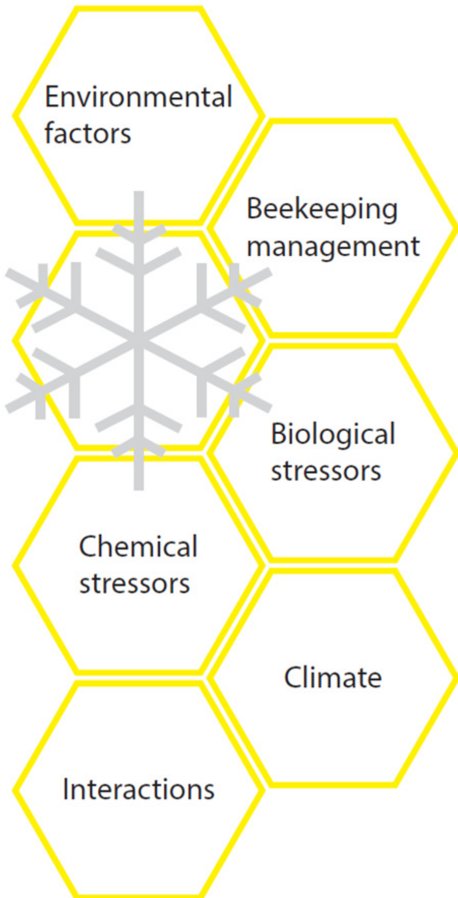


Figure 1. A conceptual risk model of factors potentially influencing winter loss in managed honey bees.

BIOLOGICAL STRESSORS

DISEASES – PARASITES AND PATHOGENS

There are several good reviews on diseases for honey bees (McMenamin and Genersch 2015; Barron 2015).

In Sweden the three dominating diseases are Varroa, American foulbrood and tracheal mites (http://www.

jordbruksverket.se/amnesomraden/djur/olikaslagsdjur/binochhumlor/beskrivningavbisjukdomar.4.1a4c164c11dcdaebe12800064.html). A description of other parasites and pathogens of relevance for Swedish beekeeping is found in the report "Massdöd av bin - samhällsekonomiska konsekvenser och möjliga åtgärder" published by the Swedish Board of Agriculture (Rahbeck Pedersen et al. 2009).

Varroa mites and viruses for which Varroa is a vector cause major bee losses in the Middle and Southern part Sweden where it has been found (Rahbeck Pedersen et al. 2009). It has been shown that the ecto-parasitic mite ***Varroa destructor*** has its main effects on bee health during winter (Berthoud et al. 2015; Chauzat et al. 2016). Honey bee pupae infested with Varroa do not develop the physiological abilities required for long-term-survival (Amdam et al. 2004), which prevents infested winter bees from surviving the winter and thus sustaining the colonies (queens) requirements regarding temperature and continuous nutrition. Hives that die over winter have been shown to have higher Varroa infestation compared to hives surviving the winter (Genersch et al. 2010; Dahle 2015; Jacques et al. 2016; Ravoet et al. 2013).

The effect of Varroa infestation can vary between years (Jacques et al. 2016). Although winter loss is related to a high infestation with Varroa in autumn (Genersch et al. 2010), there seems to be no effect from infestation in summer (van der Zee et al. 2015a). This means that effective treatment of ***Varroa*** before winter hibernation can have large impact on winter loss rates.

Varroa transmits different viruses to honey bees, such as the Kashimir Bee Virus (KBV), Deformed Wing Virus (DWV), the Acute Bee Paralyse Virus (ABPV), Chronic Bee paralyse Virus (CBPV), the Slow Paralyse Virus (SPV), the Cloudy Wing Virus (CWV), the Sacbrood Virus (SBV) or the Black Queen Cell Virus (Genersch et al. 2010; McMenamin and Genersch 2015; Chen and Siede 2007).

PESTS

Invasive Alien Species (IAS) is a large threat to biodiversity. IASs are deliberately or accidently introduced by trade and transport. Spread in IAS and other pests can be aided by a changing climate. One of the IAS of concern for honey bees is the Asian hornet ***Vespa velutina*** which was first found in France in 2004 and is now spreading (Smit, Noordijk, and Zeegers 2018; Barbet-Massin et al. 2013).

Attacks of the Asian hornet can weaken honey bee hives due to high losses of workers and thereby also could affect their food supply for the winter. So far, the species has not been found in Sweden (Lotta 2013).

The Swedish beekeeping association journals have published reports of winter losses in Sweden linked to bears or wild boars, but the intensity and spread of such attacks have not been fully investigated.

COMPETITION

Intense agricultural landscapes run a risk to not provide sufficient amounts of nectar and pollen resources to support honey bees (and other bees) after mass-flowering crops such as oilseed rape. Resource competition between honey bees and wild bees (Mallinger, Gaines-Day, and Gratton 2017), but in particular between neighbouring honey bee colonies will further increase food scarcity, which in particular for the shortage of autumn resources can facilitate the loss of colonies during winter. Since honey bees are managed they can have an advantage compared to wild pollinators in exploring resources.

CHEMICAL STRESSORS

Toxic chemicals can influence managed honey bees in several ways ranging from sub-lethal effects on individuals up to the death of whole colonies (Odoux et al. 2014; Klein et al. 2017). Many different active substances of pesticides can be found in honey bee colonies (Chauzat et al. 2006; Rahbeck Pedersen et al. 2009; Genersch et al. 2010).

The relationship between pesticides and honey bee winter losses as assessed by large scale national and international monitoring programs is fairly unclear (Genersch et al. 2010; van der Zee et al. 2015b).

The effect of pesticides can depend on the general condition on the colony. For example, the neonicotinoids Thiacloprid and Acetamiprid seem only to be dangerous for starving honey bee colonies (Laurino D. 2011) which also was suggested in van der Zee et al. (2015a) which did a field experiment under bad weather conditions.

CLIMATE AND ENVIRONMENT AT DIFFERENT SCALES

GLOBAL SCALE

In general, the globally wide distribution of then honey bee indicates its high potential to adapt even to severe climates (e.g. ***A. m. saharienis*** in the Sahara desert) (Conte and Navajas 2008).

REGIONAL SCALE

Differences in winter loss is sometimes larger between years than between regions (Brodschneider et al. 2016; Jacques et al. 2016). Pan-European studies on winter loss rates show that losses are not related to eco-climatic regions (e.g. high losses in Spain, Ireland, Sweden, Finland) (Brodschneider et al. 2016), suggesting that (currently) where beekeeping is possible, overall climate is of minor importance for colony loss. One explanation is that differences in climate are compensated by regionally adapted beekeeping management practices.

LOCAL SCALE

Extreme weather and climate events can impact winter survival. For instance, foot shortage in autumn due to drought-related availability of nectar and pollen or weather conditions under which it is impossible for honey bees to collect food (e.g. strong rain/wind) could influence their food supply during winter (Conte and Navajas 2008).

Conditions near or inside the hive can influence survival during winter. Colonies can be disturbed by fluctuating weather conditions during winter. A period of warmer weather during mid-winter may increase the activity and stress of a colony if followed by extremely cold weather (Barron 2015).

Within a specific region, winter losses can be linked to factors in the environment around a colony or apiary. This environment, also known as the resource providing unit (EFSA 2016) is influenced by land use. This land use, on natural, semi-natural and other land, influence what food resources that are available for honey bees.

Honey bees are central-place foragers, which means that workers fly back and forth to a nest to collect food to feed larvae and the queen. The size of the resource providing unit is determined by the maximum foraging distances of workers in a colony. Foraging distances vary from apiary to apiary depending on the contribution of food resources in the vicinity of an apiary (Steffan-Dewenter and Kuhn 2003). As a general rule, the resource providing unit is between 3 to 5 kilometres (but distances up to 10 kilometres have been suggested to assure the resource providing unit cover the maximal distances).

Which resources that are visited by bees in a specific colony can be determined by pollen analysis of samples from foraging bees. An alternative is to use land use information and foraging theory to map likely flower visitation rates by a honey bee colony (Olsson et al. 2015; Becher et al. 2014; Lonsdorf et al. 2009; Steffan-Dewenter and Kuhn 2003).

The resource providing unit is simultaneously a source for food but also a demand for pollination. Pollination service by a honey bee colony can be modelled by ecological productions functions (Hanley et al. 2015), integrating theory for foraging and population dynamics in a spatially explicit landscape models.

The provision of food resources in a resource providing unit varies both within and between seasons (if considering annual crops or annual land use changes) and between landscapes and eco-climatic regions (e.g. different floral species or flowering times).

Periods of lack of resources is suggested to be a likely cause for poor health in honey bees. Lack of pollen resources in late season has been connected to high winter losses in Denmark (Kryger 2010). It has also been shown that access to ***Calluna vulgaris*** (as a late season foraging resource) leads to lower winter losses (van der Zee et al. 2014).

Colony loss is also possibly linked to a nutritional effect of distinct plant species based on monotonous diet. Bees require a variety of pollen to function adequately (Naug 2009; Scofield and Mattila 2015). Bee populations in landscapes with few dominating crops, e.g. oil seed rape in high intensive agricultural regions or large almond orchards, face starvation when these crops seize to flower. Winter losses have been shown to be higher near towns and industrial areas compared to near flower-rich areas and orchards. However, this effect is not consistent between years (Chauzat et al. 2016; Jacques et al. 2016).

Agricultural landscapes can be managed to enhance pollinators and thus pollination services by providing food for both wild and managed bees (Isaacs et al. 2017). Not only do landscapes need to provide sufficient resources in the form of pollen and nectar, they need to provide these resources throughout the season (Goulson et al. 2015; Baude et al. 2016; Carvell et al. 2017). For example, in simplified landscapes with little available flower resources, bees may face resource deficiencies late in the season when mass-flowering crops have ceased flowering (Persson and Smith 2013; Westphal, Steffan-Dewenter, and Tscharntke 2009).

It is, to a certain degree, possible to control land use in agricultural landscapes. To avoid seasonal food scarcities, farmers may provide flower resources in the form of e.g. flower strips or under sown crops (Jonsson et al. 2015; Alaux et al. 2017). The presence of specific plant species, oilseed rape or wild mustard or their combination, have been found to be higher in colonies lost over winter compared with surviving colonies in the Netherlands (van der Zee et al. 2015a), but not in Germany (Genersch et al. 2010).

BEEKEEPING MANAGEMENT

Differences in beekeeping practices can be large from one region to another, as well as from one beekeeper to another. These differences arise from management adopting the local conditions, traditions and training, as well as experience and aim of the beekeeping (hobby or profit). Other management factors are beehive material, queen management, migration, methods for *Varroa* treatment, extra food resource and genetic material of honey bees.

Experience of beekeeping can explain variation in winter loss between beekeepers (van der Zee et al. 2015a; van der Zee et al. 2014; Genersch et al. 2010; Jacques et al. 2016). During the time of the German Bee Monitoring and the Dutch Bee Monitoring, most beekeepers had low losses and only a few had high losses each year, but high losses appeared for the same beekeepers each year (Genersch et al. 2010; van der Zee et al. 2015a). Across the two years of the European Epilobee project (Jacques et al. 2016), commercial beekeepers had the lowest winter mortality, followed by part-time beekeepers. Hobby beekeepers had the highest winter loss rates, which could be due to less experience but also that smaller beekeepers are more vulnerable to losses. The size of a beekeeping unit seems to play a role. Large and medium apiaries have in general lower winter loss rates (Brodschneider et al. 2016; Jacques et al. 2016; Chauzat et al. 2016).

Queen management, e.g. using swarms or new queens, can explain parts of winter losses. Problems related to queens (e.g. death, drone-egg laying queen, laying workers) have become an important role in honey bee winter losses if colonies with queen problems after winter are included (Brodschneider et al. 2016).

Varroa infestation is one of the major drivers for honey bee winter losses and thus the control of *Varroa* is of specific importance. There are various methods to control *Varroa* (Rosenkranz, Aumeier, and Ziegelmann 2010; Rahbeck Pedersen et al. 2009). These can be categorised into synthetic chemicals (”Hard synthetic chemicals”; insecticides, acaricides), natural chemicals and compounds (”Soft chemicals”; organic acids, essential oils), and the trapping of mites in worker or drone brood (”Biological/biotechnical methods”). Hard synthetic chemicals are effective but are at the same time increasing chemical stress in colonies. Usually a combination of different methods leads to higher control success (e.g. removal of drone brood over the seasons + treatment with acetic acid in late summer + treatment with oxalic acid in winter).

INTERACTIONS OF STRESSORS AND FACTORS

Winter loss in honey bee colonies is most likely caused by interactions between various stressors (Neumann and Carreck 2015; Steinhauer et al. 2018). Bad weather conditions might be an interacting factor because of starvation leading to increased toxicity of pesticides in starving bees (van der Zee et al. 2015a). Pesticides (Thiacloprid) additively interact with infestation with BQCV on larval survival and *Nosema ceranae* with Thiacloprid as well as *Nosema ceranea* with BQCV on adult survival (Doublet et al. 2015). ABPV and DWV loads were correlated in English hives lost during winter (Berthoud et al. 2015). Interactions between the parasites *Crithidia mellificae* and *Nosema cerana* have been found to explain winter losses (Ravoet et al. 2013).

The studies in Box 1 are examples of studies showing how winter loss is influenced by interactions biological stressors, beekeeping management and chemical stressors.

Box 1. Summary[1] of results for winter loss from large-scale monitoring studies in Europe.

Coloss (17 EU countries)(Chauzat et al. 2016; Brodschneider et al. 2016)

The size of the beekeeping business and apiary and the clinically detected varroosis, American foulbrood (AFB), and nosemosis before winter significantly affected winter losses 2012–2013.

German Bee Monitoring (Genersch et al. 2010)

Hives with (i) high Varroa infestation, (ii) high infestation with DWV (with relevant effects on the colony), (iii) ABPV infection in autumn, (iv) old queens and/or (v) weakening of colonies before overwintering have a low chance to survive the winter.

Dutch Bee Monitoring (based on COLOSS data)(van der Zee et al. 2015a)

Honey bee winter losses were statistically best explained by (i) Varroa infestation rate (ii) presence of the cyano-substituted neonicotinoids acetamiprid or thiacloprid in at least one of the honey bee matrices (honey, bees or bee bread (pollen)), (iii) presence of Brassica napus (oilseed rape) or Sinapis arvensis (wild mustard) pollen in bee bread, and/or (iv) location of colonies (postal code area).

Epilobee project (17 EU member states)

Highest honey bee winter losses: Hobbyist beekeepers over 65 years of age with a small size apiary, with a production including queens and with a small experience in beekeeping. The apiaries suffered from varroosis at the autumn visit.

Lowest honey bee winter losses: Commercial beekeepers between 30 and 45 years of age, with large migrating apiaries. The apiary management promoted the increase of the livestock. These commercial beekeepers attended a beekeeping training during the past three years, used an apiarist book, had a qualification in beekeeping, were members of a beekeeping organisation, and had an experience in beekeeping superior to five years. The apiaries did not suffer from any disease at the autumn visit.

1. The original text has been slightly modified.

Occurrence and impacts of biological stressors (diseases, invasive species) may be higher or lower in interaction with altered environmental conditions caused by climate change (Conte and Navajas 2008). The Asian hornet is spreading towards north-eastern Europe (Smit, Noordijk, and Zeegers 2018; Barbet-Massin et al. 2013), but has not yet reached Sweden. Shifts in climate conditions can result in the spread of new diseases and increases in the infestation with new strains of already occurring diseases (Conte and Navajas 2008).

CONCLUDING REMARKS

Honey beekeeping has important ecological and economic values and there is a need to monitor and maintain healthy bee stocks, from local to global scales. It is recognized in research and policy that holistic approaches are required to learn and understand how to manage multiple stressors on bee health (EFSA Panel on Animal Health Welfare 2016; van der Zee et al. 2014; Steinhauer et al. 2014; Pirk et al. 2014).

Winter loss of honey bees is affected by a combination of biological and chemical stressors, climate and environmental factors at different scales and beekeeping management. There are large variations in winter losses at smaller scales. This means that winter loss is difficult to attribute to a main factor. Instead, which factor that is the weakest link can vary from colony to colony.

Intensive sampling of low-scale data at colony level within seasons and countries are needed to disentangle major stressors and drivers of honey bee winter losses (EFSA 2016; Hendrikx et al. 2009). Of course, this comes with a cost and may not be feasible to collect in practice. Data collected at apiary or beekeeper levels is more cost efficient and provide useful information for monitoring and increase understanding of the factors behind winter loss (Brodschneider et al. 2018). A complementary way to intensity sampling is to make better use of the data that is collected (or could potentially be collected within current initiatives). That is what we are exploring in this report for Swedish conditions.

Data collection and analysis of honey bee winter loss in Sweden

CURRENT DATA COLLECTION AND ANALYSIS ON HONEY BEE WINTER LOSS

Data on winter loss in Sweden is primarily collected via two channels: the annual COLOSS survey and the annual member survey by the Swedish Beekeeping Association (Biodlarna, SBR).

THE COLOSS SURVEY

The honey bee research network COLOSS (Prevention of honey bee COlony LOSSes) aims to explain and prevent massive colony losses, and was initially funded through the COST Action FA0803. The COLOSS network is now supported by the Ricola Foundation - Nature & Culture.

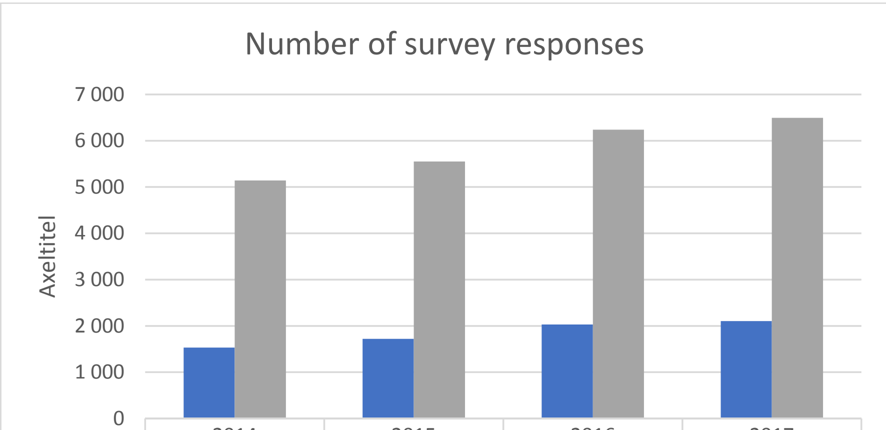
Based on a review of surveillance systems of winter loss in Europe, Hendrikx et al. (2009) concluded that there is an absence of shared loss indicators, calculated following the same procedures, and applied to comparable populations. The COLOSS network responded to this finding by creating an internationally standardised winter loss survey at the level of beekeepers.

The COLOSS international standardised beekeeper survey is made each year on colony losses for winter each year. The survey is designed to allow for comparison across countries, e.g. by asking the same questions in each country. The results are used in an international COLOSS analysis of winter loss rates and mixed effects modelling or risk factors for winter loss (van der Zee et al. 2014; van der Zee et al. 2013).

The Swedish part of the COLOSS survey is open for responses in an online form during the month of May. The survey builds on voluntary participation. This survey has been done in Sweden for ten years. Preben Kristiansen, Bihälsokonsulent at the Swedish Board of Agriculture, is responsible for the Swedish COLOSS survey.

The Swedish survey 2018 consisted of 34 questions (Appendix 1) and took in average 15 minutes to answer. The questions ask for information about the number of colonies before winter and lost during winter, causes for lost colonies, presence of *Varroa*, certain aspects of beekeeping management and disease treatment and the average honey production per colony. Each respondent is encouraged to provide the county and the postal address where most of the apiaries are situated.

The number of responses in the Swedish COLOSS survey has increased during the last four years: 1604 in 2014, 1780 in 2015, 2092 in 2016 and 2186 in 2017 (Figure 2).



	2014	2015	2016	2017
COLOSS	1 533	1719	2029	2104
SBR	5 142	5551	6237	6494

Figure 2. The number of beekeepers responding to the COLOSS survey is in average 31% of the numbers responding to the SBR survey. The average total number of members in SBR (not necessarily beekeepers) during these years is 12 000 and therefore about half of the members answer the SBR survey.

THE SBR MEMBER SURVEY

The Swedish beekeeping organisation (SBR) annual member survey is carried out in several steps. First members report to their local district the number of colonies they had before the winter, the numbers lost during winter and honey production per colony. This is done after wintering has started in end of November. The information at the local district is aggregated on to 25 districts. These districts follow the 21 Swedish County Administrative Boards (Figure 3) expect that the two largest ones are divided into sub regions. The tradition is that the responses by individual beekeepers are destroyed after reporting to the district is finished. This is done to prevent misuse of individual information.

The aggregated data for each of the 25 districts are summarised in tables and diagrams and published in the beekeepers journal Bitidningen. An extraction of this data from 2017 can be found in Appendix 2. The SBR member survey has (with some few exceptions) been carried out since 1920's with almost similar questions.

There is a comparison made between observed total colonies lost and loss rates for the last years. Time series based on complied SBR data have been used to compare winter losses over longer periods of time (see e.g. Figure 4.1. in Rahbeck Pedersen et al. 2009). Although statistical analyses are done on the SBR membership survey there are no published results.

OTHER REPORTING INSTANCES OF BEEKEEPING

The Swedish regulation on treating bee diseases (Bisjukdomsförordningen 1974:212) requires beekeepers to report the position of honey bee apiaries to their county administrative board every third year. The Swedish County Administrative Boards, who are responsible for this reporting, are currently working on improving the reporting and collecting information in similar database formats to allow for comparison. The rules for this reporting is about to change to improve rapid action and control of disease outbreaks. For example, one suggestion is to report whenever new apiaries are created or when the positions of apiaries are changed. Another is to send out text messages to beekeepers with apiaries nearby a newly discovered outbreak.

Although required by law, only about 50% of all beekeepers in Sweden report the position of their apiaries. Beekeepers are required to report the position of their apiaries to improve the capacity to prevent spread of bee diseases. Most beekeepers are aware of this regulation, but still reporting is far from 100% and varies from county to county. Positions are in most County Administrative Boards reported with geographical coordinates. There is no requirement to report the number of colonies at every apiary or any other information.

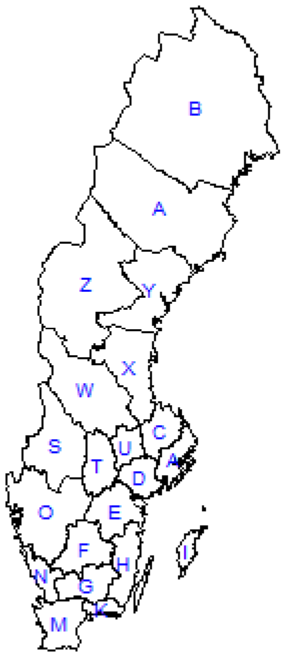


Figure 3. The 21 counties in Sweden with the county specific letter code (Table 1).

CONCLUSIONS

- Data on winter loss in Sweden is collected by two surveys, the COLOSS survey in May and the SBR membership survey in November.
- The SBR survey has about 6000 responses every year, which is about three times more than the number of beekeepers responding to the COLOSS survey.
- The COLOSS survey result in data at beekeeper levels and it possible to investigate linkages between stressors, environmental factors and beekeeping practices at a postal code resolution.
- The Swedish COLOSS data is included in a pan-European COLOSS annual analysis of winter loss and risk factors, which is published annually online. These results are also published in the member journals of the two Swedish Beekeeper Associations, focusing on the situation in Sweden and neighbouring countries.
- The SBR survey results in data aggregated at district levels (25 districts similar to the size of the

Swedish 21 counties). There is no information stored between beekeeper and district levels.

- The SBR data is published in the journals of the two Beekeeper Associations including comparison with historical winter losses.
- There is no publically available or peer reviewed annual statistical analysis of the results from COLOSS and/or SBR with high geographical resolution or with temporal trends.
- The County Administrate Boards collects under the Swedish regulation on treating bee diseases information on the position of honey beekeepers' apiaries.

Evaluation of analysis and data collection of honey bee winter loss in Sweden

Here we evaluate current collections of data and analyses of honey bee winter loss in Sweden with respect to response rates, analysis goals, survey design and other data sources and analyses made. This is a complement to existing reviews of surveillance systems of bee health (van der Zee et al. 2013; Lee et al. 2015).

Box 2. A standard categorisation of beekeepers suitable for Swedish conditions is based on van der Zee (2013).

Information about the purpose of beekeeping is often not available in survey data. The classification is based on information on the number of colonies only.	
Small hobbyist beekeepers	(<15 colonies)
Large hobbyist beekeepers	(16-50 colonies)
Small-commercial beekeepers	(51-150 colonies)
Larger-commercial beekeepers	(>150 colonies)

RESPONSE RATES

Coverage is about sampling enough and representative data such that it is possible to produce reliable estimates and avoid biases. Coverage can be evaluated in relation to the total number of beekeepers and how they are distributed across the country. It is desirable to have stratified samples over hobbyist and commercial beekeepers and over different parts of Sweden.

The number of beekeepers in Sweden at given year is not completely known. In 2016 the total number of members in BF was 378, which can be compared to ca 12 000 members of SBR. An indication can come from the SBR survey which contains information on the number of members distributed over 25 districts (Appendix 1). Not all members are beekeepers, one can just be interested or would like to have the journal, and there are beekeepers who choose to not be members of either of these associations. Further, not all beekeepers are members of SBR.

The COLOSS network distinguishes four beekeeper categories based on the number of colonies a beekeeper has in production (Box 2). As a rule of thumb, a hobbyist beekeeper is someone who do not have their beekeeping as a significant source of income. A commercial beekeeper produce and sell honey or other bee products as a large source of income. In Sweden, most beekeepers are small hobbyist beekeepers, but the actual numbers of different categories and their distribution across the country is unknown. A beekeeper is a primary producer of food for which there are requirements related to food safety. According to the Swedish regulation, all primary producers who produce more than 1000 kg per year are obliged to report their activity to the County Administrative Boards. In addition, anyone producing fodder for the bees need to report this to the County Administrative Boards as well. Similar to the requirement to report the position of apiaries, far from all beekeepers follow the regulation of primary producers. The number of commercial beekeepers cannot be derived from Swedish national statistics on business. Beekeeping enterprises are included in the SNI code 01.499 which stands for cultivation of semi-domesticated animals (www.sni2007.scb.se). Thus, this code is not unique for beekeeping. In 2017 this code had 907 registered companies. It is possible that there are commercial beekeepers listed under other SNI codes. The professional beekeeping organisation keep no records their members' beekeeping, but it is likely that a majority of large-commercial beekeepers are members of BF.

To conclude, there is no complete information on the total amount and distribution of hobbyist and commercial beekeepers in Sweden.

The SBR is organised in a hierarchical level with districts and sub-districts (local groups). Participating in activities is voluntary but there is a general interest in meeting and socialising with other beekeepers. The local group administrator contacts and reminds members to fill in the SBR member survey. Since this is a member survey, it is possible to coare the number of members reporting with the total number of members. About 50% of members report in the SBR survey. It is important to keep in mind that not all members are beekeepers.

The two large beekeeper's associations encourage their members to respond to the COLOSS survey. Neither of the organisations track how many of their members that actually has responded to the COLOSS survey.

The number of responses to the COLOSS survey compared to that of the SBR survey ranges between 12 to 68% (Table 1), with an average of 30% (Figure 2). The highest relative number of COLOSS responses compared to SBR responses are found in the county of Stockholm and Jämtland (in the north). The lowest fractions are found in the counties of Gotland, Halland and Kalmar (Table 1). Thus, there is a large variation in response rates between different counties.

To conclude, the actual response rates in relation to actual beekeepers or different beekeeper types are unknown in both SBR and COLOSS survey, since there are no reliable information of the total number of beekeepers in Sweden. Information about the actual number of beekeepers in each county would provide valuable information to judge the quality and representativeness of the COLOSS survey.

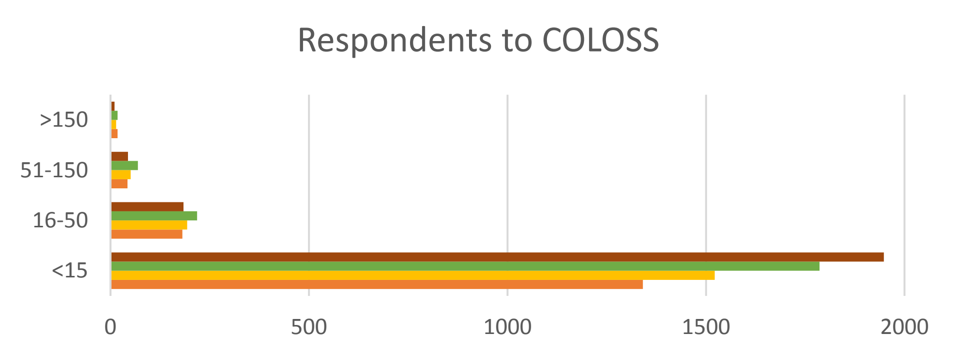
Table 1. The average number of respondents seen over the years 2014-2017 in the two Swedish winter loss surveys.

Code	County	COLOSS average number of responses	SBR average number of responses	COLOSS/SBR
T	Örebro län	55	180	30%
Z	Jämtlands län	31	49	62%
S	Värmlands län	41	202	20%
G	Kronobergs län	81	269	30%
F	Jönköpings län	121	527	23%
W	Dalarnas län	45	201	23%
U	Västmanlands län	49	115	42%
BD	Norrbottens län	55	113	49%
AC	Västerbottens län	45	105	43%
Y	Västernorrland län	42	86	49%
X	Gävleborgs län	43	90	42%
C	Uppsala län	86	224	38%
AB	Stockholms län	208	307	68%
D	Södermanlands län	86	275	31%
E	Östergötlands län	101	300	34%
H	Kalmar län	70	374	19%
I	Gotlands län	17	139	12%
K	Blekinge län	35	109	32%
M	Skåne län	198	663	30%
N	Hallands län	83	494	17%
O	Västra Götalands län	357	1036	34%

A representative data set on winter loss should contain responses from different types of beekeepers. Winter loss can be related to the type of beekeeping and level of education and it is therefore important to have responses spread out over different categories (see also the overview about causes of winter loss above).

The average numbers of responses in the Swedish COLOSS survey are in average 52 from small-commercial beekeepers (51-150 colonies), and 15 from larger-commercial beekeepers (>150 colonies) (Table 2). This means that in average 70 beekeepers with more than 50 colonies respond to the COLOSS survey every year. Commercial beekeepers constitute of about 4% of the total number of respondents in the COLOSS survey. This may reflect the relation compared to the total number of beekeepers in Sweden. However, about 15 large commercial beekeepers respond to the COLOSS survey every year (Figure 4), which is a small number for statistical estimation. Better estimates of loss rate for commercial beekeepers require higher response rates from this group, and especially the large-commercial beekeepers.

A higher and geographically distributed response rate of small but in particular large commercial beekeepers in the Swedish COLOSS survey is needed for the resulting estimates of winter losses to be more reliable for commercial beekeeping.



	<15	16-50	51-150	>150
2017	1948	184	44	10
2016	1786	218	69	18
2015	1522	193	51	14
2014	1341	181	43	18

Figure 4. The spread of respondents over different sizes of beekeeping in the COLOSS survey.

Lee et al. (2015) describe different approaches to data collection of winter loss according to its purpose, approach, type of data, timeframe and sample selection. Different combinations of these come with a relatively low investment and result in different outcomes.

In Sweden, winter loss data is collected by questionnaires (as opposed to in field observations or biological samples) where the respondents are selected by convenience (i.e. built on voluntary participation and not by random or stratified selection of participants or colonies). There is no active manipulation made to test the influence by risk factors, something that may be required to corroborate findings on the influence by risk factors. Data collection with active manipulation is usually done for research and not in annual surveys.

The Swedish data on winter loss is collected at a single point in time, which limits the possibility to consider dependencies at beekeeper or colony levels. It is possible to use data in retrospect from previous years of surveys. Repeated measurements of the same beekeeper, apiary or colony (i.e. longitudinal data) is a strong characteristic for statistical analysis. However, repeated measurements is both costly and difficult to obtain for the winter loss data collection. An experience from the German bee monitoring program is that bee health of colonies belonging to beekeepers which are repeatedly visited by disease experts were improved which made them less suitable for monitoring (Preben Kristiansen pers com). Given enough large sample size, randomisation among the voluntary respondents is one option to increase statistical validity of the data.

Our conclusion is thus that the data collected on winter loss in Sweden contains useful information at a reasonable cost. The COLOSS survey reach out to all beekeepers in Sweden, while the SBR survey is limited to its members. The COLOSS survey is done online. The SBR member survey is done on papers/email and compiled by districts.

ANALYSIS

Data collection and analyses of winter loss can be done with the goals to estimate, monitor, and explain or to forecast and inform beekeepers or policy. These goals depend on each other in a cumulating way. Estimates of winter loss are required to explain and to detect trends and anomalies by monitoring. The ability to make estimates conditional on predictive factors are necessary to forecast and evaluate management and policy strategies.

INDICATORS

It is relevant to ask what type of outputs that would come from estimation. Hendrikx et al. (2009) identify different type of indicators for winter loss: mean loss rate, median loss, percentage of beekeepers with a loss rate superior to a threshold and total winter loss. They suggest that these indicators should at least be provided with analysis of temporal trends or geographical variation (i.e. regional estimates). Here we present a modified and expanded list of indicators:

The **average loss rate** (also known as mean loss rate) acknowledges that there is variation in loss rates from beekeeper to beekeeper. This variation can be natural or due to factors influencing winter loss which are not taken into account in the analysis (i.e. non-explained variation).

The **overall loss rate** is an indicator which weights different loss rates depending on how common they are in the population. A common way to estimate overall loss rate is to simply derive a proportion of colonies lost in a sample of the population.

Median loss rate is based on the same assumptions as the average loss rate. Instead of weighting different loss rates in a population, it takes the smallest loss rate which exceeds half of the population of beekeepers. A median is less sensitive to the most extreme loss rates in a population. The more skewed the distribution of loss rates is, the larger the difference between median and average loss rate is.

It is worth to note that loss rate can be an incidence or a prevalence. To generalise, incidence is the probability of a new colony loss at a given place, type of beekeeper or other factor which can influence winter loss. Prevalence is the proportion of colonies lost during winter in a population of colonies or in a population of beekeepers. Estimates of incidence and prevalence can differ depending on the composition of the population. For example, prevalence in a region is likely to different depending on the distribution of number of colonies per beekeeper as well as the proportion of e.g. hobbyist compared to commercial beekeepers that are active in the region. In this list, average loss rate is an incidence while overall loss rate is a prevalence.

The fourth indicator is the **percentage of beekeepers with a loss rate superior to a threshold of x % of their colonies**. This uses the same assumption as the average loss rate indicator and compare loss rates to an evaluation threshold, x. This evaluation threshold is set by the analyst.

Although honey bees are managed, winter loss is a result of a natural process. A zero vision for winter losses is not realistic or useful. A variation of the last indicator is used by the US based Bee Informed Partnership. In their annual survey beekeepers are asked for what level of winter loss rate that they see as acceptable. Thus, what is acceptable can vary between beekeepers. The indicator is then the percentage of beekeepers with a loss rate superior to what is seen as acceptable. Below we refer to this as the **percentage of unacceptable winter loss**. Some beekeepers prepare for winter loss by creating new colonies during the season which can compensate for potential losses during winter. This indicator take into account anomalies in what to expect.

Total number of colonies lost is the number of colonies lost and depends on the total number before the winter. This indicator translates loss rate into a number which associates to the magnitude or the economic value of winter loss. As pointed out before these numbers can be those observed or the actual total, where the latter is more relevant as indicator. The total number of colonies lost rely on estimates on the total number of colonies before winter. There is no need to get responses from all beekeepers. Estimates of total number of colonies lost can be obtained based on information on the total number of beekeepers in different categories and region and loss rate estimated for these categories.

Winter loss influence the number of colonies in production after winter, which determines the amount of pollination during spring and thereby honey production that year. It is reasonable that beekeepers decide to compensate for an expected winter loss by creating extra colonies during summer. As a consequence the total amount of colonies in production the coming season is at least not decreasing (Moritz and Erler 2016). Some beekeepers manage their colonies at apiary level (Steinhauer et al. 2018), removing or merging weak colonies before the winter, thus lowering loss rate by selecting the best colonies to keep over the winter. An alternative indicator of winter loss (or the impact thereof) is the **total number of colonies in production after winter**. This indicator considers the actions taken by beekeepers to ensure a certain amount of production colonies after the winter. This indicator is related to the honey bee stock and domestic honey production. Surveillances usually asks for the average honey production per colony, but this is not the same as the total bee stock since one need to know the total number of colonies for that beekeeper to know the total honey production.

The number of colonies in production can be constant or increasing every year even under large winter loss. Analysis of the bee stock rather than loss may result in different perspectives, e.g. the importance of socio-economic factors rather than diseases (Moritz and Erler 2016).

The choice of indicator depends on the goal of a winter loss analysis. The goal of the COLOSS survey is to compare estimates of winter loss and test the influence of risk factors. The goal of the SBR membership survey is not specified other than to collect the data. There are today, no explicit goals specified by other organisations or agencies concerning winter loss analysis in Sweden. The Swedish Board of Agriculture have goals to ensure Swedish honey production, manage honey bee health and to enhance pollination services, but these are not expressed using explicit reference to winter loss in managed honey bees.

The annual results from the COLOSS survey is reported in a press release where there is information on the COLOSS web page. The COLOSS publish a research note including a map showing which regions winter loss is lower and higher than average of that year (Brodschneider et al. 2018). Reporting of winter loss from the SBR and COLOSS surveys for Sweden, with information on some of our neighbouring countries as well, is done in the journals by the two beekeeping associations, Gadden and Bitidningen. Indicators of winter loss can be used in combination to describe the condition on year and compare it to previous years. A summary of results can be expressed in text (such as Box 3 and in Brodschneider et al. 2016), diagrams and maps of indicators (e.g. as in van der Zee et al. 2014).

Box 3. A template to report results in without spatial resolution. The text is modified from SBR annual report, COLOSS survey report for Sweden, and the short version of reports from the US Bee Informed Partnership.

The results from the nth annual survey of managed honey bee colony losses in Sweden are ready. This year, nn beekeepers collectively managing nnn colonies in date 1 year 1 provided validated survey responses. This represents d% of the estimated dd managed honey-producing colonies in the country.

During the year1 - year2 winter (date year1 – date year2), an estimated x% of managed colonies in the Swedes were lost. This represents an increase of xx percentage points over that of the previous year, and an increase of xxx percentage points over that of the 10-year average total winter colony loss rate of xxxx%.

W% of the beekeepers who responded to the survey did not loose any colony during winter, while ww% had more than 50% in winter loss. Similar to previous years, hobbyist beekeepers lost more colonies in winter (y%) compared to those lost by small-scale commercial (yy%) and large-scale commercial (yyy%) beekeepers. Hobbyist, small-scale and large-scale commercial beekeepers are defined as those managing 50 or fewer colonies, 51 – 150 colonies, and 150 or more colonies, respectively.

The self-reported 'level of acceptable winter colony loss' increased from z% last year to zz% this year. zzz percent of responding beekeepers lost more of their colonies than deemed to be acceptable.

ESTIMATION

Analysis of winter loss can be done with different levels of complexity and resolution. Raw data, e.g. the ratio of the number of colonies lost and the number of colonies before winter, is the most simple one but does not open up for taking into account other information and is sensitive to differences in the amount and quality of data. Estimates from statistical models open up to integrate information considering observation errors, provide errors in estimation and test for factors. Using statistical models open up draw conclusions on the whole population which means that instead of reporting data one can report estimates of indicators for winter loss at different scales and types of beekeepers in a region, without being constrained by those beekeepers who has responded to the survey.

Statistical models can include geographical incidences and test for temporal trends. A common model for winter include random variation to account for natural variability or unexplained variation in estimates. The recommendation for winter loss is to use binomial random effects models for winter loss (van der Zee et al. 2013).

The COLOSS survey collect data at beekeeper levels and can be used to estimate the indicators average, overall and median loss rate and the percentage of beekeepers with a loss rate superior to x%. Since the geographical position of beekeepers' apiaries are partially known, it is possible to make estimates with a geographical resolution down to postal code level. Loss rates have been reported at county levels in Sweden (Gadden 3 2014 page 20-21). Reports on the COLOSS survey show maps of loss rates (Brodschneider et al. 2018).

To illustrate the potential of what one can do with the COLOSS data for Sweden we did a preliminary analysis of mean loss rates in Sweden at county and postal code levels in this report[2] (Figure 5). Increasing the resolution in indicators reveal patterns across space and the next step is to see if these patterns can be associated to biological and chemical stressors and environmental and climate factors.

The SBR survey collect data in 25 districts. The 25 districts are the same or subsets of the Swedish 21 counties. Data on winter loss is aggregated over all reporting members in each district. Due to this aggregation information about variation between beekeepers is lost. The SBR survey can support estimates of overall loss rates (i.e. the proportion of colonies lost) at district levels. Thus, the overall loss rate is dependent on the composition of beekeepers in each district and it is not possible to say if differences between districts is a result of different composition of beekeepers or differences in risk factors.

2. A beta-binomial random effects model was used on COLOSS data with county and year as random effects and an observation level random effect. Unstructured and structured spatial components based on the 21 Swedish counties and 3 digits postal codes. The SBR data was derived by a binomial random effects model, with county and year as random effects.

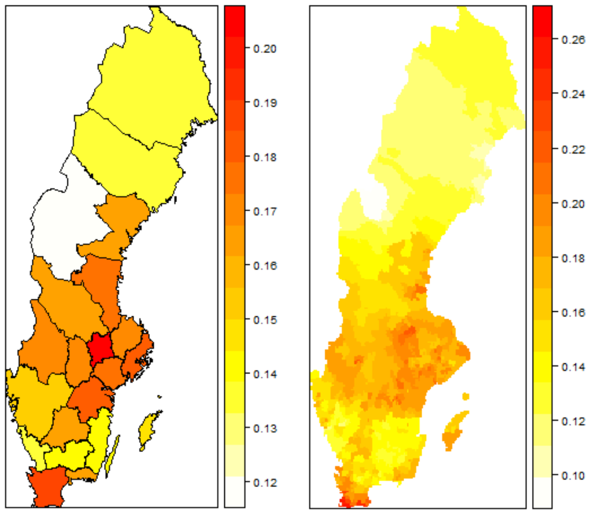


Figure 5. Estimates of average winter loss rates at county level (left) and at 3-digit postal code level (right) based on the COLOSS data from the years 2014-2017. Note different scales for the two maps.

Another consequence of aggregation from beekeeper to district level is that beekeepers with large number of colonies get a higher relative weight in the estimation, compared to if the analysis was done on individual levels. The latter analysis include the additional information that counts come from several independent beekeepers, where the observation from each beekeeper is weighted by the number of colonies before the winter for each beekeeper. Thus, large beekeepers have higher weights in estimation, but the aggregation makes this more pronounced. In case of a systematic difference in loss rate for small compared to large beekeepers, aggregation can result in biased estimators.

Here we used the data from the COLOSS and SBR surveys from the years 2014-2017 to look for such biases. First we aggregated the COLOSS data to county level and compared county specific estimates of overall loss rates to the average loss rates. Aggregating data to regional level resulted in an absolute difference on about 3% between the average and the overall loss rates (Figure 6). This can be an effect of a skewed distribution in loss rates between beekeepers, which is more pronounced when there is a correlation between loss rate and numbers of colonies. In general, large beekeepers can have lower loss rates since they have more colonies from the beginning are less sensitive to large losses due to stochastic effects in relation to small numbers. For example, if you have two colonies and loose one, the loss rate is 50%.

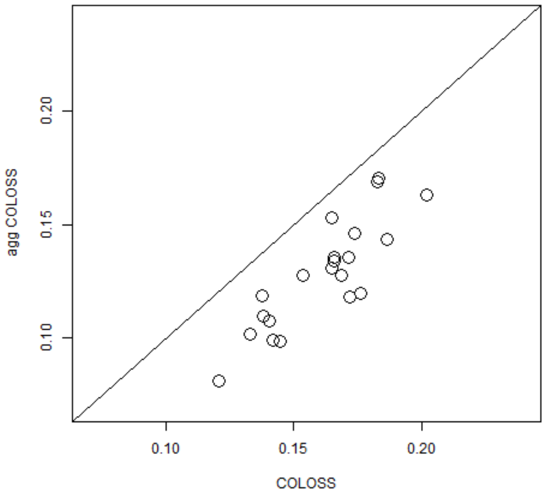


Figure 6. Temporal mean of estimated county specific average loss rates from the COLOSS data (using data at the beekeeper level) and county specific overall loss rates based on the same COLOSS data aggregated to the county level. Data are from the years 2014-2017.

We then compared county specific overall loss rates estimated from COLOSS data with those estimated from the SBR data (Figure 7a). Estimates of overall loss rate is similar or higher when based on SBR data compared to COLOSS data. The beekeepers responding to the COLOSS survey have in general more colonies compared to those responding to the SBR member survey (Figure 7b), but there is no clear trend between the difference in estimates and difference in the average number of colonies per beekeeper.

The largest differences in the average number of colonies per beekeeper between COLOSS and SBR are found for the counties Gotland (I) and Kalmar (H). It can be enough that one or a few numbers of large-commercial beekeepers take part in one of the surveys to create such differences. It is easy to show that when there is a negative correlation between loss rate and number of colonies, any aggregation of data result in overall loss rate to be lower compared to the average winter loss rate. Under a similar representation of different beekeeper categories, estimates of overall loss rates for SBR and COLOSS should be similar. This was not seen in the comparison made here. Instead, there are large similarities in prevalence estimates of mean loss rate from SBR and COLOSS surveys (Figure 7a). The distribution of small compared to large scale beekeepers mostly likely has an effect on the bias, but is not the only reason for this bias.

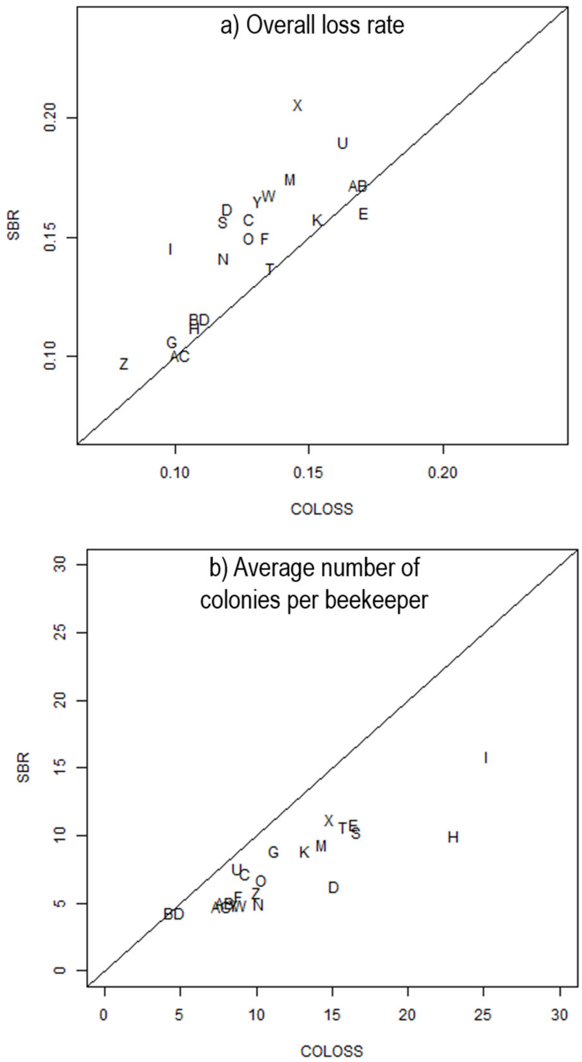


Figure 7. The COLOSS and SBR data from the years 2014-2017 were used to compare a) estimates of the overall loss rate in different counties and b) the average number of colonies per beekeeper in each county.

Another reason for differences could be different case definitions of winter loss in the surveys, e.g. what is included in winter loss and when a loss is a loss during winter. Some surveillance systems seek to reduce bias by setting dates for when the winter period start and ends (Lee et al. 2015). The last years of the COLOSS survey distinguish between colonies in production and new colonies (avläggare), whereas the SBR ask for all colonies. During the last years, the COLOSS survey have asked for different causes or types of losses during winter and there is a feedback in the survey on how many colonies that are lost in total (Table 2).

Table 2. The questions of the colonies lost and number of colonies before winter in the COLOSS survey.

Number of colonies before winter	N
Loss due to queen problem	X
Loss due to external factors (storm, fallen trees, snow, flooding, theft, mice, badgers and wood peckers)	Y
Loss due to death of a colony	Z
Total loss	X+Y+Z
Proportion colonies lost	(X+Y+Z) / N

MONITORING

Monitoring is about the ability to compare indicators to detect trends and anomalies in the state of colonies or risk factors (Lee et al. 2015). This requires reliable estimates and thresholds for early warnings, corresponding to set up management goals. What is an extreme loss rate depends on what variability in loss rates to expect at a given place and for a given geographical resolution. Variability can be broken down into variability between spatial units and variability between years.

The COLOSS data show that there is a relatively large spatial variability in winter loss rates seen over Sweden (Figure 8). To get an idea of the magnitude, an estimate of a mean loss rate of 10% is likely correspond to a variation in loss rate between 5 to 17% from place to place but also between 8 to 12% from year to year (Figure 8). These ranges increase as the loss rate becomes larger.

In order to detect trends or anomalies in winter loss, one need to separate both spatial and temporal variability in the analysis for different scales (e.g. apiary, postal code and county). Increasing sample sizes and quality of data will improve the estimates of these variabilities. Note that more data will not reduce variability per se as it is an inherent property of each biological system. Longitudinal data, i.e. repeated sampling of the same colonies or beekeepers, over several years is a strong statistical characteristic that improve the quantification of temporal and spatial variability (Lee et al. 2015)

Both the SBR data and the COLOSS data can be used for monitoring of overall loss rates, while the COLOSS data can monitor mean loss rates since it collects data at beekeeper level. For overall loss rate it is important to have a representative sample from the population of beekeepers. For mean loss rate linked to beekeeper types and risk factors it is more important to have enough samples for each predictor/covariate.

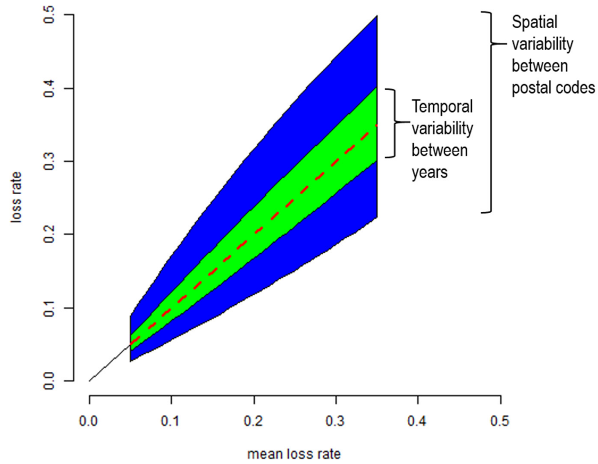


Figure 8. The temporal variability (light range) and spatial variability (dark range) in loss rates for different mean loss rates estimated based on an analysis of four years of Swedish COLOSS data with 3-digit postal code resolution.

EXPLANATION

Explanation is about the ability to test the influence of factors of relevance (van der Zee et al. 2014; van der Zee et al. 2015b; Jacques et al. 2016). For winter loss it means to evaluate the effect of biological stressors, chemical stressors, environmental and climate factors and beekeeping management (Figure 1). The more information on factors of relevance the higher possibility to evaluate their combined impact.

Studies with high explanatory power should be done at colony level (EFSA 2016). Such field studies colony level requires often expert knowledge as colonies must be opened and inspected. This is a suitable level to collect data for scientific research.

For practical reasons, both the SBR membership survey and the COLOSS survey is done at beekeeper levels. Higher response rates in more countries and better collection of data on risk factors can compensate the loss of resolution in winter loss data.

A compromise is to keep on using beekeepers to collect the data themselves, but at apiary levels. The possibility to estimate effects of stressors and other factors may increase with data on apiary level, since there can be large differences in conditions from apiary to apiary. Such effect will only influence the data collection from beekeepers with more than one apiary.

FORECASTING

Forecasting is the ability to make reliable predictions of winter loss or impact of risk factors and management. Forecasting is useful to assess what will happen with winter loss under scenarios related to stressors and management in a short or a long-term perspective. This information can be used to build realistic expectations on beekeeping in different parts of the country.

Forecasting tools use models which have been validated for their ability to predict. Assessments of precision and uncertainty in the forecast is useful to build trust in the use of such models. Forecasting models can be data driven, which requires long high quality spatial and temporal data series. In absence of data or where the aim is to forecast events which has not been experienced before, forecasting models use process-based models informed by theory and available data.

There are today, no forecasting models of winter loss in Sweden. A model to forecast winter loss based on current status and trends in risk factors is helpful for beekeepers as well as risk managers and bee health officers. There are currently no plans for such tool, but as pointed out in this report, there are plenty of conditions to make one for Sweden.

FACTORS INFLUENCING WINTER LOSS

Steinhauer et al. (2018) conclude that since honey bee colony health is a complex system, modelling is an important component of analysis to better understand the importance of risk factors and identify trends and anomalies. This means that statistical analysis need to go beyond estimates on data to infer winter loss indicators as parameters in more complex models. This can make it possible to distinguish the influence of changes in respondents from actual changes in winter loss on between year and between region differences in winter loss.

Data on biological stressors are collected in several ways. A recent project BaslinjeBi was conducted 2016 by the Swedish Agricultural University (SLU) and the National Veterinary Institute (SVA) had the aim to set a reference for diseases in honey bee colonies in Sweden. Samples taken from 385 randomly selected apiaries were analysed for Varroa, American foulbrood, European foulbrood and two other viruses. The project was financed by the Swedish Board of Agriculture.

There are no ready available data on chemical stressors with high resolution in Sweden. Direct field sampling of chemical stressors outside and inside a colony is costly and unrealistic for monitoring. In agricultural areas, pesticides usages can be approximated from information on crops grown and production region. Information to approximate chemical use can also be derived based on information on beekeeping management practices and about the presence of certain land use types around the apiary. These types of questions are included in the COLOSS survey (Appendix 1).

There are many sources of data on environmental and climate factors. With spatial explicit information on land use is a necessity to create what is found in the proximity to honey bee colonies behind each winter loss observation. Estimates of honey bee food in the resource providing unit can be obtained by GIS modelling combined with assumptions on food and foraging. Floral resources has been assessed from land use information derived satellite images or from land use databases. A common approach is to combine the IACS (Integrated Administration and Control System) database, which contains for each year the crops grown in each field block, and the Swedish Marktäcke Data (SMD) database, which is largely analogous to land cover data from the CORINE (coordination of information on the environment) held by the European Environmental Agency. Such GIS modelling maps floral and nesting resources by transforming land-use classes into nesting quality and floral values (e.g. in Häussler et al. 2017; Koh et al. 2016).

Knowing the position of honey bee apiaries increase the possibility to provide good estimates of floral resources. In this way it will be possible to combine the survey responses on winter loss with information on land use from the landscape around the honey bee apiaries, and evaluate the combined impact on floral resources and lack thereof, biological and chemical stressors and beekeeping practices. There are monitoring tools using land use and pesticide information in combination with other factors on health in honey bees in agricultural landscapes (Odoux et al. 2014).

ORGANISATION

It is important to look at how the efforts towards improved bee health is organised. Hendrikx et al. (2009) suggested several points of improvement of surveillance of winter losses in honey bees (Box 4). The first point of improvement is to specify the goal with data collection. Today, Swedish beekeepers can report data to two independent and partially overlapping instances, the SBR survey and COLOSS. Although the SBR survey covers many beekeepers, it does not include many of the commercial beekeepers. Further, data is collected on district level which limits it use to estimate overall loss rates at district levels only. As we point out below, small changes in the data collection made by SBR can open up the possibility to use this data for more of the analysis goals and indicators specified above.

From a beekeeper perspective, it can be difficult to find the motivation to respond to two surveys (interviews with individual beekeepers). Sharing information on the position of apiaries, the number of colonies and amount of honey produced requires trust in the data collecting organisation that data is used for the intended purposes. There is already a reluctance among beekeepers to report under the regulations of diseases and primary producers. It is a challenge to create incentives to report. It may require more reasons than to monitor and to improve our understanding of factors behind winter loss.

This situation highlights the need for a Swedish central organisation of data collection (Box 4). This organisation can have a larger role, e.g. to provide advice to beekeepers and the health the Swedish bee stocks. A useful model is a partnership, organising the stakeholders and regulators in beekeeping. Joint efforts are needed to get continuous and reliable data and monitoring of winter losses (Steinhauer et al. 2018).

There are plenty of examples of successful partnerships of beekeeping. The US based Bee Informed Partnership (https://beeinformed.org/) builds on a coalition between researchers, advisers and other stakeholders, with national and international collaborations. The main goal with the Bee Informed Partnership is to investigate and continuously update which beekeeping management that works best to improve bee health and communicate this to business and the beekeepers. In the UK the Animal and Plant Health Agency's (APHA) National Bee Unit is designed for beekeepers and supports Defra, Welsh Government and Scotland's Bee Health Programmes and the Healthy Bees Plan, which set out to protect and sustain our valuable national bee stocks (www.nationalbeeunit.com/).

Box 4. Suggested improvement points of surveillance of winter losses in honey bees (Hendrikx et al. 2009)

- Specify objectives for colony loss surveillance

Central institutional organisation:

- A specific steering committee for colony loss monitoring
- Use a technical committee comprised of scientists able to support the development of surveillance protocols and data interpretation
- Use a central coordination unit constituted by several persons at a central level

Field institutional organisation:

- Formalisation of procedures – develop common set of case definitions (e.g. what is winter loss). Clear and specific case definitions are important to ensure a common description of colony loss
- Collect representative data for each region
- Promote the use of relational databases gathering population data with geo-referenced information
- Develop a common data model

CONCLUSIONS

Neither the Beekeeping Associations nor the Swedish Board of Agriculture have any explicit management goals for winter loss in honey bees in Sweden. There is no description of what is acceptable winter loss in different regions or beekeeping types in Sweden. Without any goals there is no need for additional and tailored analyses on winter loss in Sweden. A joint organisation of winter loss in Sweden is one way to make it possible to set shared goals and improve data collection and analysis to achieve these goals.

There is an unleashed potential for different types of analysis of winter loss. It is a good sign of quality that a large part of Swedish beekeepers respond to the SBR or the Swedish COLOSS surveys. An exception is large commercial beekeepers, which since they have so many bees are likely to play a dominating role in the landscapes around them.

The lack of a common data model in the COLOSS and SBR surveys is a weak point. Under current data collection, the overall loss rate is the only indicator that can be estimated from both data sets. The COLOSS survey can support estimation of more indicators, since data is collected on beekeeper levels.

The aggregation done by SBR of loss rates from beekeeper to district levels, introduces an unknown bias in estimates of winter loss which depend on the distribution of small and large beekeepers within each district. Collecting the SBR data at beekeeper level will make the data set more comparable to the COLOSS data.

The response rate in the COLOSS survey is uneven across the country, and in some counties very low in comparison to the SBR survey. This shows that there is a potential for more responses to the COLOSS survey.

There is a high spatial variability in winter loss inside each county. In order to do a comparative study of areas with low and high winter loss, it is necessary to use estimates on a lower level, e.g. local district, municipal or postal code level.

There is a problem with the under-representation of large-scale commercial beekeepers in both these surveys. There can be several reasons for this. Not all commercial beekeepers are members of SBR, so there is a shortage of large scale beekeepers among the possible respondents in the first place. It can be difficult to find the motivation to answer two surveys with 5 months apart.

Multiple year statistical analysis of winter loss in Sweden which considers variation across the country and possible interaction between space and time is required to identify trends and anomalies in winter loss.

The possibility to estimate the combined effect of factors influencing winter loss is held back by the lack of estimates of winter loss with high spatial resolution (e.g. at municipal or postal code levels) and data and estimates of environmental factors (e.g. floral resources in landscape around an apiary).

The historical data on winter loss collected by SBR and COLOSS can, in combination with more detailed data on winter loss during the coming years, be used to build forecasting tools of relevant indicators such as winter loss or the number of colonies in production.

The possibility to estimate relevant indicators for winter loss is constrained by lack of information of the total number and distribution of beekeepers of different types in Sweden.

Recommendations

In Sweden, there is a constant shortage of domestic honey. Although there is a growing interest in beekeeping in Sweden, the majority of new beekeepers are small-scale hobbyist beekeepers. As a consequence, the increase in the total number of colonies is not that large. Small or declining honey bee stocks is a problem for pollination services provided by honey bees and domestic honey production.

Swedish beekeeping must be able to face pressures from biological and chemical stressors, alone and in combination with environmental and climate factors. A major cause for high winter loss is poor beekeeping practices. Beekeeping can be improved by adequate training and information to support the beekeepers ability to prepare for winter loss. Beekeepers ability to plan and respond to signals of winter loss may use information on geographical incidences, including trends and variation and signs of early detection of winter loss.

Unacceptably high winter losses despite good practice beekeeping is a problem, in particular for commercial beekeepers with high economic interests at stake. Commercial beekeepers (i.e. those with more than 50 colonies) contribute with a large part of the Swedish bee stock. A national strategy for honey bee health including honey production and pollination service by honey bees must take these economic interests into account. An adaptive strategy to manage honey bee winter loss (and bee health) consists of monitoring aimed to fill data gaps and to provide reliable estimates of the status of honey bee health, reduce uncertainty in the effect of management and give recommendations. Today, Sweden lack a shared strategy for winter loss in managed honey bees.

The first thing to do is to decide the aims of a strategy. The second step is to get an idea of the condition on bee health and winter loss in Sweden. Third, data collection and analysis must be evaluated for its ability to provide answers. Annual data on winter loss is today primarily collected by two instances, the COLOSS survey and the SBR membership survey. These data can be used for additional and tailored analysis of winter loss in Sweden. Small changes in the way data is collected by SBR would have a large effect on reliability of any results. The fourth step is to improve knowledge where it is needed. This means to take actions to reduce uncertainty in causes of bee health under Swedish conditions. Finally, a strategy should include a plan to make sure the best available knowledge is presented to and understood by the beekeepers.

Based on the findings in this report we recommend the following:

- Create a national partnership for bee health and beekeeping in Sweden. This central organisation has the task to set goals for the management of winter loss in Sweden and ensure a cost effective data collection and analysis to achieve these goals.

This partnership should at least include the two Beekeeping Associations to ensure that the major part of both commercial and hobbyist beekeepers are represented and representatives of the County Administrative Boards, the Swedish bee health officers (we currently have only one) and the Swedish Board of Agriculture.

- Create a shared web page which publish annual reports on winter loss, information about surveys, and advice on beekeeping management to reduce winter loss. This information should be accessible for anyone – not only members of the beekeeper associations.
- Create a Swedish winter loss analysis expert group consisting to representatives from the two beekeeping associations, a Swedish bee health officer, the Swedish Board of Agriculture and scientific experts. A first task of this group is to perform a temporal and spatial analysis of historical SBR data and publish this in a scientific paper.
- Encourage the COLOSS community to publish statistical analysis of COLOSS data with temporal trends and spatial incidences at high resolution, preferably in Sweden only. Support bachelor and master's thesis on this topic.
- Make efforts to increase the response rate by commercial and especially large commercial beekeepers to the COLOSS survey.
- Investigate the low response rate of commercial beekeepers in the COLOSS survey. The commercial beekeeping organisation is recommended to do a survey to their members asking for their view on the need for winter loss analysis and problems with reporting to the COLOSS survey and if applicable to the SBR survey.
- Investigate the possibility to store information in the SBR survey at a higher spatial resolution, e.g. local district or beekeeper levels. In this way, aggregation is not needed and the survey can be made online. An online survey make data collection easier and less prone for errors.
- Collect data on potential overlap between surveys as way to improve our understanding of response rates and representativeness. For example, in the COLOSS survey to ask respondents if they will respond to the SBR survey as well. The COLOSS survey is done in the month of May in all countries in Europe and the results are published later the same year. The SBR survey is done 5 months later and include information of how many colonies that are kept during the coming winter. A possibility to increase response rate to COLOSS is to open up for a late responses to the COLOSS survey in December, which can be added to future analysis looking at winter loss over several years.
- Investigate the possibility to make a joint survey of SBR and COLOSS. A joint survey can consist of several sub surveys asking for different levels of detail. This will simplify reporting for Swedish beekeepers which only need to respond to one survey. A collaboration between the two Beekeeping Associations will make it possible to strengthen data collection efforts by increasing response rates, reduce biases and quality control of data. It will require resources to develop a shared survey system as well as resources to SBR and BF to make their members to respond to it.
- Evaluate the possibility to answer on the COLOSS survey at apiary level, as way to increase precision in the estimates of winter loss and stressors.
- Consider the possibility to synchronising reporting of position of apiaries, honey production and winter loss for Swedish beekeepers.
- Establish a baseline for winter loss, honey production and beekeeper types in Sweden. This can be achieved by an intensified data collection during a limited --period. The EPILOBEE project is an example such task, but it was limited to three regions in Sweden. The baseline can also include the total number and distribution of beekeepers and honey bee colonies in Sweden.
- Complement overall and average loss rates with indicators of complementary and relevant information, e.g. the distribution of loss rates, the proportion of beekeepers with an unacceptable winter loss or the total number of colonies in production after winter. For example, to report the proportion of beekeepers with no loss and with a loss larger than 50% as well.
- Ask for acceptable levels of winter loss in the surveys. The perceptions by beekeepers can provide relevant information both with respect to identifying anomalies but also to set management goals.
- Complement monitoring and estimation with systematic reviews on the effect of beekeeping management in combination with different risk factors suitable for Swedish conditions. A partnership can be used to identify assessment questions to support evidence based beekeeping in Sweden.

Appendix 1. Questions in the COLOSS survey for the winter 2017/2018

The questions have been extracted from the online survey and are in some places shortened by the authors of this report.

1) Namn och bostadsort
2) Vilket kön har du?
3) Hur många år har du varit biodlare?
4) I vilket län har du huvudsakligen din biodling?
5) Vad heter orten som ligger närmast din bigård eller där de flesta av dina bigårdar befinner sig?
6) Ange postnumret där din bigård eller de flesta av dina bigårdar befinner dig.
7) Hur många bigårdar har du?
8) Hur många avläggare bildade och invintrade du 2017?
9) Hur många av de invintrade avläggare som producerades 2017 gick förlorade under vintern 2017-2018 (dvs från invintringen 2017 fram till cirka 1 maj 2018)?
10) Hur många produktionssamhällen hade du före vintern 2017-2018?
11) Hur många av dessa samhällen var efter vintern:
    a) förlorade på grund av att de var viselöse eller hade puckelyngel
    b) förlorade på grund av yttre faktorer som t.ex. storm, nedfallna träd, snö, översvämning och stöld.
    c) förlorade samhällen till följd av djur som möss, grävlingar och hackspetter
    d) förlorade på grund av att de var döda
12) Hur många av de döda samhällen, dvs de samhällen som du angett under d i fråga nummer 12:
    a) hade många döda bin i eller framför kupan?
    b) hade inga eller endast några få döda bin i eller framför kupan?
    c) hade döda arbetsbin i cellerna och inget foder kvar i kupan?
    d) hade döda arbetsbin i cellerna och foder kvar i kupan?
    e) hade inga av de ovannämnde symptomen eller okända symptom?
13) Hur många av de övervintrade samhällen, som hade en fungerande drottning och som inte angetts som förlorade, var svaga efter vintern 2017-2018
14) Hur många produktionssamhällen hade du våren 2017 (dvs. i fjol)?
15) Hur många produktionssamhällen hade du våren 2018?
16) Hur många av de invintrade samhällen hade en ny drottning 2017 (dvs. en drottning som parades 2017)?
17) I vilken omfattning observerade du drottningproblem i dina samhällen under säsongen 2017 jämfört med de problem du brukar observera?
18) Jämfört med dina samhällen med äldra drottningar, hur har dina samhällen med unga drottningar överlevt vintern 2017-2018?
19) I hur många av dina överlevande samhällen fanns det en stor mängd exkrementfläckar (utsot) inne i kupan efter vintern 2017-2018?
20) Flyttade du något/några av dina samhällen minst en gång för honungsproduktion eller pollinering under säsongen 2017
21) Använder/tillämpar du följande i huvudparten av din biodling:
    a) Nätbotten under vintern
    b) Drottningar av varroatolerant-/resistent härstamning
    c) Cellstorlek 5,1 eller mindre
    d) Kakbygge utan användning av mellanväggar
22) Ungefär hur stor andel av yngelramarna bytte du ut mot mellanväggar under säsongen 2017?
23) Observerade du bin med missbildade vingar i dina samhällen under säsongen 2017?
24) Hade merparten av dina samhällen ett omfattande drag på en eller fler av följande dragkällor 2017?
    a) Fruktodling

- b) Oljeväxter (raps eller rybs)
- c) Majs
- d) Ljung
- e) Lusdrag

25) Hur många kg honung fick du i genomsnitt per bisamhälle under 2017?

26) Om du utfodrade dina samhällen inför vintern 2017-2018 med antingen sockerlösning eller inverterat foder (t.ex. Bifor), hur många kg socker (torrsubstans) gav du i genomsnitt per samhälle?

27) Undersökte du dina samhällen för varroa under perioden april 2017 – april 2018?

28) Har du din biodling i ett område där varroa ännu inte har påvisats (dvs. i varroazon 2, 3 eller fri zon)?

29) Behandlade du dina samhällen mot varroa under perioden april 2017 – april 2018?

30) Var god att ange i vilken månad och vilket år du undersökte för varroa i dina samhällen OCH när du PÅBÖRJADE en åtgärd mot varroa under perioden april 2017 – april 2018.

- a) Undersökning av angreppsgrad (t.ex.genom nedfallsundersökning eller undersökning av kvalster på vuxna bin)
- b) Drönaryngelbortskärning
- c) Värmebehandling av yngel/vuxna bin
- d) Spärrbox, total yngelborttagning eller liknande
- e) Myrsyra –korttidsbehandling
- f) Myrsyra –långtidsbehandling
- g) Mjölksyra
- h) Oxalsyra -droppmetoden
- i) Oxalsyra – sublimering (förångning)
- j) Produkt med oxalsyra (t.ex.Hiveclean/Bienen-wohl/Varromed)
- k) Tymol (t.ex. Apiguard)
- l) Tau-fluvalinate (Apistan)
- m) Flumethrin (t.ex.Bayvarol, Polyvar)
- n) Amitraz (t.ex. Apivar,Apitraz)
- o) Kumafos (t.ex.Perizin)
- p) Kumafos (t.ex.Checkmite+)
- q) Annan kemisk substans
- r) Annan metod

31) Får vi kontakta dig för eventuella ytterligare frågor angående övervintring och bihälsa eller studier kring detta?

Appendix 2. Statistics in the SBR survey for the winter 2016/2017

County code	County	SBR district	Colonies during winter last year	Colony loss	Honey-production in kg	Members reporting	Members
AB	Stockholms län	Stockholm	2059	453	49670	411	1198
C	Uppsala län	Uppsala	2701	427	83786	278	542
D	Södermanlands län	Södermanland	1576	312	68003	285	497
E	Östergötlands län	Östergötland	3103	497	196551	306	669
F	Jönköpings län	Jönköping	3287	589	72882	581	822
G	Kronobergs län	Kronoberg	2820	348	54302	325	557
H	Kalmar län	Kalmar norra	1218	210	39396	161	221
H	Kalmar län	Kalmar södra	3672	405	145859	283	541
I	Gotlands län	Gotland	808	123	18945	74	163
K	Blekinge län	Blekinge	1017	258	23161	104	296
M	Skåne län	Skåne	6830	1446	139361	811	1599
N	Hallands län	Halland	2278	391	45419	468	648
O	Västra Götalands län	Göteborg & Bohus	2784	396	49963	532	1016
O	Västra Götalands län	Älvsborg norra	1305	148	41741	201	485
O	Västra Götalands län	Skaraborg	2791	443	128386	318	701
O	Västra Götalands län	Sjuhärads	927	144	25870	159	409
S	Värmlands län	Värmland	1556	259	47711	181	335
T	Örebro län	Örebro	1824	334	44832	177	360
U	Västmanlands län	Västmanland	629	151	22414	87	211
W	Dalarnas län	Dalarna	1143	209	32823	265	355
X	Gävleborgs län	Gävleborg	989	222	20589	120	259
Y	Västernorrland län	Västernorrland	364	100	7421	76	227
Z	Jämtlands län	Jämtland	324	29	6755	46	169
AC	Västerbottens län	Västerbotten	601	52	8487	145	283
BD	Norrbottens län	Norrbotten	477	71	5294	100	219

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