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Prolonged Persistence of Fecally Excreted Ivermectin from Reindeer in a Sub-Arctic Environment

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In December 2001 and 2002, feces from reindeer calves treated with ivermectin were distributed on plots established on two types of forested reindeer pasture in northern Finland. The ungrazed plots were on an enclosure that had been fenced to prevent reindeer access for the last 6 years. The grazed plots were on an area that had been heavily stocked by reindeer during the last 5 years. After enclosures had been established, reindeer and large wildlife were prevented from entering by a fence. Topsoil samples (feces, vegetation, and soil) were collected monthly during the summers of the following 2 years, over a period of from 25 to 95 weeks after deposition. The samples were analyzed for ivermectin using HPLC. Although ivermectin degradation rapidly took place during the first spring, considerable residual ivermectin could be measured throughout the sampling time, showing that ivermectin in feces on pasture may not be photodegraded as rapidly as previously believed. The results support the need for further environmental evaluation studies on the use of ivermectin to control reindeer parasites.

KEYWORDS: Residues; environmental impact; soil; microarthropods; anthelmintics; *Hypoderma*; *Rangifer*

INTRODUCTION

Ivermectin (22,23-dihydroavermectin B1) is a broad-spectrum antiparasitic drug in worldwide use for the control of internal and external parasites in production livestock (*1*), including reindeer (*2*). Most of the drug is excreted unaltered in the feces irrespective of route of administration (*3*, *4*). Ivermectin is highly lipophilic, with correspondingly low solubility in water (*5*), binding strongly to particulate material in feces, with very little leaching or elution induced by rain (*3*, *6*). It is not phytotoxic, antibacterial, or antifungal, is practically immobile in soil, and there is little uptake by plants (*5*, *7*). When present in water or as thin films on surfaces, ivermectin is rapidly photodegraded to less bioactive compounds (*7*).

After the introduction of ivermectin to the marketplace in 1981, there has been concern about possible impacts of excreted ivermectin on nontarget organisms, such as soil or dung dwelling fauna, and thus also pertaining to dung degradation and nutrient cycling (e.g., ref *8*). With the lapse in patent protection in the late 1990s, ivermectin is now open to generic manufacture, leading to less expensive products and thus the likelihood of greater use. The environmental impact of the drug remains an issue of continued controversy (e.g., ref *9*).

Ivermectin treatment of reindeer is targeted at the larval stages of the warble fly (*Hypoderma tarandi*) and throat bot fly (*Cephenemyia trompe*) and various nematode species (*10*). A large proportion (>80% in some locations) of reindeer in northern areas of Finland, Norway, and Sweden is treated with ivermectin once annually, during the winter round-ups between October and February. This early winter treatment recommendation is based mainly on the understanding that the larvae of the flies will be targeted before they cause excessive harm to the host and at the latest before their spring pupation. Summer antiparasitic treatment is not commonly practiced since it is managerially difficult with the free ranging reindeer herds and also is considered epidemiologically inappropriate (*9*).

Following treatment of reindeer with ivermectin by subcutaneous injection, the fecal concentration increase to a maximum around day four after treatment, followed by gradual decrease, and residual levels can still be detected more than 30 days after treatment (*11*). Feces from treated reindeer thus lead to high local concentrations of ivermectin in the field.

There are discrepancies concerning the degradation of fecally excreted ivermectin. For instance, Lumaret et al. (*12*) reported

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concentrations of ivermectin in dung from cattle to be reduced to zero about 7 days after treatment, whereas Sommer and Steffansen (*6*) found no apparent degradation of ivermectin in cattle dung on pasture over a 45-day period of aging under both temperate and tropical conditions. With the exception of Nilssen et al. (*11*), there are no other published reports on the persistence of fecally excreted ivermectin from reindeer on pasture. This study addresses the issue of persistence in reindeer dung on natural reindeer pasture.

MATERIALS AND METHODS

Animals and Treatments. In November 2001, eight 25-week-old female reindeer calves, obtained from the Finnish Reindeer Herders' Association Field Station herd, Kaamanen, Finland, were retained indoors and fed lichen ad libitum. The daily fecal production was collected during a 2-week period, pooled, and stored at 4 °C (control-dung-01). One week later, the calves received ivermectin by subcutaneous injection (Ivomec 10 mg/mL vet. injection; Merial Inc., Haarlem, Holland) or by the oral route (Ivomec 0.8 mg/mL vet. mixture, Merial). The dose rate was 200 μg of ivermectin/kg of body mass as recommended by the manufacturer. The daily fecal production from each treatment group was collected during the first 9 days following treatment and pooled in two bags (IVM-01 oral and IVM-01 SC) and stored at 4 °C for subsequent distribution on experimental plots.

In November 2002, the feed and ivermectin treatment regime was repeated with another set of eight reindeer calves, and feces were collected resulting in control-dung-02 and ivermectin treatment group dung (IVM-02 oral and IVM-02 SC).

Experimental Plots and Study Area. In December 2001, 1 m × 1 m plots were established in two separate enclosures of a forested reindeer pasture of the Reindeer Research Station in Kaamanen, Finland (69° N, 27° E): one fenced to prevent reindeer access (ungrazed) since 1995, the other (grazed) on an area that had been heavily stocked by reindeer for 5 years up until the commencement of the experiment. The plots within each area were located 1−5 m away from each other and delimited by a survey stake in each corner. A 2.5 m high wooden fence delimited each of the enclosures, preventing reindeer and large wildlife from entering.

The vegetation of both enclosures was dominated by approximately 100-year-old pine, *Pinus sylvestris*. On the ungrazed enclosure, there was reindeer lichen (*Cladina* spp.), moss (*Pleurozium* spp., *Dicranum* spp., and *Polyrihum* spp), lingonberry (*Vaccinium vitis-idaéa*), blueberry (*Vaccinium myrtillus*), heath (*Calluna vulgaris*), Labrador tea (*Ledum palustre*), crowberry (*Empetrum nigrum*), and a variety of fungi. The grazed enclosure had a sparse vegetation of heath, shrubs, and moss, and reindeer lichen was absent.

Meteorology. The Finnish Meteorological Institute provided the precipitation data from the airport at Ivalo and temperature and sunlight hours from the township of Kevo. Both localities are within 80 km from Kaamanen. Snow depth and ambient temperature were measured at the Reindeer Research Station in Kaamanen.

Distribution of Feces on Plots. On December 5, 2001, 400 g/plot of each of the IVM-01 oral dung, IVM-01 SC dung, and control-dung-01 was distributed on one plot each at the ungrazed and grazed enclosure. This amount per plot is comparable to what would be deposited on an area with a few reindeer roaming during the year. In addition, one plot on each enclosure was designated as a true control void of all feces (no-dung-01 plots). On December 11, 2002, 5 kg/plot of each of the IVM-02 oral dung, IVM-02 SC dung, and control-dung-02 was distributed on one plot each of the ungrazed and grazed enclosures. This amount per plot represents a heavy load per area unit, comparable to what would be deposited on an area densely populated with reindeer, such as on areas where reindeer are gathered in corrals for winter confinement and antiparasitic treatment. Both years, 10−20 cm of snow covered the experimental area at the time of fecal deposition. The feces were evenly distributed between the delimiting survey stakes to ensure, as far as possible, that it would remain within the plot boundaries. Some of the plots had sloping gradients, and observation by subsequent sampling times showed that the feces tended to settle toward the lower parts.

Soil Sampling Procedure. A 1 m^2 point frame was used as a guide to locate sampling points previously determined using random numbers. With a 10 cm × 10 cm square stainless steel soil corer, two subsamples were taken to a depth of 5 cm from each plot at each sampling time. Samples were located at least 10 cm away from each other. Each sample included feces, vegetation, and soil. Feces comprised a minor and varying part of the total weight or volume.

For the plots with dung from 2001, sampling times were in May, July, and September 2002 and in June, July, August, and October 2003, spanning 25−95 weeks after fecal deposition. For the plots with dung deposited in 2002, sampling times were in June, July, August, and October 2003 and in June, July, August, and October 2004, spanning 25−95 weeks after fecal deposition. The samples were stored in plastic bags at −20 °C for subsequent determination of ivermectin.

Determination of Ivermectin. The ivermectin concentration in feces was determined by HPLC using abamectin as an internal standard (*13*). Concentrations in composite (soil corer) samples were determined using the same method, with the only modification being that after thawing at room temperature, 10 g of wet weight of the sample was used for analysis instead of 1 g of feces. Prior to weighing, samples were thoroughly mixed in their plastic bags, and pebbles >3−5 mm in size were removed. The heterogeneity of samples was great due to varying amounts of humus and mineral particles, vegetation components (pine needles, lichens, moss, grass, etc.), and reindeer feces.

Calculation of ivermectin concentration was based on linear calibration lines for the concentration ranges of 2−100 and 100−500 ng/portion found after analysis of a range of ivermectin standards in samples from no-dung-01 plots. Concentrations were recorded as nanograms of ivermectin/g of dry weight sample, according to Åsbakk et al. (*13*). All samples were analyzed in a blind manner, only with random numbers on sample bags and no further information available until after all samples had been analyzed. However, after the 40 control plot (no-dung and control-dung plots) samples devoid of ivermectin had been analyzed, the remaining samples from control plots were identified and removed from the pool of samples to be analyzed. For the sampling times in 2002 for plots with dung deposited in 2001, only one of the two subsamples from each plot and time was available for the analysis work.

Concentration of Ivermectin in Feces Deposited on Plots. The mixing of the contents of each of the bags with the composite dung samples consisted of end-over-end shaking by hand. Fecal pellets were mechanically not substantially broken down by this form of mixing. Four subsamples of each of the IVM-02 oral and the IVM-02 SC dung prior to deposition on plots were analyzed. For the IVM-02 oral dung subsamples, concentrations were determined to 119, 179, 1555, and 2335 ng/g of dry weight feces, and for the IVM-02 SC dung subsamples, concentrations were 7, 10, 49, and 70 ng/g of dry weight feces. Concentrations for the IVM-01 dung (oral and SC) before deposition on plots were not obtained.

Statistical Calculations. Ivermectin concentrations in groups of subsamples were compared using Student's *t*-test. Pearson's *r* statistic was used to check for any correlation between time of stay of feces on experimental plots and residual levels of ivermectin.

RESULTS

Ivermectin Analysis. The retention times for the B_{1a} peaks of abamectin and ivermectin (*13*) were approximately 4.8 and 7.2 min, respectively, as evidenced from the analysis of samples from no-dung-01 plots fortified with ivermectin and abamectin. All chromatogram peaks were well-separated, making identification of peaks and concentration calculations unequivocal. The combined analysis results for the control samples showed that there were no components present in the soil or feces giving peaks interfering to any significant extent with the abamectin or ivermectin peaks (**Figure 1**).

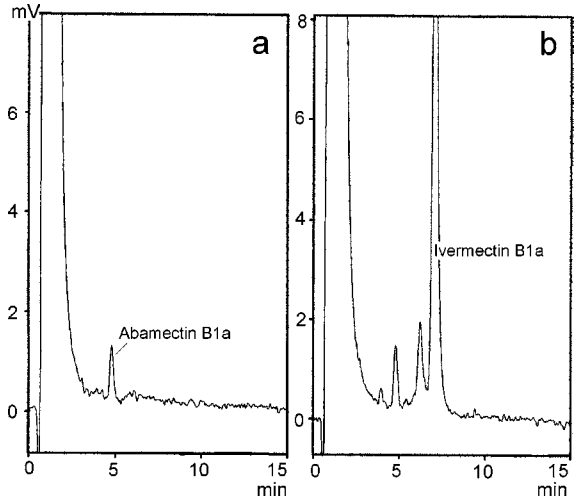

Figure 1. Typical HPLC chromatograms. Sample with no ivermectin, from plot with control dung (**A**) and sample with relatively low ivermectin concentration, 66 ng/g of dry weight (**B**). Retention time in minutes, detector response in mV. The $B1_a$ peaks for each of the abamectin and ivermectin are indicated.

Control Plots. Six no-dung-01 plot samples and 34 control-dung plot samples (24 from control-dung-01 plots, 10 from control-dung-02 plots, ungrazed, and grazed enclosures) were analyzed (**Table 1**). Of these 40, ivermectin was absent in 38, while the latter two concentrations were determined to be 2.1 and 16 ng/g of dry weight, respectively. The two were from the same plot of the ungrazed area, from June 2003 (77 weeks after deposition) and October 2003 (95 weeks after deposition).

Plots with Dung Deposited in 2001. The results for the 44 IVM-01 oral and SC plot samples analyzed are shown in **Table 2**.

Plots with Dung Deposited in 2002. Table 3 gives the results for the 60 IVM-02 oral and SC plot samples analyzed. Student's *t*-test revealed a significant difference between the concentration of the June 2003 subsamples from the ungrazed (oral and SC) plots as one group and the subsamples from the grazed (oral and SC) plots as another group ($p = 0.01$). Pearson's r statistic showed that there was no significant reduction ($r = 0.27$) in the mean of the levels for the eight subsamples (ungrazed and grazed, oral and SC) during the period from July 2003 (time zero in calculation) to August 2004 (13 months in calculation). **Figure 2** shows the mean of the levels for the eight subsamples from June 2003 to August 2004 together with standard deviations.

Meteorology and Plot Observations. Meteorological data for the period of May 2002 to December 2004 are given in **Figure 3**. Snow cover was present from September to October and until May to early June, with maximum depths of nearly

Table 1. Ivermectin (ng/g Dry Weight) in Control Plot Samples

	2002			2003		
plot	May (25)[a]	July (34)	September (39)	June (77)	July (82)	October (95)
no-dung-01, ungrazed or grazed	0 ($n = 2$)	0 ($n = 2$)	0 ($n = 2$)			
control-dung-01, ungrazed or grazed	0 ($n = 4$)	0 ($n = 4$)	0 ($n = 4$)			
control-dung-02, ungrazed				0 ($n = 3$)	0 ($n = 3$)	0 ($n = 3$)
				16 ($n = 1$)		2.1 ($n = 1$)
control-dung-02, grazed				0 ($n = 4$)	0 ($n = 3$)	0 ($n = 4$)

[a] Weeks after deposition.

Table 2. Ivermectin (ng/g Dry Weight) in Samples from Plots with Dung Deposited in 2001

		2002			2003			
	plot	May (25)[a]	July (34)	September (39)	June (77)	July (82)	August (87)	October (95)
ungrazed	IVM-01 oral	3.2	12	1.0	4.0	0 ($n = 2$)	0 ($n = 2$)	4.5
					28			28
	IVM-01 SC	0.4	16	21	12	0	16	3.6
					23	9.0	0	14
grazed	IVM-01 oral	3.9	10	8.6	0	0 ($n = 2$)	0 ($n = 2$)	3.9
					36			23
	IVM-01 SC	0	6.1	0.4	1.3	0 ($n = 2$)	0 ($n = 2$)	0
					3.2			5.6

[a] Weeks after deposition.

Table 3. Ivermectin (ng/g Dry Weight) in Samples from Plots with Dung Deposited in 2002

		2003				2004			
	plot	June (25)[a]	July (29)	August (34)	October (42)	June (80)	July (84)	August (87)	October (95)
ungrazed	IVM-02 oral	368	34	139	259	153	31	41	88
		557	22	24	56	264	167	252	21
	IVM-02 SC	515	147	44	282	100	39	65	19
		254	22	43	95	301	0	250	17
grazed	IVM-02 oral	113	147	86	268	22	258	35	n.d.[b]
		143	144	94	70	650	145	145	
	IVM-02 SC	66	17	302	213	2.7	93	64	n.d.
		111	60	47	163	0	84	34	

[a] Weeks after deposition. [b] Not determined.

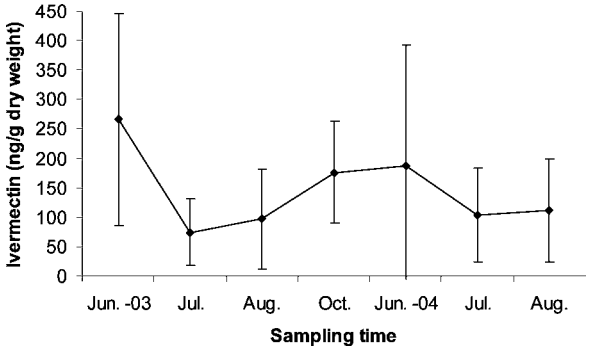

Figure 2. Mean and standard deviation for ivermectin concentrations of the eight subsamples (ungrazed and grazed plots, oral and SC treatment) by the different sampling times until August 2004 (October, with only four subsamples, was omitted from figure) for plots with dung deposited in December 2002.

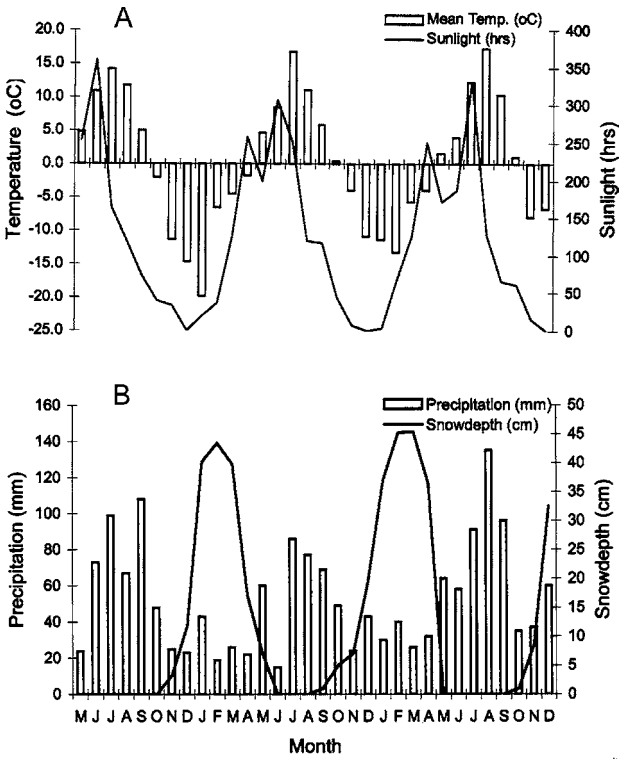

Figure 3. Meteorological data. Precipitation data from the airport at Ivalo, temperature and sunlight hours from Kevo, and precipitation and snow depth from the Reindeer Research Station in Kaamanen. (**A**) Mean monthly ambient temperature and total monthly sunlight. (**B**) Total monthly precipitation (rain + snow) and monthly snow depth. The *x*-axis represents consecutive months beginning in May 2002 and ending in December 2004.

45 cm in February and March. Below zero temperatures were common from October to April, with the lowest temperatures in January (below −40 °C). Maximum temperatures were in July, exceeding 20 °C. At this latitude, there is 24 h of sunlight between mid-May and late July.

Visual observation showed that by the time the first sampling took place immediately after spring thaw, fecal material on all plots was moist, pelleted, and did not appear to have broken down. With increasing day length and sunshine hours, feces became dry, hard masses.

DISCUSSION

Topsoil samples from ungrazed and grazed enclosures of the reindeer pasture with evenly distributed feces from reindeer calves treated orally or subcutaneously with ivermectin, or with control feces from untreated calves, were analyzed by HPLC. Although each bulk of fecal material distributed on plots (IVM-02 oral and IVM-02 SC) was mixed before use, four subsamples of the IVM-02 SC bulk showed ivermectin concentrations from 7 to 70 (mean 34) ng/g of dry feces, and four subsamples from the IVM-02 oral bulk showed concentrations of from 119 to 2335 (mean 1047) ng/g of dry feces. The dung consisted of small and loosely packed pellets that mostly remained intact after the mixing, and since it was collected over a 9 day period following treatment, there would have been pellets with near zero concentrations (day 1 posttreatment, p.t.) and pellets with high concentrations (e.g., days 3−5 p.t.) (*11*). The great variation between subsamples from the same bulk can most likely be explained in terms of the small amount (1 g) analyzed. Each 1 g of sample consisted of a few pellets, each with either low, medium, or high concentration. The difference between the IVM-02 oral and the IVM-02 SC bulk results may be explained partly by differences in excretion profiles. Following oral (intraruminal) administration of ivermectin to sheep, most of the dose was not absorbed to the body (*14*) but rather bound to the ingesta, leading to more rapid excretion than after subcutaneous administration. Similar absorption differences can be seen in the reindeer (*15*). According to previously reported concentrations in dung from reindeer treated with ivermectin (*11*), and supported by the results presented here for the various plots, it is evident that considerable amounts of dung-excreted ivermectin were distributed on the plots, but distribution in terms of amount of ivermectin has obviously been uneven within each plot and between plots. The uneven distribution within the dung distributed on the plots was evident also by the great variation in concentration between subsamples from each plot at the various sampling times. The heterogeneity of the topsoil samples, each consisting of different amounts of humus, mineral soil, feces, and herbage, obviously also contributed to the variation between subsamples. Also, the tendency of settling of feces toward the lower parts of plots with sloping gradients may have contributed to the differences in measured levels. During the collecting and mixing of dung samples prior to distribution on plots, some pellets would inevitably be mechanically disintegrated, and uneven distribution with respect to pellet degradation on the plots would also contribute to concentration differences since ivermectin in comminuted pellets would be more exposed to photodegradation.

Of the total of 40 samples from control plots analyzed, 38 showed zero concentration of ivermectin, demonstrating that there were no components in those samples interfering with the ivermectin peak of the chromatograms. Two, however, showed concentrations of 2.1 and 16 ng/g, respectively. Both were from a plot of the ungrazed area, and contamination of the area with ivermectin-containing feces prior to or after deposition on plots can therefore be excluded as an explanation for the ivermectin levels. An alternative explanation could be that the feces had been contaminated with ivermectin-containing pellets during the collection. The explanation is, however, most likely to be found as part of the ivermectin analysis procedure itself. Samples were run on HPLC in groups of five, with intermittent time of sample preparation for each five sample group between HPLC runs. The 16 ng control sample was run as the fifth sample in the first group of five after the HPLC analysis work had started. The sample analyzed on the apparatus prior to this one showed a very high level of ivermectin (557 ng/g), and therefore, the most likely explanation is that there has been a spill-over from this sample to the subsequent sample due to insufficient washing

of the sample injection syringe and needle. Samples 1−3 of this first five sample group all had high levels of ivermectin (254−515 ng/g), so insufficient washing resulting in ivermectin residues in the syringe in the range of 16 ng/g would have relatively little effect on results for these samples. However, after analysis of this first group of samples, control HPLC runs where acetonitrile alone was injected showed low levels of remnants in the injection device from the previous sample injected. After this, the number of washing cycles was sufficiently extended. Reanalysis would probably have resolved this discussion. The 2.1 ng control was part of a group of five samples where the peak height for the abamectin internal control was very low as compared to the abamectin peak of all other samples analyzed. This was most likely due to accidental addition of too little volume of abamectin solution to the samples. The height of the peak corresponding to the ivermectin peak of the chromatogram was very low, virtually not higher than peaks that normally would be interpreted as noise in chromatograms with a more normal height of the internal control peak. Thus, normally, this peak would not have been interpreted as ivermectin. The finding that this whole group of five samples showed these low internal control peak heights was not clearly discovered until after the completion of the analysis work, and the samples were unfortunately not reanalyzed. The other samples of this five sample group all showed zero concentrations.

For the plots established in 2002, by June 2003, approximately 6 months after distribution of feces, concentrations for the four IVM-02 ungrazed plot (oral and SC) subsamples ranged between 254 and 557 ng/g of dry weight (mean 423), and for the four subsamples representing the IVM-02 grazed plots (oral and SC), concentrations ranged between 66 and 143 ng/g (mean 108). Student's *t*-test revealed that concentrations for the ungrazed plot subsamples as one group were significantly higher than concentrations for the grazed plot subsamples as a group. This could have resulted from a higher rate of photodegradation on the grazed area during late winter and early spring due to the more abundant lichen and other vegetation on the ungrazed plots, with dung pellets buried in prostrate vegetation. According to the meteorological data, there could have been some days before the sampling in June where plots were free from snow cover. Another factor contributing to the explanation of the lower degradation on the ungrazed enclosure could be that the presence of light colored reindeer lichen on this enclosure could make the snow cover persist longer than on the generally darker surface of the lichen-free grazed enclosure. A third factor that may also have contributed to the higher rate of degradation on the grazed enclosure could be accelerated weathering and mechanical breakdown of dung pellets due to greater exposure to wind and rain erosion of pellets not buried in vegetation. Weathering, livestock trampling, and disturbance by birds contribute to the rate of livestock dung degradation (*7*).

By July and August 2003, levels on the ungrazed plots had declined so that the mean of the levels was similar for the ungrazed and grazed plot samples. The highest concentration determined, 650 ng/g, was in June 2004, 80 weeks after deposition, in a sample from a grazed plot. During the entire period of approximately 20 months from December 2002 to August 2004, the mean concentration for each set of eight subsamples by each sampling time was higher than 74 ng/g, and mean levels did not decrease significantly from July 2003 until August 2004. The results for the concentrations on the plots established in 2001, with no obvious decrease in concentrations over the time of the study as inferred from the different single sample results, supported the results for the plots established in 2002. The results clearly show that considerable amounts of ivermectin can persist in the reindeer pasture for a time exceeding two grazing seasons following treatment and thus for considerably longer time than shown in any earlier reported study.

It is well-documented that ivermectin residues in feces of livestock may have detrimental effects on several species of dung-dwelling insects such as various species of *Diptera* and *Coleoptera*, particularly their larval stages (*4*, *16*, *17*). The effects, which range from being sublethal to lethal (*8*), may result in retarded rates of dung degradation (*18*). It has, however, also been shown that dung from cattle treated with ivermectin can degrade normally (*19*). Many studies on the impact of ivermectin on dung fauna and dung degradation were conducted in temperate climatic zones of the northern hemisphere, where earthworms play a major role in the degradation process (*20*). Several of these studies concluded that following typical usage of ivermectin in cattle, there was no adverse effect on the survival and growth of earthworms (e.g., *Lumbricus terrestris*) (*3*, *7*, *21*). Thus, where earthworms are abundant, detrimental effects of fecally excreted ivermectin on the activity of insect larvae in dung pats may be overridden by the effect of earthworms (*18*).

Barth et al. (*16*) found that numbers of some dung-specific saprophytic nematodes were reduced in pats from cattle treated with ivermectin. They registered no toxic effects on soil nematodes that invaded the pats. Similarly, there were no toxic effects on the soil nematode *Pristionchus maupasi* in naturally excreted concentrations of ivermectin in cattle feces (*22*). Yeates et al. (*23*, *24*) found no detrimental effects on total numbers, diversity, or functional groups of nematodes from fecally excreted ivermectin from cattle. Results of a companion study to this investigation indicate that fecally excreted ivermectin from reindeer had no detectable negative effects on the soil nematode communities beneath the dung (*9*).

The arctic soil faunal composition is characterized by reduced species diversity as compared to more temperate regions. In the Arctic, earthworms are scarce or absent, and springtails (*Collembola*), mites (*Acari*), enchytraeids (*Annelida*: *Oligochaeta*: *Enchytraeidae*), and nematodes (*Nematoda*) are particularly important in the decomposition of organic matter and nutrient cycling (*25*). Mites and springtails disperse detritus particles and feed on microorganisms (*26*), and the abundance of springtails may reach up to several million/m^2. The highest biomasses of springtails have been demonstrated on the tundra biome (*25*), but the biodiversity also of springtails is characteristically low in arctic regions. Enchytraeids are part of the saprophageous fauna of the litter and upper layer of mineral soils, and also the largest populations of enchytraeids have been found in cold to temperate habitats (*27*). Through their feeding activity and digging ability, they promote a fine-grained structure of surface soil layers that improve aeration and water drainage. Also, soil nematode diversity is low in the arctic (*28*). If one or more species of these few and important organism groups are particularly vulnerable to soil ivermectin residues, the ecological impact may be more pronounced than in ecosystems with a higher species diversity.

Since the antiparasitic treatment of reindeer is normally done in early winter, the feces with ivermectin are usually deposited on frozen ground where the presence or activity by most insects is excluded. In addition, egg-laying adults of coprophilic dung beetles and flies are attracted only to freshly deposited dung (*29*). Reindeer winter dung consists of small (11−12 mm) dry

pellets that appear to be unattractive for most coprophilic beetles and flies in the subsequent warmer seasons. These insects therefore play insignificant roles in the degradation of dung from reindeer after winter treatment (*11*).

Because of photodegradation, it would be reasonable to assume that fecally excreted ivermectin on pastures would disappear during the subsequent summer under light regimes such as in Kaamanen and other northern sites (24 h daylight during summer months). In contrast to the considerable amount of information available on the impact of fecally excreted ivermectin residues on coprophilic organisms in more environmentally equitable climates, very little is known of possible impacts in relation to springtails, mites, and enchytraeids of Arctic and sub-Arctic ecosystems. Because of the hydrophobicity of ivermectin, the drug will remain bound to the fecal organic matter in pastures (*3*). In the opaque reindeer dung pellet, ivermectin will be protected from photodegradation, as has been demonstrated under more temperate conditions for ivermectin within pats or in dung stored below ground by dung beetles (*8*). It can thus be speculated that ivermectin in interior parts of intact reindeer dung pellets can remain largely unchanged as long as the dung is not mechanically degraded.

A report on two soil dwelling species, the springtail *Folsomia fimetara* and the enchytraeid *Enchytraeus crypticus* (*30*), demonstrated a threshold value for the toxicity of ivermectin (10% reduced reproduction or EC10 values) to the springtail of 0.26 mg/kg (260 ng/g) of dry soil. The threshold value for the enchytraeid was higher. The value for the springtail is within the range of sample concentrations determined in the present study. Thus, there are strong grounds to support the need for further environmental evaluation studies on the use of ivermectin to control the parasites of reindeer.

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