

Treatment of reindeer with ivermectin - effect on dung insect fauna

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Abstract: Ivermectin is an antiparasitic drug widely used in reindeer (*Rangifer tarandus* (L.)) in Fennoscandia and North America. Most of the ivermectin injected in the animal is excreted unchanged in the faeces. Several reports show that ivermectin in cattle dung disrupts colonisation and survival of beneficial dung breeding insects. The present study investigated the effect of ivermectin on the reindeer dung fauna. Four reindeer calves (males, 6 months of age) were injected subcutaneously with standard doses of ivermectin (0.2 mg/kg body weight) in early December. The daily produced faeces was collected until day 30 after treatment, and the concentration of ivermectin was determined by high pressure liquid chromatography (HPLC) with fluorescence detection. The highest concentration measured (mean 1632 ng/g faeces (dry weight), range 907 to 2261 ng/g among the animals) was on day 4 after treatment. The concentration decreased gradually to 28 ng/g (range 6 to 58 ng/g) on day 30. Faeces portions from day 4 and from untreated reindeer were placed in the field on 2-4 July and recollected on 13-22 September in order to detect possible differences in decomposition fauna between the samples. The most important coprophilous beetles (*Aphodius* spp.) and flies (*Scatophaga* spp.) were not detected in this winter dung whether it contained ivermectin or not, probably because of the dry consistency and small size of the pellets. On the other hand, these insects (larvae and imagines) were common in summer dung, which had been deposited naturally in the field and later placed together with the ivermectin-containing winter dung for comparison. The summer dung has a more soft and lumpy consistency. Treatment in autumn or early winter implies that the bulk of the ivermectin from the animal will be present in faeces with winter consistency, since this bulk portion is excreted during the first 30 days after treatment. This dry and pelleted faeces is not utilized by the important coprophilous insect species, and the current practice of treatment of reindeer with ivermectin in autumn or early winter is therefore the regime representing the least danger of harmful influence on the coprophilous fauna and their contribution to the dung decomposition process.

Key words: *Rangifer tarandus*, faeces, dung, ivermectin, parasite, treatment.

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Introduction

Ivermectin (22,23-dihydroavermectin B₁) is a broad-spectrum anti-parasitic drug introduced onto the market in 1981 (Roncalli, 1989). It is prepared from abamectin, a natural fermentation product of the soil bacterium *Streptomyces avermitilis* (Payne *et al.*, 1995). Ivermectin is effective against many

nematodes, insects and acarines (Roncalli, 1989), and pentastomids (Haugerud *et al.*, 1993; Negrea, 1997). The drug is extensively used on domestic livestock in many parts of the world to control for internal and external parasites (Roncalli, 1989; Forbes, 1993). It is also used in the reindeer industry, in North America (Dieterich & Craigmill,

1990), Fennoscandia (Haugerud *et al.*, 1993) and Russia (Klement'eva, 1987). The main target parasites are the larvae of the warble fly (*Hypoderma* (= *Oedemagena*) *tarandi* (L.)) and the nose bot fly (*Cephenemyia trompe* (Modeer)) (Diptera: Oestridae), and the drug is also effective against nematode species (Nordkvist *et al.*, 1983; Nordkvist *et al.*, 1984; Heggstad, 1988; Norberg, 1989; Haugerud *et al.*, 1993).

Most of the dose given to an animal is excreted unaltered in the faeces (Halley *et al.*, 1989). Studies on cattle show that ivermectin residues in faeces may have a negative effect on the dung fauna (Wall & Strong, 1987; Fincher, 1992; Strong, 1992, 1993; Gunn & Sadd, 1994), and the wide use of ivermectin in reindeer (*Rangifer tarandus*) has given rise to a concern among reindeer herders, veterinarians, environmental authorities as well as the general public, on possible negative ecological effects on reindeer grazing areas, as reflected especially in Norwegian newspapers (Berg, 1991; Tonstad, 1991; Anonymous, 1992).

Little is known about the natural degradation of reindeer dung and the contribution by insects in this process. To our knowledge, the only published report on the coprophilous species utilising reindeer dung is a short faunistic note by Lipkow (1992). Answers to essential questions concerning degradation rate of reindeer dung under the various conditions and the importance of the coprophagous insects and other organisms in this process are still lacking. The concentration of ivermectin in faeces as a function of days after treatment has been investigated in cattle (Sommer *et al.*, 1992; Sommer & Steffansen, 1993; Lumaret *et al.*, 1993; Payne *et al.*, 1995; Herd *et al.*, 1996), but so far not in reindeer.

The present study investigated: 1) How fast and in what quantities is ivermectin delivered through faeces after standard treatment of reindeer; and 2) Does current practice in treatment of reindeer with ivermectin have any effect on the reindeer dung insect fauna?

Materials and methods

Ivermectin residues in reindeer faeces

Seven reindeer calves (males, 6 months of age, mean weight 43.9 kg) were brought in from winter pastures and caged December 3, 1995. On December 7, four of these animals were injected subcutaneously with a standard dose (0.2 mg/kg body weight) of ivermectin (Ivomec veterinary injection 10 mg/ml;

Merck, Sharp & Dohme B. V., Haarlem, Holland). The other three animals remained untreated (controls). The animals were fed only lichens (*Gladina stellaris* (Opiz) Brodo). The daily produced faeces was collected until day 30 after treatment. The samples were stored at -20°C for subsequent determination of ivermectin. The ivermectin concentration was determined by HPLC (Åsbakk *et al.*, 1999) in samples from each of the four treated animals from day 2, 4, 6, 8, 10, 13, 16, 20, 24 and 30 after treatment.

Estimation of decrease of ivermectin concentration in dung under field conditions

Halley *et al.* (1989) reported a rapid decrease of ivermectin concentration in cattle dung under field conditions during the summer (half-life 7-14 days), whereas the rate of decrease during the winter was much lower (half-life 91-217 days). The corresponding decrease rates in reindeer faeces are not known. Based on these rates reported for cattle, we assumed, as a working tool, that the half-lives for ivermectin in reindeer faeces are 217 and 14 days for dung in the winter and summer, respectively. The change between winter and summer was set to May 1. As starting values for the decrease-rate curves in Fig. 2, we used the mean values in Fig. 1 from the analysis of recently delivered faeces from the four treated reindeer. The decrease with time was calculated by the half-life equation

$$y = a \cdot 0.5^{(x/b)}$$

where: y = remaining concentration, a = original concentration, x = time, b = is half-life (217 days from December through April, 14 days from May 1). By means of a spreadsheet we modelled the remaining concentration throughout winter and summer for dung delivered each day from 2 to 30 days after the treatment. The basis was the initial (December) excretion profile in fresh dung (mean values in Fig. 1).

Dung fauna investigation

Samples of dung from day 4 after treatment (highest concentration of ivermectin measured) and from untreated animals (control samples) were placed in the field to see whether there were any differences between the decomposition fauna of the dung with ivermectin and the control dung. Each sample was placed directly on the ground, freely exposed to sunlight and in natural habitats, on July 2-4, 1996.

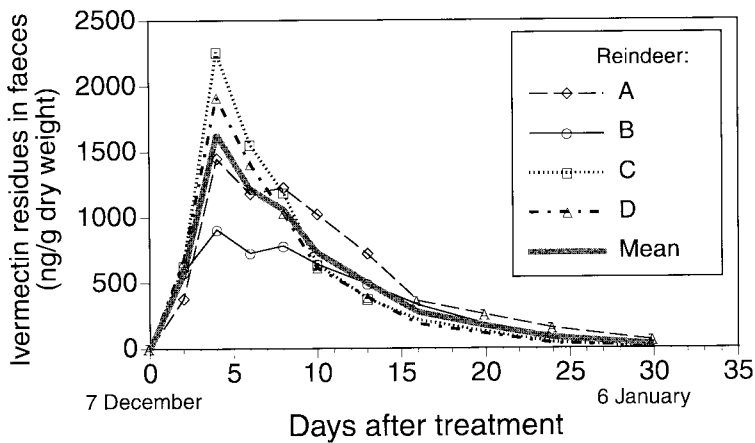


Fig. 1. Excretion profiles of ivermectin in reindeer faeces after treatment with a standard dose of ivermectin (0.2 mg ivermectin/kg body weight, injected subcutaneously). Values for each of the four reindeer and a combined mean value are given.

The disposal sites were: above the tree line at Kvænangsfjellet (69°53'N, 21°30'E; 460 meters above sea level); and in birch forests at Kvaløya and Tromsøya (69°40'N, 18°50'E and 69°37'N, 18°52'E; 80 and 50 meters above sea level, respectively). At each site, portions of faeces (\cong 200 g wet weight each) with ivermectin and controls were placed in pairs spaced 1 meter apart. At Kvænangsfjellet, locally deposited fresh dung (later designated summer-dung) was collected and portions (\cong 200 g wet weight each sample) were placed near the dung from the treated animals for comparison.

The faeces samples (summer and winter dung) were recollected September 13-22, 1996 and brought to the laboratory for investigation of its fauna of decomposers. Care was taken to avoid soil adhering to the faeces. The samples were carefully broken up and scrutinised. While still alive, the total number of invertebrates found in the samples were hand sorted under a dissecting microscope. The summer-dung was examined in the same way. The organisms were identified (usually to family or class), counted and preserved in 70% ethanol.

Results

Ivermectin residues in reindeer faeces

Fig. 1 shows the concentration of ivermectin in the faeces collected from the four treated reindeer. The highest concentration measured was on day four after treatment (mean 1632 ng/g faeces dry weight, with individual variation ranging from 907 to 2261 ng/g). After day four, the concentration decreased,

and on day 30, the concentration had decreased to a mean level of 28 ng/g dry weight (range 6-58 ng/g). The animal with the highest concentration on day 4 (reindeer C) had the lowest level on day 30 (6 ng/g dry weight) (Fig. 1).

Estimated decrease of ivermectin in dung exposed under field conditions

By using half-life times of 217 and 14 days for winter and summer, respectively, we estimated the decrease of the ivermectin concentration in dung exposed to natural conditions in the field from January to August 15 (Fig. 2). The actual half-life times

used for the construction of the model imply that ivermectin disappeared from the faeces at a slow rate during the winter months and faster during the summer. The model shows that on July 15, there will be little ivermectin remaining even in the faeces which initially had the highest concentration (day 4 after treatment) (concentration estimated to 26 ng/g).

Dung fauna investigation

Table 1 shows the invertebrate fauna results for the dung placed under natural field conditions from early July to mid-September 1996. The wet weight of the recollected dung ranged from 14 to 85 g (7 and 42.5% of original weight). The dung consisted of dry and hard single pellets with mean size 11.8 (standard deviation 0.7) x 6.5 (0.7) mm and mean wet weight 262 mg (67) ($n=30$, mixture of pellets from all four treated reindeer). Natural summer dung, on the other hand, was soft and consisted of larger "lumps".

Winter-dung appeared to be unattractive to the coprophilous beetles (Scarabaeidae) and flies (Scathophagidae), and insects from these families were never found in this pelleted dung (Table 1). Other organisms, such as larvae of other small beetles and flies, nematodes, collembolids, chironomids and mites were sometimes found (usually in small numbers), but their degradation ability appeared negligible as indicated by the fact that the dung looked completely untouched and intact after the summer under field conditions. We did not detect any differences in the fauna, nor degree of decompo-

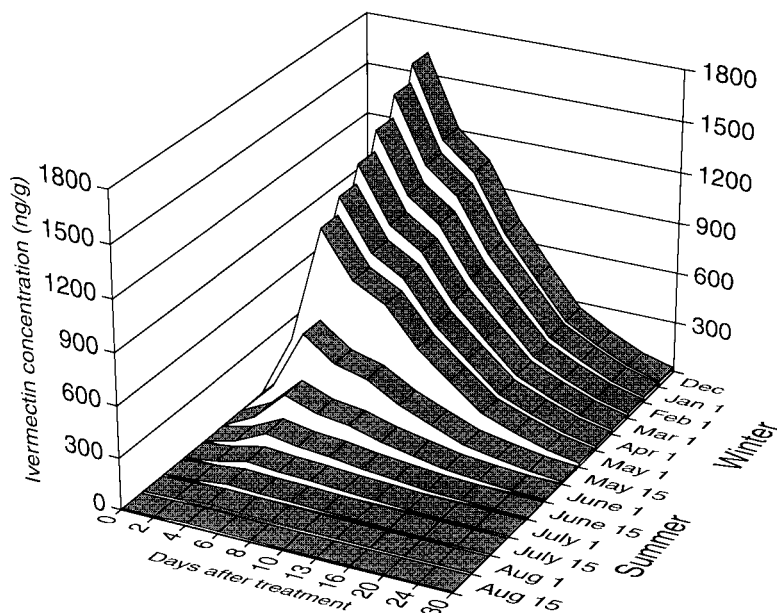


Fig. 2. Estimated decrease of ivermectin concentration in reindeer dung during winter and summer exposure under natural field conditions. The model is based on concentrations determined after treatment on December 1 (mean profile in Fig. 1) and half-lives of 217 and 14 days in winter and summer (after May 1), respectively.

sition, between the dung containing ivermectin and the control dung, apart from the presence of nematodes. Nematodes were usually more numerous in control dung than in dung containing ivermectin (Table 1). The sampling technique used, however, was not suitable for small organisms like nematodes, and the number of nematodes given should therefore be considered only as an indication of their abundance. Earthworms (*Lumbricidae*) were found in considerable numbers in faeces at Tromsøya (the number of these organisms was similar in the samples with ivermectin and in the controls), but not at other sites.

Natural summer dung was colonised by large numbers of dung beetles (predominant species *Aphodius lapponum* Gyllenhall) (see Fig. 3) and dung flies (*Scathophaga* spp.) (Table 1). In most cases, these insects had effectively fragmented or perforated the dung. Also small numbers of the other species of small invertebrates observed in the experimental dung (see above) were present in the summer dung.

Discussion

The discussion on the possible environmental effects of ivermectin has so far focused mainly on cattle dung and its fauna (Roncalli, 1989; Strong &

James, 1992; Wratten *et al.*, 1993; Barth *et al.*, 1994; Barth *et al.*, 1995; Sherratt *et al.*, 1998). There are strong controversies concerning the degree of impact ivermectin may have on pastureland ecology (e.g. Barth, 1993; Strong, 1993; Forbes, 1993; Holter *et al.*, 1994; Wratten *et al.*, 1993; Herd, 1995; Forbes, 1996). The impact of ivermectin on dung insects probably ranges from negligible to catastrophic, depending on factors like manner of administration, time of year, and treatment frequency (see the recent models by Sherratt *et al.* (1998)). The present study illuminates the situation when reindeer are treated with ivermectin.

The chemical analyses of faeces from reindeer treated

with a standard dose of ivermectin revealed that the ivermectin delivered through faeces peaked approximately on day four after treatment (Fig. 1). Thereafter, the ivermectin concentration decreased rapidly, but was still measurable on day 30 after treatment. We did not sample faeces after day 30, however, the curves in Fig. 1 indicate that levels below detectable limits will be reached 35 to 40 days after treatment. This is at least 10 days longer than the values obtained by Dieterich & Craigmill (1990), who analysed ivermectin residues in reindeer tissues after treatment, but similar to the ivermectin profile found in plasma levels (Oksanen *et al.*, 1995).

The excretion profile for ivermectin in reindeer faeces presented here (Fig. 1) is somewhat consistent with curves obtained for cattle. Sommer *et al.* (1992) found a peak concentration of 3810 ng/g two days after treatment, and the concentration decreased to 310 ng/g after 13 to 14 days. Lumaret *et al.* (1993) observed the peak of elimination (4200 ng/g) at day 5, and were unable to detect any ivermectin beyond day 12. Our results, with the highest level of ivermectin in dung 3 to 5 days after treatment, are similar to the findings of Herd *et al.* (1996). They found a peak concentration of 1200 ng/g on day 3 after treatment, followed by a gradual

Table 1. Number of invertebrates collected in reindeer faeces after one summer in the field; total counting, but here given as individuals per 10 grams faeces wet weight for comparison. Portions of faeces (\cong 200 g each) were placed directly on the ground in three natural habitats above and below the tree line on July 2-4, 1996. At each site, faeces with ivermectin (dung from day 4 after treatment, containing 1632 ng ivermectin/g faeces dry weight) and control dung also from day 4, were placed in pairs, spaced 1 meter apart. In addition, summer faeces, recently deposited naturally near the study sites, were used at Kvænangsfjellet. The faeces was recollected September 13-22, 1996.

Kvænangsfjellet (69°53'N, 21°30'E, 460 meter above sea level, above tree line).

Site*	With Ivermectin		Without Ivermectin		Natural summer faeces	
	1	2	1	2	1	2
Weight of faeces (g)	40	41	16	48	85	81
<i>Aphodius</i> larvae	0	0	0	0	4.2	3.82
<i>Aphodius</i> adult	0	0	0	0	0	0.12
Staphylinidae	0	0.2	0	0	0.1	0
<i>Scathophaga</i> larvae	0	0	0	0	13.1	0
Diptera larvae	0	0	0.6	0.6	0	0
Acari	0	0	0.2	0	0.1	0.1
Collembola	0	0.2	0	0.2	0.9	0.1
Nematoda	0.5	0	>20	0	>20	0

*1: Open mountain plateau with grass and heath. 2: Open mountain plateau with heath. Samples (with the same number) were placed \cong 1 meter apart and are comparable.

Kvaløya (69°40'N, 18°50'E, 80 meter above sea level).

Site*	With Ivermectin		Without Ivermectin	
	1	2	1	2
Weight of faeces (g)	28	54	71	32
Coleoptera larvae**	0.36	1.11	0.4	0.6
Diptera larvae	0	0	0.4	1.56
Chironomidae larvae	0.71	3.32	2.41	3.12
Acari	1.07	0.37	0.1	1.56
Collembola	0	1.48	0	0
Nematoda	0.36	\cong 2	\cong 6	\cong 6

*Both 1 & 2 are birch forest. ** Unidentified, but not *Aphodius* spp. Samples (with the same number) were placed \cong 1 meter apart and are comparable.

Tromsøya (69°37'N, 18°52'E, 50 meter above sea level).

Site*	With Ivermectin		Without Ivermectin	
	1	2	1	2
Weight of faeces (g)	20	14	28	31
Chironomidae larvae	0	2.9	0	0.97
Lumbricidae	39.6	36.7	40.7	44.2
Acari	0.51	0.72	0.36	0.32
Gastropoda	0.51	0	0	0
Collembola	4.6	42.4	7.27	7.10
Nematoda	\cong 10	>20	>20	>20

*1: Open meadow. 2: Birch forest. Samples (with the same number) were placed \cong 1 meter apart and are comparable.

decline to 80 ng/g on day 28. Discrepancies between the four studies may have several causes, including technical and biological ones. Cook *et al.* (1996) found that diet affected the excretion profile of ivermectin in cattle faeces. Generally, however, ivermectin in faeces peaks at 2 to 5 days, and decreases to reach levels near zero after 12 to 35 days.

Ivermectin concentrations as low as 10 ng/g (wet weight) are toxic to some dung breeding insects (Strong & James, 1992; Strong, 1993). Therefore, ivermectin concentrations in reindeer dung during the first 30 days after treatment (Fig. 1), are probably high enough to have a lethal or sub-lethal effect on the decomposing fauna. Rein-

deer, however, are normally treated once a year, in late autumn or early winter (Anonymous, 1993; unpubl.), *i. e.* when insects and other decomposers are inactive. In sub-alpine and sub-arctic climates, most insects become active in June or July. What happens to ivermectin residues when the reindeer faeces ages in the field from November-December to June-July? Halley *et al.* (1989; 1993) studied ivermectin degradation in dung under various experimental conditions, and their upper range of values (half-lives of 14 days in summer and 217 days in winter) were used in our model (Fig. 2). Lumaret *et al.* (1993) found that the concentration of ivermectin in decaying cattle dung declined to zero after about 7 days. No ivermectin was found in dung samples after 6-7 days exposure to field conditions (Bernal *et al.*, 1994). By contrast, Sommer & Steffansen (1993) found that the ageing of faeces did not lead to a significant lowering of the ivermectin level through 45 days post-deposition. Obviously, more experiments are necessary to resolve apparent discrepancies and clarify the stability of ivermectin in ageing dung. Strong (1993) and Herd (1995) both argue in review articles that avermectins do not decompose rapidly once dung has been deposited.

There may be important differences in the stability of ivermectin in cattle dung versus reindeer dung. Results indicating that ivermectin is degraded rapidly in faeces/soil mixtures under the influence of sunlight and soil microbes have been presented (Halley *et al.*, 1989). Reindeer dung, in con-

trast to cattle dung, is more or less pelleted during the winter season (see below), and has a high surface to volume ratio. On the other hand, the pellets are very compact and opaque and the interior is thus probably protected from light. The degree to which ivermectin is affected by external influences like light, heat and precipitation (rain, snow) awaits further studies.

Our model, as presented in Fig. 2, illustrates the theoretical decrease in ivermectin concentration when half-life values are set to 217 and 14 days for winter and summer season, respectively. According to the model, the concentration of ivermectin in dung from reindeer treated in December will have reached low levels at the time when the insect activity starts in June-July. It is also essential to note that only a small proportion of a reindeer's annual dung production will be contaminated by the drug, since the animal is treated only once a year. If a treated reindeer produces contaminated dung for one month (Fig. 1), then only 1/12 of the yearly dung volume should have the potential of being harmful to the decomposer fauna. The proportion will be even smaller if not all reindeer are being treated (e.g. in Norway often only calves are treated), or if reindeer consume less food in winter than in summer.

We can read from Table 1 that the dung produced by calves in winter with a diet of lichens is unsuitable for the important (large) coprophilous beetles and flies, and consequently the use of it by the insects is very limited. One reason seems obvious. Winter dung consists of small dry pellets or "pearls" (Fig. 3). Summer dung is usually softer, consisting of large moist lumps. Thus, the winter faeces are too fragmented and dry to be attractive to most coprophilous beetles and flies. Petra Hirschberger (pers. comm.) had similar results with pelleted sheep dung. There are, however, small insects that are able to use small pelleted faeces (Table 1; A.C. Nilssen, unpubl.). Lipkow (1992) found individuals of Ptiliidae, the world's smallest beetles, in reindeer faeces in northern Finland, but such

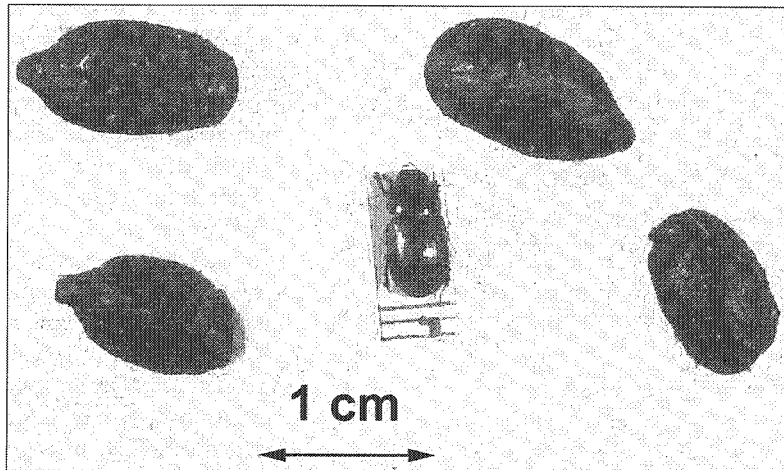


Fig. 3. Winter dung from the experimental reindeer. For comparison of size, a pinned specimen of the dung beetle *Aphodius lapponum* is also shown. This species is one of the most common dung beetles in reindeer summer dung, but it was never found in pelleted dung, probably because the beetle find each unit of dung too small.

small insects probably play a secondary role in the decomposition process.

Further study is needed to elucidate the differences between winter dung and summer dung and the influence of diet and water availability on the consistency of the faeces. The faeces may be less pelleted if the reindeer graze herbs and other plants in addition to lichens, and possibly adult reindeer produce dung different from calves.

It has been observed that dung is attractive to the majority of coprophilous insect species for a limited time only, i.e. attractivity decreases with time (Skidmore, 1991). The dung flies *Scathophaga* spp. can use only fresh (few hours old) dung pats for oviposition, while the dung beetles *Aphodius* spp. only feed on relatively fresh pats before laying eggs (Hirschberger, 1996). Sherratt *et al.* (1998), who modelled the impact of ivermectin on dung insects, regarded the faeces as attractive for only 7 days in North Europe. Accordingly, reindeer dung deposited months ago is not useful for these important initial decomposers, and probably the decomposition of this kind of reindeer dung is mostly caused by weathering (rain, frost), trampling by the reindeer themselves, micro fauna (e.g. nematodes, collemboles, mites, small beetles, see Table 1), fungi and bacteria. In certain habitats, earthworms (Lumbricidae) are obviously important (Table 1). Ivermectin may have a negative effect on some of these small organisms (insects, nematodes, and earthworms), but in our limited experiment, we could not detect any difference in decomposition level between ivermectin containing dung and control dung (Table 1).

Natural summer faeces, however, was readily invaded by *Aphodius* spp. and *Scathophaga* spp. (Table 1). The density, especially of *Aphodius lapponum*, was sometimes very high (Table 1; A.C. Nilssen, unpubl.). Therefore by summer's end, this dung type was substantially fragmented, and this important first step in the degradation process seemed well established.

With the current practice of treating the reindeer once a year in autumn or early winter, summer dung will not be contaminated with ivermectin, and will thus not interfere with the natural degradation process, at least the part of it caused by the large coprophilous insects. The contaminated winter dung, which may have lost most of its ivermectin content when the summer arrives (Fig. 2), is not useful for the most important coprophilous beetles and flies, regardless of the presence or absence of

ivermectin. The degradation of ivermectin in reindeer faeces caused by sunlight, temperature fluctuations, and precipitation awaits further studies.

Although there are reasons for moderating the use of ivermectin in the reindeer industry (e.g. Haugerud, 1988, 1989, 1990, 1999; Haugerud *et al.*, 1993), a negative impact on the most important decomposition insects is not one of them, since impact will be negligible if the current treatment practice is continued.

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