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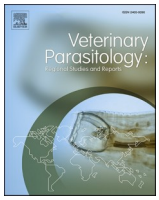

Original Article

Farmers' perception on the control of gastrointestinal parasites in organic and conventional sheep production in Sweden

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ABSTRACT

A questionnaire was sent to sheep owners in Sweden to get information about anthelmintic drug use. The survey also investigated how respondents experienced problems with gastrointestinal nematode infections (GIN) focusing on *Haemonchus contortus*. The response rate was 31% and included both conventional and organic farms. The use of anthelmintics was low (45%), among which a majority (76%) drenched ewes on a single occasion, mostly with ivermectin (59%) followed by albendazole (19%). Other drugs were used rarely, however, unawareness of GIN risk was high (19%), especially among respondents with few animals. Anthelmintic dose calculations were done after visual appraisal by 63% and 22% calibrated the equipment before drug delivery, which is worrying since underdosing is a risk factor for the development of anthelmintic resistance. Like with anthelmintics, the perceived risk for GIN increased with herd size both by conventional and organic farmers. Faecal examination for the presence of GIN was done by 65% of the respondents and, among their sheep, *H. contortus* was or had been diagnosed in 41% of the herds. Irrespective of new stock had been imported from other countries or not, common problems were reported by 5% and 7% of the organic and conventional producers, respectively. Land use and grazing management strategies differed more in relation to herd size than by production form, with a majority (47%) having their sheep grazed in several paddocks, or at least the lambs were moved when separated from the ewes at weaning (25%). In contrast set stocked grazing was mainly reported on smaller farms. Co-grazing with cattle and horses were also frequently reported irrespective of production form, but with cattle to a somewhat greater degree on larger organic farms. Wild cervids, especially roe deer, were frequently observed on sheep pastures (87%). The veterinary involvement was higher on organic (65%) than on conventional farms (53%), and only 5% considered advice unimportant. Still, some conventional and organic producers treated sheeps routinely without a prior diagnosis, against the national regulations. 46% of the respondents drenched new and replacement stock. In conclusion, although some differences were observed between conventional and organic producers, the divergences were mainly due to herd size categories. Furthermore, despite a high veterinary involvement, we identified factors which can contribute to anthelmintic use, such as poor quarantine procedures, and deworming routines that can contribute to anthelmintic resistance in *H. contortus*.

1. Introduction

Although meat consumption is declining, there is still a demand for locally produced prime lamb among Swedish consumers (Kumm, 2009). Local sheep are increasing in popularity partly because production is a grazing-based livestock system that is considered animal welfare friendly, and partly because grazing livestock is considered ecologically sustainable as it contributes to maintain biological diversity and the aesthetic values of grassland (Kumm, 2009; Metera et al., 2010). Even though national sheep production currently is undergoing structural changes, there is still a wide range of farm types represented in Sweden. Apart from hobby herds, there are mostly smaller semi-commercial herds but also a number of big producers who follow the global trend towards larger agricultural units with intensified production (Kumm, 2009). The total number of sheep in Sweden (i.e., ewes, rams and lambs) was 417,000 in 2018 (SJV, 2019a). Today, about 20% of the farms are

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organic, but housing conditions are similar to those on conventional farms as all sheep must have access to the outdoors at least from May to October, regardless of production type (SJV, 2019b). As an organic producer, the farm must be approved by a national certification body working in accordance with European Union regulations. They are required to feed their animals with fodder grown without pesticides and have stable buildings that meet the animals' natural needs. Blanket prophylactic treatment is not allowed, but according to national guidelines, it is permitted to deworm the animals after diagnosis.

An established issue when grazing sheep, is the constant exposure to gastrointestinal nematode (GIN) infections, which in the foreseeable future could develop a major obstacle to their health and well-fare, not least in the face of changing climate patterns (Morgan et al., 2013; Skuce et al., 2013). Despite its high latitude location, GIN are common in Swedish sheep. In a recent study *Chabertia ovina, Haemonchus contortus, Teladorsagia circumcincta, Trichostrongylus vitrinus* and *Oesophagostomum venulosum* were identified as the dominant species (Halvarsson and Höglund, 2021). Although clinical cases are rare today, disease occasionally occurs, mainly in lambs or pregnant ewes and in particular when heavily infected with *H. contortus* (Lindqvist et al., 2001; Troell et al., 2005; Höglund et al., 2020). However, also subclinical parasitism can have drastic consequences for productivity, as even mixed nematode infections can affect grazing behaviour and impair feed conversion (Sutherland and Scott, 2010). As this affects farm sustainability and economics whilst the sheep are grazing, parasite infection levels must be controlled by reducing exposure to infective larvae (Morgan et al., 2013). In a future perspective, it has been recognised that intensified production cannot take place at the expense of increased and uncontrolled drug use as it may lead to anthelmintic resistance (Vercruysse et al., 2018).

The regulations for sheep production in Sweden differ in part from the rules in other European countries. Besides that, the Swedish Animal Welfare Act (Djurskyddslagen (2018:1192), 2018) is among the strictest in the world, anthelmintics to livestock can, according to current regulations, only be prescribed after the faecal examination and a conclusive GIN diagnosis (SJV, 2010). There is also a societal concern about the potential impact of anthelmintics residues in the environment and in food (McKellar, 1997; Beynon, 2012). Nevertheless, due to its ease of implementation, efficacy and low cost of treatment compared to other methods, use of anthelmintic drugs is still the cornerstone in most parasite control programs in Sweden, whether organic or conventional production (Höglund et al., 2019). Along with frequent and incorrect use of anthelmintics on an intense scale across livestock industries, the development of resistance to one or more anthelmintic classes is now widespread in Europe (Vineer et al., 2020). About 15 years ago, anthelmintic resistance was significantly more favourable in Sweden than in several other European countries (Höglund et al., 2009), where multidrug resistance is now established (Sargison et al., 2007a; Geurden et al., 2014; Glover et al., 2017; Ploeger and Everts, 2018; Claerebout et al., 2020). However, ongoing monitoring and case studies indicate that the situation has deteriorated (Höglund et al., 2015, 2020). Therefore, it is of interest to find out how sheep owners perceive GIN and handle anthelmintics, which is important for identifying drivers of resistance development. Not least as there is evidence that ivermectin-resistant *H. contortus* has spread along with imports and animal movements between farms (Höglund et al., 2015), and recently a case of multiple resistance was also described (Höglund et al., 2020).

Knowledge of how parasite control methods are applied and how sheep farmers seek advice is important to identify risk factors related to the development of anthelmintic resistance. It is also of interest because it enables assessment on how high demands on animal welfare combined with restricted use of anthelmintics can affect GIN infection levels in sheep herds in general terms. This study aimed to investigate Swedish sheep owner's perception of the impact of gastrointestinal parasites and how they are controlled by anthelmintics.

2. Materials and methods

2.1. Questionnaire

All people with an e-mail address and sheep registered as a production animal (SE-number) at the Swedish Board of Agriculture (SJV, 2019b) were invited to participate in a web-based questionnaire survey. The questionnaire was divided into four sections: 1) farm demographics and general management, 2) production-related questions (not dealt with here), 3) parasite control measures including information sources with a focus on the use of anthelmintics, 4) type of farmland, its use and potential wildlife interactions.

The online survey platform Netigate (www.netigate.net) was used to host the survey that consisted of 52 questions, among which seven were follow-up questions not shown to all respondents (Suppl. mtrl. 1). Therefore, the number of answers completed by each respondent could vary. Most of the questions were multiple-choice, among which six offered the possibility to answer more than one alternative. A total of 15 questions included option free-text answer, and three had a drag-to-select-bar.

Prior to distribution, the questions were pilot tested on a limited number of farmers and sheep advisors to check for clarity and thus prevent misinterpretations. The questionnaire was distributed via e-mail in October 2019 and three reminders were sent out. In the invitation, the participants were informed about the purpose of the study and by participating, they gave their consent according to GDPR (Regulation (EU) 2016/679 (General Data Protection Regulation). To ensure full anonymity, the link between the respondent's location (questions 2 and 3) and the rest of the survey responses (including herd size) were permanently broken by separating them into two separate tables. These two questions were only used to generate a participation map.

2.2. Statistical methods

The responses were migrated to Microsoft Excel and curated before descriptive statistical analyses were conducted in R v4.0.5 (R Core Team, 2021) and visualized with ggplot2 v3.3.3 (Wickham, 2016). In the statistical analyses, the farms were size categorized into few animals (1–10 sheep), small farms (11–30 sheep), medium farms (31–80 sheep) and large farms (>81 sheep), as well as whether the production form was conventional or organic. The categories were set so the average size sheep farm in Sweden (26 sheep at the end of 2020 according to the Board of Agriculture) encompassed in the medium-size group.

3. Results

3.1. Response rate

In total, 15,007 invitations were sent out via e-mail. This represents approximately 75% of the total number of farms registered as sheep production units, according to the SE-number registry at the Swedish board of Agriculture. Among these, 4635 invitees responded (31%) of which 3949 stated that they still had sheep. According to official statistics, 12,231 farmers had sheep in December 2020 (Swedish Board of Agriculture). Based on this, the response rate was approximately 32% of all sheep owners in Sweden.

Half of the respondents participated using a computer and half using a mobile device. The average response time was 12 min 5 s. In total, 4007 respondents completed the whole survey, and they represented all major production types such as hobby farmers, wool, skin, meat- and milk producers. The respondents were located across Sweden but especially in the southernmost county (Skåne), as well as in Central Sweden (Uppland), Western Sweden (Västra Götaland), and on the Baltic Island Gotland. The latter reflects where most sheep are kept in Sweden (Fig 1).

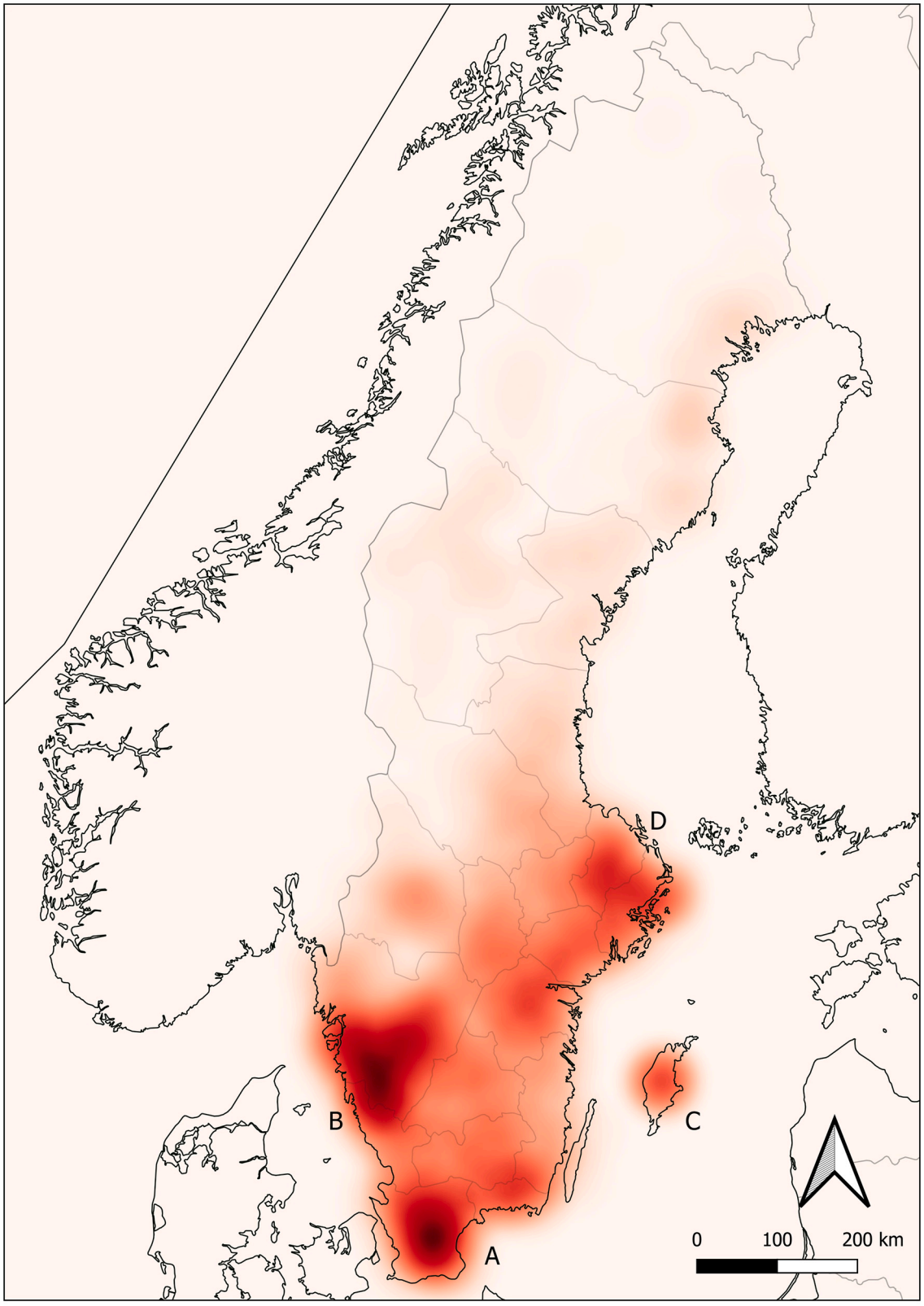

Fig. 1. Heatmap displaying where the respondents' farms are located. Most of them are concentrated to four regions: (A) Skåne, (B) Västra götaland, (C) Gotland and (D) Uppland.

3.2. Farm characteristics

The mean and median number of sheep (lambs, ewes plus rams) per farm was 60 and 22 respectively. The farmers self-classified their farm production focus, but there was no pattern based on the four size categories among the production types mentioned above (data not shown).

A total of 12 different sheep breeds were reported. The four most common breeds were Gotland Pelt (Gotlandsfår), Texel, Swedish

Finewool (Svenskt finullsfår) and Suffolk and crosses thereof, which were increasingly more common on medium and large-sized farms than hobby and small farms (Supplemental material 2, Fig. S1). These are the most common breeds on Swedish commercial farms and are kept for meat and/or pelt production mainly. East Friesian sheep for milk production are uncommon and are mainly represented on a few farms. Gute sheep (Gutefår) is the most common landrace breed in Sweden that, like other landraces, are mainly found on hobby farms with few animals.

3.3. Parasitological analysis in faeces

Habits for examining faecal samples for strongyle eggs varied between respondents, but in general, the sampling intensity increased with herd size irrespective of the production form (Fig 2A). Among those with organic farming ($n = 466$), 76% examined their herds for the presence of GIN by examination of faecal egg counts (FEC), whereas those with conventional farming ($n = 3276$), 58% did so. Among respondents who did FEC on a regular basis, this was carried out by 35% and 60% with organic and conventional farming, respectively (Fig 2A). The proportion examining FEC was high (65%) among respondents considering veterinary advice important ($n = 3109$). The largest proportion was found among respondents who rely on advice from Farm and Animal Health (Gård&Djurhälsan), which is a veterinary organization owned by the Swedish meat industry and farmer organizations. In these, the faecal examination was performed in 85% ($n = 541$) of the farms and among those with more than 80 animals in 98% ($n = 236$).

3.4. Use of Anthelmintics

The use of anthelmintics was more common and increased with herd size irrespective if the production form was conventional or organic. In total, 45% of the respondents ($n = 3742$) drenched their animals. Among these, 22% were treated after faecal diagnosis, whereas 23% performed routine drenching without the prior faecal diagnosis. The corresponding figures on farms with 31–80 sheep ($n = 906$) was 28% and 24%, respectively. On those with more than 81 sheep ($n = 637$) was 51% and 16% treated, respectively. However, the proportion of conventional producers with routine drenching was nearly four times higher on conventional farms (24%, $n = 1219$) than on organic farms (6.5%, $n = 324$) (Fig 2B).

Among the respondents that used anthelmintics, sheep were on an annual basis dewormed: once (76%), twice (23%), or at three or more occasions (2%) irrespective of herd size and production form. However, the trend was that the use of anthelmintics increased with herd size (Fig 2C). Organic producers ($n = 215$) had a slightly higher percentage that drenched the animals than conventional ($n = 1468$), 79% vs 75%. For

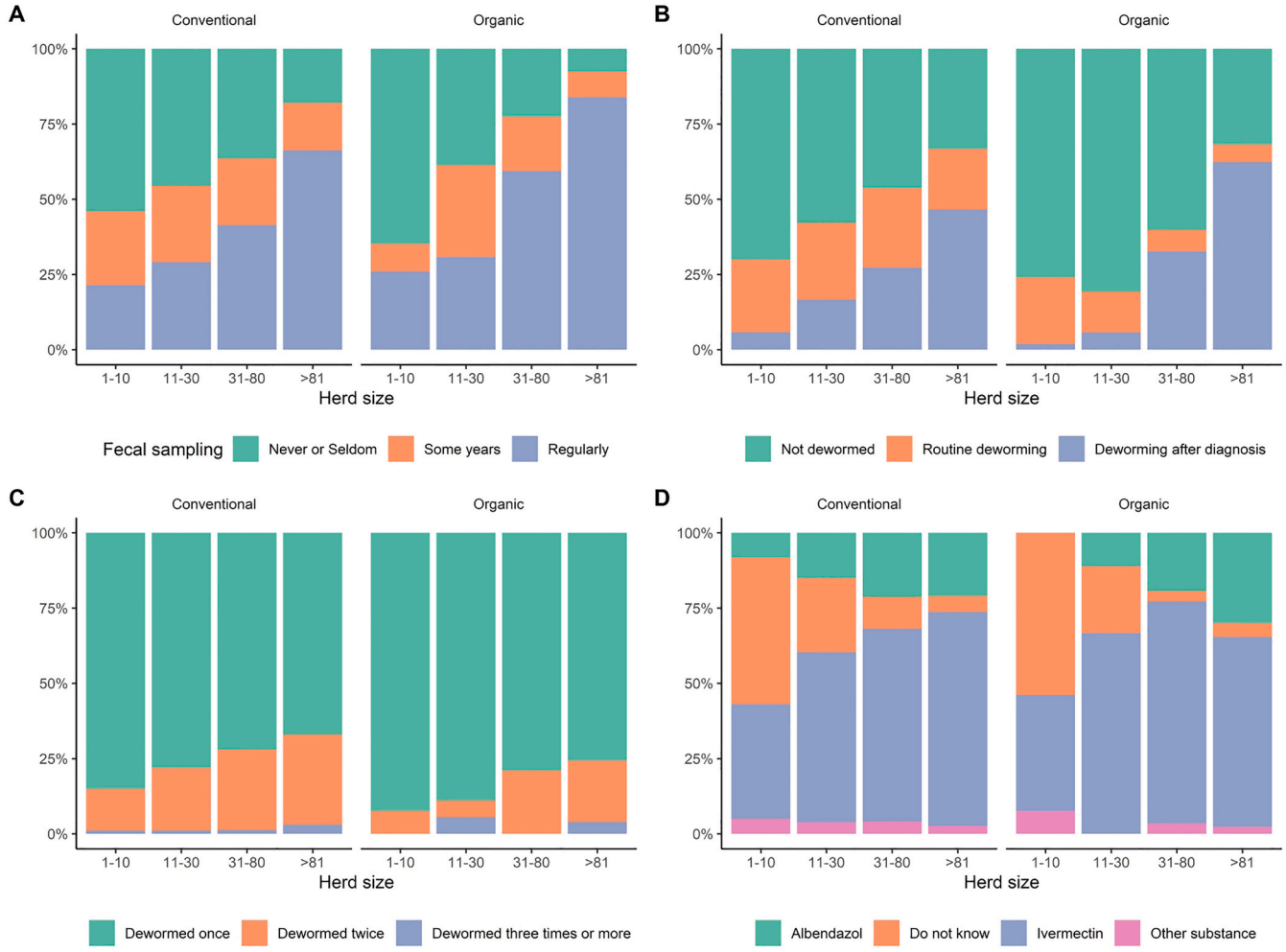

Fig. 2. Faecal examination for gastrointestinal nematodes increased with herd size among conventional and organic farms (2A). Deworming after diagnosis increased with increasing herd size. While routine deworming remained the same for the conventional farms, it was smaller on large organic farms than on small (2B). Most farms dewormed their sheep once per year irrespectively of conventional or organic production type (2C). The most common anthelmintic drug used was ivermectin. Noteworthy is that the awareness of which anthelmintic drug was used increased with herd size (2D).

anthelmintic dose calculations, 63% based it on a visual appraisal of animal weight, whereas 20% after weighing single animals and 17% after weighing all animals, irrespective of production form. The anthelmintic was delivered by a dosing gun by 64% of the farmers, but only 22% calibrated the equipment before drug delivery.

Respondents with large and medium-sized herds were, in general, more aware of which anthelmintic substance was used (92%, $n = 898$) than those with smaller herds (34%, $n = 781$). The anthelmintic mostly used, irrespective of herd size and whether the production form was conventional or organic, was ivermectin (59%, $n = 988$) followed by albendazole (18%, $n = 295$). Other substances, mainly levamisole, was only used by 3.7% ($n = 63$), both on conventional and organic farms (Fig 2D). Totally 20% ($n = 333$) of the respondents (mostly on smaller farms) do not remember which anthelmintic they used. Rotation between substances or drug classes at different treatment occasions was reported by 6% ($n = 107$) of the respondents. In addition, this was reported to occur annually by 14% ($n = 325$), whereas no substance rotation was applied by 56% ($n = 938$).

Ewes were more commonly dewormed than lambs and rams (Fig 3). Regarding the ewes, this was noted irrespective of herd size and whether the production was organic or conventional. Treatment of lambs and rams, on the other hand, was less intensive but increased with herd size. For the organic farms, the treatment was more or less the same for rams irrespectively of herd size.

3.5. Perception of GIN and veterinary involvement

The perceived risk for sheep being infected with GIN varied between respondents and was positively correlated with increasing herd size, both on conventional ($n = 3275$) and organic ($n = 466$) farms (Fig 4A). Thus, respondents with more sheep (>81 sheep) reported that GIN constitute a problem more often than those with smaller herds (<10 sheep). In total, 3742 respondents answered the question on how they obtained veterinary advice. Among the conventional farms, 53% received veterinary advice, while 65% were among the organic ones. The majority got advice from veterinary surgeons (54%), among which 15% mainly from those employed by Farm and Animal Health. In total, only 6% got advice from one source, whereas 35% relied on a variety of sources including veterinarians and 5% considered advice unimportant (Fig 4B).

3.6. Haemonchus contortus and associated problems

Among the respondents that examined their herds for the presence of GIN by faecal egg counts ($n = 2546$), *H. contortus* was or had been diagnosed in 41% ($n = 1044$) of the herds. Among these, *H. contortus* was identified more than two years ago (15%), sometimes (21%), and always (5%) (Fig. S2A). The proportions increased gradually with herd size both on conventional and organic farming enterprises.

The 1044 respondents that reported *H. contortus* were also asked whether they perceived problems related to the infection. In total, this was reported by 33% ($n = 343$) of the producers irrespective of production form. Among the conventional ($n = 826$) and organic ($n = 218$) respondents, respectively, problems were always observed in 7% and 5%, as well as 25% and 29% only in certain years. The trend was that the problems perceived by respondents increased with herd size. However, unawareness was reported to be relatively high both among conventional (33%) and organic (26%) respondents (Fig. S2B). Among the respondents reporting always having problems ($n = 69$), 26% did not deworm their sheep. Of these, all but one was conventional producers.

3.7. Grazing lands

The two most common types of grazing land are natural pastures (grassland) and cultivated arable land. Many of the farmers also used a combination of the two types (Fig 5A). No major differences were observed between conventional and organic producers in use of grazing land. However, the proportion of respondents mostly relying on natural pastures decreased with increasing herd size. A negligible fraction of smaller farms also utilized forest and mountainous areas, especially in Northern Sweden, where sheep are sometimes grazed on hill farms (fäbodar) during summer.

Despite huge variations in the number of animals per hectare, grazing intensity increased with the number of animals on the farms (Fig

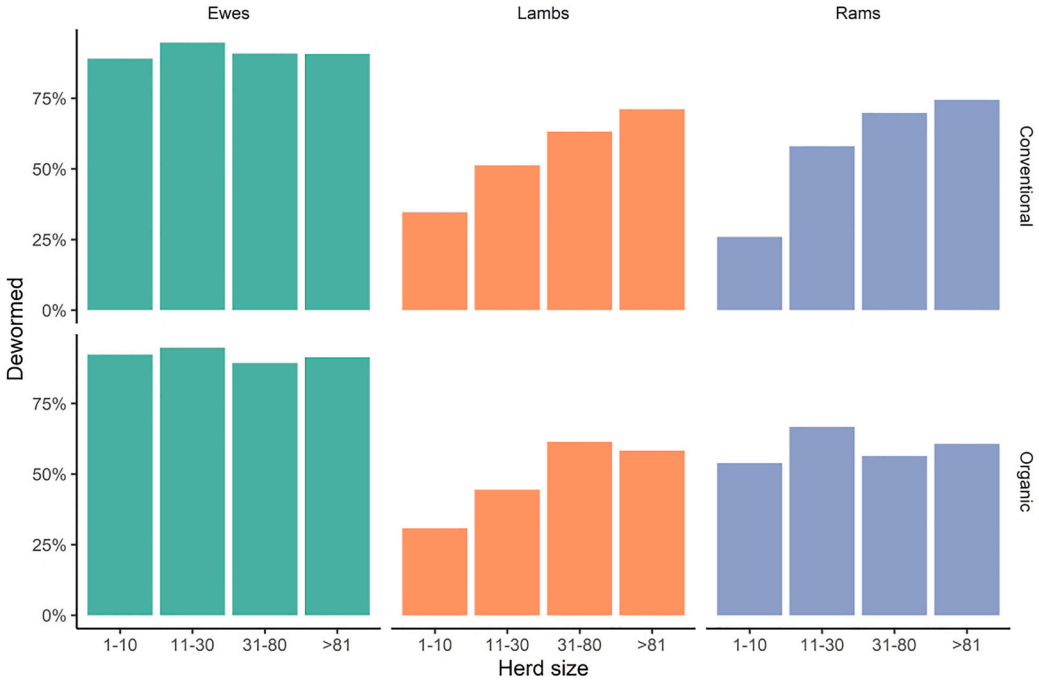

Fig. 3. Most farms dewormed ewes. The deworming pattern was the same except for small organic farms where rams were dewormed to a greater extent than conventional farms.

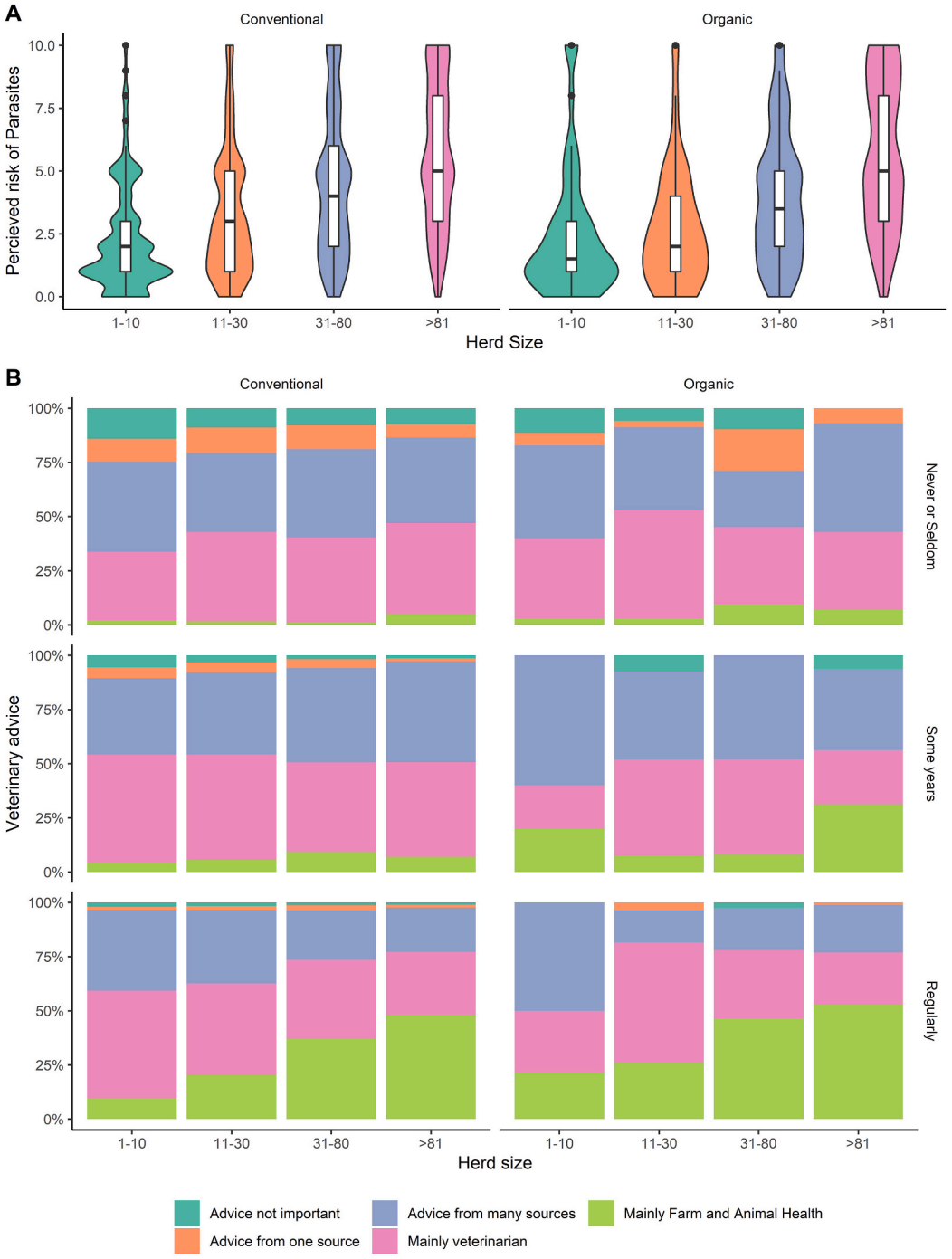

Fig. 4. Irrespective of production was conventional or organic, the larger the farm, the higher the perceived risk of parasites was. The respondent was asked to grade the risk from 0 to 10 (4A). Farmers who took regular faecal samples, relied on advice from veterinarians and Farm & Animal Health to a greater extent than those who never or seldom took faecal samples (4B).

5B). Wild cervids occasionally observed on the grazing lands for the sheep were roe deer (*Capreolus capreolus*), red deer (*Dama dama*) and fallow deer (*Cervus elaphus*). Roe deer was most frequently observed, and there was a trend of more observations with increasing herd size (Fig. S37). When asked how the animals grazed ($n = 3653$), the majority responded that ewes and lambs were kept in different groups that were moved at least three times (47%) during the season or together until the lambs were weaned (25%). Grazing in several paddocks increased with herd size in both production forms (Fig 6A). Mixed or sequential grazing with other livestock or horses occurred both on conventional (66%) and organic farms (54%). The most commonly reported animals were cattle and horses, and when it comes to cattle, this was more commonly reported on larger organic farms (Fig 6B).

4. Discussion

This study is the first large scale nationwide on parasite management routines in Swedish sheep herds. We also collected information on how the respondents perceive the risk for GIN. The total number of sheep in Sweden is low, and farms are mostly smaller than in countries where

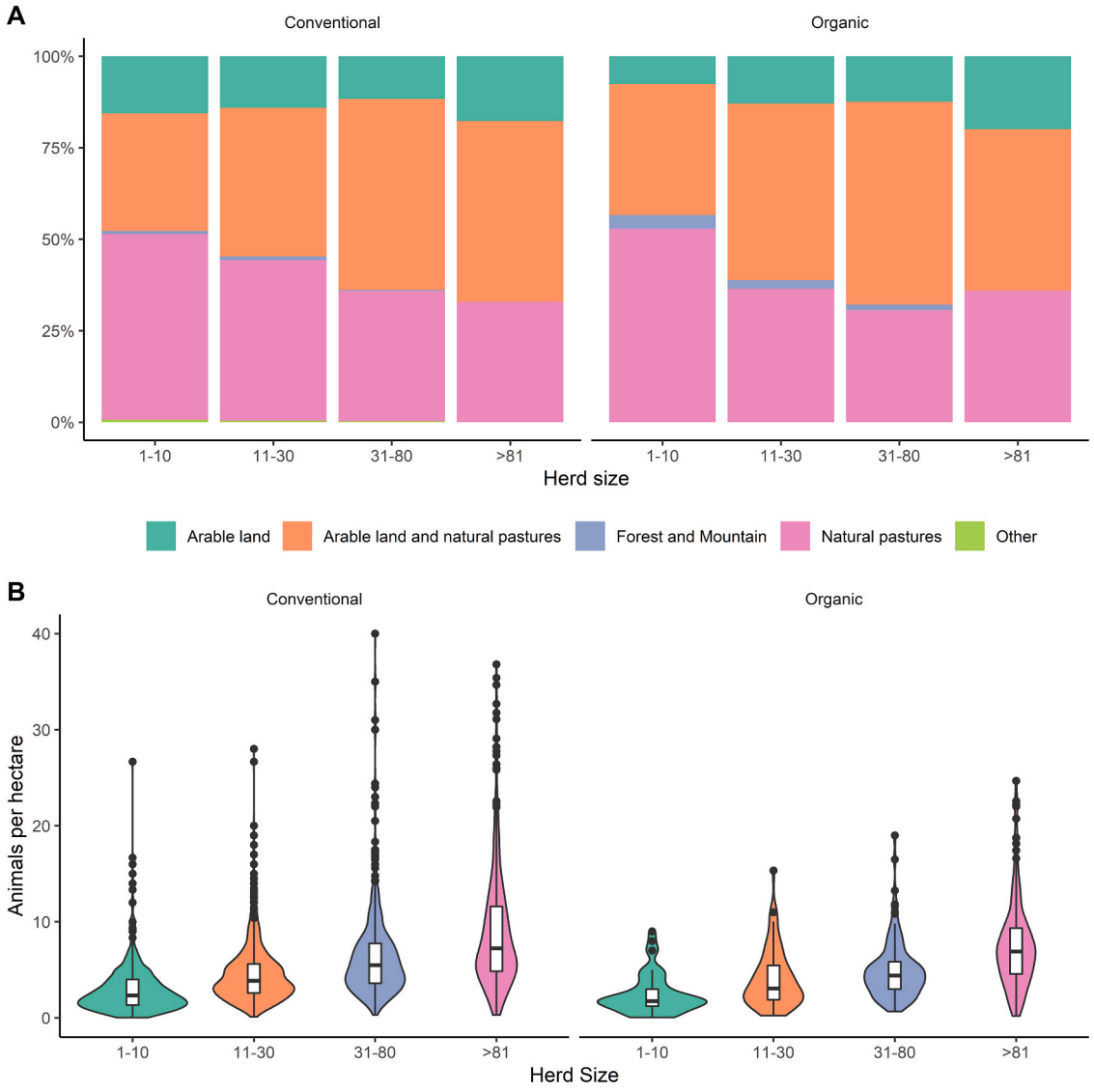

Fig. 5. Reliance on a combination of arable land and natural pastures increased with an increased herd size. A few, mostly small farms reported grazing in forests and on mountains (5A). Animal density per hectare increased with farm size, irrespectively of production type. Six values with farmers reporting over 40 animals per hectare were omitted from the fig. (5B).

sheep production is economically more important. Besides, from many hobby herds, there are also commercial farms in which about 20% are organic producers. However, regardless of whether the production form is organic or conventional, sheep must be on pasture from spring to autumn in Sweden, whereby they are constantly exposed to GIN infections. The requirements for animal welfare are high, and anthelmintics can only be sold on prescription (SJV, 2010). The results of this study, presented as descriptive summaries, show some important trends and patterns but rather in relation to herd size than to whether the production form is conventional or organic. This is important to keep in mind when designing future studies but also when identifying drivers for optimized parasite control and improvements in recommendations for sustainable parasite control.

4.1. Use of anthelmintics

According to this survey, *H. contortus* was diagnosed in 41% of the herds in Sweden, which agree with small scale surveys based on coproscopy (Lindqvist et al., 2001; Höglund et al., 2020). Only 45% of all respondents dewormed their animals, but the use of anthelmintics increased with herd size and irrespective if the production was conventional or organic. Often dewormers were used after diagnosis, probably attributed to the fact that faecal examination was carried out at a high frequency, but routine drenching still occurred, and it was nearly four times more common on conventional than on organic farms. The treatment was mainly directed to ewes before turn-out to ensure the season build-up of larval challenge on pasture is delayed as long as possible and thereby reduce the risk for GIN infection in lambs. With increasing herd size also lambs and rams were treated but to a lesser extent than ewes, which contrasts the findings in Belgium (Claerebout et al., 2020) and across the UK (Burgess et al., 2012), reporting a higher treatment frequency in lambs than in ewes.

To date, information about the use of anthelmintic treatments from Northern Europe are scarce, but the frequency seems to be somewhat more limited in Sweden even compared with neighbouring countries such as Norway (Domke et al., 2011) and Lithuania (Kupcinskas et al., 2017). Moreover, half the number of treatments are carried out in Sweden compared to Belgium (Claerebout et al., 2020), and it is also lower than in England (Fraser et al., 2006; Morgan and Coles, 2010), Northern Ireland (McMahon et al., 2013b) and Scotland (Bartley et al.,

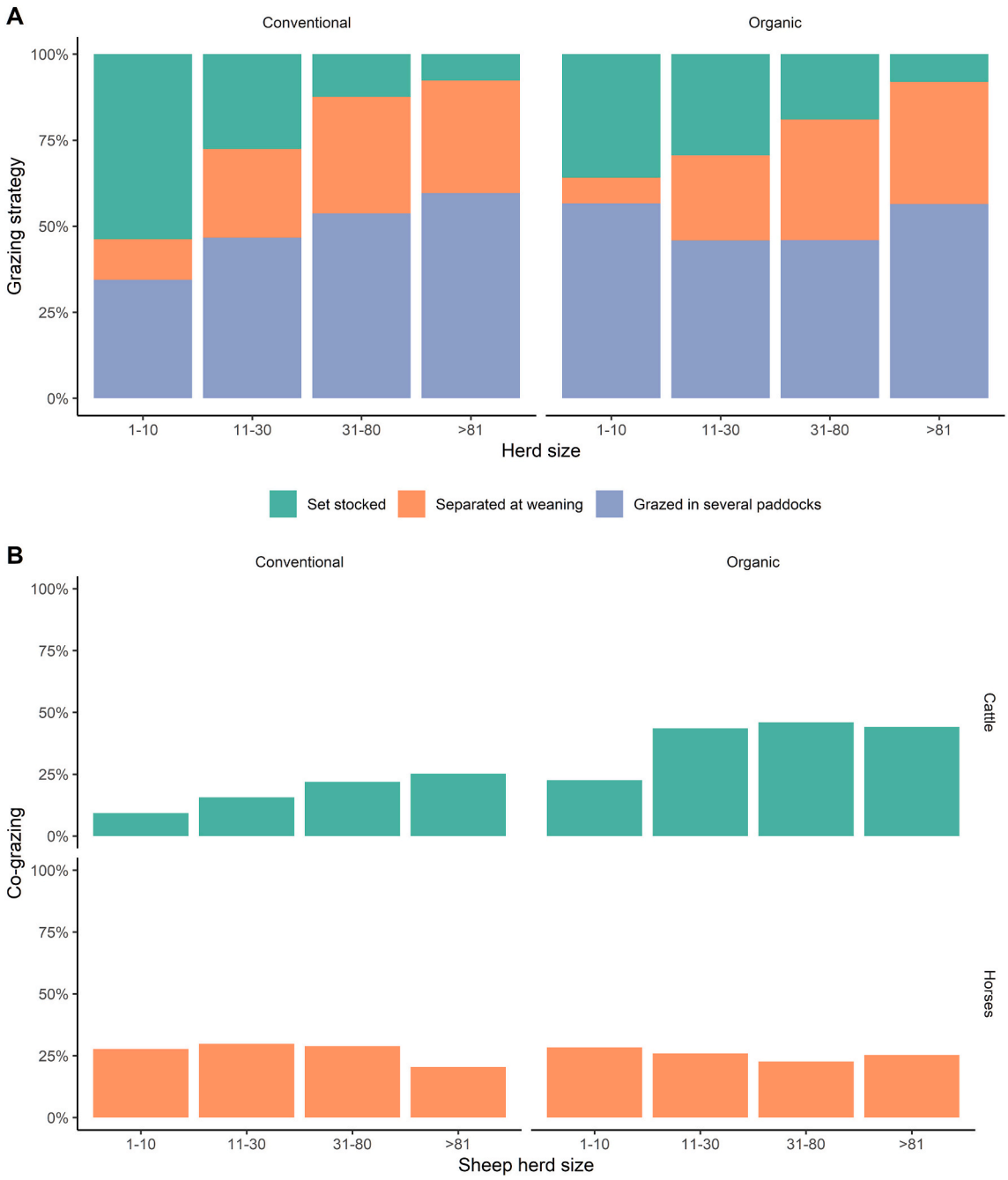

Fig. 6. Farmers with a small herd size let their animals graze in a single paddock to a greater extent than farmers with larger herd sizes (6A). Organic sheep farms co-grazed their lands with cattle to a greater extent than conventional, while this pattern was not seen for horses (6B).

2003), where most sheep on average are treated on two to three occasions per annum. This despite ongoing SCOPS (Sustainable Control of Parasites in Sheep) information campaigns on "best-practice" that appear to have reduced the number of treatments (Learmount et al., 2015). There are wide variations in the climate in Sweden from the north to the south. Although most sheep are in the southern and central parts of the country, it seems reasonable that the observed low use of anthelmintics can be linked to regional differences in weather conditions affecting parasite epidemiology, but probably also to the perception of GIN parasitism and the economic relevance of sheep production at the national level. Other contributing factors to the low use of anthelmintics are probably a high degree of diagnostic testing (see below) and the extensive involvement of Swedish veterinarians who, unlike in many other countries, do not work with a business model with a focus on drug sales.

Ivermectin and albendazole/fenbendazole are the only single substances registered against GIN of sheep in Sweden, although also levamisole and monepantel as well as a combination including closantel and moxidectin is allowed (for details see Höglund et al., 2020). The awareness about which substance that is used was in general high, with the exception on smaller farms. Ivermectin was most frequently (59%) used, followed by albendazole (18%), while use of the other drugs was rare (3.7%). Thus, it seems that the choice of drugs in Sweden differs in part from other European countries, where in addition to increased use of ivermectin, also closantel, doramectin, moxidectin and combinations are used to an increasing extent (Fraser et al., 2006; Ploeger and Everts, 2018). On the other hand, rotation of different anthelmintics with a different mode of action seemed to be uncommon. However, whether

the concept of drug rotation delays anthelmintic resistance is under discussion (Fleming et al., 2006). Of great interest is that the responses as regards the use of anthelmintics with few exceptions were surprisingly similar between conventional and organic respondents. The above confirms with the results in a recent but more restricted study on 39 farms with more than 70 pregnant ewes in south-central Sweden (Höglund et al., 2019).

Mostly deworming was performed on a single yearly occasion with ivermectin or albendazole. Despite the legal requirement only in about half of the cases where drenching was done, this occurred after the faecal examination. Mainly conventional but also organic producers drenched routinely without prior diagnosis (see above). Nevertheless, the magnitude of faecal testing in our survey was high (76%). This frequency is much higher than figures from Belgium (Claerebout et al., 2020) and Norway (Domke et al., 2011). According to this survey, drugs were predominantly delivered by an uncalibrated dose gun (78%) following visual appraisal of animal weight for dose calculations (63%). Thus, the dosing equipment was checked to a lesser extent (22%) than, for example, in Norway (73%) (Domke et al., 2011), but was in the same range as in Northern Ireland (26%) (McMahon et al., 2013b). Still, many but a smaller proportion of the respondents based the amount of drench on a visual appraisal of animal weight in Sweden compared to Norway (79%). Combined, this is worrying as underdosing of animals has been recognised as a risk factor for the development of benzimidazole resistance (Calvete et al., 2012; Niciura et al., 2012). It has been suggested that underdosing with substances belonging to the same class may be more critical than the drenching frequency (Burgess et al., 2012), which was low in our survey.

As elsewhere, livestock trade within and between countries (Schnyder et al., 2005; Álvarez-Sánchez et al., 2006; Borgsteede et al., 2007) seems to contribute to the spread of resistant parasites in Sweden (Höglund et al., 2015). Surprisingly few of the respondents that purchased animals (46%) drenched new or purchased stock being introduced onto farms, most likely without prior knowledge about the GIN species composition and their resistance status. When comparing our figure with other studies, only 21% of farmers in New Zealand utilized an effective quarantine-drench (Hughes et al., 2007). In contrast, between 88% of the Scottish farmers had a quarantine procedure to brought-in stock, but which many were from the benzimidazole class exclusively despite widespread resistance to this group of anthelmintic (Bartley et al., 2003). Carrying out quarantine treatment has been recommended in the United Kingdom for several years (McMahon et al., 2013a; Learmount et al., 2015). Farms, where these were not effective, had a higher risk of *H. contortus* than those using more than one class of anthelmintic (Burgess et al., 2012). As a first step, it is important to encourage sheep owners in Sweden to implement effective quarantine treatment regimes. Today the advice is to use ivermectin with faecal sampling before and after deworming. It seems reasonable to evaluate the use of two separate families of effective anthelmintics as has been advocated, for example, in Australia (Dobson et al., 2001) unless it is known that the sheep come from a farm with no anthelmintic resistance.

4.2. Perception of the risk for GIN

Problems related to *H. contortus* were experienced by a third of the respondents on farms where it was diagnosed. The perceived risk for GIN among the respondents also increased with herd size, regardless of whether the production form was organic or conventional. Even so, it is clear that unawareness about GIN was relatively high among both conventional (33%) and organic producers (26%) even though it decreased along with increasing herd size. Although other GIN also are important, *H. contortus* is considered to be the most serious GIN pathogen among Swedish sheep veterinarians. It is a blood-sucking species with global distribution (Besier et al., 2016), and problems have also been shown in cool temperate regions (Troell et al., 2005; Sargison et al., 2007b; Höglund et al., 2020). Thus *H. contortus* deserves special attention, as female worms are extremely prolific, and this parasite is eager to develop resistance to anthelmintics (Kotze and Prichard, 2016). In contrast to the study by Claerebout et al. (2020), we did not ask whether clinical signs related to worm infections were observed. Nevertheless, it turned out that the perception of *H. contortus* was affected by the degree of veterinary participation, but it also increased with the number of animals on the respondent's farms. Problems were experienced among respondents who dewormed their animals either with or without results from the parasitological examination of faecal samples. The involvement of veterinarians was the source that dominated the advice, especially on medium and large-sized farms. From the survey, it is clear that the respondents collected information from a single source or considered advice less important, *H. contortus* was never or rarely reported. However, *H. contortus* was often found during certain years or regularly among those who received advice from several sources. While the study shows that veterinarians play an important role in providing advice, it is at the same time surprising that a relatively large proportion (73%) of medium-sized and large farms did not seek advice primarily from Farm and Animal Health. For the future, it is important to evaluate the economic value of diagnostic information and overcome barriers to stakeholder engagement. Not least to counteract seemingly increasing problems with GIN parasitism and anthelmintic resistance (Höglund et al., 2015, 2020), which is difficult for the respondents to detect early.

4.3. Grazing

According to the results, land use was more or less the same irrespective of production form. A majority of respondents with larger herds had a combination of natural pastures and arable land, which usually were grazed by animal groups that were moved between different paddocks, whereas set stocked grazing was predominately reported on the smaller farms. In addition, mixed or alternate grazing with cattle and/or horses was common both on conventional and organic farms, although cattle were reported more often on organic (42%) than conventional (17%) farms. It is well known that the grazing strategies aforementioned can help to reduce parasite pressure and thereby reduce reliance on anthelmintics for achieving parasite control (for a review, see Torres-Acosta et al., 2012). However, it was beyond the scope of this study to assess how grazing management strategies contribute to effective parasite control.

Roe deer (*C. capreolus*) are common in Sweden and in the areas where most sheep farms are located, while fallow deer (*D. dama*) and red deer (*C. elaphus*) have a more aggregated distribution in certain regions in south-central Sweden (Götaland and Svealand). This context provides opportunities for parasite transmission between domestic and wildlife hosts. Although there is evidence that, in particular, roe-deer may contribute to the spread of anthelmintic-resistant *H. contortus* (Chintoan-Uta et al., 2014), it must be investigated to what extent this occurs under Swedish conditions.

4.4. Limitations of the study

The questionnaire survey was distributed electronically to all SE-number producers registered to have sheep in Sweden. The above may have generated a bias, but the use of electronic devices is generally high in Sweden. The number of responses was higher in some regions than in others (Fig. 1) but is reflecting the distribution of the Swedish sheep population. Since the response rate was high (31%), it can be assumed that the survey describes the current situation on common practice in a reliable manner. In fact, the number of respondents, the regional coverage and the response rate were higher or comparable with similar studies in other countries (i.e. Sargison and Scott, 2003; Domke et al., 2011). At the same time, it is important to keep in mind that there can be large variations in the level of GIN parasitism between years, and this may have affected the outcome of the survey. The summer of 2018 was

the warmest and driest for several decades and most likely reduced the level of parasitism, which probably resulted in spillover effects into 2019. Another factor to be considered is how the questions were understood by the respondents. However, by including: a clear introduction stating the purpose of the study, user-friendly mostly closed questions, piloting the questionnaires with representatives of the target population, and by utilizing internet/online, response bias was hopefully minimized.

5. Conclusion

The objective of this study was to provide information about the current parasite control measures and the respondent's perception of the risk for GIN on both conventional and organic farms on sheep farms in Sweden. Overall, it can be concluded that the veterinary involvement in providing advice about GIN appears to be high in Sweden. In general, diagnostic examinations were carried out on a relatively large scale and use of anthelmintics was low. Despite this, treatments are not always carried out as required. For example, half of the respondents that drenched their sheep did so routinely without prior diagnosis, in spite of current regulations. We also identified that there is little focus on introduced animals and many of the farmers use uncalibrated dosing guns and dose calculations were often based on visual appraisal which provides opportunities for under-dosing. Thus, there is room for improvement to reduce the risk for development and spread of anthelmintic resistance. Of great interest is also that the differences between the herd size categories were in general more prominent than between production form (conventional and organic). In summary, these results are interesting, not only from a national perspective but also for the wider international community, as they describe how GIN is handled in a situation where society places high demands on animal health and well-being and where sales of anthelmintics to livestock are under prescription.

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Ethical statement

Farmers' participation in the questionnaire was done on a voluntary basis and individual responses have been anonymized. This report does not include any experimentation on animals.

CRediT authorship contribution statement

Peter Halvarsson: Conceptualization, Data curation, Investigation, Formal analysis, Visualization, Writing – original draft. **Katarina Gustafsson:** Writing – review & editing. **Johan Höglund:** Conceptualization, Investigation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vprsr.2022.100713.

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