Threat of an invasive parasitic fly, the deer ked (Lipoptena cervi), to the reindeer (Rangifer tarandus tarandus): experimental infection and treatment

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Range expansion of ectoparasites can cause parasites to attack new host species. In these cases it is important for the parasite to be able to adapt to the new environment and to reproduce on the host. For the host, it is crucial to hinder successfully the development of long-lasting parasitic relationship. The deer ked (Lipoptena cervi) is a novel ectoparasite for northern cervids. We investigated if the deer ked can use the reindeer (Rangifer tarandus) as a host and, if it can, whether antiparasitic treatment against this parasite would be available. Three groups of reindeer were monitored: two groups of 6 reindeer were infected with 300 flies per each individual; a control group comprised 6 animals. One of the infected groups was treated with subcutaneous ivermectin. At the end of the experiment the infestation rate of the infected animals was low. The reindeer in the non-treated group had both live and dead deer keds and also a single pupa while the ivermectin-treated reindeer had only dead deer keds. As some deer keds survived and reproduced, the deer ked can potentially use the reindeer as a host but antiparasitic treatment may be effective against this parasite.

Introduction

Invasion or range expansion of parasites requires that suitable hosts are available, as parasites cannot exist in isolation from their hosts (Wall 2007). Free-living invasive species have different
Arthropod parasites are usually ectoparasites. The deer ked (Lipoptena cervi) is an ectoparasitic louse fly capable of infecting various cervids (Haarløv 1964, Kaunisto et al. 2009). It was detected in south-eastern Finland in the 1960s, presumably originating from Russia and since then it has been spreading towards larger areas in Finland (Hackman 1977, Kaitala et al. 2009). According to Reunala et al. (1980) Linné described the deer ked in Sweden in the 18th century. This louse fly entered Norway from the south-east in 1983 (Ottesen 2007). In Finland, the principal host of the deer ked is the moose (Alces alces), usually with 2000–10 000 parasites per host in areas, where the deer ked is abundant (T. Paakkonen unpubl. data). The moose has been a beneficial host species for the deer ked allowing it to widen its distribution, as cervids are known to migrate long distances (Cederlund & Liberg 1995). As the deer ked has spread rapidly towards the northern latitudes in Finland, it can be considered a host-dependent invasive species (Hackman et al. 1983, Kaitala et al. 2009). At present, the northern distribution limit of this louse fly is in the southern part of the Finnish reindeer herding area, at approximately 65°N (Kaitala et al. 2009) but there have been occasional discoveries in areas situated two hundred kilometres further north. Outside the current range of the deer ked, there are suitable climatic conditions and environments, where pupal development would be possible and suitable hosts available (Härkönen et al. 2010).

In addition to the moose, the deer ked can utilize, e.g., the roe deer (Capreolus capreolus) and the red deer (Cervus elaphus) as hosts (Ivanov 1974). Samples collected recently from skins of Finnish wild forest reindeer (Rangifer tarandus fennicus) and their bedding sites on the snow contained deer keds or a few pupae, and the same was also observed for semi-domesticated reindeer (R. t. tarandus) in the southern part of the reindeer herding area (Kaunisto et al. 2009). Previously, Kettle and Utsi (1955) observed reindeer infested with deer keds in Scotland. Moreover, Ivanov (1981) reported that deer keds could also infect cattle (Bos taurus), sheep (Ovis aries) and horses (Equus caballus) that grazed the forests in Belarus. The numbers of keds on cattle varied between 166 ± 12 and 315 ± 9 in 1973–1979 and 5–10 keds/cow were sufficient to cause restlessness to the hosts.

The deer ked and some other louse flies differ from most other ectoparasites because they shed their wings after they have found a host animal. Both female and male deer keds attack animals passing by and live on the host feeding on its blood (Hackman et al. 1983). Reproduction of the deer ked takes place in the fur of the host animal and females deposit one puparium at a time (Haarløv 1964). It has been suggested that the breeding of the deer ked could last for up to 8–10 months (Kaitala et al. 2007, but see Popov 1965). Adult deer keds emerge in the areas, where they dropped as pupae in the preceding autumn and winter (Haarløv 1964).
Also humans are susceptible to numerous attacks of the deer ked during professional or recreational forest use (Kortet et al. 2010). The bites can cause allergic dermatitis and secondary infections to sensitized individuals (Ivanov 1974, Rantanen et al. 1982, Reunala et al. 2008). The deer ked has also been proposed to act as a vector for bacteria of the *Bartonella* genus (Dehio et al. 2004). Deer keds are likely to have stressful effects on their hosts and affect the health of animals by causing scratching and associated skin changes (Ivanov 1981). Skin and hide damages of moose have been connected to chronic deer ked infection (Laaksonen et al. 2008a).

Antiparasitic treatment with ivermectin is routinely used in reindeer management in Finland (Laaksonen et al. 2008b). Ivermectin is a synthetic derivative of avermectins without antibacterial activity (Dourmishev et al. 2005). It affects endo- and ectoparasites by preventing the conduction of nerve impulses in synapses gated by glutamate or γ-aminobutyric acid causing eventual paralysis. In vertebrates, these synapses are not located in the peripheral nervous system (unlike in invertebrates) but only in the central nervous system. As ivermectin cannot cross the blood-brain barrier it is harmless to vertebrates.

As the deer ked is a potential threat to reindeer health and husbandry, this study focused on two crucial questions: (1) are deer keds able to attach on reindeer and use them as hosts for feeding and reproduction, and (2) could this parasite be controlled by using the antiparasitic agent ivermectin? The latter would be logistically possible as the semi-domesticated reindeer are regularly subjected to annual treatment and medication against other ecto- and endoparasites (Laaksonen et al. 2008b).

**Material and methods**

**Experimental procedures**

The study was carried out in the Zoological Gardens of the University of Oulu, Finland (65°N, 25°E) with permission of the Committee on Animal Experiments of the University of Oulu (licence decision STH378A; 16.5.2007/ESLH-2007-03532/Ym-23) between 29 May and 13 Dec. 2007. The experimental animals were 18 adult reindeer (11 females and 7 males; age 2.8 ± 0.6 years). On 29 May, the reindeer were assigned into three experimental groups with an equal sex ratio and average age (Infection group, Infection & Medication group and Control group). Each reindeer was fitted with a collar with individual colouring and a numbered ear tag for identification.

At the start of the experiment, on 29 May, before the reindeer were infected with deer keds, the animals were treated against other possible endo- and ectoparasites with subcutaneous (sc) ivermectin (0.2 mg kg⁻¹; Bimectin vet®, Vetpharma AB, Lund, Sweden/Vetcare Oy, Vantaa, Finland) and topical deltametrin (75 mg/reindeer; pour-on lotion on dorsal skin; Coopersect spot on vet®, Schering Plough, Ballerup, Denmark). The ivermectin treatment was repeated on 13 June. The males were castrated on 29 May to prevent rut behaviour in autumn as it can be disturbing and result in injuries or stress to other reindeer. Moreover, the handling of males in rut can be difficult. The reindeer were fed *ad libitum* with a commercial diet [Poron-Herkku, Rehuraisio, Espoo, Finland, energy content 11.7 MJ metabolizable energy kg dry matter⁻¹] supplemented with lichen (*Cladonia* spp.), hay and dried birch (*Betula* spp.) and willow (*Salix* spp.) leaves.

The animals of Infection and Infection & Medication groups were immobilized in a handling crib without sedation for the experimental infections. Each reindeer in Infection and Infection & Medication groups was similarly infected on six occasions between 16 Aug. and 27 Sep. with an equal number of deer keds (35, 35, 35, 45, 35, 115, *n* = 300/reindeer; Table 1). The keds were applied on the anterior back of each animal. During the subsequent infections, signs of previously implanted deer keds were examined. Because there were no previous data to indicate how the reindeer would react to the deer ked infection, we used infection intensity approximately 20 times lower than previously observed in wild Finnish moose (T. Paakkonen unpubl. data). The number of deer keds was relatively low in order to mimic the situation in nature in the southern reindeer herding
area and to avoid unexpected stress reactions of
the reindeer. Some keds (n = 1260) were reared
at the University of Oulu from wild-collected
pupae from various parts of Finland (60–65°N).
The numbers of deer keds used for the infection
on specific dates depended on their hatching
rate. Due to the low emergence rate, deer keds
(n = 2340) collected by hand in the communes
of Rantsila (64°N) and Liperi (62°N) were also
allocated equally to both infection groups. The
genders of the keds were not determined. All
reindeer groups were kept at natural ambient
temperature and photoperiod in their own enclo-
sures (570 m²) to prevent deer ked contamination
between the groups.

On 6 Nov. 2007, Infection & Medication
group was treated with sc ivermectin (0.2
mg kg⁻¹). Infection and Control groups were
given equi-volume 0.85% saline injections as a
placebo treatment. The experiment was termi-
nated between 10 and 13 Dec., and the reindeer
were stunned with a bolt pistol and killed by
exsanguination. An individual (ID no. 13) dis-
playing strong stress, behavioural and physical
reactions (i.e. hair loss) probably caused by the
infection, was killed earlier on 24 Oct. for ethi-
cal reasons. The pelts were examined in detail
by cutting the hair with scissors and calculating
the numbers of live and dead deer keds and other
possible ectoparasites.

Results

Immediately after the experimental infections the
deer keds disappeared into the reindeer pelts and
dropped their wings (Fig. 1a). During subsequent
infection dates, live deer keds that had consumed
blood (flat, more lightly-coloured, distended
abdomen) and females that contained developing
larvae (round, dark, distended abdomen) could
be observed in the reindeer hair. In both Infection
and Infection & Medication groups the reindeer
scratched themselves leaving bare patches and
chasers in the pelt. Also hair discoloration caused
probably by deer ked faeces could be observed,
especially in white individuals.

No deer keds were found on Control group
at the end of the experiment (Table 2). Infection
group had 6 ± 3 live and 5 ± 1 dead flies per
reindeer (total 11 ± 3) and Infection & Medication
group had no live but 17 ± 3 dead flies per
reindeer. The total number of deer keds at the
end of the experiment did not differ statistically
between Infection and Infection & Medication
groups (Mann-Whitney U-test, reindeer no. 13
excluded: \( U = 10.0, n = 5–6, p = 0.429 \)). The dif-
ferences in the numbers of live (Mann-Whitney
U-test, reindeer no. 13 excluded: \( U = 0.000, n
= 5–6, p = 0.004 \)) and dead deer keds (Mann-
Whitney U-test, reindeer no. 13 excluded: \( U
= 3.0, n = 5–6, p = 0.030 \)) between Infection group
and Infection & Medication group were statisti-
cally significant. Those differences remained sig-
nificant also when reindeer no. 13 was included
(data not shown).

The total recovery of deer keds in Infection
and Infection & Medication groups was 4.7%:
1.1% for live and 3.6% for dead keds. The recov-
ery of live deer keds in Infection group was 2.1% (including reindeer no. 13). Only one pupa could
be found from an individual reindeer of Infection
group. No other ectoparasites were observed in
any of the study groups.

Table 1. Infection dates and numbers of transplanted deer keds/reindeer.

<table>
<thead>
<tr>
<th>Group</th>
<th>16 Aug.</th>
<th>23 Aug.</th>
<th>4 Sep.</th>
<th>17 Sep.</th>
<th>20 Sep.</th>
<th>27 Sep.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>45</td>
<td>35</td>
<td>115</td>
<td>300</td>
</tr>
<tr>
<td>Infection &amp; Medication</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>45</td>
<td>35</td>
<td>115</td>
<td>300</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Discussion

Our main results were: (i) deer keds seem to be able to attach to reindeer and use them as hosts, and (ii) the parasitism could be controlled with ivermectin. However, the survival rates of the deer keds were very low and only a single pupa was observed in the pelt of an individual reindeer at the end of the study. Nevertheless, even these low rates of survival and reproduction suggest that the deer ked could potentially become a parasite of reindeer and reproduce on them. This conclusion is supported by field observations, where few pupae dropped on bedding sites of reindeer were observed in Hyrynsalmi municipality (65°N) in winter 2008 (Kaunisto et al. 2009). Our findings may have significant applications to reindeer herding, as deer keds have already expanded their northern distribution limit into the southern area of reindeer husbandry (Kaitala et al. 2009). Preliminary behavioural observations (S.-M. Kynkäänniemi unpubl. data) and data from another host species, the moose (Ivanov 1981, Laaksonen 2006), suggest that the deer ked could cause considerable stress to its host. Due to strong indications of stress that may have been caused by the deer keds, one female reindeer in Infection group had to be killed for ethical reasons before the end of the experiment.

From the point of view of invasive parasite species the situation can be described as follows: the deer ked, infesting primarily the moose in Finland, has reached areas where other cervids, such as the reindeer, are available as potential hosts. A dense moose population may be able to support the existence and spread of the deer ked in the north. However, for the alternative host species, the reindeer, this would mean an increasing number of deer ked attacks. According to the present study, the deer ked, although potentially irritating for reindeer, may not be well adapted to infest reindeer for longer periods. Thus, it is possible that slower adaptation of the deer ked to the new host species or coevolution with it could occur in the north where the reindeer is at present the principal potential cervid host.

An important factor regarding the possible health effects of the deer ked on the reindeer is that the time period when host-seeking deer keds are the most abundant in nature is during Aug.–Sep. (Ivanov 1981), immediately after the mass appearance of other blood-consuming insects (Helle & Tarvainen 1984). It is known that summer disturbance caused by insects reduces the grazing time and increases the energy expenditure of reindeer (Weladji et al. 2003). Thus, a novel type of disturbance leading to continuing insect harassment in autumn could possibly affect reindeer winter survival in a deleterious manner. In the present study, bare patches
and chafes were observed in the fur, which could cause detrimental health effects especially in harsh winter conditions. For example, McLaughlin and Addison (1986) reported increased heat loss and a poor physiological condition in captive moose with loss of winter hair caused by attempts to remove winter ticks (Dermacentor albipictus).

It is worth noting that while deer keds were recently observed in the Finnish reindeer husbandry area (Laaksonen et al. 2007, 2008a), the dispersion of deer keds on reindeer further to the north could be limited by the seasonal feeding behaviour of reindeer herds. The reindeer graze in different areas in spring and autumn (Laaksonen 2006) and, thus, under this scenario, the flies that have fallen in winter/spring as pupae would emerge in the next autumn in areas with less seasonal reindeer grazing and could be unable to find reindeer as hosts. However, the moose population is quite dense in the southern area of the reindeer husbandry (Pusenius et al. 2008) and, thus, deer keds can possibly continue expanding their distribution area.

As the number of live deer keds on the reindeer decreased dramatically during the experiment, it could be suggested that as compared with e.g., the moose, the reindeer could have a natural ability to partly resist and discard deer keds from its skin similar to the partial resistance against the sheep ked (Melophagus ovinus) in experimentally infected sheep (Nelson 1962). The density of hair in the winter pelage of the reindeer is higher than that of the moose (Fig. 1a; Timisjärvi et al. 1984, Sokolov & Chernova 1987). A very dense hair could hypothetically prevent the deer keds from gaining sufficient access to skin for feeding on blood. Reindeer might also be able to remove the deer keds that are unable to intrude through the dense underfur even though the sharp claws of the deer keds enable it to attach to hairs (Fig. 1b). This may also help another reindeer subspecies, the wild-forest reindeer, to resist deer ked infection. An alternative cause for the decline in the numbers of live keds could be the complicated route of experimental transplantation (i.e. stored pupae and transported flies) causing an impaired physiological condition of the deer keds used in the experiment. In addition, the natural course of deer ked infection must also be taken into account, as according to Ivanov (1981), the duration of parasitism is between 120–180 days for an individual fly. Thus, it is possible that some of the flies used in the experiment had reached the end of their lifespan at the end of the study. We did not observe any live deer keds from the pelts of Infection & Medication group, indicating that ivermectin would be efficient against deer keds. It has a broad spectrum of antiparasitic activity

Table 2. The numbers of live and dead deer keds and pupae per study group (mean ± SE) and gender of the experimental reindeer at the end of the experiment on 10–13 Dec. 2007. a = this reindeer was removed from the experiment on 24 Nov. for ethical reasons. * = significant (p < 0.05) difference between Infection and Infection & Medication groups.

<table>
<thead>
<tr>
<th>ID number and gender</th>
<th>Live keds</th>
<th>Dead keds</th>
<th>Total</th>
<th>Pupae</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4♀</td>
<td>1</td>
<td>11</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>7♂</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>12♂</td>
<td>10</td>
<td>1</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>13♀</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>17♂</td>
<td>18</td>
<td>5</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>18♀</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Infection &amp; Medication</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1♀</td>
<td>0*</td>
<td>17 ± 3*</td>
<td>17 ± 3</td>
<td>0</td>
</tr>
<tr>
<td>2♀</td>
<td>0</td>
<td>21</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>5♂</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10♂</td>
<td>0</td>
<td>26</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>11♀</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>15♀</td>
<td>0</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><strong>Control (♀, 6♂, 8♀, 9♀, 14♂, 16♀)</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
against gastrointestinal nematodes, lungworms, warbles, mange mites and other nematodes and arthropods in cattle, other livestock and reindeer (Oksanen 1999). The endectocid antiparasitic treatment is at present routinely used in Finland almost in the whole area of reindeer husbandry in late autumn and early winter, when the breeding animals are treated with ivermectin. Thus, the impact of the deer ked on reindeer husbandry could probably be controlled but the high intensity of parasitism and potential disturbance on wild cervids will possibly remain. So far, there is virtually no information available on the impact of the deer ked on the health of wild cervids (but see Kaunisto et al. 2009). While ivermectin seemed to be efficient against deer keds, more studies on the basic biology of the species are required for the exact timing of the treatment. Moreover, the effectiveness of the medication against the deer ked in natural conditions and against a higher number of parasites should be explored in controlled experiments without forgetting the possible emergence of drug resistance against ivermectin (Shoop 1993) and environmental aspects (reviewed by Hrabok 2006).

The general pattern of the potential establishment of the deer ked in northern environments such as the Finnish Lapland may be that the principal supporting or determining factors in the spread of the deer ked are the climate change together with the possible increase in moose population densities. To support this, other ectothermic species have been observed to widen their distribution northward due to the global warming (Beaumont & Hughes 2002, Vanhanen et al. 2007). In fact, in the circumpolar area, there are observations on increasing temperatures, precipitation and anthropogenic landscape change, which can cause changes in plant and insect phenologies — the major factors affecting the cervid populations in arctic areas (Vors & Boyce 2009). Once the deer ked has established itself in the area of reindeer husbandry, the development of pupae seems to be possible there (Härkönen et al. 2010, A. Kaitala unpubl. data). Further research is needed to verify if the potentially shorter flying period in the north as compared with that in the present range would be long enough for emerging deer keds to find suitable hosts. For alternative host species, such as the reindeer, the development of a long-term host–parasite interaction is a long-lasting adaptive process. However, if the deer ked will be established in Lapland, it could cause an increasing threat of parasitism to the reindeer similar to southern Scandinavia, where the parasite can be found in all available cervid host species (P. Välimäki unpubl. data).

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