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Endoparasites of red deer (*Cervus elaphus*) from a deer farm endemic with fascioloidosis in Germany

Endoparasitenbefall bei Rothirschen (Cervus elaphus) in einem Wildgehege mit Fascioloidose in Deutschland

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Summary

Endoparasite status of 27 red deer (25 calves and two hinds) culled in three consecutive months in a deer farm with endemic *Fascioloides (F.) magna* liver fluke infection in Bavaria, Germany was studied. Apart from *F. magna* recovered from the liver of 3 out of 27 animals, examination of the lungs, gastrointestinal tract and muscle samples revealed the presence of *Dictyocaulus* lungworms (26/27 animals), gastrointestinal nematodes (27/27 animals; 11 species identified), and *Sarcocystis* cysts in the cardiac and/or diaphragmatic myocytes (7/27 animals). In addition, examination of rectum feces indicated the presence of protostrongylid nematode (*Varestrongylus* lungworms and *Elaphostrongylus* tissue worms; 1/27 and 17/27 animals, respectively) and *Eimeria* coccidial infections (12/27 animals). Nematode parasite burdens averaged 61 *Dictyocaulus* lungworms (range, 0 to 554) and 950 gastrointestinal nematodes (range, 134 to 2649). At necropsy, there was a correlation between adult lungworm and fecal *Dictyocaulus* larval counts ($p<0.0001$) and adult strongylid nematode and fecal strongylid egg counts ($p=0.0740$). Total gastrointestinal nematode counts of the 25 calves did not show significant variability related to the month of harvest (November, December or January, respectively). However, the proportion of mucosal larval ostertagids increased significantly ($p<0.05$) in number from November to December and January. *Dictyocaulus* lungworm infection of the 25 calves showed a significant ($p<0.05$) reduction of lungworm counts with increasing age of the animals.

Keywords: Gastrointestinal nematodes, *Dictyocaulus* lungworms, *Elaphostrongylus, Sarcocystis*

Zusammenfassung

Untersucht wurde der Endoparasitenbefall von 27 Rothirschen (25 Kälber, 2 Alttiere), die innerhalb von drei aufeinanderfolgenden Monaten in einem Wildgehege mit *Fascioloides (F.) magna*-Problematik in Bayern erlegt worden waren. Neben *F. magna*, die aus der Leber von drei Stücken isoliert wurden, sind *Dictyocaulus*-Lungenwürmer (26/27 Rothirsche), gastrointestinale Nematoden (27/27 Rothirsche; 11 Arten) sowie Sarkosporidienzysten in der Herz- und/oder Zwerchfellmuskulatur (7/27 Rothirsche) identifiziert worden. Darüber hinaus wurden durch Untersuchung von Enddarmkot Larven von Protostrongyliden (*Varestrongylus*-Lungenwürmer, 1/27 Rothirsche; *Elaphostrongylus*-Gewebenematoden, 17/27 Rothirsche) und *Eimeria*-Kokzidienoozysten (12/27 Rothirsche) nachgewiesen. Die Rothirsche waren durchschnittlich mit 61 *Dictyocaulus*-Lungenwürmern (0–554 pro Rothirsch) und 950 Magen-Darm-Nematoden (134–2649 pro Rothirsch) befallen. *Dictyocaulus*-Lungenwurmzahl und *Dictyocaulus*-Larvenausscheidung ($p < 0{,}0001$) bzw. Anzahl gastrointestinaler Nematoden und Strongyliden-Eiausscheidung ($p = 0{,}0740$) waren korreliert.
Die Befallsintensität der 25 Rothirsch-Kälber mit gastrointestinalen Nematoden variierte nicht in Abhängigkeit vom Monat der Erlegung (November, Dezember bzw. Januar), der Anteil an inhibierten Stadien von Ostertagiinae nahm allerdings von November zu Dezember/Januar signifikant zu ($p < 0{,}05$). Die Befallsstärke der 25 Kälber mit *Dictyocaulus*-Lungenwürmern zeigte einen signifikanten ($p < 0{,}05$) Rückgang mit zunehmendem Alter der Rothirsche.

Schlüsselwörter: Gastrointestinale Nematoden, *Dictyocaulus*-Lungenwürmer, *Elaphostrongylus, Sarcocystis*

Introduction

Farming of deer commenced in Germany in the 1970s. Fallow deer (*Dama dama*) form the largest group of all deer farmed while red deer (*Cervus elaphus*) have proved less popular. Farming of other species of deer and other wild ungulates is of less importance in Germany. Emphasis is on the production of venison ('prime farmed venison') such that mainly well grown young deer (calves and yearling deer, mainly stags) are used for the market. Products other than venison are of low commercial importance (Anonymous 2009, Golze 2007).

Deer, like all domesticated ruminants kept on grass have a great variety of endoparasites. Lungworm (*Dictyocaulus* spp.) is the most important parasite for farmed red deer, especially in young stock (weaners, yearlings), but meanwhile gastrointestinal nematodes, present mainly in the abomasum, are recognized as considerable production limiting factors for farmed deer (Alexander and Buxton 1994, Audigé et al. 1998, Baxter et al. 1988, Hattel et al. 2007, Hoskin et al. 2007, Mackintosh and Wilson 2003, Mackintosh et al. 2014).

In contrast to countries with a significant deer farming industry, there is only limited data providing insight in the situation on parasite infections in normal farmed deer in Germany. The majority of the studies, involving fecal examination and/or parasite counts following necropsy, were conducted in farmed fallow deer (Barth and Matzke 1984, Haupt and Eulenberger 1988, Rehbein et al. 1993, Rehbein and Bienioschek 1995, Rehbein and Haupt 1994, Ribbeck and Haupt 1989) while information regarding parasitism of captive red deer is restricted to examination of few animals from parks (Haupt and Ribbeck 1995, Haupt et al. 1994, Rehbein 2010) and one farm (Rehbein et al. 1997).

Consequently, in the course of an epidemiological study on the occurrence of the giant liver fluke, *Fascioloides magna*, in a deer farm in Bavaria, Germany in the years of 2012 and 2013 (Plötz 2015, Plötz et al. 2015), viscera from 27 red deer were examined in order to establish basic data on the overall endoparasite burden of the farmed red deer.

Material and Methods

Study site and animals

The deer farm Pfrentsch was established as pilot deer farm of the Bavarian State Research Center of Agriculture (Bayerische Landesanstalt für Landwirtschaft) in the district of Upper Palatinate, Bavaria in the year of 2004. It carries mainly red deer but also some fallow deer and sika deer (*Cervus nippon*); in total, approximately 120 hinds are kept. No routine control of endoparasites is practiced; however, in order to maintain the health status of the deer and to limit the impact of fascioloidosis, triclabendazole was offered via supplemental feed over five consecutive days in March 2012 (Plötz et al. 2015).

Organs and rectal feces of 27 red deer, 25 calves (17 male, body weight 50–82 kg, 65,4±9,5 kg; eight female, body weight 40–70 kg, 57,3±8,5 kg) and two hinds (10 to 15 and 15 to 20 years old, weighing 100 kg and 68 kg, respectively), were examined. The deer, which have been considered 'healthy', were culled as part of the annual harvest in three batches at one day each in the months of November 2012 (six calves, one hind), December 2012 (eight calves) and January 2013 (11 calves, one hind).

Parasitological examination

The endoparasite status of the deer was characterized by the examination of rectum feces (collected at necropsy) using standard fecal procedures (modified sedimentation, McMaster and Baermann techniques; Plötz 2015) and by differential worm counts of the abomasum, small and large intestines contents, the lungs and liver using standard parasitological necropsy techniques and histological examination of heart and diaphragmatic muscle samples as described elsewhere (Rehbein 2010). For the recovery of mucosal larval stages, the abomasum of each animal was incubated overnight at ~37°C in saline (saline soak). Mucosal larval counts were made after washing the soak on a 25 µm sieve based on the examination of a 10% aliquot (Connan 1991). In addition, DNA extracted from single *Dictyocaulus* lungworms from 11 calves were examined by PCR (amplification and sequencing of a fragment of the ITS2-Gen; as previously detailed by Schwarz et al. 2011).

Statistical analysis

Spearman's rank correlation (r_s) coefficient was calculated to assess the relationship between adult lungworm and fecal *Dictyocaulus* larval counts and adult strongylid nematode and fecal strongylid egg counts, respectively. In order to test for variability of parasite counts in relation to age, parasite data of the 25 calves grouped by the month of cull (November, December and January, respectively) were compared using the Wilcoxon rank sum test (two-sided at α=0.05). All analyses were carried out by using R3.0.1 (R Core Team 2015).

Results

The results of the parasitological examination are summarized in Table 1 and Table 2.

Rectum feces analysis

Rectum feces analysis identified eggs of gastrointestinal strongylid nematodes in all deer. In addition, *Trichuris* eggs (%rate of positive animals, 3.7%), *Capillaria* eggs (40.7%), *Fascioloides* eggs (3.7%), eimerian oocysts (44.4%), *Dictyocaulus* larvae (70.4%), *Varestrongylus* larvae (3.7%) and *Elaphostrongylus* larvae (63.0%) were identified. For all fecal stages, a considerable variability in counts was found.

All deer harbored gastrointestinal nematodes. Five species of nematodes (and *S. kolchida*, the minor morph of *O. leptospicularis*) were recovered from the abomasum and three species each from the small intestine and the large intestine. Individual animals harbored between three and 11 species/morphs of gastrointestinal nematodes, averaging 7.7 species/morphs per deer.

Gastrointestinal nematodes

The mean total gastrointestinal nematode count was 950 parasites (geometric mean count, 799 parasites). Nematode counts of the 25 calves ranged from 378 to 2,679 parasites with 16 calves harboring ≤1,000 nematodes, six calves harboring between 1001 and 2000 nematodes and three calves harboring >2,000 nematodes. The two hinds had 134 and 933 gastrointestinal nematodes,

TABLE 1: *Results of rectum fecal analysis of 27 red deer from the deer farm Pfrentsch*

Parasite fecal stage	Positive deer		Count[1]		
	n	%	AM	Min–Max	GM
Eimeria oocysts[2]	12	44.4	68.9	30–630	6.6
Strongylid eggs[3]	27	100	138.9	30–1,470	78.4
Trichuris eggs[3]	1	3.7	NC[4]	(390)	NC
Capillaria eggs[3]	11	40.7	40.0	30–380	4.5
Fascioloides eggs[3]	1	3.7	NC	(7.6)	NC
Dictyocaulus larvae[5]	19	70.4	27.0	0.4–427	3.8
Elaphostrongylus larvae[5]	17	63.0	15.7	0.1–181	2.9
Varestrongylus larvae[5]	1	3.7	NC	(0.2)	NC

[1] AM, arithmetic mean count – all deer; Min, Minimum/Max, Maximum count – positive deer; GM, geometric mean count – all deer
[2] Oocysts per gram of feces
[3] Eggs per gram of feces
[4] NC, not calculated
[5] Larvae per gram of feces

TABLE 2: *Parasite counts of 27 red deer from the deer farm Pfrentsch*

Organ	Positive deer		Count[1]		
Parasite	**n**	**%**	**AM**	**Min–Max**	**GM**
Abomasum					
Ostertagia leptospicularis	22	81.5	43.7	15–165	20.2
Skrjabinagia kolchida	19	70.4	18.5	10–70	8.2
Spiculopteragia asymmetrica	25	92.6	64.6	10–685	32.5
Spiculopteragia boehmi	26	96.3	263.0	65–1,700	165.5
Spiculopteragia houdemeri	27	100	103.9	30–220	94.4
Mucosal fourth-stage larval ostertagids	25	92.6	324.6	10–1,460	135.7
Trichostrongylus askivali	2	7.4	2.6	15–55	0.3
Total abomasum	27	100	820.4	125–2,595	674.7
Small intestine					
Nematodirus roscidus	4	14.8	39.4	20–935	0.9
Cooperia pectinata	9	33.3	5.6	5–40	1.5
Capillaria bovis	14	51.9	9.3	5–60	3.0
Total small intestine	15	55.6	54.3	5–970	6.1
Large intestine					
Oesophagostomum sikae	27	100	32.6	1–140	21.1
Oesophagostomum venulosum	26	96.3	35.4	1–132	24.1
Trichuris globulosa	7	25.9	7.1	1–67	0.9
Total large intestine	27	100	75.2	9–307	58.2
Total gastrointestinal tract[2]	**27**	**100**	**949.8**	**134–2,697**	**798.8**
Liver					
Fascioloides magna	3	11.1	0.6	5–7	0.2
Lungs					
Dictyocaulus species	26	96.3	60.9	1–554	18.8

[1] AM, arithmetic mean – all deer; Min, Minimum/Max, Maximum parasite count – positive deer; GM, geometric mean – all deer
[2] Abomasum + small intestine + large intestine

respectively. Overall, abomasum nematodes accounted for approximately 86% of the total nematode burden of the gastrointestinal tract while large intestine and small intestine nematodes contributed approximately 8% and 6% to the total burden. Approximately 40% of the abomasal nematode burden was made by mucosal fourth-stage larval ostertagids.

At necropsy, there was a correlation between adult strongylid nematode and fecal strongylid egg counts (Spearman's r_s=0.3494; p=0.0740).

Total gastrointestinal nematode counts of the 25 calves did not show significant variability related to the age of the animals (expressed by the month of harvest); however, there was a shift in the proportions contributed by the abomasum, small intestine and large intestine nematode counts to the total gastrointestinal nematode count. Proportion of nematodes recovered from abomasum and large intestine increased with the age of the animals (month of harvest): November, 71.0% and 5.1%; December, 89.3% and 8.0%; and January, 90.1% and 8.8%, respectively, while the proportion of nematodes recovered from the small intestine decreased accordingly: 23.9%, 2.7% and 1.1%. Concurrently, there was a significant ($p<0.05$) increase in the total number of mucosal fourth-stage larval ostertagids (month of harvest; geometric mean count): November, 17.2; December, 290.0; January, 324.2 (Fig. 1). Similarly, the proportion of mucosal fourth-stage larval ostertagids in the total ostertagid burden increased significantly ($p<0.05$) from November (12.7%) to December and January (49.0% and 41.7%, respectively) (Fig. 2).

Dictyocaulus lungworms

Dictyocaulus lungworms were recovered from the lungs of 26 deer. Counts of the 24 lungworm-positive calves ranged from 1 to 554 worms with 12 calves harboring ≤25 nematodes, seven calves harboring between 26 and 100 nematodes and five calves harboring >100 nematodes. The two hinds harbored three and five lungworms, respectively. Sequencing of the DNA isolated from the lungworms of 9 deer revealed sequences corresponding to sequences deposited in GenBank® as '*Dictyocaulus* sp. of red deer' (5 deer; 99–100% identity with Accession Number AJ580765) or '*Dictyocaulus* sp. of fallow deer' (4 deer; 97-99% identity with Accession Number AY168865). No sequencing result was obtained from the lungworms of the two other calves.

Dictyocaulus lungworm infection of the 25 calves showed a significant ($p<0.05$) reduction of lungworm counts with increasing age of the animals (month of harvest; geometric mean count): November, 83.4; December, 19.2; January, 10.4 (Fig. 3) which was associated with a reduction of the percentage of calves passing *Dictyocaulus* larvae in their feces (November, 100%; December, 100%; January, 45%).

Dictyocaulus larvae were recovered from the rectum feces of 19 deer. The eight deer which tested negative for *Dictyocaulus* larvae at necropsy had either zero (one calf) or two to eight *Dictyocaulus* worms (five calves and the two hinds) in their lungs. At necropsy, there was a correlation between adult lungworm and fecal *Dictyocaulus* larval counts (Spearman's r_s=0.7876; $p<0.0001$).

Fascioloides magna

Fascioloides magna were recovered from the liver of three calves (5, 6 or 7 flukes); livers of one other calf and one of the two hinds had lesions characteristic for fascioloidosis (Plötz et al. 2015).

Sarcocystis

Histologically, *Sarcocystis* cysts were present in small numbers in the muscle samples of six calves and one of

the two hinds (up to one or three cysts per cm^2 cut area of cardiac and diaphragmatic muscle, respectively).

Discussion

Similar to other studies in farmed red deer from Germany (Rehbein et al. 1997) and other countries (Connan 1991, 1996, Hoskin et al. 2005, Mackintosh et al. 2011, 2014), the most common worms of the red deer from the farm Pfrentsch were abomasal nematodes of the ostertagid group (subfamily Ostertagiinae) and *Dictyocaulus* lungworms. All species of gastrointestinal nematodes found have been previously identified in both free-living and/or captive red deer in Germany. However, the number of species that was identified indicated a less diverse spectrum of species parasitizing the deer in the farm, which resembles an 'island situation', compared to the range of species which is pervasive in free-living deer (Barth 1972, Haupt et al. 1994, Rehbein 2010, Rehbein et al. 1997, 2002).

Abomasum nematode population was dominated by *Spiculopteragia boehmi*, the characteristic ostertagid of red deer while *S. asymmetrica* and *S. houdemeri* are the characteristic ostertagids of fallow deer and sika deer, respectively (Rehbein 2010, Rehbein et al. 2001). The latter two nematodes have been identified also in wild red deer sharing the habitat with fallow deer or sika deer, respectively (Rehbein 2010, Rehbein et al. 2002). Both fallow deer and sika deer are kept in the deer farm in paddocks adjacent to the red deer fields. However, it may be also possible that the two species of nematodes have been imported with red deer purchased when the farm Pfrentsch was established in 2004 as the founding stock originated from several deer farms.

As described earlier in white-tailed deer from Canada and roe deer from Germany (Baker and Anderson 1975, Haupt and Stubbe 1984), examination of the red deer calves in this study showed an accumulation of mucosal ostertagid fourth-stage larvae at the transition from autumn to winter which resulted in a decrease of the ratio of adult to larval nematodes. This change in the structure of the abomasal ostertagid population is consistent with a phenomenon known as hypobiosis which has an important role in the epidemiology of ostertagid infections in grazing ruminants, especially cattle but is also known from farmed red deer (Connan 1991, 1996, 1997, Mackintosh et al. 2011). In the UK, heavy infection with early fourth-stage larvae, which made up to 70% of the total abomasal ostertagid population, were reported to cause disease in red deer stags comparable to type II ostertagiosis in cattle (Connan 1991).

The burden of both gastrointestinal nematodes and *Dictyocaulus* lungworms of the deer from the farm Pfrentsch is in the range of counts established previously in Germany in red deer from game parks and from one farm (Haupt and Ribbeck 1995, Haupt et al. 1994, Rehbein 2010, Rehbein et al. 1997) as well as in free-living red deer (Rehbein et al. 2002). In New Zealand, where anthelminthics are used routinely in deer farms (Audigé et al. 1998), calves were reported to harbor up to several thousand *Dictyocaulus* lungworms while gastrointestinal nematode counts were comparable to the counts found in the red deer calves from the deer farm Pfrentsch (Hoskin et al. 2005, Mackintosh et al. 2011, 2014). Red deer from deer farms in the south of the UK

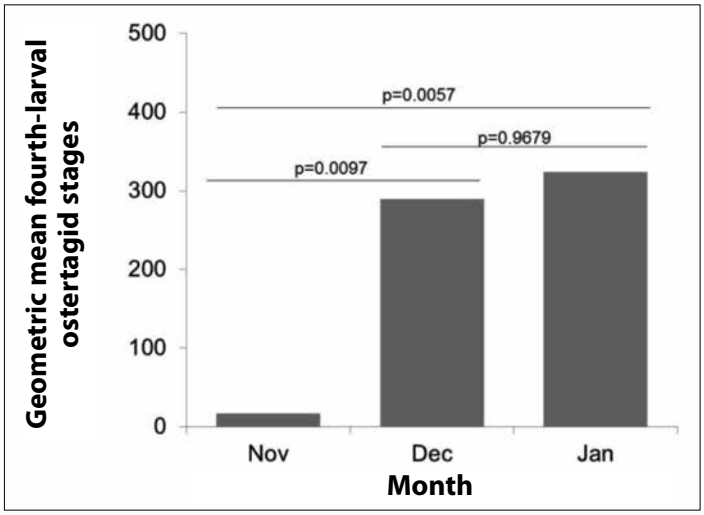

FIGURE 1: *Geometric mean inhibited fourth-stage larval ostertagid counts recovered from farmed red deer calves per month including pairwise comparisons of the counts*

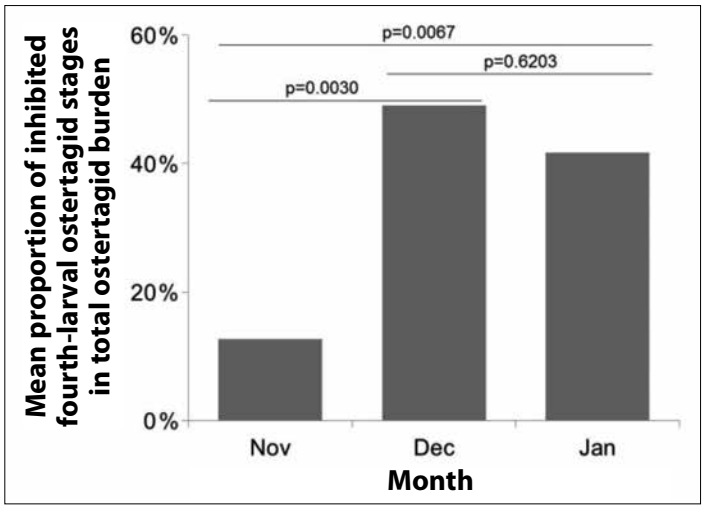

FIGURE 2: *Proportion of inhibited fourth-stage larval ostertagids in the total ostertagid burden from farmed red deer calves per month including pairwise comparisons of the proportions*

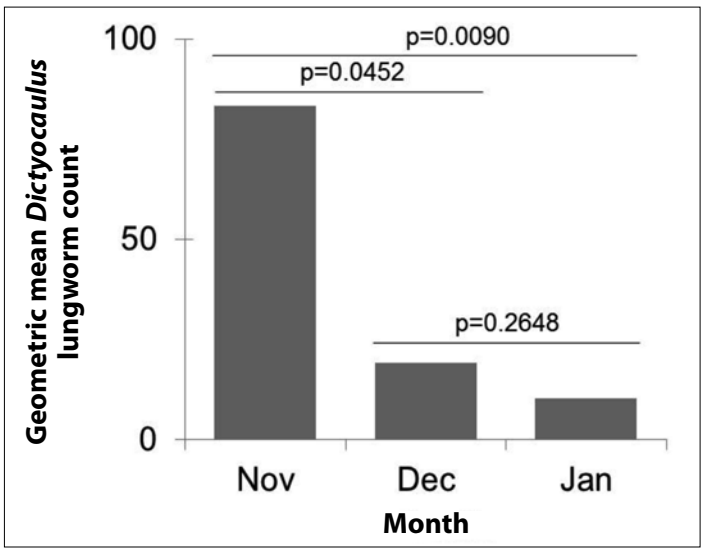

FIGURE 3: *Geometric mean Dictyocaulus lungworm counts recovered from farmed red deer calves per month including pairwise comparisons of the counts (Graphics: Boehringer Ingelheim Vetmedica GmbH, Kathrinenhof Research Center)*

were reported to harbor frequently between 10,000 and 100,000 abomasal nematodes in late autumn and winter with mucosal larvae representing a high percentage of the population (Connan 1991, 1996).

As indicated similarly by the shift of the proportion of small intestinal nematodes contributing to the total nematode count of the gastrointestinal tract, the inverse relationship between the *Dictyocaulus* lungworm counts and the age of the red deer calves is probably because immune response to lungworm begins to operate. Analogous conclusions can be drawn from the examination of wild red deer (Rehbein et al. 2002). Results of that study as well as the recovery of lungworms from the two hinds from the deer farm indicate that, despite continuous exposure, there is no complete protection from infection with lungworm in older deer as is with bovine lungworm infection (Forbes 2018).

Using PCR assays of the ITS2 rDNA allowed to distinguish two *Dictyocaulus* genotypes parasitizing the red deer of the farm Pfrentsch. Lungworms of these genotypes and lungworms determined as *D. eckerti* have been identified recently in red deer from the wild and from game parks in Germany (Raue et al. 2016, Schwarz et al. 2014). These findings confirm the diverse nature of the *Dictyocaulus* lungworm fauna of cervids, which has been a matter of discussion since some time, and support the need for further systematic molecular studies of lungworms collected from sympatric cervids in order to better understand the epidemiology and phylogeny of the dictyocaulid lungworms (Ács et al. 2016; Pyziel et al. 2017).

Although the number of study animals was relatively small, this study demonstrated a correlation between the fecal strongylid egg and *Dictyocaulus* larval counts and the counts of the respective adult parasites. Similar findings were reported in red deer calves from New Zealand deer farms (Mackintosh et al. 2011, 2014).

One calf passed larvae of which the morphology was consistent with that of *Varestrongylus* lungworm larvae and 17 deer passed larvae of *Elaphostrongylus* tissue worms. Both protostrongylid nematodes are common parasites of wild red deer in Germany (Rehbein 2010, Rehbein et al. 2002). Following low level excretion of protostrongylid larvae during summer and autumn, larval excretion increases from late October and reaches peak values in late winter/spring in red deer in central Europe (Plötz 2015, Prosl and Kutzer 1982, Řezáč 1991). Although not a significant pathogen for farmed red deer, *Elaphostrongylus* nematode infection may cause undesirable lesions (greenish discoloration adjacent to the worms found in the connective tissue) which can be identified at meat inspection and may require trimming or condemnation of the carcass in severe cases (Mason 1994, 1995).

Although of North American origin, the highly pathogenic giant liver fluke, *F. magna*, has been initially described from deer in a game park in the Turin area, Italy where repeated severe endemics were observed (Balbo et al. 1987, 1989, Králová-Hromadová et al. 2016, Pybus 2001). Occurrence of *F. magna* in deer farms has been reported from Canada in the past (Kennedy et al. 1999, Whiting and Tessaro 1994). In Europe, *F. magna* infections have been described from deer farms in the Czech Republic (Hirtová et al. 2003, Novobilský et al. 2007) and Poland (Karamon et al. 2015) involving mainly fallow deer.

Fascioloides magna were isolated from three of the 27 deer examined in the deer farm Pfrentsch. In preliminary studies conducted in the deer farm from November 2011 to January 2012, between two and 22 *F. magna* flukes were recovered from the livers of three of eight red deer calves and five of six hinds (Rehbein, unpublished data). Concurrent examination of livers from wild ungulates harvested in hunting grounds in the close vicinity of the deer farm revealed *F. magna* in seven of ten red deer, three of eight sika deer, one of five roe deer and one of two wild boar (Rehbein et al. 2012).

The occurrence of *F. magna* in the deer farm is thought to be related to the migration of wild cervids from Bohemia, Czech Republic into Bavaria, Germany subsequently to the fall of the 'Iron Curtain' in the 1990s. The immigration of deer from Bohemia has initially been indicated through the occurrence of red deer/sika deer hybrids in northeastern Bavaria (Hartl 2000) and later by sika deer establishing in the area. Sika deer, which did not occur in Bavaria in the past (Gangl 2013, Helm 2013, Herzog et al. 2018), is abundant in Czech Republic (Bartoš et al. 2010, Feuereisel and Vala 2016). In Czech Republic, the *F. magna* endemic territory expanded considerably in the past decades, mainly in western direction (Králová-Hromadová et al. 2016, Novobilský et al. 2007), coincidently with a significant increase of the population of cervids in the wild (Bartoš et al. 2010, Feuereisel and Vala 2016). Genotyping of *F. magna* recovered from red deer of the deer farm Pfrentsch revealed identity with flukes from Czech Republic (Bazsalovicsová et al. 2017).

As discussed previously (Plötz 2015, Plötz et al. 2015), introduction of *F. magna* into the deer farm is likely related to passive transportation of free stages of the parasite or infected mollusc intermediate hosts via a stream that passes the farm. Noteworthy in this context is the absence of the abomasal nematode, *Ashworthius sidemi*, in the deer of the farm while it has been identified in red deer, sika deer and roe deer harvested in hunting grounds surrounding the deer farm (Rehbein et al. 2012). This *Haemonchus*-resembling nematode was described in Europe for the first time from park sika deer in former Czechoslovakia (Kotrlá and Kotrlý 1973) and is currently expanding its range at the continent (Csivincsik et al. 2017, Demiaszkiewicz 2014, Demiaszkiewicz et al. 2009, 2017, 2018, Dróżdż et al. 2003, Kowal et al. 2015, Lehrter et al. 2016).

The nematode burdens of the three red deer calves which harbored *F. magna* and of the one calf whose liver had lesion characteristic of *F. magna* infection (20, 109, 133 and 39 *Dictyocaulus* lungworms, respectively; and 822, 1158, 2122 and 2679 gastrointestinal nematodes, respectively) tended to be in the upper range of the parasite counts of the red deer calves examined. However, the body weight of the four calves (53, 55, 70 and 70 kg) was not different from the body weight of the other calves which are all considered representative for deer calves of the respective age (Golze 2007, Naderer 1998).

Rate of detection of *Sarcocystis* cysts in the farmed deer was substantially lower than the rate of approximately 80% found by examination of muscle samples from wild red deer in Germany (Drost and Graubmann 1975, Partenheimer-Hannemann 1991, Spickschen and Pohlmeyer 2002). This finding probably results from a lower environmental contamination of the farm with *Sarcocystis* fecal stages because fencing lowers the opportunity of access of wild carnivores to the paddocks. It

may also reflect, at least in part, the age of the examined animals as rate of *Sarcocystis* infection of wild ungulates is usually directly correlated to their age (Rehbein 2010) indicating that the risk of infection increases with period of exposure to possible environmental contamination. Although canids only have been identified as final hosts of the *Sarcocystis* species infecting red deer (Odening 1998), heavily parasitized venison is to be condemned because of unaesthetic appearance and/or other organoleptic abnormalities (Wagner and Richter 2009). It should, however, be noted that there are anecdotal reports on illness in humans following consumption of heavily *Sarcocystis*-infected roe deer meat (Schulze 1988, Schulze and Zimmermann 1982).

Knowledge on parasite infection is a basic element of the health monitoring in farmed deer. Beside of the examination of mortalities or animals suffering from clinical disease, differential parasite counts of the gastrointestinal and respiratory tract organs of routinely culled or slaughtered 'healthy' deer have been shown to be a very useful diagnostic tool to estimate the potential impact of parasitism in farmed deer and to allow for the outline of appropriate management measures to reduce losses of productivity and to prevent impaired animal welfare (Connan 1996, Haupt and Ribbeck 1995, Mackintosh and Tolentino 2009, Mackintosh et al. 2011). Based on the study of Plötz (2015)/Plötz et al. (2015) and the results of the present work, the deer farm Pfrentsch continues practicing the annual single flukicidal treatment of the deer which has been shown to ensure suppression of *F. magna* infection on a low level. Eradication of *F. magna* in the farm is not considered given the location of the farm in an *F. magna* endemic area and the stream passing the farm and allowing for recurring exposure of the deer. Because of the lack of signs related to nematode parasitism, no routine nematode parasites management measures are used (Bamler, unpublished data 2018).

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Conflict of interest

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Authors contribution

This work was designed by SR, HB and KP. MV, CP, LS and TL analyzed the samples and data, respectively. The manuscript was drafted by SR and reviewed and approved by all authors.

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