Parasitol Res (2017) 116:S11–S30 DOI 10.1007/s00436-017-5488-9

ENDOPARASITES

Original Article

Lungworms in Germany 2002–2016: Is there an Increase in Occurrence and Geographical Spread?

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Abstract

Angiostrongylus vasorum and *Crenosoma vulpis* are metastrongylid nematodes that are now considered to be widespread in Europe. The results of coproscopic examination of faecal samples submitted for routine diagnosis to the Veterinary Laboratory Freiburg were analyzed in order to study the occurrence of lungworm infections in the dog population in Germany. A total of 65,967 canine faecal samples from 2002–2016 were examined by flotation and the Baermann funnel technique. Lungworm larvae were found in 883 (1.34%) samples, of which 606 (0.92%) and 277 (0.42%) were positive for *A. vasorum* and *C. vulpis,* respectively. The share of *A. vasorum* positive dogs increased from 0.09% in the period 2002–2006 to 0.83% in 2007–2011 and 1.29% in 2012–2016. The share of *C. vulpis* positive dogs was 0.15% in the period 2002–2006, 0.50% in 2007–2011 and 0.48% in 2012–2016. The rates of infection with *A. vasorum* were significantly higher in 2014 ($p < 0.05$) compared to 2002–2007, and in 2015 and 2016 ($p < 0.05$) compared to 2002–2010. For *C. vulpis*, significantly higher infection rates were found only in 2008. There were no significant differences in relation to age or sex. Seasonality of infections was observed for both species, as the infections were significantly less prevalent in summer (*A. vasorum*, $p = 0.0179$; *C. vulpis*, $p = 0.0095$) than in winter. The data support the hypothesis that the prevalence of *A. vasorum* in the dog population in Germany has increased in recent years. By contrast, this could not be confirmed for *C. vulpis*.

Introduction

Lungworm infections in dogs have attracted quite a lot of attention from veterinarians and researchers during the last two decades. This is true, in particular, for *Angiostrongylus vasorum*, also referred to as French heartworm, which may manifest with a sometimes severe and even fatal clinical picture. A literature search in PubMed (https://www.ncbi.nlm.nih.gov/pubmed/) with the term *Angiostrongylus vasorum* conducted for the period 2012–2016 shows an average of about 20 new research publications per year and demonstrates the breadth of research conducted in this area. The key area is the determination of prevalence data in regions for which information is limited, and there are now data available for most European countries. The existence of the parasite is well documented over a period of many years in France, the UK and Denmark. More recent research from 2012–2016 in the form of large-scale cross-sectional prevalence studies also supports the occurrence of the parasite in Italy, Germany, Hungary, Poland, Switzerland, Portugal, Belgium, Slovakia and Sweden. These studies investigated different subpopulations and used different methodologies (summary in Table 1). A lot of effort has gone into researching the epidemiology of Angiostrongylosis, in particular in the wildlife reservoir fox (Table 2) and other species including mustelids (Simpson et al. 2016) and wolves (Hermosilla et al. 2017), but also in the intermediate hosts snails and slugs (Aziz et al. 2016, Di Cesare et al. 2015). *Crenosoma vulpis* is less the focus of research, probably because the pathology of this parasite is less severe and usually not life-threating, and veterinarians pay less attention to crenosomosis.

Despite the results of many cross-sectional prevalence studies, data concerning the epidemiology of lungworm infections over a longer period are scarce and there is little evidence for a potentially increasing prevalence and regional spread. The availability of prevalence data for certain populations over several years obtained with comparable methodologies now allows us to investigate the potential spread of the disease over time. This may reveal higher prevalence rates, a regional spread, or a combination of both.
One of the first studies to look into this was a comparison of the prevalence and regional distribution of *A. vasorum* studied in a fox population in the UK, where data from 2005/2006 (Morgan et al. 2008) were compared with data from 2013/2014 using identical methods (Taylor et al. 2015). It was concluded that the prevalence of *A. vasorum* increased from 7.3% to 18.3% (exact binomial confidence limits 14.9–22.3). In addition, *A. vasorum* was also found in regions where it had previously not been recorded (northern UK), thus demonstrating regional spread too (Taylor et al. 2015).

In a more recent study Maksimov et al. (2017) analyzed data from 12,682 dogs submitted for routine diagnosis from 2003–2015 with a request to perform a Baermann funnel test in addition to the faecal flotation test, so a suspected lungworm infection might have played a role. They concluded that in this specific subpopulation of dogs a significant increase in infections with *A. vasorum* and *C. vulpis* was detectable when the examination period was subdivided into three time spans covering 4–5 years each. In addition, the authors postulate a spread of *A. vasorum* into new areas.

The aim of the present study was to analyze retrospectively the results of parasitological examination of faecal dog samples submitted for routine faecal diagnosis to the Veterinary Laboratory Freiburg. Further aims were to determine the percentage of *A. vasorum* and *C. vulpis* positive dogs, to document the seasonal distribution and age structure of lungworm positive dogs, and to assess the regional distribution of natural infections with *A. vasorum* and *C. vulpis* in the dog population in Germany over the last 15 years.

Table 1 Summary of recent results (2013–2016) of cross sectional dog prevalence studies of *Angiostrongylus vasorum* in Europe performed with different methodologies (serological examination: AG = antigen, AB = antibody)

Country	No. of samples	Population type	Method used	% positive (method)	Reference
Italy (central and north)	265 central 447 north	routine diagnostics	AB/AG ELISA	1.5 % (AB) central 2 % (AB) north	Guardone et al. 2013
Denmark	181	hunting dogs	Baermann	2.20 %	Al-Sabi et al. 2013
UK	4030	routine diagnostics	AB/AG ELISA	3.2 % (AB)	Schnyder et al. 2013a
Germany	4003	routine diagnostics	AB/AG ELISA	2.5 % (AB)	Schnyder et al. 2013a
Poland	3345	routine diagnostics	AB/AG ELISA	1.29 % (AB)	Schnyder et al. 2013b
Italy (Sardinia)	146	routine diagnostics	Baermann	3.40 %	Pipia et al. 2014
Bulgaria	150	routine diagnostics	AB/AG ELISA	0 % (AB)	Pantchev et al. 2015
Hungary	1247	routine diagnostics	AB/AG ELISA	2.73 % (AB)	Schnyder et al. 2015
Switzerland	6136	routine diagnostics	AB/AG ELISA	3.08 % (AB)	Lurati et al. 2015
Italy (Campagna region)	68 kennels with 1360 boxes	kennel dogs	Flotac	13.2 % kennels 1.8 % boxes	Del Prete et al. 2015
Slovakia	225	routine diagnostics	AB/AG ELISA	4.4 % (AB)	Miterpakova et al. 2015
Portugal	906	shelter dogs	AB/AG ELISA	1.32 % (AB)	Alho et al. 2016
Belgium (south)	979	222 clinical suspicion 757 routine diagnostics	AG Angiodetect® IDEXX	Clinical suspicion: 8.7 % (AG) Routine diagnosis: 3.6 % (AG)	Lempereur et al. 2016
Sweden	3309	routine diagnostics	AB/AG ELISA	1.48 % (AB)	Grandi et al. 2017
France	2289	routine diagnostics	AB/AG ELISA	3.15 % (AB)	Schnyder et al. 2017

Materials and methods

Study population

Data from parasitological examinations performed at the private diagnostic laboratory "Veterinary Laboratory Freiburg" covering the years 2002–2016 were analyzed to determine the development of infection rates of lungworms in dogs and the geographical spread of cases within Germany (Table 3). The results of 65,967 samples obtained from privately owned dogs presented at local veterinary clinics from all parts of Germany were included. The consultations with the veterinarians took place for mostly unknown clinical problems, routine examination and animal vaccination or a general health check. The sex and age of 60,157 and 57,605 dogs respectively were known. According to this information, 31,993 of the dogs were male (29,376 intact, 2,617 castrated) and 28,164 were female (24,771 intact, 3,393 spayed). The age of 57,605 sampled dogs was documented. The animals were divided into age groups and evaluated at annual intervals.

Faecal examination and data analysis

Faecal samples were tested routinely using a standardized flotation method with a saturated salt solution and a modified Baermann funnel technique to detect first-stage larvae (L1) of lungworms as described in the literature (Barutzki and Schaper

Tab. 2 Summary of recent results (2014–2016) of cross-sectional studies on prevalence of *Angiostrongylus vasorum* in hunted foxes in Europe performed with different methodologies

Country	No. of samples	Species	Method used	% positive (method)	Reference
Netherlands	96	fox	Necropsy	4.20%	Franssen et al. 2014
Poland	76	fox	Necropsy	5.20%	Demiaszkiewicz et al. 2014
Hungary	937	fox	Necropsy	17.90%	Tolnai et al. 2015
Italy (north-west)	165	fox	Necropsy	78.20%	Magi et al. 2015
Spain (Pyrenees)	87	fox	Necropsy	3.40%	Garrido-Castane et al. 2015
UK	442	fox	Necropsy	18.30 %	Taylor et al. 2015
Germany (Brandenburg)	122	fox	PCR	9.00 % (PCR)	Hartwig et al. 2015
Bosnia / Herzegovina	221	fox	Necropsy / PCR	0 (Necropsy / PCR)	Hodzic et al. 2016
Italy (Campagna region)	102	fox	Necropsy	33.30 %	Santoro et al. 2016

Tab. 3 Number of coproscopically examined dog samples between 2002 and 2016

	Number of examined faecal samples 2002–2016															
Month	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
January	193	210	179	239	234	304	324	304	279	319	406	506	577	607	600	5,281
February	231	181	196	190	212	261	329	307	251	356	374	393	522	579	709	5,091
March	236	212	259	208	244	313	300	383	363	393	476	423	593	744	775	5,922
April	230	197	214	224	204	281	347	325	329	305	451	494	471	616	824	5,512
May	226	212	220	216	248	304	320	322	318	424	417	487	486	583	703	5,486
June	206	152	235	259	249	299	375	331	351	347	479	447	498	599	751	5,578
July	250	193	254	235	207	251	382	360	332	369	410	462	562	691	690	5,648
August	213	168	218	265	235	340	348	287	361	378	446	420	539	591	750	5,559
September	232	197	235	242	204	291	337	297	332	380	390	483	593	644	720	5,577
October	192	156	223	227	225	306	402	296	298	338	504	495	581	595	630	5,468
November	232	170	219	239	227	353	357	295	344	369	482	486	566	632	720	5,691
December	186	199	213	197	230	280	334	338	273	352	356	458	533	636	569	5,154
Total	2,627	2,247	2,665	2,741	2,719	3,583	4,155	3,845	3,831	4,330	5,191	5,554	6,521	7,517	8,441	65,967

2009). The results of the coproscopic examinations were analyzed in a Microsoft® SQL Server® 2012 Express database system. The collected data were analyzed using a geographical information system (GIS) and the program RegioGraph 10 (GfK GeoMarketing, Bruchsal) to determine the rates of infection with lungworms and their geographical distribution. The spatial distribution of *A. vasorum* and *C. vulpis* was visualized by merging the first three digits of the owners' five-digit postcodes into single districts and plotting them on maps with administrative and postcode boundaries. In total, the origin of 65,843 samples was included in the geographical analysis.

Statistical analysis

Rates of infection with *A. vasorum* and *C. vulpis*, their geographical distribution and differences in the age groups, gender and seasons of infection were determined and analyzed statistically. Comparisons over time for the different years and the different age groups of dogs were made with the help of 95% two-sided confidence intervals. The comparisons between gender and seasons (winter = December–February; spring = March–May; summer = June–August; autumn = September–November) were made by applying the Fligner-Wolfe many-to-one test (two-sided, alpha = 0.05).

Results

In a retrospective study, the results of parasitological examinations of faecal samples from 65,967 dogs obtained between 2002 and 2016 in Germany were

Table 4 Number (n) and share (%) of coproscopically examined and lungworm positive dogs of known age between 2002 and 2016

Age of dogs examined (years)	Number of dogs examined	*Angiostrongylus vasorum* positive dogs		*Crenosoma vulpis* positive dogs		Lungworm positive dogs	
		n	%	n	%	n	%
< 1	9,584	106	1.106	50	0.522	156	1.628
1–2	10,264	116	1.130	52	0.507	168	1.637
>2–3	6,001	50	0.833	20	0.333	70	1.166
>3–4	4,326	40	0.925	11	0.254	51	1.179
>4–5	3,632	24	0.661	11	0.303	35	0.964
>5–6	3,171	20	0.631	15	0.473	35	1.104
>6–7	2,962	33	1.114	16	0.540	49	1.654
>7–8	2,806	20	0.713	8	0.285	28	0.998
>8–9	2,757	22	0.798	16	0.580	38	1.378
>9–10	2,547	18	0.707	8	0.314	26	1.021
>10–11	2,521	25	0.992	11	0.436	36	1.428
>11–12	2,105	18	0.855	10	0.475	28	1.330
>12–13	1,889	14	0.741	7	0.371	21	1.112
>13–14	1,362	19	1.395	6	0.441	25	1.836
>14–15	952	6	0.630	6	0.630	12	1.261
>15–16	447	0	0.000	2	0.447	2	0.447
>16–17	183	0	0.000	1	0.546	1	0.546
>17–18	61	0	0.000	0	0.000	0	0.000
>18–19	27	0	0.000	0	0.000	0	0.000
>19–20	5	0	0.000	0	0.000	0	0.000
>20–21	2	0	0.000	0	0.000	0	0.000
>21	1	0	0.000	0	0.000	0	0.000
Total	57,605	531	0.922	250	0.434	781	1.356

Table 5 Number of coproscopically examined and number/share of lungworm positive dogs in four periods of time

Period	*Angiostrongylus vasorum* positive dogs		*Crenosoma vulpis* positive dogs		Number of examined dog samples
	n	%	n	%	
2002–2016	606	0.92	277	0.42	65,967
2002–2006	12	0.09	20	0.15	12,999
2007–2011	164	0.83	99	0.50	19,744
2012–2016	430	1.29	158	0.48	33,224

Table 6 Number of coproscopically examined dogs and number/share of *Angiostrongylus vasorum* and *Crenosoma vulpis* positive dogs in federal states of Germany

Federal state of Germany	Dogs examined	*Angiostrongylus vasorum* positive dogs		*Crenosoma vulpis* positive dogs	
	n	n	(%)	n	(%)
Baden-Wuerttemberg	17,868	315	1.8%	75	0.4%
Bavaria	9,852	36	0.4%	48	0.5%
Berlin	85	0	0.0%	1	1.2%
Brandenburg	84	2	2.4%	0	0.0%
Bremen	43	0	0.0%	0	0.0%
Hamburg	10	0	0.0%	0	0.0%
Hesse	3,432	31	0.9%	25	0.7%
Mecklenburg-Western Pomerania	29	0	0.0%	1	3.4%
Lower Saxony	259	0	0.0%	1	0.4%
North Rhine-Westphalia	25,099	120	0.5%	79	0.3%
Rhineland-Palatinate	4,541	17	0.4%	22	0.5%
Saarland	4,378	76	1.7%	21	0.5%
Saxony	41	1	2.4%	3	7.3%
Saxony-Anhalt	29	0	0.0%	0	0.0%
Schleswig-Holstein	80	0	0.0%	0	0.0%
Thuringia	13	0	0.0%	1	7.7%
Total	65,843	598	0.9%	277	0.4%

analyzed. The number of samples varied between 2,247 and 2,741 per year in 2002–2006, increasing to 4,330 in 2011 and then continuously to 8,441 in 2016 (Table 3). In total, 883 (1.34%) out of 65,967 examined dogs were found to be lungworm positive (*A. vasorum* or *C. vulpis*). In 606 (0.92%) canine faecal samples the infectious agent was identified as *A. vasorum* and in 277 (0.42%) as *C. vulpis* (Table 5). The percentage of dogs infected with *A. vasorum* varied annually, increasing from 0.09% in 2002–2006 to 0.83% in 2007–2011 and subsequently to 1.29% in 2012–2016 (Table 5). The percentage of *C. vulpis* positive dogs was 0.15% in the period 2002–2006, it increased to 0.50% in

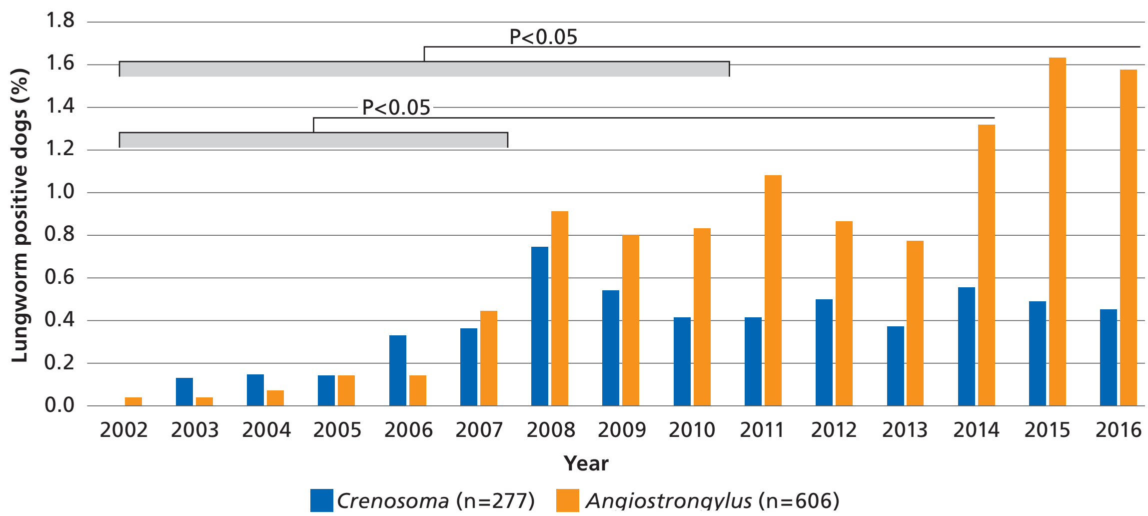

Fig. 1 Lungworm positive dogs (n = 883) in Germany 2002 – 2016 diagnosed by examination of 65,967 faecal samples from dogs

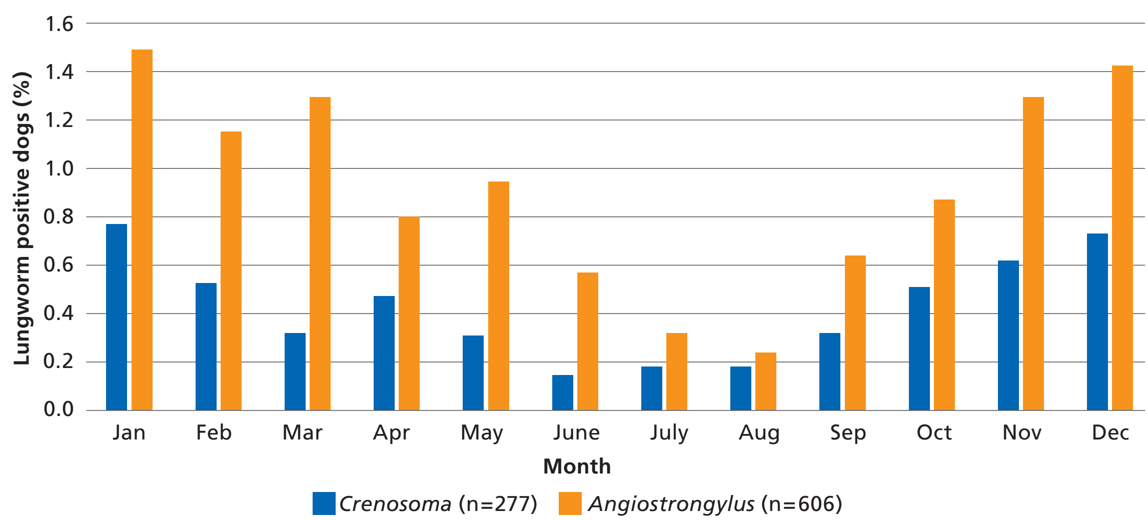

Fig. 2 Seasonal distribution of *Crenosoma vulpis* (n = 277) and *Angiostrongylus vasorum* (n = 606) positive dogs in Germany 2002 – 2016 diagnosed by examination of 65,967 faecal samples from dogs

2007–2011 and remained at 0.48% in 2012–2016 (Table 5). In comparison with *C. vulpis* the percentage of *Angiostrongylus* positive dogs was lower than in subsequent years only from 2002 to 2006 (Fig. 1). From 2007 to 2016 the percentage of *A. vasorum* positive dogs was higher than the percentage of *C. vulpis*. In 2014 the rates of infection with *A. vasorum* were significantly higher ($p < 0.05$) compared to the period 2002–2007; in 2015 and 2016 they were significantly higher ($p < 0.05$) than in the period 2002–2010 (Fig. 1). There were no statistically significant differences between the rates of infection with *C. vulpis* every year between 2002 and 2016 except for the year 2008, when the

Legend Fig. 3 – Fig. 6 Regions where no sampling was performed (white = not sampled), with a low number of sampled dogs (light green = 1 sample per postcode), with a moderate number of sampled dogs (medium green = 10 samples per postcode) and with a high number of samples (dark green = 25 samples per postcode).
(Red symbols = *A. vasorum*; blue symbols = *C. vulpis*)

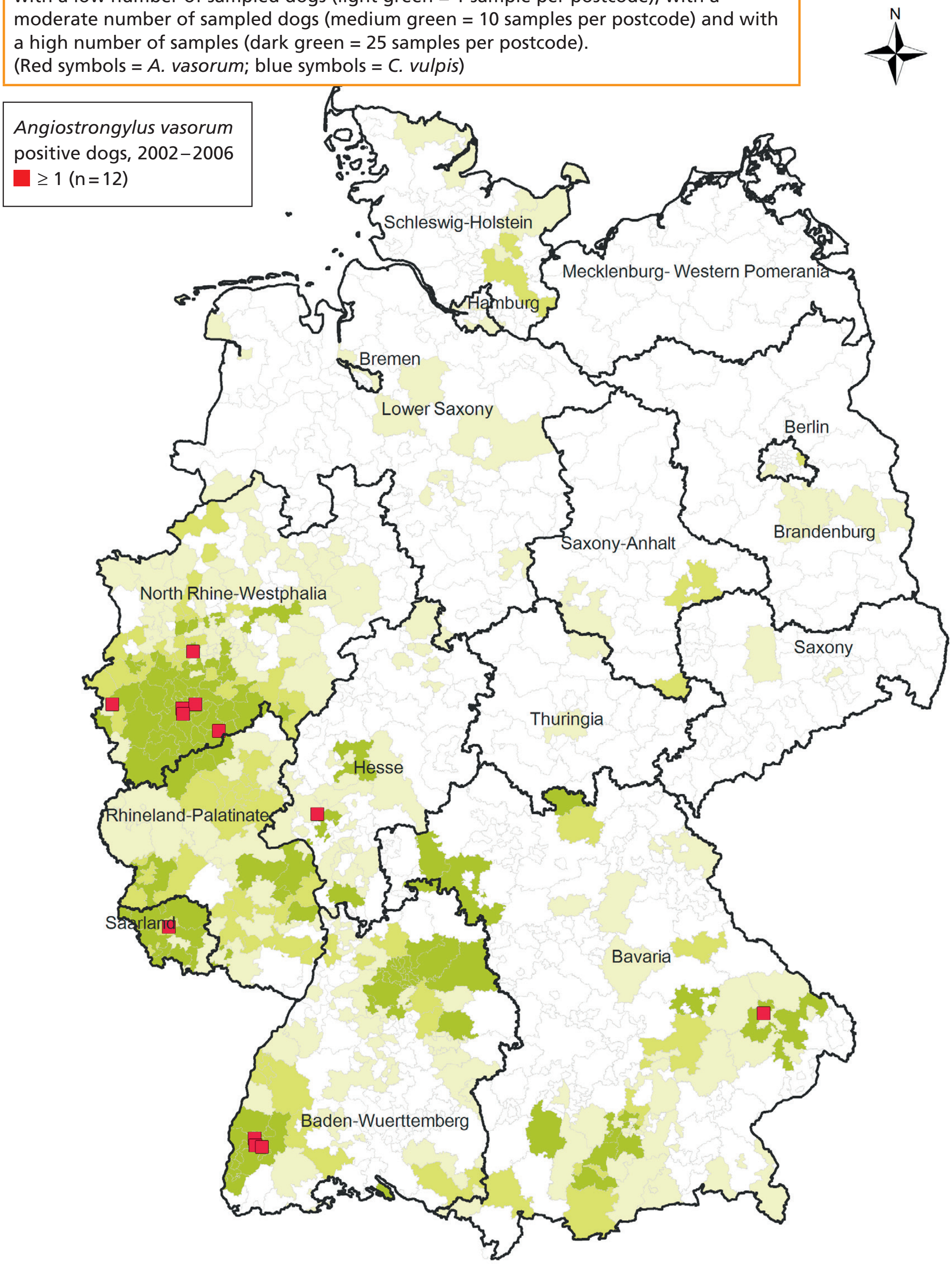

Fig. 3a Natural infections with *Angiostrongylus vasorum* in dogs in Germany 2002 – 2006

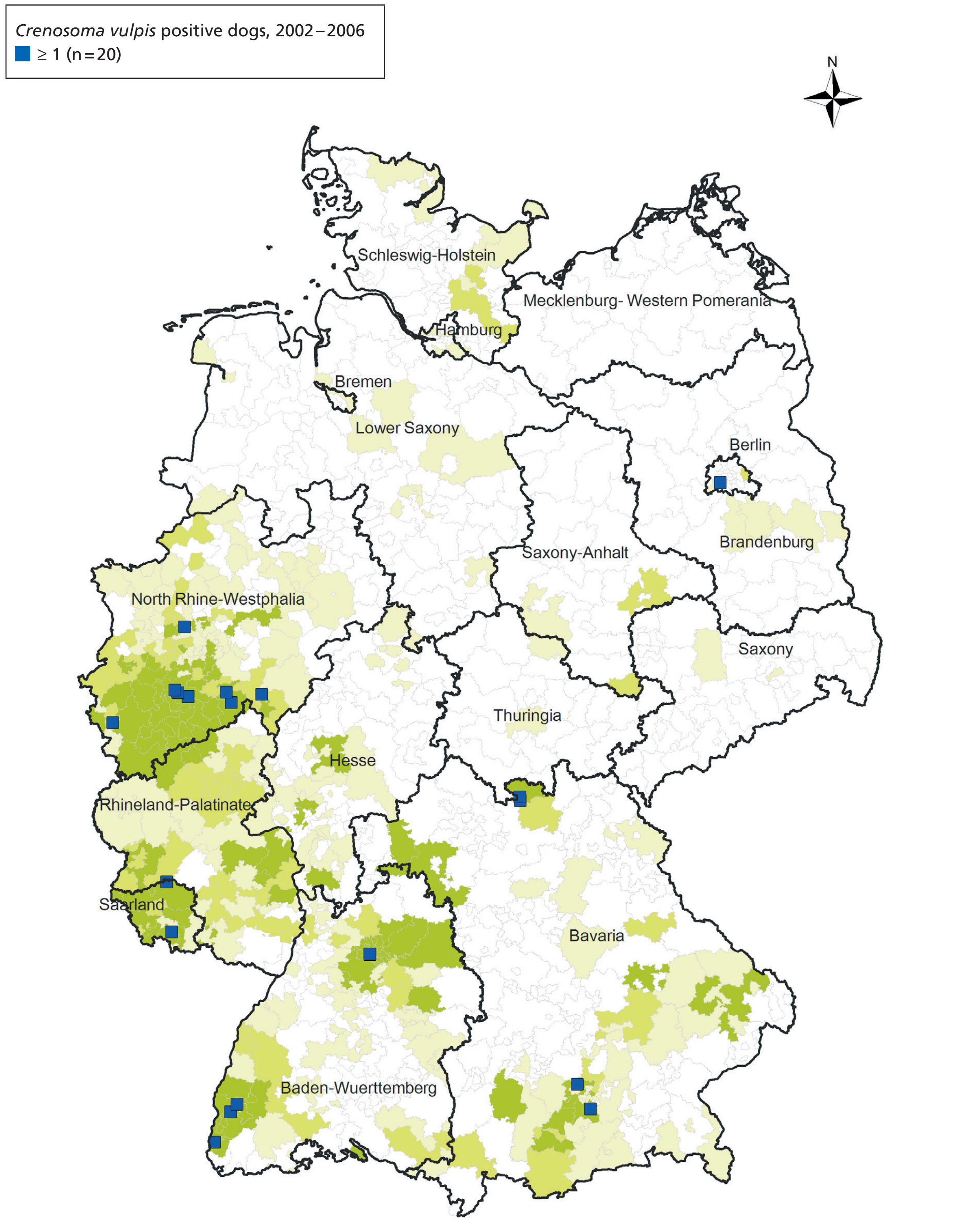

Fig. 3b Natural infections with *Crenosoma vulpis* in dogs in Germany 2002 – 2006

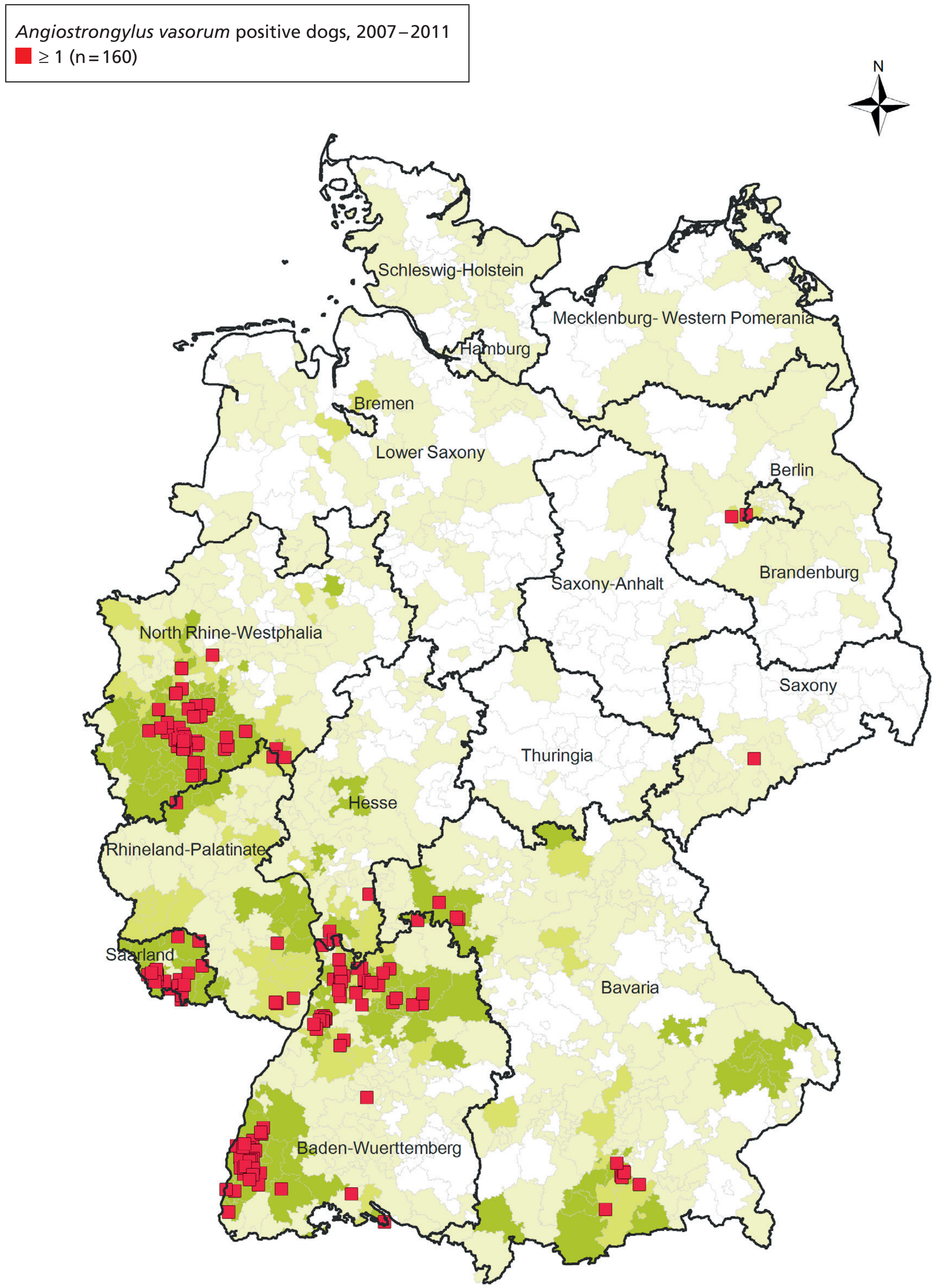

Fig. 4a Natural infections with *Angiostrongylus vasorum* in dogs in Germany 2007 – 2011

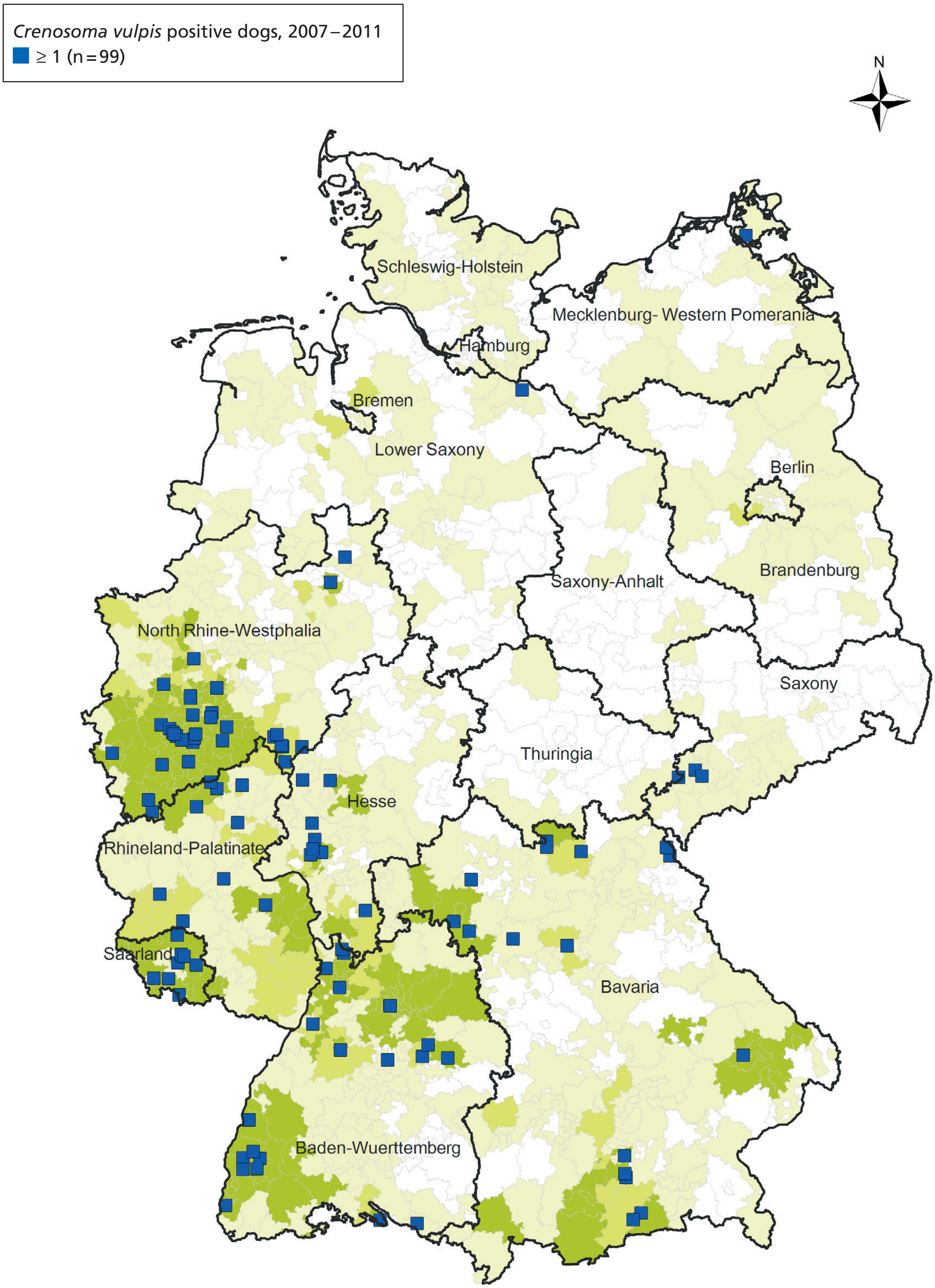

Fig. 4b Natural infections with *Crenosoma vulpis* in dogs in Germany 2007 – 2011

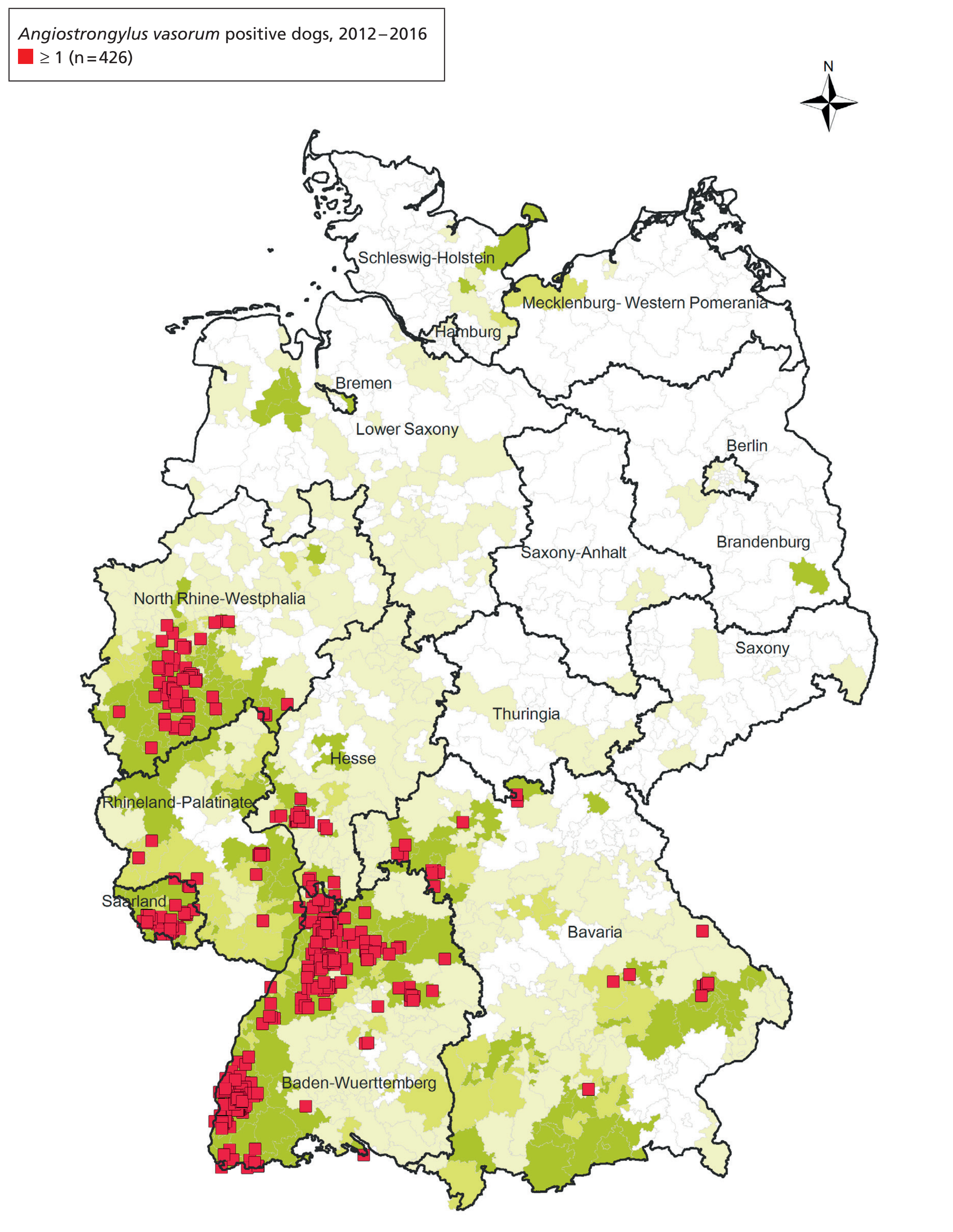

Fig. 5a Natural infections with *Angiostrongylus vasorum* in dogs in Germany 2012 – 2016

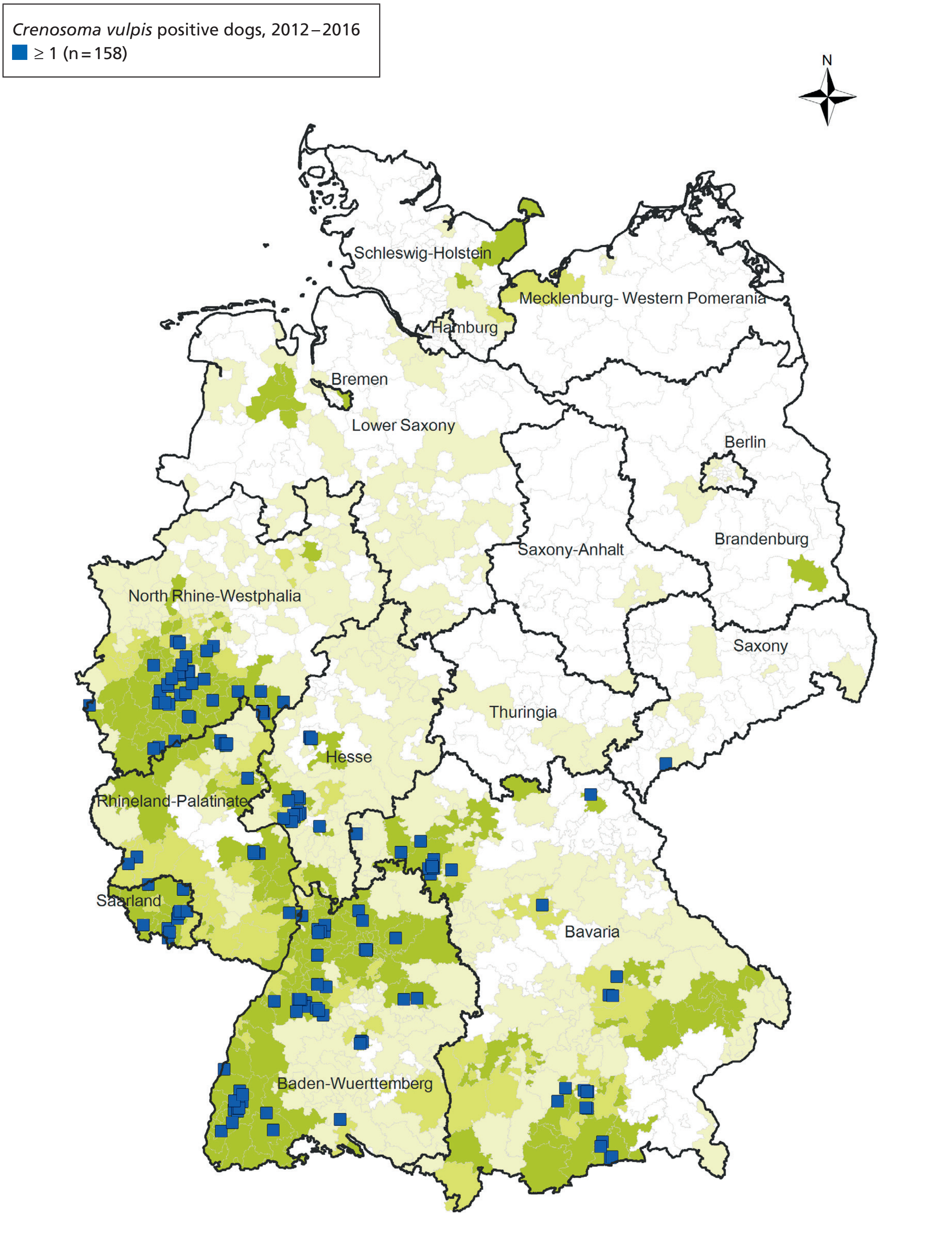

Fig. 5b Natural infections with *Crenosoma vulpis* in dogs in Germany 2012 – 2016

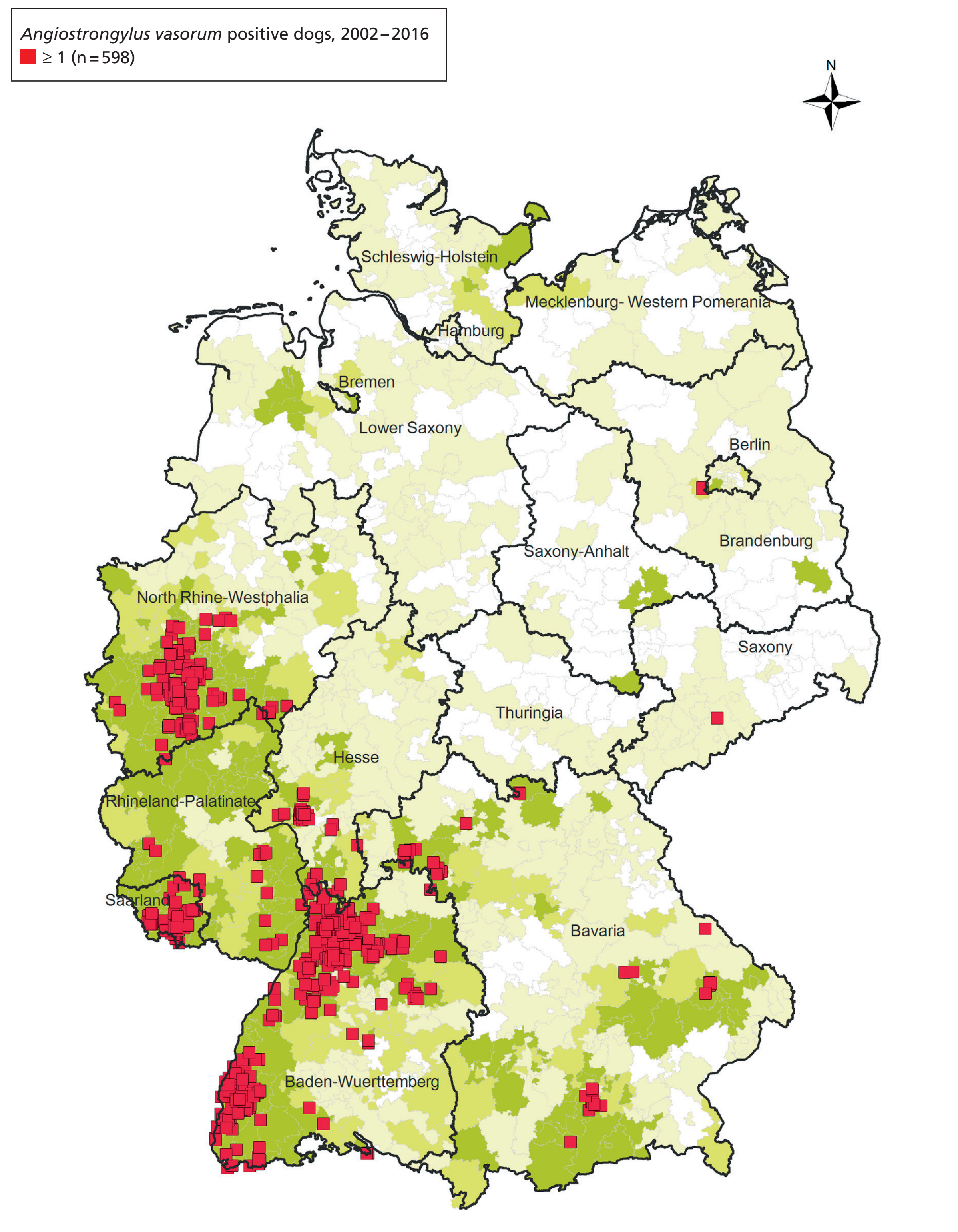

Fig. 6a Natural infections with *Angiostrongylus vasorum* in dogs in Germany 2002 – 2016

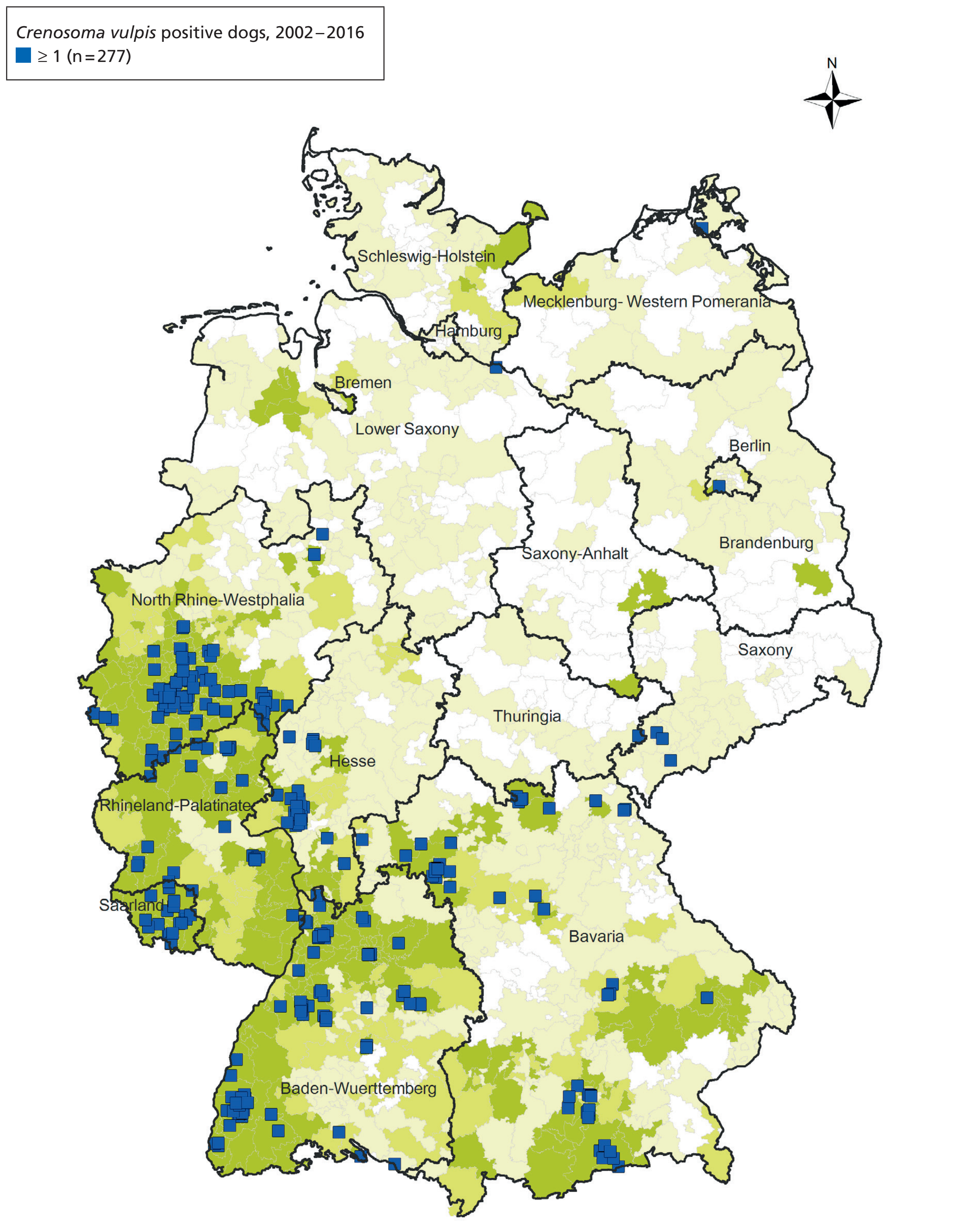

Fig. 6b Natural infections with *Crenosoma vulpis* in dogs in Germany 2002 – 2016

rates of infection were significantly higher ($p < 0.05$) than in 2002–2005.

With regard to gender, 55.1% and 44.9% of the *A. vasorum* positive dogs were male and female, respectively. For *C. vulpis* 46.7% of the positive dogs were male and 57.3% were female. Analysis of the data did not show a significant difference between gender and lungworm infection.

With respect to the age of the sampled dogs (Table 4), most of the dogs were in the youngest age groups: up to 1 year of age (n = 9,584), > 1–2 years of age (n = 10,264) and > 2–3 years of age (n = 6,001) (Table 4). With increasing age the number of sampled dogs declined from 4,326 in the age group > 3–4 years to 1,362 in the age group > 13–14 years (Table 4). In the senior group the number of sampled dogs decreased markedly. The highest numbers of dogs infected with *A. vasorum* and *C. vulpis* were found in the classes of young dogs up to 1 year of age (106 and 50 respectively) and > 1–2 years of age (116 and 52) (Table 4). As the number of sampled dogs was high in classes with young dogs and low in classes with old dogs, it was not possible to confirm a statistically significant difference between age and lungworm infection in any age group.

Concerning the seasonal variation of lungworm infections, the lowest percentages of dogs infected with *A. vasorum* and *C. vulpis* were found from June to August (Fig. 2). The infection rate of *A. vasorum* in summer was significantly lower (0.4% vs. 1.4%; $p = 0.0179$, multiple-level alpha not controlled) than in winter, and the infection rate of *C. vulpis* was lower in summer (0.2% vs. 0.7%; $p = 0.0095$) than in winter too.

Most of the lungworm positive dogs were detected in the south-west and west of Germany (Table 6). *A. vasorum* was mainly located in Baden-Wuerttemberg with 315 cases (1.8% of the sampled dogs in this federal state), followed by North Rhine-Westphalia with 120 (0.5%), Saarland with 76 (1.7%), Bavaria with 36 (0.4%), and Hesse with 31 (0.9%). Concerning geographical distribution, *C. vulpis* positive dogs were mostly found in North Rhine-Westphalia with 79 cases (0.3%) and Baden-Wuerttemberg with 75 (0.4%), followed by Bavaria with 48 (0.5%), Hesse with 25 (0.7%), Rhineland-Palatinate with 22 (0.5%) and Saarland with 21 (0.5%).

The locations of the sampled dogs were displayed on the basis of the owner's postcode on maps showing the administrative and postcode boundaries of Germany. The areas are colour-coded to represent regions where no sampling took place (white = not sampled), with a low number of sampled dogs (light green = 1 sample per postcode), with a moderate number of sampled dogs (medium green = 10 samples per postcode) and with a high number of samples (dark green = 25 samples per postcode). Red symbols indicate cases of *A. vasorum* and blue symbols cases of *C. vulpis*. The four maps show the changing regions in which the samples were taken, the development of the number of lungworm positive dogs within the periods 2002–2006 (Fig. 3a, b), 2007–2011 (Fig. 4a, b), 2012–2016 (Fig. 5a, b) and 2002–2016 (Fig. 6a, b) and the spatial distribution of *A. vasorum* and *C. vulpis*. The first map (Fig. 3a, b) representing the period 2002–2006 shows only 12 *A. vasorum* and 20 *C. vulpis* cases. The second map (Fig. 4a, b) represents the period 2007–2011 and shows 160 *A. vasorum* and 99 *C. vulpis* positive dogs. The third map (Fig. 5a, b) represents the period 2012–2016 and shows 426 *A. vasorum* and 158 *C. vulpis* positive dogs. The fourth map (Fig. 6a, b) represents the period 2002–2016 and shows 598 *A. vasorum* and 277 *C. vulpis* positive dogs. The spatial distribution indicates an increasing accumulation of *A. vasorum* cases in certain areas with four main clusters. One cluster is located in the south of Baden-Wuerttemberg, a second in the north of Baden-Wuerttemberg and Rhineland-Palatinate, and two others in Saarland and North Rhine-Westphalia.

Discussion

The metastrongylid nematode *A. vasorum* lives in the pulmonary arteries and heart of the definitive hosts, i.e. dogs, foxes and other canids. The course of disease in dogs infected with *A. vasorum* can be severe and sometimes even fatal (Denk et al. 2009, Schnyder et al. 2010). Infection with *A. vasorum* causes various symptoms, mainly respiratory clinical signs including coughing and dyspnoea but also coagulopathy combined with thrombocytopenia, bleeding disorders, arterial hypertension, and neurological disorders (Nicolle et al. 2006). Because of the severe and sometimes fatal outcome, lungworm infections are of special interest to veterinarians, researchers and dog owners. Over the last 10 to 15 years infections with *A. vasorum* in dogs have increasingly been reported in Europe, mainly confined to isolated endemic foci. But increasing numbers of cases in south-east England and series of case reports involving dogs from northern parts of the UK, including Scotland, suggested the northward spread of *A. vasorum* within the UK (Hayes and Rowlands 2004, Helm et al. 2009, Yamakawa et al. 2009). These observations were backed up by post mortem surveys of foxes, suggesting that *A. vasorum* has increased in prevalence and has spread geographically outside of known loci in Great Britain (Morgan et al. 2008, Taylor et al. 2015). In dogs, infections with *A. vasorum* have also increasingly been found in areas previously believed to be free from infections, and the prevalence of canine infections has increased in endemic areas (Helm et al. 2010). Recent data from a survey of the fox population support the suggestion that *A. vasorum* has increased in prevalence and has spread geographically in Great Britain.

There is little research into epidemiological data, prevalence rates and regional distribution or comparative studies over long time periods of the changing geographical distribution of *C. vulpis* in dogs. Current epidemiological data obtained from dogs with suspected lungworm infection support the hypothesis of the geographical spread of *A. vasorum* and *C. vulpis* as well (Maksimov et al. 2017).

Epidemiological analyses of the results of faecal examination demonstrated a wide distribution of *A. vasorum* and *C. vulpis* in dogs in Germany (Barutzki and Schaper 2009, Taubert et al. 2009). However, in Germany there are no studies that substantially demonstrate the potential spread of *A. vasorum* and *C. vulpis*. Maksimov et al. (2017) used georeferenced data in a recently published paper to support the hypothesis that both lungworms are spreading geographically in Germany as well. The reasons for the potential geographical spread are unknown. *A. vasorum* and *C. vulpis* are both gastropod-borne lungworms. They need slugs and snails as intermediate hosts to develop from larva 1 to infective third-stage larvae. Furthermore frogs (*Rana temporaria*) can act as paratenic and intermediate host (Bolt et al. 1993) and even birds (e.g. *Gallus gallus domesticus*), after ingestion of infected snails or slugs, are able to function as paratenic host for *A. vasorum*. Red foxes (*Vulpes vulpes*) provide an important wildlife reservoir for *A. vasorum* and *C. vulpis* infections in pet dogs. Other potential wildlife host species such as wolves (*Canis lupus*) are of minor or no importance in Germany, and raccoon dogs (*Nyctereutes procyonoides*) seem to be irrelevant so far with regard to their role as a reservoir host (Hartwig et al. 2015). Therefore, the number of foxes and dogs and the bioavailability of intermediate hosts are probably the main epidemiological factors influencing changes in the prevalence and distribution of lungworms. This corresponds with the results of a study in south Wales and south-west England, where the composition of the slug fauna and prevalence of slugs infected with *A. vasorum* varied spatially and appeared to play a role in the distribution of *A. vasorum*. The authors postulated a correlation between the density of competent intermediate and definitive hosts and the patchiness of the prevalence of *A. vasorum* (Aziz et al. 2016). Finally, the influence of climate change is currently under discussion (Morgan et al. 2009), but further studies are needed to clarify its role and mechanisms in the spread of *A. vasorum*.

In addition, a greater number and the urbanization of red foxes (*Vulpes vulpes*) and the increased movement of dog owners taking their pets on holidays within and between countries (Morgan and Shaw, 2010) may play a supporting role in the epidemiology of lungworms in Germany. Increasing interest, research and knowledge of this topic may also influence public perception and impressions. All these factors are able to influence the geographical spread of lungworms, changes in geographical distribution and/or perception of lungworm disease. Yet all these factors should affect *A. vasorum* and *C. vulpis* in a similar manner. In the study presented here, the rates of infection with *A. vasorum* were significantly higher in 2015 and 2016 than in the period 2002–2010, whereas no statistically significant differences were found for *C. vulpis*. In addition, the spatial distribution indicated an increasing accumulation of *A. vasorum* cases in certain federal states, but not for *C. vulpis*. In particular, a high number of cases were observed in Baden-Wuerttemberg, Saarland, Hesse, North Rhine-Westphalia and Bavaria (Figs 3a-6a), suggesting an increase in *A. vasorum* prevalence in these areas that were already known to be affected (Barutzki and Schaper, 2009). These regions in the federal states already mentioned overlap with those described in a seroepidemiological study and a survey using the Baermann technique (Maksimov et al. 2017, Schnyder et al. 2013a).

A fast and intensive geographical spread of *A. vasorum* could have developed due to the high larval shed in naturally infected dogs, which can be as high as 280,000 larvae per gram faeces (Martin et al. 1993), combined with a long period of larval excretion, which was determined to be at least 300 days (Oliveira-Junior et al. 2006). Comparable data on the role of slugs and snails in the epidemiology and the duration of larvae excretion of *C. vulpis* are lacking.

In contrast to our findings, Maksimov et al. (2017) noticed increasing prevalence rates and geographical spread for both *A. vasorum* and *C. vulpis*. There might be a difference between our dog population, which was presented to veterinarians for mostly unknown clinical problems, routine examination, animal vaccination or a general health check, and the dog population examined by Maksimov et al. (2017), where a suspected lungworm infection could be a predisposing factor. However, this discrepancy cannot be clarified on the basis of the data currently available in Germany and should be investigated in future studies.

Acknowledgements
We would like to thank Dipl.-Stat. Marion Ocak, MD research, Munich, Germany, for performing the statistical analysis of the data.

Compliance statement
All the studies reported here were performed in compliance with current applicable local laws and regulations.

Disclosure statement
D. Barutzki is the director and V. Dyachenko is an employee of the Veterinary Laboratory Freiburg. R. Schaper is an employee of Bayer Animal Health GmbH. Bayer Animal Health GmbH provided financial support for the data analysis.

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