# *Haemonchus contortus* in Swedish sheep

Compilation of two decades of diagnostics

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*Haemonchus contortus* **in Swedish sheep - Compilation of two decades of diagnostics**

Stor löpmagsmask hos svenska får – sammanställning av två decennier av diagnostik

Towe Olsson

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# List of Abbreviations

Anthelmintic = Dewormer
Ram = Male sheep
Ewe = Female sheep
GIN = Gastrointestinal nematode
*Haemonchus contortus* = Scientific name for Barber's poleworm
Infection pressure = Parasite load
Nematode = Parasite
Prevalence = Parasite occurrence
Precipitation = Meteorological term for rain, snow, hail or any other type of water falling from the sky

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# Abstract

The aim of this quantitative study was to compile and map the Swedish *Haemonchus contortus* data from sheep to compare with temperature, precipitation and hours of sunshine as well as with a compilation of the earlier decade (2005-2014). The key findings of this study are that the prevalence of *H. contortus* has decreased between the last two decades although there are significant differences between some years. There was also a decrease in the number of sheep, an increase in the number of tests being sent in for diagnosis and overall no difference in the number of sheep holdings. The results further show no correlation between prevalence and temperature, precipitation and hours of sunshine, much like the findings of the earlier decade. The results also show a geographical spread of *H. contortus* in Sweden with time. These findings show a need to analyse this kind of data in greater detail, as annual means might not give accurate or true results. In other words, the number of parasites cannot be determined using only annual weather means. On the other hand, visualising the geographical spread using coordinates proved to be an effective method to show possible *H. contortus* spread. Further research into how detailed weather data needs to be established for making accurate correlations could be crucial to determine the impact on future prevalence.

# 1 Introduction

The Barbers Pole worm or its scientific name *Haemonchus contortus* is an adaptive, blood-feeding gastrointestinal nematode (GIN) in sheep (Emery et al., 2016; Fogarty et al., 2023; Troell, 2006). Data from 2005 to 2014 showed that the nematode affects about 30-40 % of Sweden's sheep holdings (Höglund, 2015). Infections of *H. contortus* are a big threat to Swedish sheep populations as the nematode impact animal welfare, especially to the more vulnerable growing lambs and pregnant ewes (Hammarberg, 2008; Höglund et al., 2021). The animals could experience anaemia or even death as a result of *H. contortus* infection (Emery et al., 2016; Flay et al., 2022; Rose et al., 2016). Sheep infected with *H. contortus* could also affect farm productivity and sustainability, as infections require treatment (Charlier et al., 2020; Flay et al., 2022; Rose et al., 2016). *H. contortus* is adaptable and common across the globe as it can survive in different and changing temperatures and humidity (Emery et al., 2016; Gravdal, 2024; Salle et al., 2019) and is hypothesized to have adapted to the cold Swedish climate (Troell et al., 2005). The infections are today most commonly controlled with anthelmintics, which in turn is causing a rising number of *H. contortus* that is resistant to those treatments (Hammarberg, 2008; Höglund et al., 2022; Troell, 2006). Another concern for the sheep industry is global warming, which is causing changes in climate (Adduci et al., 2022; Rose et al., 2016), weather and temperature (Adduci et al., 2022; Rose et al., 2016). These changes could affect the prevalence and spread of *H. contortus* and therefore also affect animal welfare (Adduci et al., 2022; Rose et al., 2016). The Swedish Meteorological and Hydrological Institute (SMHI) predicts that the future Swedish weather and temperature could change, leading to more precipitation during the winter and less precipitation and higher temperatures during the summer (SMHI, 2015; SMHI, 2024a; SMHI 2024b).

The aim of this quantitative study is therefore to compile and map data already collected from sheep faeces samples at a routine diagnostic laboratory (Vidilab AB) on *H. contortus* over the years 2016 to 2025 in Sweden and to compare this with the years 2005-2014 with a similar compilation by Johan Höglund (2015). The compiled data will then also be statistically compared to data on temperature, precipitation and hours of sunshine provided by SMHI. The sheep faeces samples were randomly sent in from anonymous sheep owners all over Sweden and only marked with *H. contortus* test results, date and approximate coordinates for map-making. Lastly, the 2016-2025 compilation will be compared to other possible alternative factors that might have affected the prevalence and geographical spread, such as the number of sheep, the number of tests, the number of farms and stocking density. The research questions are therefore: how has the total number of tests, positive results and prevalence of *H. contortus* changed over the last two decades?

Are there any climatic factors that could explain any possible changes in prevalence or geographical spread? If not, are there any other possible influencing factors?

# 2 Background

## 2.1 *Haemonchus contortus* - Physiology and the effects of weather and humidity

*Haemonchus contortus* is as earlier mentioned a parasitic nematode that spends part of its lifecycle in the sheep's gastrointestinal system (Carson et al., 2023; Hammarberg, 2008; Salle et al., 2019). The lifecycle begins as the infectious third-stage larvae (L3) are eaten by sheep on pasture (Carson et al., 2023; Flay et al., 2022). Once the nematode is inside the sheep's gastrointestinal system the female nematode lays its eggs. The eggs then travel through the sheep's intestines and are excreted onto the pasture where they will hatch in the faeces and develop into new infective L3 larvae (Carson et al., 2023; Flay et al., 2022). The L3 larvae then travel up the grass on the pasture, get eaten by a sheep and thus a new lifecycle begins (Carson et al., 2023; Flay et al., 2022). In order for the nematode to survive the colder winter months it remains in the sheep in an inhibited state (Gravdal, 2024; Höglund et al., 2021). *H. contortus* lifecycle, survival and geographical spread could be affected by abiotic factors such as precipitation and temperature (Amaradasa, 2010; Gravdal, 2024; Jas et al., 2022). Both temperature and precipitation are therefore determining factors for *H. contortus* (Gravdal, 2024; Iliev et al., 2018) that could also affect prevalence (Gravdal, 2024).

For the nematodes' external development, *H. contortus* seems to prefer soil temperatures between about 19 °C and 42 °C (Leathwick, 2013; Santos et al., 2012). Temperatures below 9 °C and above 42 °C can instead negatively affect the development of the larvae (Leathwick, 2013; Santos et al., 2012). As L3 can migrate during spring, summer and fall (Rose et al., 2016; Santos et al., 2012) to then be restricted when temperature falls (Flay et al., 2022, Leathwick et al., 2013; Santos et al., 2012) such as in Northern Europe (Rose et al., 2016), it would seem that temperature is a determining factor that affects the number of parasites and infections (Flay et al., 2022). Leathwick (2013) states that it´s not only the general temperature that affects development and spread, but also the variability of temperature. Sudden changes in temperature over a short period of time will negatively affect the development of L3. This effect might be even greater than a constantly lower than ideal temperatures for *H. contortus.* Leathwick (2013) therefore concludes that investigating the short term weather data could make for more accurate and true results, as more temperature variations are taken into account. The time frame when collecting weather data might therefore have to be quite short. Even daily means could result in inaccurate results, as it could be too broad (Leathwick, 2013).

Humidity and precipitation could as already mentioned also affect the development and migration of *H. contortus* (Flay et al., 2022; Leathwick, 2013; Rose et al., 2016). Moderate humidity or precipitation softens the faeces, making it easier for the nematode to emerge (Amaradasa, 2010; Santos et al., 2012). Larger quantities of precipitation could instead result in the nematode being washed away. This could lead to fewer nematodes reaching the pasture herbage where they otherwise would have completed their lifecycle.

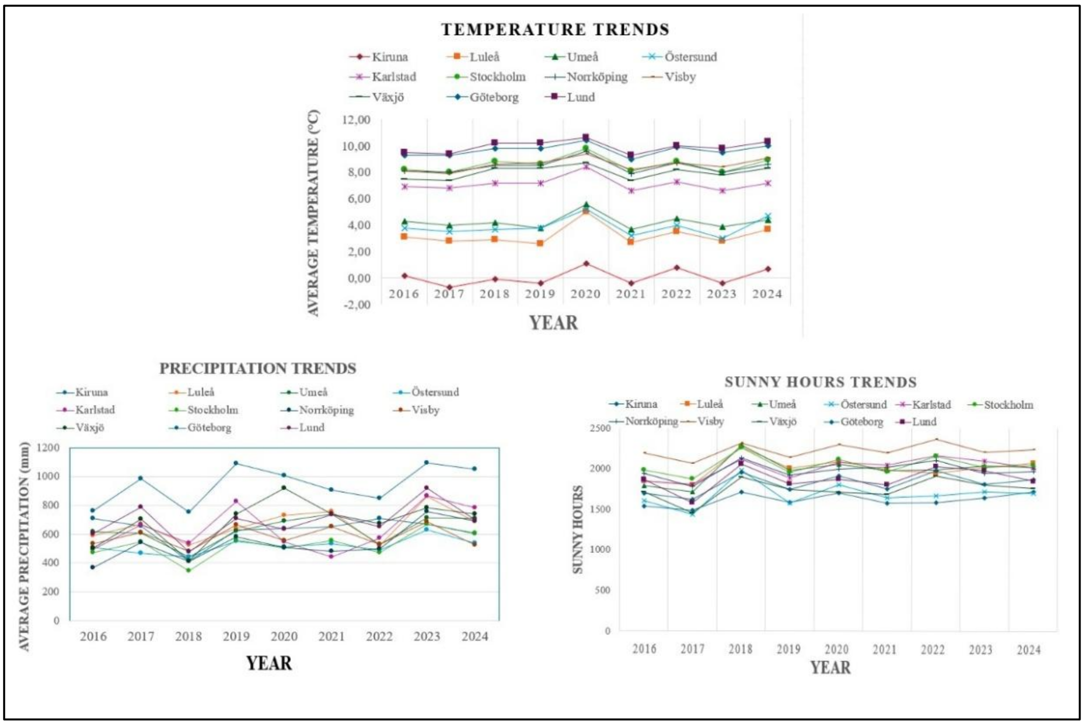
Several studies have shown positive correlations between rainfall and soil temperature on the migration of L3 (Amaradasa, 2010; Flay et al., 2022; Santos et al., 2012) as well as the nematodes' geographical distribution (Rose et al., 2016). Even though *H. contortus* may thrive in the wet conditions typical for northern Europe (Carson et al., 2023; Flay et al., 2022) and temperate Sweden (Flay et al., 2022; Troell et al., 2005), the nematode is currently restricted by the low winter temperatures as it falls below 9 °C (Flay et al., 2022; Rose et al., 2016). This may not be the same in the future as both Rose et al. (2016) and SMHI (2024b) predicts a change in northern Europe's climate. This would lead to higher mean temperatures and milder winter temperatures in northern Europe and Sweden, meaning fewer limitations for *H. contortus.* Rose et al. (2016) further concludes that this future climatic change could benefit the nematodes' survival. The transmission season could get longer and affect the nematodes' migration. This longer transmission season could therefore lead to an increased infection pressure in today otherwise unaffected regions.

## 2.2 Global warming and annual Swedish weather

Several studies such as Belusic et al. (2019), Kronnäs et al. (2023), as well as the Swedish Meteorological and Hydrological Institute (SMHI, 2015; SMHI, 2024a; SMHI, 2024b) mentions that global warming may change the future Swedish climate. These climatic changes could impact abiotic factors such as precipitation and temperature. Sweden may therefore experience an increase in precipitation in the future, especially during wintertime in northern Sweden (Kronnäs et al., 2023; SMHI, 2015; SMHI, 2024a). In contrast, the estimation by Kronnäs et al. (2023) shows that there might be a decrease in precipitation in future Swedish summer months, leading to more frequent droughts and higher temperatures. Belusic et al. (2019) and SMHI (2015) instead mentions a positive correlation between increasing precipitation and temperature, especially in Europe (Belusic et al., 2019). Belusic et al. (2019) also notes that this effect might not occur in the same way in all regions of Europe. Both Belusic et al. (2019) and Kronnäs et al. (2023)

mentions that the warm weather in Sweden 2018 can be seen as a weather extreme caused by climate change. Belusic et al. (2019) further defines a weather extreme as weather that deviates from the average weather recorded over the last 30 years. This average weather will likely change due to the globally rising temperatures. This is also supported by SMHI (2015) which estimates that there could be an increase in annual temperature by 3 to 6 °C and an overall increase in precipitation by the year 2100. Northern Sweden is estimated to be especially affected by these climatic changes during the spring and winter months (SMHI, 2015).

Figure 2.2.1 Temperature trends 2016-2024




*Note: Annual mean temperature, precipitation and sunny days for the Swedish weather stations based in Kiruna (Lat: 67.8558 | Long: 20.2253), Luleå (Lat: 65.5848 | Long: 22.1547), Umeå (Lat: 63.8258 | Long: 20.2630), Östersund (Lat: 63.1792 | Long: 14.6357), Karlstad (Lat: 59.37.93 | Long: 13.5036), Stockholm (Lat: 59.3293 | Long: 18.0686), Norrköping (Lat: 58.5877 | Long: 16.1924), Visby (Lat: 57.6348 | Long: 18.2948), Växjö (Lat: 56.8788 | Long: 14.8090), Göteborg (Lat: 57.7089 | Long: 11.9746) and Lund (Lat: 55.7047 | Long: 13.1920) (Google Maps, 2025), from the years 2016 to 2024. The mean precipitation in Umeå in 2024 was not available and therefore the mean in Vindeln-Sunnansjönäs was used instead, which contained 707 mm. Precipitation is measured in mm, temperature in Celsius and sunny time in hours. Information from SMHI.*

Table 2.2.2 Annual mean precipitation, temperature and hours of sunshine

| Year | Precipitation | Temperature | Sunny hours | Prevalence |
|---|---|---|---|---|
| **2024** | 694 | 6,9 | 1933 | 22 |
| **2023** | 787 | 6,1 | 1935 | 26,7 |
| **2022** | 591 | 6,8 | 1992 | 32,2 |
| **2021** | 654 | 6 | 1879 | 31,3 |
| **2020** | 659 | 7,6 | 1966 | 26,7 |
| **2019** | 692 | 6,5 | 1850 | 21,3 |
| **2018** | 476 | 6,6 | 2088 | 29,2 |
| **2017** | 659 | 6 | 1690 | 24,7 |
| **2016** | 560 | 6,3 | 1817 | 26,6 |

*Note: Annual mean temperature, precipitation and sunny days are based upon 11 weather stations in Sweden: Kiruna, Luleå, Umeå, Östersund, Karlstad, Stockholm, Norrköping, Visby, Växjö, Göteborg and Lund from the years 2016 to 2024. The mean was taken from each city and added together for each year and divided by the number of cities (11). Information from SMHI (2024c). The mean precipitation in Umeå in 2024 was not available and therefore the mean precipitation in Vindeln-Sunnansjönäs (Lat: 64.1386 | Long: 19.7618) was used instead, which contained 707 mm. Precipitation is measured in mm, temperature in Celsius and sunny time in hours. From this table the mean precipitation is 641 mm, mean temperature is 6,517 Celsius and mean sunny hours is 1905 hours counting between the 11 weather stations. The range in this table is 475-786 mm precipitation, 5,97-7,6 Celsius and 1690-2088 sunny hours.*

Figure 2.2.1 and Table 2.2.2 shows that the cities Lund, Göteborg and Stockholm had some of the annually highest temperatures in Sweden, while Kiruna, Luleå and Östersund annually displayed as lowest. The cities Göteborg, Växjö and Karlstad displayed annually higher in precipitation while Norrköping, Östersund and Stockholm displayed lower precipitation over the years.

The decade 2016-2024 was initiated with 2016 being globally classified as one of the warmest years so far[1]. Even though Sweden experienced a generally warm year with February and March measuring above average temperatures, the average temperature was decreased by the cold January temperatures. The precipitation for this year was below average values, especially in the southeast of Sweden. In contrast, the summer in Northeastern Norrland was quite wet. Lastly hours of sunshine were above the average recorded by SMHI[2]. In comparison to the results of SMHI[3], Table 2.2.2 shows that precipitation, temperature and hours of sunshine were all below the average for 2016.
The following year of 2017 is described as a generally warm year that went above SMHI's average temperature[4]. In contrast, Table 2.2.2. shows that the yearly average temperature was below the average recorded for the decade. 2017 had

[1] SMHI (2016). *Året 2016 – Varmt men inget rekordår*
[2] SMHI (2016)
[3] SMHI (2016)
[4] SMHI (2017). *Året 2017 – Varmt men mest odramatiskt väderår*

above average precipitation, especially in southern Sweden and the Norrland region[5]. Similar results can be seen in Table 2.2.2. The summer was quite mild with an annually average amount of sunshine hours[6]. The year ended with an overall mild winter with high precipitation.
SMHI describes 2018 as a record-breaking year for temperature with low precipitation[7]. South of Sweden was especially affected during the months of May and July. Similar results can be seen in Table 2.2.2 where 2018 had above average temperature and the lowest precipitation of the decade. Hours of sunshine were also above normal according to both SMHI[8] and Table 2.2.2.
In 2019 the temperature and precipitation were once again above average, even though April was quite dry[9]. This pattern cannot be seen in Table 2.2.2 where the temperature is below average and precipitation above the decade's average. Lastly 2019 had an above average number of sunny hours according to Table 2.2.2.
2020 was once again recorded by SMHI as the warmest year so far with an average temperature of 7,6 °C [10]. Similarly Table 2.2.2 also shows 2020 as the warmest year of the decade, even though May and July were cooler in temperature[11]. Furthermore precipitation was overall above average, especially in Norrland. Similar results are shown in Table 2.2.2. This above-average trend can also be seen in the number of sunny hours according to both SMHI[12] and Table 2.2.2. Lastly the winter had mild temperatures with high precipitation[13].
Even though 2021 is considered the coldest year since 2013, the summer of 2021 was quite warm[14]. The overall cold weather is also reflected in Table 2.2.2. Furthermore sunny hours were above average according to SMHI[15], while sunny hours were below the average according to Table 2.2.2. SMHI[16] describes the precipitation as mixed while Table 2.2.2 shows slightly above average precipitation.
2022 was once again noted as being the new warmest year on record by SMHI with south and northeastern Norrland being affected the most[17]. This year also holds the new record for the number of sunny hours. This trend can also be seen in Table 2.2.2 where temperature and hours of sunshine were above the decade's average. Lastly Sweden experienced below average precipitation, especially southeastern Sweden and northern Öland[18]. This can also be noted in Table 2.2.2 where

[5] SMHI (2017)
[6] SMHI (2017)
[7] SMHI (2018). *Året 2018 – Varmt, soligt och torrt år*
[8] SMHI, 2018
[9] SMHI (2019). *Året 2019 – Varmt och blött*
[10] SMHI (2020). *Året 2020 – Rekordvarmt år*
[11] SMHI (2020)
[12] SMHI (2020)
[13] SMHI, 2020
[14] SMHI (2021). *Året 2021 – Kraftiga sommarregn men inga stormar*
[15] SMHI (2021)
[16] SMHI (2021)
[17] SMHI (2022). *Året 2022 – Mycket torrt i sydöstra Sverige*
[18] SMHI (2022)

precipitation was below average. Even though the year was overall warm, December was cold[19].
2023 was in some areas considered cold, though the overall temperature was average[20]. Sweden generally experienced high precipitation, especially in the south. A similar pattern can be seen in Table 2.2.2 which shows high precipitation but lower than average temperatures. Sunny hours were annually above average, as recorded by both SMHI[21] and Table 2.2.2.
The last year of this decade was 2024 with generally warmer than average temperature, especially in the north of Sweden[22]. A similar pattern can be seen in Table 2.2.2. Southern Sweden experienced above average precipitation while the east experienced less rainfall[23]. Sunny hours were noted as average by SMHI's[24] records and above average by Table 2.2.2.

## 2.3 *Haemonchus contortus* – tests, infection and causes

According to Ljungström et al. (2018) and Morgan et al. (2013) there are currently four different methods for diagnosing *H. contortus*. These methods can be grouped into either parasitological methods or molecular techniques. Diagnosing is an important part of being able to manage *H. contortus* infections.

### Parasitological methods

The most commonly used diagnostic methods are the parasitological methods known as McMaster egg counting and peanut agglutinin staining (PNA) (Ljungström et al., 2018; Morgan et al., 2013). These methods identify either eggs or larvae in faecal samples (Ljungström et al., 2018).
The McMaster egg counting is low in cost and allows for faecal egg counts (FEC) by educated personnel (Ljungström et al., 2018; Morgan et al., 2013). Although the McMaster egg counting method is not as specific or sensitive as other methods, it's still the most commonly used one out of the two parasitological methods (Ljungström et al., 2018; Morgan et al., 2013) and is suitable for routine monitoring (Morgan et al., 2013).
The second method is PNA staining which uses peanut agglutinin to stain, making it possible to differentiate between nematode species and count the number of nematode eggs (Ljungström et al., 2018). PNA staining is both time-consuming and expensive but allows for more specific identification than McMaster egg counting and detection at low prevalences (Ljungström et al., 2018; Morgan et al.,

[19] SMHI (2022)
[20] SMHI (2023). *Året 2023 – Mycket nederbördsrikt i södra Sverige*
[21] SMHI (2023)
[22] SMHI (2025). *Året 2024 - Längst i norr ett rekordvarmt år*
[23] SMHI (2025)
[24] SMHI (2025)

2013). Even so, it's not as common for laboratories to use the PNA staining method (Ljungström et al., 2018; Morgan et al., 2013).

### Molecular Diagnostic Techniques

*H. contortus* can also be identified using the quantitative polymerase chain reaction (qPCR) technique and the loop-mediated isomethral amplification (LAMP) technique (Ljungström et al., 2018; Morgan et al., 2013). Both molecular techniques give higher sensitivity and more accurate results than the two parasitological techniques, as both qPCR and LAMP detect nematode DNA in faecal samples.
The qPCR technique requires more advanced equipment and expertise than the LAMP technique, with the benefits of being more accurate at detecting DNA and the possibility of analysing mixed samples (Ljungström et al., 2018; Morgan et al., 2013). The LAMP technique does however benefit from being both cheaper and faster than qPCR.

## 2.4 Why is the spread and prevalence of *H. contortus* changing?

The geographical spread and prevalence of *H. contortus* are affected by several factors linked to both climate change and management practices such as land use and farming intensification (Morgan et al., 2013).

### Climate change

Climate change could affect *H. contortus* by changing temperature and precipitation which influences L3 development and seasonal transmission (Morgan et al., 2013; Rose et al., 2016; Santos et al., 2012). Changes in these climatic factors could therefore within certain limits increase the chance of nematodes developing, surviving on pasture (Morgan et al., 2013) and therefore lead to stronger infection pressure (Rose et al., 2016). This may be especially true in temperate regions (Rose et al., 2016) such as Sweden (Flay et al., 2022). Van Dijk (2008) linked these climatic factors to the increasing *H. contortus* infections in the United Kingdom, while Rose et al. (2016) similarly stated that the increasing *H. contortus* infections in Scotland are likely due to climate change. Similarly Morgan et al. (2013) also mentions that there has been a geographical spread of *H. contortus* infections near the Arctic circle in Sweden as well as Switzerland.

One of the determining factors for the development and survival of *H. contortus* is as earlier mentioned temperature (Fox et al., 2012; Rose et al., 2016). As also mentioned earlier *H. contortus* cannot develop below 9 °C, which has limited its survival during parts of the year in Sweden and the UK (Rose et al., 2016; Troell, 2006). Rose et al. (2016) argues that the nematodes might be able to develop and survive longer into the winter months due to increasingly warmer winter temperatures. In contrast, an abnormally warm summer might have the opposite effect by decreasing the number of surviving larvae. Though warmer weather could also affect the grazing period by prolonging it, increasing the time-period of which ruminants are exposed to *H. contortus* (Morgan et al., 2013). Precipitation also plays a role in the changing geographical spread and prevalence of *H. contortus* as periods of drought hinder the development of eggs and L3 as well as its migration (Jas et al., 2022; Rose et al., 2016). While warmer winters may increase the chances of survival, dry summers could have the opposite effect (Rose et al., 2016). Rose et al. (2016) assessed the impact of climate factors and stocking density on parasites using a Q0 model, which showed a predicted future increase in infection pressure in several regions in Europe.

## Stocking density and husbandry

Stocking density also plays a role in the increase of parasite infections (Fox et al., 2012; Rose et al., 2016). More animals lead to an increase in faeces and therefore also an increase in the number of animals that encounter infective larvae (Fox et al., 2012; Hammarberg, 2008; Rose et al., 2016). This could lead to an increased infection pressure. Rose et al. (2016) mention that the Q0 model predicted higher values in Norway as it has a higher stocking density, while Poland showed lower values due to its also lower stocking density. Parasite burdens and infection risks could also be affected by factors such as nutrition, grazing patterns (Hammarberg, 2008; Morgan & Wall, 2009), breeding (Morgan & Wall, 2009), policies and land use (Rose et al., 2016).

## Anthelmintic resistance

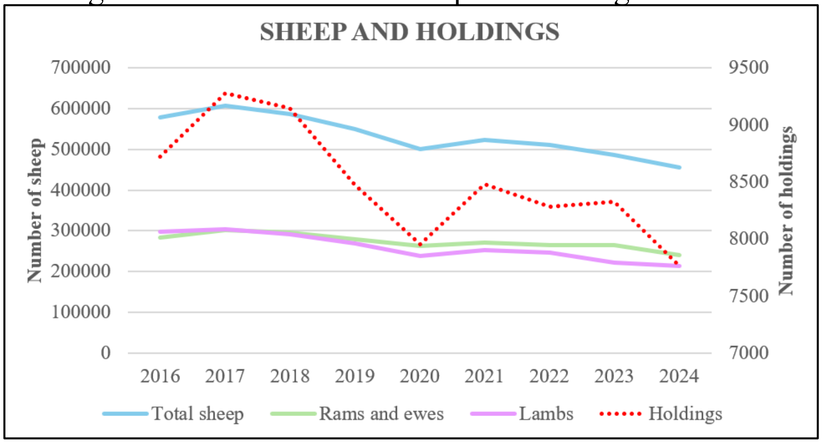
A third reason for the change in geographical distribution and prevalence of *H. contortus* could be anthelmintic resistance (Morgan et al., 2013). Anthelmintic resistance in *H. contortus* is observed all over Europe due to unnecessary overuse, which affects the options to control the parasite (Höglund et al., 2022; Morgan et al., 2013). The current anthelmintics used are Benzimidazoles, Closantel, Imidazothiazoles (Levamisol), Macrocyclic lactones (Ivermectin) and Monepantel (Arsenopoulos et al. 2021; Salle et al., 2019). There also exist nematodes in Sweden that are resistant to several anthelmintics (Höglund et al., 2022), which were discovered as early as in the 1990’s (Troell, 2006). If even more anthelmintics are to be used due to the increasing infection pressure, the anthelmintics may lose their effectiveness (Höglund et al., 2022). This would in turn lead to treatments failing more frequently and the anthelmintic resistance spreading further (Morgan et al., 2013).

## 2.5 Swedish sheep production

### Sheep and holdings

The number of sheep holdings in Sweden has overall declined over the past decade, according to the Swedish Board of Agriculture[25]. As seen in Figure 2.5.1 the number of sheep holdings in June were at its highest in 2017 with 9278 holdings[26]. Since then the number of holdings declined to 7956 in year 2020[27]. The number then grew to 8479 in year 2021[28] only to decline again until June 2024 with 7763 holdings[29]. This is the lowest number of the decade. Overall, the number of sheep holdings has declined by 16,3 % since June 2017[30][31].

Figure 2.5.1 – Number of sheep and holdings 2016-2024




*Note: The left axis shows the number of sheep in Sweden. The right axis shows the number of sheep holdings in Sweden. The total number of sheep (rams, ewes and lambs) is represented by the blue line. Holdings is the number of Swedish farms with sheep and is represented by the red dotted line.*

Similar to the declining number of holdings, the number of Swedish sheep and lambs has also seen an overall decline over the last decade[32]. Once again 2017 contained 606,079 sheep in June which is the highest number of the decade[33]. Since then the number of sheep has steadily declined (see figure 2.5.1). In June 2024 there was a total number of 454,540 sheep which is the lowest number of the decade[34]. From June 2017 to June 2024 there has been a decline of 151,539 sheep or a 25 % in the total number of Swedish sheep[35][36].

### Stocking density in Sweden

Another important part of this research is the number of sheep within each sheep holding. The Swedish Board of Agriculture defined the median number of sheep in a Swedish holding in 2016 as 16 rams and ewes[37]. 10 % of the holdings had almost half of all the sheep (48 %) with an average of 66 ewes and rams while the other 52 % of the holdings held the remaining 90 % of the sheep. Lastly it was mentioned

[25] Jordbruksverket (2024b). Antal djur och jordbruksföretag med djur efter län. År 1981-2024
[26] Jordbruksverket (2017b). *Husdjur i juni 2017*
[27] Jordbruksverket (2020). *Lantbrukets djur i juni 2020*
[28] Jordbruksverket (2021). *Lantbrukets djur i juni 2021*
[29] Jordbruksverket (2024a). *Lantbrukets djur i juni 2024*
[30] Jordbruksverket (2017b)
[31] Jordbruksverket (2024a)
[32] Jordbruksverket (2024a)
[33] Jordbruksverket (2017b)
[34] Jordbruksverket (2017b)
[35] Jordbruksverket (2017b)
[36] Jordbruksverket (2024a)
[37] Jordbruksverket (2017a). *Hälften av fåren finns vid de 10 största fårföretagen*

that a large number of the holdings had only a small number of sheep. SMHI[38] conducted a study which revealed that those holding fewer sheep (50 or less) mostly did so to keep an open landscape. Similar results from 2008 show that a large amount of the holdings (85,4 %) had a smaller number of sheep (1-49 ewes) (Kumm, 2009). Only 5,6 % of all ewes were kept in larger holdings of 400 or more. In 2020, the average sheep holdings had 33,2 ewes and rams[39]. 69 % of the holdings had 25 or fewer ewes and rams and in these holdings 25 % of the total amount of sheep could be found. The largest number of sheep (56 %) could instead be found at 14 % of the holdings that had 50 or more sheep. Lastly year 2024 had a mean of 31 ewes and rams in each holding[40]. 66 % of the holdings had 25 or more ewes and rams and in these holdings 23 % of the total number of ewes and rams were found. The largest number of sheep (58 %) were found in 10 % of the holdings with 49 or more sheep[41].

## Geographical spread of sheep

To further investigate the Swedish sheep production, the approximate location of the sheep and holdings can be explored. The Swedish Board of Agriculture has data for each year and region of Sweden[42]. The regions can be grouped into the north (Norrbotten, Västerbotten, Jämtland, Västernorrland and Gävleborg), the middle (Norrbotten, Västerbotten, Jämtland, Västernorrland and Gävleborg) and the south (Västra Götaland, Halland, Östergötland, Jönköping, Kalmar, Kronoberg, Gotland, Skåne and Blekinge) to give an overall spread[43].

According to Jordbruksverket[44] northern Sweden during June 2016 contained 52,067 sheep and 1057 holdings. In other words 9 % of all sheep and 12 % of Sweden's sheep holdings. The middle of Sweden contained 129,953 sheep and 2202 holdings, resulting in 22 % of all sheep and 25 % of all holdings. Lastly, the south of Sweden contained the largest number of both sheep and holdings, with 576,176 (68 %) sheep and 5465 (63 %) holdings. North, middle and south accounted in total for 576,176 sheep and 8724 holdings in 2016.
As mentioned before both the number of sheep and holdings declined over the last decade (Table 2.5.1). This can be seen in northern Sweden in June 2020 as the number of sheep was 44,222 (8,8%) and 961 holdings (12%)[45]. Middle Sweden also declined in sheep and holdings since 2016 with 110,248 sheep (21,9%) and 2041 holdings (25,6%). Lastly southern Sweden accounted for 346,681 sheep (69%) and 4954 (62%) of all the holdings. This gives a total of 501,151 sheep and 7956 holdings, a decline since June 2016[46].

[38] Jordbruksverket (2017a)
[39] Jordbruksverket (2020). *Lantbrukets djur i juni 2020*
[40] Jordbruksverket (2024a)
[41] Jordbruksverket (2024a)
[42] Jordbruksverket (2024b)
[43] Jordbruksverket (2024b)
[44] Jordbruksverket (2016). *Husdjur i juni 2016*
[45] Jordbruksverket (2020)
[46] Jordbruksverket (2016)

June 2024 contained even fewer sheep than in previous years, in all regions[47]. Northern Sweden had 41,599 sheep (9%) and 1011 (13%) holdings, which is a decrease in sheep but a slight increase in holdings since 2020[48]. Middle Sweden accounted for 98,744 sheep or 21,7 % and 2046 holdings or 26 %. Lastly southern Sweden contained the largest number of sheep and holdings with 314,199 sheep (69%) and 4706 (60%) holdings. This gives a total of 454,542 sheep and 7763 holdings, an overall decrease in both sheep and holdings since 2016[49].

## 2.6 A decade with *Haemochus contortus* in Swedish sheep flocks

For the present study, the author of this study was given access to similar unpublished data but from the years 2005 to 2014 (Höglund, 2015) which are summarised below. Like in the present study the data from 2005 to 2014 was collected from Vidilab AB with the aim to "Describe long-term changes in the prevalence and distribution on *Haemonchus contortus* in Swedish sheep flocks in relation to weather data" (Höglund, 2015). During this decade a total of 16,468 samples were collected from 2961 herds using the sampling instructions from Gård & Djurhälsan (GD). GD instructed sheep holders to sample their sheep two times a year, each sampling occasion collecting faeces from six individual sheep which was analysed in triplicates with the McMaster egg counting technique. Similarly to the present study the weather data was retrieved from SMHI and handled in Excel. The QGIS software was also used to make maps for data visualization.

In Höglunds (2015) background it is described that the number of sheep farms is growing. From 2005 to 2014 the number of both adult sheep, lambs and the total amount of sheep were generally growing with a peak in 2011. The study shows that most of the sheep populations are based in southern Sweden: Skåne, Blekinge, Halland, Småland, Öland and Gotland, with Gotland having the largest density of sheep per area. Central Sweden has a moderate distribution of sheep but not as dominant as in the south. Areas around the lakes Vänern and Vättern show a slightly higher density of sheep and there seems to be a concentration of sheep in both the eastern and western coasts of Sweden. Lastly the sheep distribution in northern Sweden is the lowest.

### Total amount of tests, positive tests and prevalence

According to the findings of Höglund (2015) the decade 2005-2014 saw a rise in the number of total tests being sent in over the years. The decade started with 747 *H. contortus* tests with a prevalence of 42 % in 2005. The following year of 2006

[47] Jordbruksverket (2024b)
[48] Jordbruksverket (2020)
[49] Jordbruksverket (2016)

contained 919 tests with a significantly lower prevalence of 31 %. The number of tests in 2007 did once again rise, this time to 1133 tests with a prevalence of 33%. 2008 contained 1210 tests and a lower prevalence of 30 %. The number of tests did once again rise in 2009 to 1578 tests, though with one of the lowest prevalences of this decade with 29 %. There were a total of 1761 tests being sent in during 2010 and a relatively high prevalence of 35 %. 2011 had 1811 tests sent to Vidilab, though the prevalence of this year decreased to 32 %. There were 1994 tests in total in the year of 2012 with an even lower prevalence of 29 %. The number of tests increased by 332 for the next year in 2013, totalling 2326 tests with a 32 % prevalence. Lastly 2014 contained the highest number of tests for this time period with a total of 2861 tests and a prevalence of 31 %. These years resulted in a mean prevalence of 32 % and a total of 16,468 tests (Höglund, 2015).

### Samples per farm

During this decade the average sheep flock had 5.6 tests sent in per year, while 19 % decided to send in tests 10 times or more in a year (Höglund, 2015). It can further be seen that 63 % submitted 1-5 tests per year, 22 % 6-10 times, 10 % 11-15 times, 3 % 16-20 times and only 1 % had submitted tests more than 20 times (Höglund, 2015).

### Positive results in Sweden and prevalence

In terms of long-term trends it can also be seen that (Figure 4.5.6) the prevalence of *H. contortus* was at its lowest in 2006 with under 35% and reached above 40 % in both 2010 and 2013 (Höglund, 2015). The number of farms were steadily growing as well between the years 2005-2014.

### Correlations and conclusions

Höglund (2015) could not find any correlations between the prevalence of *H. contortus* as the correlation between mean annual temperature and prevalence were 0,09, correlation between rainfall and prevalence was 0,02 and lastly correlation between hours of sunshine and prevalence was 0,002. However Höglund (2015) concluded that *H. contortus* in Sweden had spread geographically as well as the first positive *H. contortus* results showing up on Gotland from 2006 and forward.

# 3 Methodology

### Study aims and research questions

The aim of this quantitative study is to compile and map already collected data from sheep faecal samples from Vidilab AB focusing on *H. contortus* in Sweden over the years 2016 to 2024. This data will then be compared to data of the years

2005-2014 with a similar compilation (Höglund, 2015) and the data provided by SMHI on temperature, precipitation and sunny days in these decades. The research questions are therefore: How have the tests and positive results of *H. contortus* changed over the last two decades? Are there any climatic factors that could explain any possible changes in prevalence and geographical spread? Are there any other possible influencing factors?

## Structure

The study is structured with a background discussing and analysing information about *H. contortus*, how climate may affect *H. contortus,* Swedish annual weather and statistical means, how *H. contortus* infections are diagnosed, Swedish sheep production and data from 2005-2014 provided by Johan Höglund (2015). The results include the total number of tests, positive tests, the number of investigated farms, samples per farm, prevalence and 3 QGIS maps containing all positive results from 2016-2024, a comparison of positive results from 2019 and 2022 and a comparison of positive results from 2017 and 2024. The discussion will contain compiled and compared data of what has changed over the two decades regarding the number of sheep, the number of farms, the number of tests, the number of positive tests, the comparison of climatic factors, the correlations between prevalence and climatic factors, as well as a discussion of other possible influences on prevalence.

The research philosophy applied in this study is positivism in which all the data is handled objectively, inductive research and an iterative or action-oriented research strategy (Saunders, 2009). The time horizon could be seen as longitudinal (Saunders, 2009) as the information that was collected by Vidilab AB had been gathered over a long period of time. However it could also be seen as cross-sectional (Saunders, 2009) as the data provided was already collected and submitted for this thesis at specific point in time. The method is quantitative (Saunders, 2009) and is based on already existing data from Vidilab AB.
The collected data is analysed using descriptive statistics (Alabi & Bukola, 2023). The average prevalence, number of animals, number of farms, number of tests and positive tests are displayed in Excel column tables. Correlation between the prevalence and the annual averages for temperature, precipitation and hours of sunshine are displayed using scatter plots in Excel, also showing the R-square for each scatterplot.

## Data preparation

The data was prepared for analysis by first sorting the original Excel spreadsheet provided by Vidilab AB. All blanks, tests without results as well as unknown and irrelevant species were removed from the Excel sheet. Tests from irrelevant nematode species and irrelevant values were also removed. These were removed in order distinguish between the wanted values as well as to remove any values that might otherwise skew the end results. All sheep genders were labelled as F using the ”find and replace” function in Excel, dates were generalised into “Year, month” and *H. contortus* results were labelled as either 1 (positive) or 0 (negative) for easier viewing of the final results. The data was then put into Pivot tables for easier compilation of the results. Data on the year and number of sheep, number of farms, number of total tests and number of positive tests were also put into individual Excel sheets to make figures for easier viewing. One sheet was dedicated to date, positive tests and postal numbers. This was made both to show how many individual farms sent in tests each year and how many tests were sent in by each farm. The postal numbers were also transformed into x and y coordinates using the SE-zip file from the website GeoNames (GeoNames, n.d) for approximate coordinates for each postal number. These coordinates for each year and positive results were then put into the software QGIS to make maps showing the distribution of *H. contortus* in Sweden for each year. Nine maps were made of each year to show the differences in spread as well as four maps for comparison between different years. The Swedish map and borders were set to the assigned coordinate system EPSG:3006 – SWEREF99 TM in QGIS. The borders were set with 90 % opacity in order for the borders to show up and the points were set to the assigned coordinate system EPSG:3857 – WGS 84/Pseudo-Mercator.

## Limitations

Since this data was sent in by anonymous and random sheep owners it is difficult to know how the faeces samples were handled. In an ideal design there would be strict orders as to how to handle the samples: how many sheep in each sample, freshness and so on. On the other hand this would not be practical or possible when handling so many results that are based on people sending them in for both preventive and diagnostic reasons. It would also not be possible because of the human factor; mistakes will be made. A further limitation of this random data is that it can only give a general overlook. Not every sheep farmer will send in tests or could perhaps send tests to another company or do the tests themselves. Furthermore the postal numbers will only give a general location which means that the maps will only give a general view of the spread.

The correlations between prevalence and temperature, precipitation and sunny hours was based on annual means. Looking only at the annual results may have been too broad as it did not provide the scatterplots with enough points to show more than a general view. Collecting weather data from each quarter of each year or each month of each year might have been more ideal in order to make a scatterplot with more realistic and accurate results. This was not done due to a lack of time and the goal of compiling the data similarly to the former decade. The correlations could still provide value as they show a general view and confirms the need for more detailed data in order to accurately predict prevalence in correlation to weather.

## Programs and keywords

The program QGIS 3.40 Bratislava long-term release was used for map-making and weather data was provided by SMHI. Statistical data was compiled in Excel version 2501 (Build 18429.20158 Click-to-Run) (Microsoft 365). The search engines Web of Science, Scopus, Google Scholar and PubMed were used to find literature for this project. Keywords: Climate, climate change, Europe, geographical spread, *Haemonchus contortus*, husbandry, infection pressure, livestock, nematode, nordic, precipication, ruminant, sheep*, Scandinavia, stocking density, Sweden, temperate, temperature, transmission, weather

The selection of articles was mostly decided by publication year and its relevance to the subject but also by countries with similar climate to Sweden.

# 4 Results

## 4.1 Total amount of tests

Table 4.1.1 shows the total number of diagnostic tests analysed by Vidilab AB to give an overview of the number of tests for each year and how they may differ. In this table only the tests from ewes, lambs and rams are listed and then summarised using a PIVOT-table in Excel. Each year in the PIVOT-table was then divided into quarters of months: Q1, Q2, Q3 and Q4 (Table 4.4.6 and Table 4.4.7). Q1 containing January, February and March, Q2 containing April, May and June, Q3 containing July, August and September and lastly Q4 containing October, November and December. This shows the habits of when sheep owners most frequently send in faeces samples for investigation.

Table 4.1.1- Total number of sheep faeces tests sent to Vidilab AB from the years 2016 to 2025

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of tests | 6381 | 8749 | 7926 | 8943 | 10418 | 12190 | 12756 | 11413 | 10594 | 109 | 89479 |

*Note: This table shows the total number of sheep faeces tests sent to Vidilab AB from Sweden within the years 2016 to 2025, both negative and positive tests. 2016 contains tests from the dates 2016-04-16 to 2016-12-01. The year 2025 contains tests from 2025-01-02 to 2025-02-05. Most years consistently show that the months of Q2 contain the most tests, highlighting the most common months for sheep owners to send them in. The percentage of Q2 compared to the total number of tests for each year is as follows: 2016 59,2 %, 2017 52,9 %, 2018 64,6 %, 2019 52,9 %, 2020 55,1 %, 2021 56 %, 2022 52 %, 2023 58,4 % and 2024 53,1 %. Furthermore it can consistently be seen that Q2 contains the largest number of tests followed by Q3, Q4 and lastly Q1.*

## 4.2 All investigated farms

Table 4.2.1 shows the number sheep farms that sent in tests to Vidilab from 2016 to 2025. The table was created in Excel using the formula =COUNTA (UNIQUE (A2:A10000)) to determine both the total number of farms (based on postal numbers) and the unique number of farms. The number of unique farms were compiled to clarify that one farm (or postal code) may have submitted multiple tests in a single year. This would result in incorrect values if not every unique farm were counted only once per year. This shows the number of individual farms that choose to send in tests each year.

Table 4.2.1 - Total number of farms and unique farms from 2016 to 2025

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total | 6380 | 7886 | 7483 | 8891 | 10416 | 12179 | 12742 | 11407 | 10594 | 109 |
| Unique | 1386 | 1557 | 1511 | 1604 | 1732 | 1839 | 1825 | 1930 | 1844 | 45 |
| Total HC pos | 1697 | 1953 | 2161 | 1898 | 2781 | 3809 | 4101 | 3045 | 2328 | 4 |
| Unique HC pos | 752 | 817 | 800 | 722 | 923 | 1054 | 1092 | 1044 | 863 | 3 |

*Note: "Year" represents the year that the test was sent in and analysed in Vidilab AB. "Total" represents the total number of times a farm has sent in a test and "Unique" represents number of unique farms that have sent in a test (i.e. correcting doublets, triplets and so on). "Total HC pos" represents the number of farms with a positive result that had sent in one or more tests and lastly "Unique HC pos" represents the unique number of farms with positive results that had sent in one or more tests.*

## 4.3 Samples per farm

Table 4.3.1 and 4.3.2 were made to show many times the farms chose to send in faeces samples in Sweden, both for each year and for the period 2016-2024. These tests do not take into account whether the test result is negative or positive. They only show how many times a test was sent in from each farm defined by its unique postal number.

Table. 4.3.1 - Yearly number of samples per farm

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sum 1-5 | 40% | 35% | 36% | 30% | 28% | 24% | 23% | 29% | 29% | 61% |
| Sum 6-10 | 33% | 24% | 27% | 27% | 24% | 25% | 22% | 24% | 28% | 0% |
| Sum 11-15 | 12% | 14% | 14% | 16% | 17% | 16% | 14% | 18% | 17% | 0% |
| Sum 16-20 | 8% | 7% | 7% | 9% | 11% | 9% | 9% | 10% | 10% | 0% |
| Sum <20 | 7% | 19% | 16% | 18% | 20% | 25% | 32% | 19% | 16% | 39% |

*Note: "Year" represents the year that the tests were sent in to Vidilab AB. "Sum-" represents the number of times a farm chose to send in tests. The number of times the tests can be sent in has been grouped into intervals of 1-5, 6-10, 11-15, 16-20 or <20 times in a year. Excel has accounted for the number of tests sent in for each unique postal number, ensuring that the values are counted correctly. This table shows that its most common for unique farms to send in 1-5 tests each year, followed by 6-10, 11-15, <20 and lastly 16-20 (2016 being the exception for the last two* *mentioned). There is a chance for several farms to share a postal number.*

Table 4.3.2 - Sample per farm total trend 2016-2025

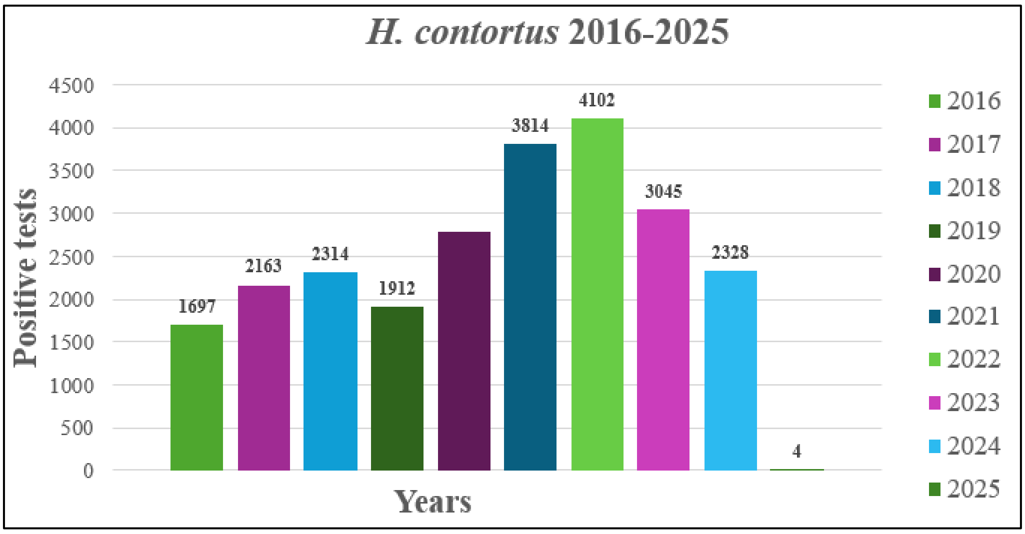
| Year | 2016-2025 |
|---|---|
| Sum 1-5 | 29% |
| Sum 6-10 | 26% |
| Sum 11-15 | 15% |
| Sum 16-20 | 9% |
| Sum <20 | 20% |

*Note: 2016-2025 represents the decades' worth of tests sent in to Vidilab AB. "Sum-" is grouped into the intervals 1-5, 6-10, 11-15, 16-20 or <20 times in a year. This shows the trend of how often each unique farm decide to send in tests over the decade. In the span of 2016-2025 the most common number of tests to send in is 1-5 times, followed by 6-10, <20, 11-15 and lastly 16-20 times.*

## 4.4 Positive H. contortus results in Sweden

In order to investigate how many of the total number of animals tested gave a positive *H. contortus* result, the following tables, figures and maps were produced. In Figure 4.4.1 and Figure 4.4.2 the years with the highest number of positive *H. contortus* tests can be seen and will later be compared to the collected weather data. Map 4.4.3 was made to show a general picture of the spread of *H. contortus* in Sweden over the years 2016-2024.

Figure 4.4.1 - Positive *H. contortus* tests 2016-2025

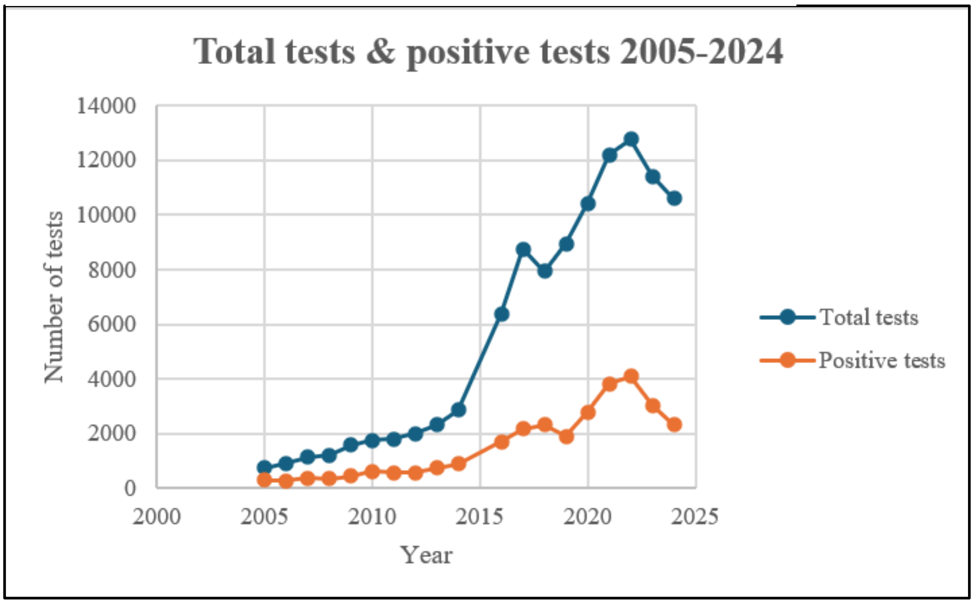



*Note: Figure 4.4.1 shows the number of positive Haemonchus contortus results in sheep between 2016 and 2025. 2016 contains results from 2016-04-16 to 2016-04-30. 2025 contains results from 2025-01-02 to 2025-02-05. This figure show that the year 2022 contained the highest number of positive H. contortus tests with a prevalence of 32,15 %, followed by 2021 with a 31,28 %*

*prevalence and 2018 with a 29,19 % prevalence. The lowest prevalences can be found in 2019 which contained 21,3 %. In relation to these values, 2024 (21,97 %) and 2017 (24,72%) can also be accounted for as relatively low. The prevalence for each year is as follows: 2016: 26 %, 2017: 24 %, 2018: 29 %, 2020: 26 %, 2021: 31 %, 2022: 32 %, 2023: 26 %, 2024: 22 %, 2025: too little material.*

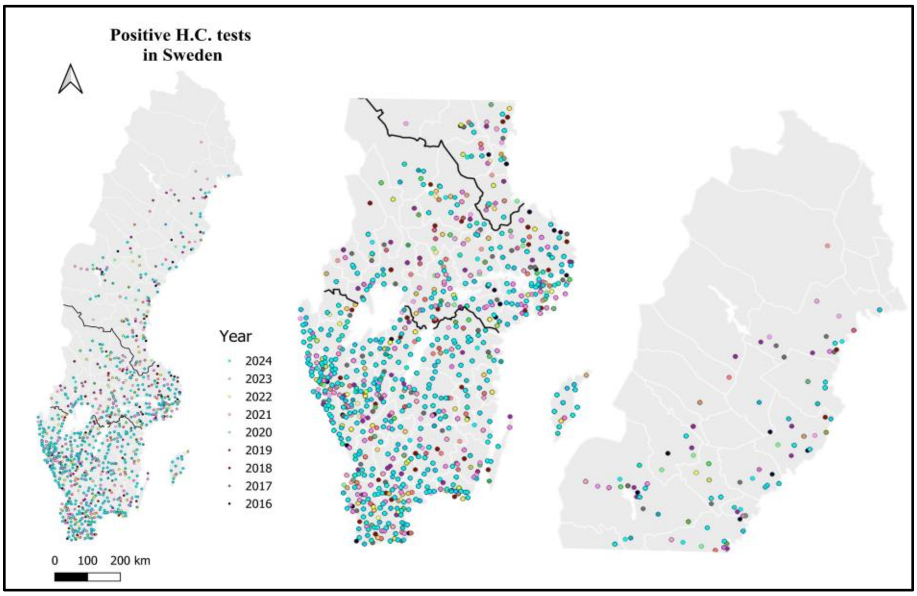
Results also show that the prevalence for the decade 2016-2024 was 32 % for southern Sweden, 27 % for middle Sweden and 19 % for northern Sweden. Middle Sweden contained a total of 45,022 tests and 12,408 positive ones. Southern Sweden contained 24,924 tests and 8013 positive ones. Lastly northern Sweden contained 19,424 tests and 3736 positive ones. See attachment 1 for more information about southern, middle and northern Sweden for each year.

Figure 4.4.2 – Total tests & positive tests of two decades




*Note: This figure shows both the number of total tests and positive H. contortus tests sent in to Vidilab AB from the years 2005 to 2024. The left axis shows the number of tests and the lower axis the years.*

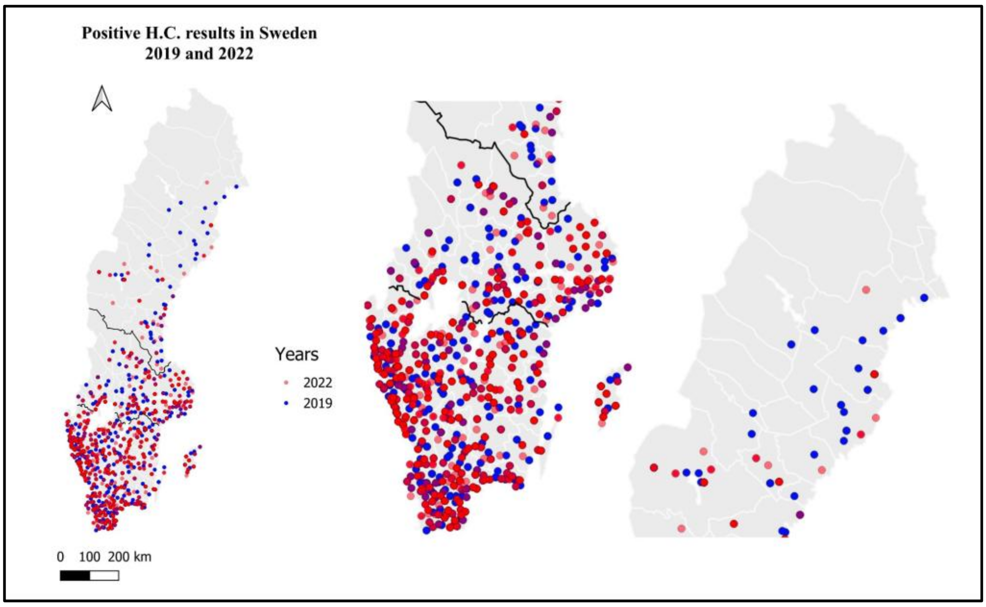
Map 4.4.3 - Positive *H. contortus* tests in Sweden 2016-2024




*Note: Positive test results of Haemonchus contortus in Sweden from 2016 to 2024. Each year is displayed in a different colour for easier distinction between the years. The years 2020 to 2024 is displayed in lighter, brighter colours with 68 % opacity while the years 2016 to 2019 is displayed with dull, darker colours with 100 % opacity for easier showing of overlapping results from different years. All overlaps may still not show (see Attachment 1 for each year's positive results in detail with no overlapping between the years). The black lines (borders) splits the map into north, middle and southern Sweden for easier viewing and distinction between regions. This map shows that visually the largest portion of positive H. Contortus results are located southern Sweden, followed by middle and northern Sweden. There seems to be a trend of a larger number of H. contortus in the southwest of Sweden, the east in the middle of Sweden and the eastern part of northern Sweden. As this map shows all the years 2016 to 2024 it can be difficult to distinguish any overlaps. Looking at attachment 1, map 1-9, it can be noted that in the south of Sweden (as separated by the black lines) there is a trend of higher prevalence in Västra Götaland, Halland, Blekinge and Skåne. 2022 showed a high prevalence in all regions and 2024 showed higher prevalence in Västra Götaland, Halland, Blekinge and Skåne and Östergötland. Furthermore, it can be seen that in the middle of Sweden there are trends of high prevalence in Örebro, Stockholm, Uppsala and Södermanland. Higher prevelances can also be seen in södra Värmland in 2017, 2020, 2023 and 2024. Lastly, a trend can be seen in the north of Sweden towards higher prevalence in Gävleborg, Västerbotten and Jämtland. Västernorrland as well as Norrbotten pops up as higher prevalence as the years go by and becomes more often higher in prevalence. A slight spread of H. contortus tests can be seen in the northeast of Norrbotten.*

As can be seen in Figure 4.4.1 the highest number of positive *H. contortus* results was found in 2022 (32%) and the lowest in 2019 (21 %). To more easily show the differences or similarities of the spread and prevalence of *H. contortus* in these years map 4.4.5. was created to show possible trends.

Map 4.4.5 - Positive *H. contortus* results 2019 and 2022




*Note: Positive H. contortus results in Sweden from the years 2019 and 2022. 2022 is displayed as the colour red with 50 % opacity (dull red signifying no overlap of red colour and a bright red signifying an overlap of several red colours) and 2019 as the colour blue with 100 % opacity. The red colour has 50 % opacity as it is the upper layer of the two colours in QGIS, making the blue show up underneath in the event of an overlap. Purple shades indicate an overlap of the years 2019 and 2022. For further distinguishing between the two maps (2019 and 2022) see Attachment 1. The greatest difference between the maps can be seen in Norrbotten and Västerbotten where more points appear in 2019 than 2022. Otherwise 2022 seems to have an overall larger spread and prevalence in Sweden than in 2019. Gotland: Red seems to dominate the map of Gotland with a spread from north to south, the most concentrated in the middle and south. The map is divided in the middle to show lower and upper Sweden, making it easier to distinguish between colours and spread.*

As seen in Map 4.4.4 there seemingly is a larger spread of blue points (2019) than red ones (2022) in the northern Sweden. The spread in southern Sweden seems to be generally the same. As seen in Attachment 1 there is a larger overlap of points from 2019 and 2022 which does not show up in this map. Overall general spread of points can be seen from 2019 to 2022, both in the west and slightly north of Sweden. Both 2019 and 2022 showed positive results in northern Öland.

Table 4.4.6 and Table 4.4.7 - Positive *H. contortus* tests in quarters (2019 and 2022)

| **2019** | **Q1** | **Q2** | | | **Q3** | **Q4** |
|---|---|---|---|---|---|---|
| | | April | May | June | | |
| Positive H. contortus tests | 55 | 492 | 448 | 80 | 557 | 280 |

| **2022** | **Q1** | **Q2** | | | **Q3** | **Q4** |
|---|---|---|---|---|---|---|
| | | April | May | June | | |
| Positive H. contortus tests | 75 | 1030 | 1294 | 235 | 1198 | 270 |

*Note: Table 4.4.6 shows the positive results from 2019. Qtr. 2 contained the most positive results. Within Q2 April had the highest number of positive tests (492), followed by May (448) and June (80). As seen in Figure 4.4.12019 contained the lowest number of positive results (a total of 1912)* *with Q2 totally containing 1020 positive tests. In contrast Table 4.4.7 shows the number of positive results from 2022. Again, Qtr. 2 contained the most positive results. Within Q2 May had the highest number of positive tests (1294), followed by April (1030) and June (235). As seen in Figure 4.4.1 this year contained the largest number of positive results (a total of 4102) with Q2 containing 2559 positive tests. To summarise this data, 2019 contained 54 % fewer positive results than 2022. Q2 in 2019 contained 61 % fewer positive results than in 2022.*

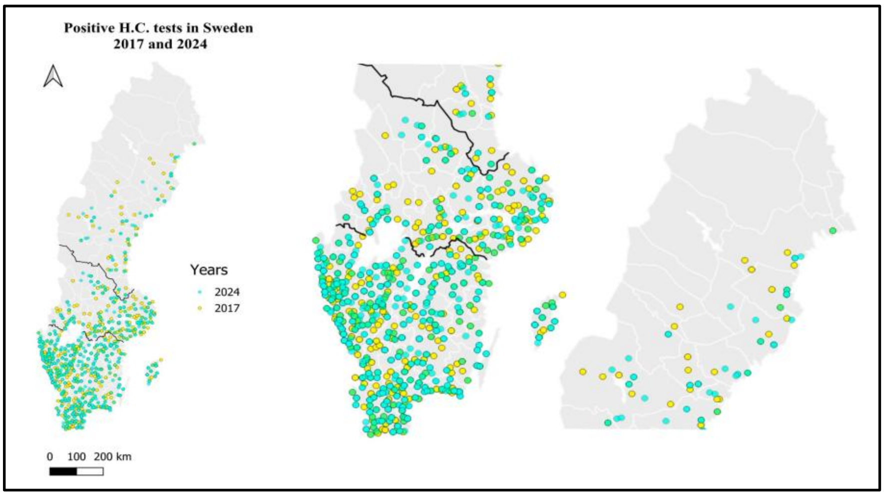
Qtr2 (April, May, June) has shown significantly more positive *H. contortus* test results in the period 2016-2024. In these months, April has consistently shown the highest number of positive results, followed by May and finally June.

Looking at the number of tests regardless of the results, a similar pattern can be noted in Qtr2. Qtr2 contains the most tests, but with a smaller difference in the number of tests between April and May. In 2022 and 2024, May contained more tests than in April.

The year 2019 contained the fewest positive results (1912 results) (not counting 2016 as it was incomplete), while 2022 contained the most positive results (4102 results). This does not correlate with the total number of tests, which shows that 2018 contained the fewest tests overall. The year 2022 had the largest number of tests.

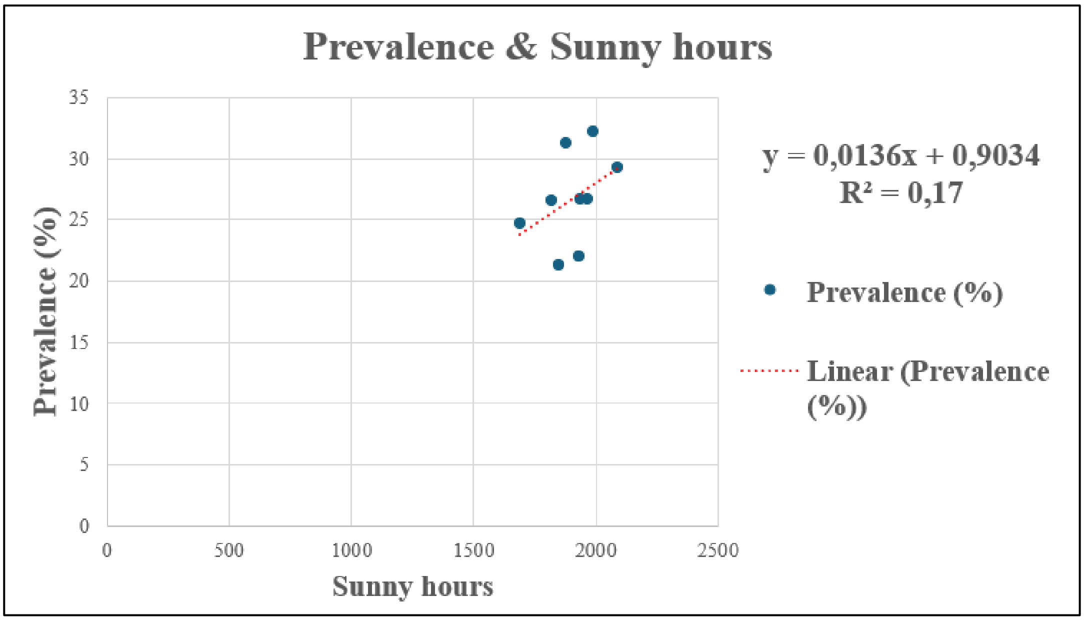
## 4.5 A comparison of the decades

*Map 4.5.1 – A comparison of the decade.* This map contains an overview of the years 2017 and 2024 which can also be seen separately in attachment 1.




*Note: Comparison of positive results between the years 2024 and 2017 to show any difference in spread over the years. 2024 is displayed as the colour turquoise with 50 % opacity and 2017 as yellow with 100 % opacity. The green colour shows an overlap between the years 2017 and 2024. The map is divided in the middle to show lower and upper Sweden, making it easier to distinguish between colours and spread.*

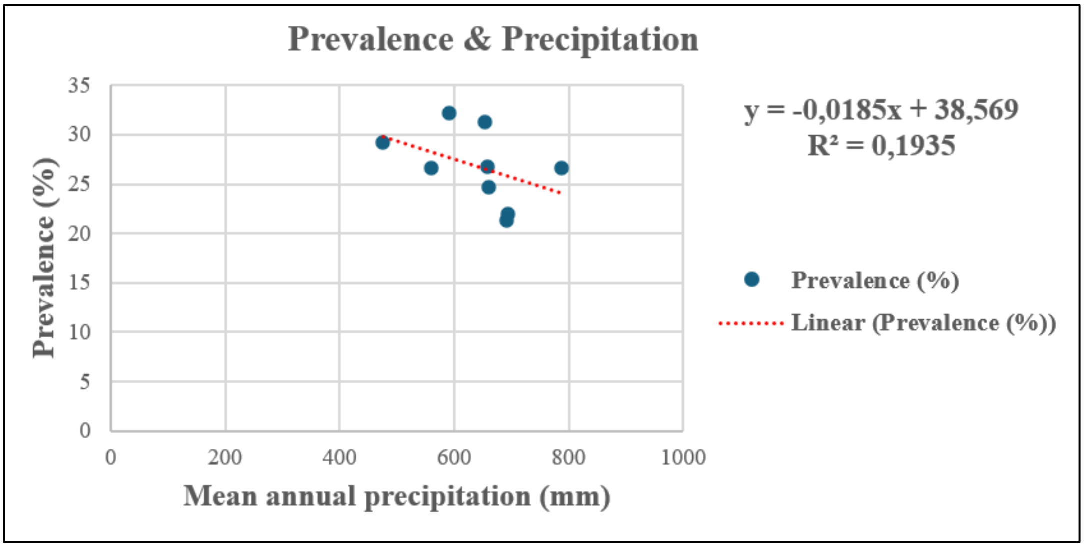
Figure 4.5.2 – Prevalence and sunny hours




*Note: Scatterplot showing the correlation between the prevalence (%) and mean sunny hours of the years 2016-2024. The Y axis shows the prevalence in percentage and the X-axis shows the number of sunny hours. "Linear (Prevalence (%))" shows the linear trendline with its equation (y = 0,0136x + 0,9034) and $R^2$ = 0,17 shows the fit.*

In Figure 4.5.2 no correlation can be seen between prevalence and annual mean sunny hours of the years 2016 to 2024. The coefficient of determination ($R^2$) equals 0,17 in this scatterplot and the positive linear regression trendline is Y = 0,0136x + 0,9034.

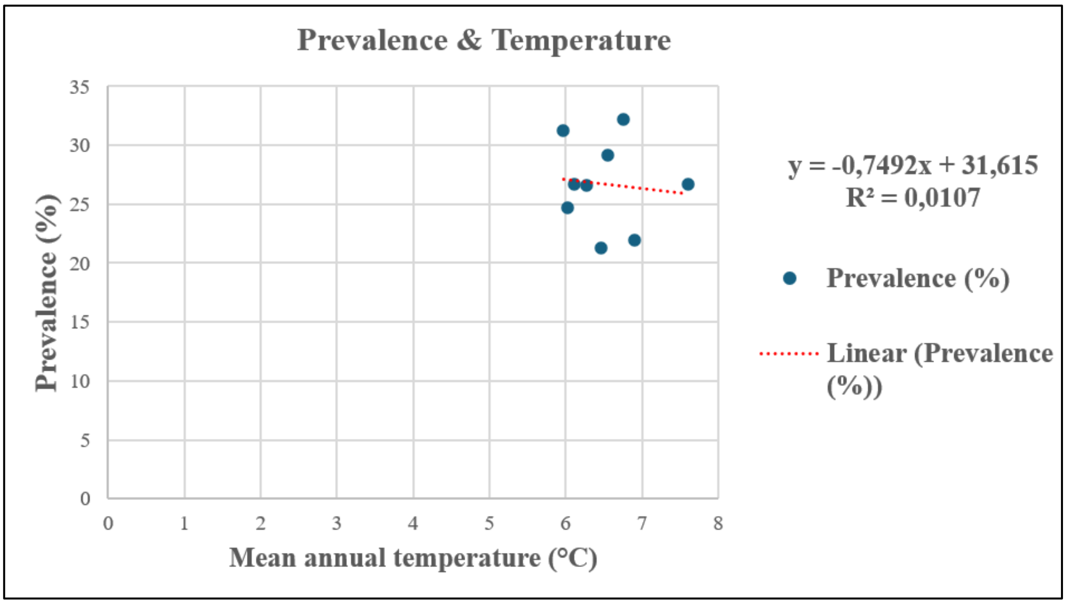
Figure 4.5.3 – Prevalence and precipitation




*Note: Scatterplot showing the correlation between the prevalence (%) and mean precipitation (mm) of the years 2016-2024. The Y axis shows the prevalence in percentage and the X-axis shows the precipitation measured in mm. "Linear (Prevalence (%))" shows the linear trendline with its equation (y = -0,0185x + 38,569) and $R^2$ = 0,1935 shows the fit.*

In Figure 4.5.3, no correlation can be seen between the prevalence and annual mean precipitation of the years 2016 to 2024. $R^2$ equals 0,1935 in this scatterplot and a negative linear regression of Y = -0,0185x + 38,569.

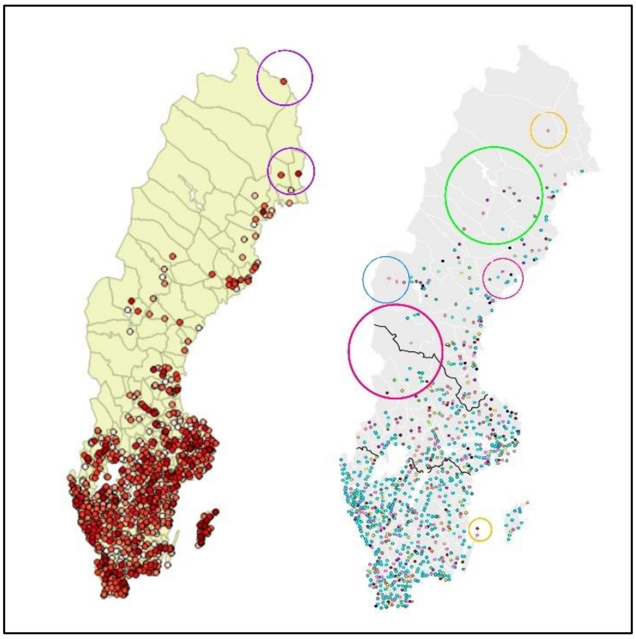
Figure 4.5.4 – Prevalence and temperature




*Note: Scatterplot showing the correlation between the prevalence (%) and mean temperature (°C) of the years 2016-2024. The Y axis shows the prevalence in percentage and the X-axis shows the average temperature measured from the years 2016-2024. "Linear (Prevalence (%))" shows the linear trendline with its equation (y = -0,7492x + 31,615) and* $R^2$ *= 0,0107 shows the fit.*

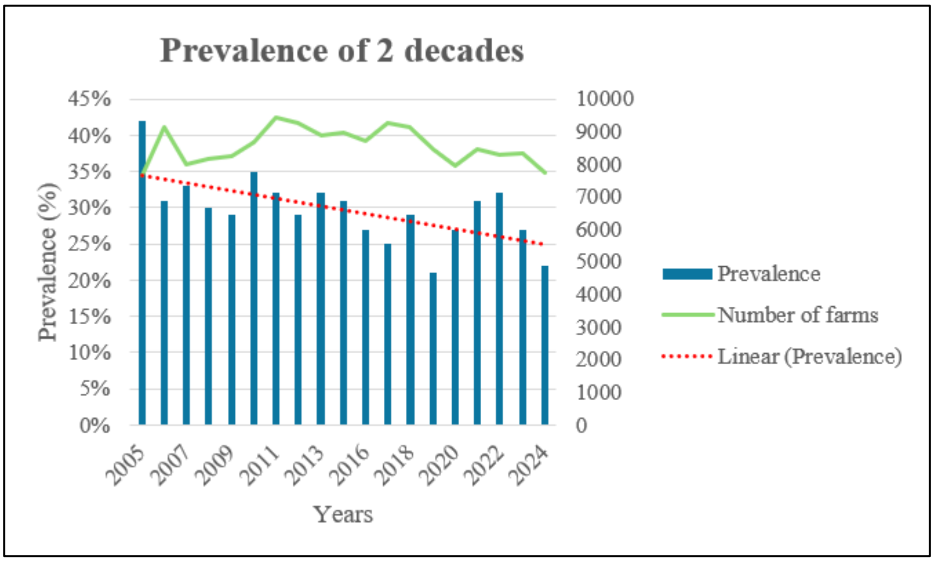
In Figure 4.5.4 no correlation between the prevalence and mean temperature of the years 2016 to 2024. $R^2$ equals 0,0107 in this scatterplot and a negative linear regression of Y = -0,7492x + 31,615.

Map 4.5.5 – Geographical spread in Sweden



*Note: The left map shows the prevalence of H. contortus in Sweden between the years 2005-2014 (Höglund, 2015). Lighter points for earlier years and darker points for more recent years of that decade. The two purple circles show occurrences of H. contortus in Norrbotten that cannot be found in the more recent decade. The right map shows the prevalence of H. contortus in Sweden between the years 2016-2024. The six circles show occurrences of H. contortus in Norrbotten, Västerbotten, Västernorrland, Jämtland, Dalarna and northern Öland that cannot be seen in the earlier decade.*

Figure 4.5.6 – Prevalence and number of farms over two decades




*Note: This figure shows an overview of the prevalence of H. contortus and the number of sheep farms over the last two decades (2005-2014 and 2016-2024). The left axis title shows the prevalence in % and the right axis title shows the number of farms.*

This figure (4.4.4) shows that the prevalence has generally decreased over the last two decades with 2005 containing the highest percentage and 2020 the lowest.

# 5 Discussion

The general consensus is that annual weather (temperature, precipitation and hours of sunshine) and prevalence show no correlation and only weak linear trendlines. However there has been a spread of positive *H. contortus* results in Sweden during the last decade, both in the northern part of Norrbotten, northern Öland, Västerbotten, Västernorrland, Jämtland and Dalarna. There are three points in Norrland between 2005 and 2014 that no longer appear in the most recent decade from 2016 to 2024 (Map 4.5.5).

This discussion compares data from 2005-2014 (Höglund, 2015) with data from 2016-2024 (Vidilab, 2025) and relates the results to both weather data and changes in the sheep production. The data from all three sources are compared both on their own and with each other.

## 5.1 Changing sheep values

Between 2005 and 2011 the number of sheep in Sweden increased steadily with a peak in 2011 (Höglund, 2015). There were 471.284 sheep in 2005 and 620.000 in 2011, an increase of 148.716 or 32 %. In 2017 there were 606.000 sheep, a decrease of 3 % since 2011. In 2024 there was 454.540 sheep, a decrease of 25 % compared to 2017. It can be noted that the number of sheep has steadily decreased from 2011 to 2024 (Figure 2.5.1). Even so, the number of sheep at the beginning and end of the two decades, 471,284 in 2005 and 454,540 in 2024, shows there has only been a 4 % decrease. This trend could be explained by the fact that the number of sheep was generally still at its highest in 2017 at the same time as the number of farms peaked (9278). While the number of farms grew upwards from 2005 to 2017 (7653 to 9278) and downwards from 2017 to 2024 (9278 to 7763), the number of sheep generally remained the same between the two decades with only a 1 % increase. The average holding size has increased with 27 % from 2008 to 2024 and a trend can be seen towards larger sheep farms holdings keeping most of the sheep in Sweden (58 %) (Kumm, 2008; Jordbruksverket, 2024a).

## 5.2 Changing number of tests and prevalence

The total number of tests and the number of positive tests have developed differently over the last two decades. From 747 total tests and 314 positive tests in 2005 to 10,594 total tests and 2328 positive tests in 2024, an increase of 1319 % and 641 % respectively (Figure 4.4.2). This increase in tests could have affected the annual prevalence of *H. contortus* that has also changed from 2005 to 2024. The prevalence has generally decreased over the last two decades. The years 2005 to 2014 showed an average prevalence of 32 % (Höglund, 2015). Between these years 2005 had the highest prevalence at 42 % while 2009 and 2012 had the lowest prevalence of the decade at 29 % each. The years 2016 to 2024 showed an average prevalence of 27 %. The years 2022, 2021 and 2018 had the highest prevalence with 32 %, 31 % and 29 % respectively. The years 2019, 2024 and 2017 displayed the lowest prevalence with 21 %, 22 % and 25 % respectively. Overall this results in an average prevalence of 30 % over the last two decades. This decrease in prevalence could be explained by several factors such as the number of sheep and the number of farms, as a higher number of sheep should also increase the number of sheep tested for *H. contortus.* As seen in the data provided by Jordbruksverket (2016;2024) and Kumm (2008) there is on average a higher concentration of sheep in 2024 than earlier years as both the average holding size has increased as well as larger sheep farms are now holding 58 % of the sheep. This could affect the number of positive results and prevalence. It could also be argued that farmers' strategies may have changed over the last two decades. An increase in tests being sent in for preventive reasons, rather than just because the sheep appears to be sick, could lead to more testing in general. Increasing the number of tests could also potentially reduce the number of positive tests, as it is not expected that every test will be positive for *H. contortus*.

These changes in prevalence, both between decades and between different years, could also be influenced by the climate. As can be seen in Figure 4.4.1 the years 2018, 2021 and 2022 had the highest prevalence (29 %, 31 % and 32 % respectively). Table 2.2.2 shows that the year 2018 had the top one lowest precipitation, close to average temperature and top one highest sunny days. Similarly 2022 had the top three lowest precipitation, a higher temperature than average and the top two highest number of sunny days. 2021 did on the other hand have the top four lowest but still above mean precipitation, top one lowest temperature and lower than average sunny days.

As can be seen in Figure 4.4.1 the years 2017, 2019 and 2024 had the lowest prevalence (25 %, 21 % and 22 % respectively). As can be seen in Table 2.2.2 2017 had more precipitation than average. The temperature was lower than average and the number of sunny days was lower than the mean (top three lowest). 2019 had higher than mean precipitation (top three highest), close to mean temperature and lower than mean (top three lowest) sunny days. Lastly, 2024 also had more precipitation (top three highest), higher than the mean (top two highest) temperature and more sunny days than average.

A trend towards low precipitation, many hours of sunshine and a high prevalence can be seen for both 2022 and 2018 (see Table 2.2.2), which had the highest prevalence. In contrast, a trend towards higher precipitation and lower prevalence can be seen in 2017, 2019 and 2024 (Table 2.2.2). Unexpectedly the year 2021 which also had high prevalence had neither particularly low precipitation or particularly many hours of sunshine, something that otherwise seems to apply to years with high prevalence. Instead the lowest temperature was measured in 2021 (Table 2.2.2). Even if one could interpret a slight trend in precipitation compared to the mean value and the hours of sunshine in relation to the prevalence, Figure 4.5.2, 4.5.3 and 4.5.4 show a different picture.

Similar to the results of Höglund (2015), no correlation between prevalence and temperature, precipitation or hours of sunshine was found (Table 4.5.2, 4.5.3, 4.5.4). R-squared for prevalence and precipitation is 0,02 for 2005-2014 and 0,1935 for 2014-2024. $R^2$ for prevalence and precipitation is 0,09 for 2005-2014 and 0,0107 for 2014-2024. Lastly, $R^2$ for prevalence and hours of sunshine is 0,002 for 2005-2014 and 0,17 for 2016-2024. Even though it can be argued that the correlation for hours of sunshine has become stronger, the correlation is still weak. Overall there are no strong correlations between the annual weather data and prevalences, like the results of Höglund (2015).

The lack of correlations found could mean that looking at weather data such as average annual temperature, hours of sunshine and/or precipitation is not sufficient to determine the prevalence of *H. contortus.* In line with Leathwick (2013) this could mean that relying on monthly or annual averages is not specific enough for this type of study and there is a need for more specific data such as quarterly, monthly or even narrower intervals to get more accurate results (Leathwick, 2013).

## 5.3 Geographical spread

A look at the maps (Map 4.4.3) shows a certain geographical distribution trend. *H. contortus* seems to favour southern Sweden and its coasts, followed by central Sweden and the east coast. It can also be seen from the maps that the parasite is more common near larger lakes such as Vänern, Vättern and Siljan than in areas without larger bodies of water nearby. It could be argued that the reason for this is that larger water bodies might cause higher humidity and milder temperatures, which make it easier for *H. contortus* to survive. This is in line with Leathwick et al. (2013) and Rose et al. (2016) that also mention that *H. contortus* can only survive within certain ranges of temperature and humidity.
As can be seen in Appendix 1 the positive tests for *H. contortus* in 2016 did not spread further north than the Skellefteå region (Lat: 64.7500 | Long: 20.9500). In 2017 a spread can already be seen with new results near Arvidsjaur (Lat: 65.5900 | Long: 19.1700), Piteå (Lat: 65.3167 | Long: 21.4833) and Haparanda (Lat: 65.8358 | Long: 24.1281) with a total of six new findings signifying a geographical spread. 2018 shows a similar pattern with one new finding and 2019 shows a spread to the Sorsele area (Lat: 65.5361 | Long: 17.5372) with three new points. No new spreads in 2020. In 2021 two new points can be seen, one spreading higher than ever before in this decade. There is one new spread in 2022, one new spread in 2023 and nothing new in 2024. Comparing this with the results of Höglund (2015) in Map 4.5.5 there are some differences. The left map (2005-2014) shows three positive *H. contortus* results marked with purple circles that no longer appear in the last decade. Several circles on the right map show a spread of *H. contortus* that did not occur in the previous decade. This indicates that there has been a geographical spread in both central and northern Sweden. There is also a spread marked with smaller yellow circles in northern Öland where *H. contortus* has not appeared in the past ten years. This spread could be because of changes in weather, husbandry practices or as seen in the notes of Attachment 1 a higher number of overall positive results in both central and northern Sweden.

## 5.4 About Table 4.4.6, Table 4.4.7 and SMHI data

As can be seen in Table 4.4.1 2019 contained the lowest number of positive results for this decade (1912) with 492 positive results in April, 448 in May and 80 in June. Q4 (October, November, December) contained 280 positive tests and 14 % of the total positive results which is the highest percentage for this decade. In comparison 2022 contained the highest number of positive results this decade (4102) with 1030 positive test results in April, 1294 in May and 235 in June. Q4 contained 270 positive results and 6 % of the total positive results for this year, which is the lowest percentage for this decade. SMHI (2022) mentions that 2022 had once again record-breaking temperatures and sunny hours, though paired with little to no precipitation in some areas and a cold winter.

## 5.5 Overview and limitations

These summaries show that there has been significant variation in prevalence both in the last two decades and between 2016 and 2024. Neither in Höglunds (2015) nor in the results of this study is there a correlation between prevalence and temperature, precipitation and hours of sunshine. While using yearly weather data gave a general picture, this study shows that it would be beneficial to use shorter intervals for gathering weather data for better insight into the correlation between prevalence and weather (Leathwick, 2013). The study further indicates that there could potentially be a correlation between different types of weather data as well as the number of sheep and sheep density. It can be argued that the issue is complex as one factor could possibly affect another. On the other hand a geographical spread of *H. contortus* can be seen over the decades, both between 2005 and 2014 and between 2016 and 2024, indicating that there are possible factors affecting the spread. As stated by Emery et al (2016) *H. contortus* affects farm productivity and sustainability. In order to keep sheep farming both economically and environmentally sustainable as well as to improve sheep health, there might be a need for new management strategies and predictions of future infection risks.

The data compiled in this study may have been influenced by various factors such as the uncertainty of how the samples were collected from the farmers and varying numbers of tests each year. The strengths of this study were the large amount of data, which could increase the statistical certainty. The randomness of the results could also be seen as a positive as it could show a truer representation of the coordinates and positive results in the maps. Other factors such as anthelmintic resistance, husbandry and population size could also influence the results.,

# 6 Conclusion

The aim of this study was to compile and map Swedish *H. contortus* data from sheep to compare with temperature, precipitation and hours of sunshine and the compilation from the earlier decade. The main findings of this study are that the prevalence of *H. contortus* has decreased between the two decades, although there are also significant differences between some years within the two decades. The number of sheep has also decreased while the total number of sheep farms has remained the same and the number of tests submitted has increased. However the results show no correlations between prevalence and temperature, precipitation and hours of sunshine, similar to the findings of the previous decade. The results also show a geographical spread of *H. contortus* in Sweden over time. These findings show that there is a need to analyse this type of data in more detail. Visualising the data and its geographical spread using coordinates proved to be an effective method to show possible spread. Further research is needed regarding how detailed the collected weather data needs to be in order to show accurate correlations between weather and prevalence.

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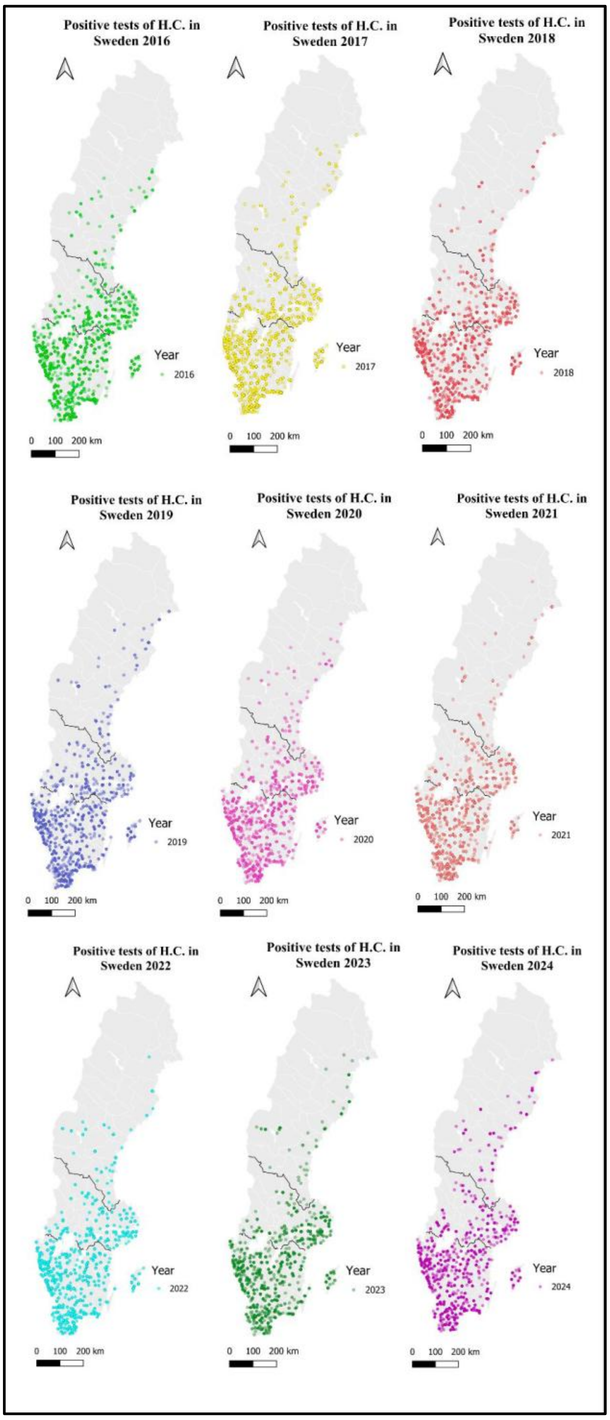
# Attachments

## Attachment 1 – Positive results from 2016 to 2024




*Maps 1-9. These QGIS maps show the approximate coordinates for each positive H. contortus result for the years 2016 to 2024. The black line splits the maps into north, middle and south Sweden. The maps and points are in different colours for easier viewing. The points have 50 % opacity which enables viewers to determine if one or more points is stacked on top of another, as darker coloured points show any overlaps. 2016: south: 509 positive results (31 %), middle: 900 positive results (26 %), north 288 positive results (20 %). 2017: south: 773 positive results (27 %),*

*middle: 1071 positive results (25 %), north 319 positive results (18 %). 2018: south: 773 positive results (34 %), middle: 1103 positive results (30 %), north 319 positive results (17 %). 2019: south: 662 positive results (26 %), middle: 1006 positive results (22 %), north 244 positive results (13 %). 2020: south: 917 positive results (33 %), middle: 1527 positive results (27 %), north 338 positive results (15 %). 2021: south: 1311 positive results (37 %), middle: 1896 positive results (31 %), north 607 positive results (22 %). 2022: south: 1154 positive results (36 %), middle: 2184 positive results (33 %), north 764 positive results (25 %). 2023: south: 1085 positive results (34%), middle: 1412 positive results (25 %), north 548 positive results (20 %). 2024: south: 768 positive results (25 %), middle: 1197 positive results (23 %), north 363 positive results (15 %).*

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