Wild boar (*Sus scrofa*) as a possible vector of mycobacterial infections: review of literature and critical analysis of data from Central Europe between 1983 to 2001

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ABSTRACT: Infected animals in the wild, which can act as a reservoir and/or vector for the origin of bovine tuberculosis, are a great problem for national programmes seeking to free herds of cattle from the infection. The circulation of *Mycobacterium bovis* in the wild animal population might cause a slow-down in the progress of control programmes through the reinfection of herds of livestock. The Eurasian badger (*Meles meles*) and red deer (*Cervus elaphus*) living in the wild in Great Britain and Ireland, brushtail possum (*Trichosurus vulpecula*), ferrets (*Mustela putorius* f. *furo*) in New Zealand and wild buffalo (*Bubalus arnee*) in Australia are among already known reservoirs and vectors of bovine tuberculosis. In 7 countries of Central Europe (Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Poland, Slovakia and Slovenia) bovine tuberculosis in cattle was controlled as part of national control programmes more than 20 years ago. In the last decade *M. bovis* has been diagnosed extremely sporadically in cattle and other domestic animals as well as in wild animals held in captivity or living in the wild. This favourable situation could be threatened by the mycobacteria spreading via the wild boar (*Sus scrofa*) which is susceptible to mycobacterial infection and very abundant in Central Europe. According to available literary data, mycobacteria were detected in 361 wild boar originating from countries other than those of Central Europe, such as Australia, Bulgaria, Germany, the Hawaiian island of Molokai, Italy and Spain. *M. tuberculosis* complex (33.9%) and *M. bovis* complex (39.8%) isolates were most frequently detected in the faeces and/or parenchymatous organs of wild boar. Of other mycobacterial species, *M. intracellulare* (3.8%), *M. avium* subsp. *avium* (3.8%), *M. terrae* (2.4%), *M. fortuitum* (2.2%), *M. scrofulaceum* (2.2%), *M. gordonae* (0.8%), *M. simiae* (0.5%), *M. szulgai* (0.5%), *M. xenopi* (0.5%), *M. smegmatis* (0.2%), *M. vaccae* (0.2%), fast-growing, further unspecified species (0.2%) and unidentified mycobacteria (8.8%) were isolated. Following the analysis of literary data and our own results, it was found that, in the area covered by the above-mentioned 7 countries of Central Europe, a total of 431 wild boar were examined for mycobacterial infections in the years 1983–2001. Tuberculous lesions in parenchymatous organs were found in 43 (10.0%) animals. *M. bovis* was identified in 22 (5.1%) animals, *M. a. avium* in 2 (0.4%), *M. a. paratuberculosis* in 1 (0.2%) animal and atypical

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mycobacteria in 27 (6.3%) animals. The wild boar may therefore represent, under certain unfavourable epizootiological conditions, a vector of some mycobacterial infections in not only animals, but also humans.

Keywords: veterinary epidemiology; risk assessment; wild boar; tuberculosis; Johne's disease

The circulation of obligatorily pathogenic mycobacteria (*Mycobacterium tuberculosis*, *M. bovis* and others) as well as other clinically important species of mycobacteria (*M. a. avium*, *M. intracellulare*, *M. scrofulaceum*, *M. kansasii*, *M. a. paratuberculosis*, *M. fortuitum* and others) in populations of wild animals can lead to the contamination of the environment (Horvathova *et al.*, 1997; Matlova *et al.*, 1998; Havelkova *et al.*, 1998). The state of health of livestock and people (above all individuals with an immunocompetency dysfunction) can then be threatened not only by contact with infected wild animals, but also with a contaminated environment. Animals living in the wild which have been infected by causal agents of serious mycobacterial infections can, under certain conditions, become reservoirs of these mycobacterial infections (Little *et al.*, 1982a,b; Hejlicek *et al.*, 1994; Fischer *et al.*, 2000).

M. bovis is the species of mycobacteria with the most serious consequences for health, causing infection in a wide range of hosts including people. Bovine tuberculosis was identified in cattle (*Bos primigenius* f. *taurus*), the Indian buffalo (*Bubalus arnee* f. *bubalis*), pig (*Sus scrofa* f. *domestica*), wild boar (*Sus scrofa*), goat (*Capra aegagrus* f. *hircus*), dog (*Canis lupus* f. *familiaris*), cat (*Felis silvestris* f. *catus*), wild ruminants such as red deer (*Cervus elaphus*), fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*), bison (*Bison bison*), the European bison (*Bison bonasus*), carnivores such as red fox (*Vulpes vulpes*), coyote (*Canis latrans*) and various other animals such as badger (*Meles meles*), brushtail possum (*Trichosurus vulpecula*), rat (*Rattus norvegicus*) and primates as well as people (Krul, 1962; Little *et al.*, 1982a,b; Zorawski and Lipiec, 1997, 1998; Machackova *et al.*, 2000; Pavlik *et al.*, 2002c). The success of control programmes against bovine tuberculosis in cattle and farmed deer in Australia and New Zealand is considerably complicated by bovine tuberculosis endemias, above all in populations of brushtail possum, badger, red deer and Indian buffalo living in the wild (Cheeseman *et al.*, 1989; Tweddle and Livingstone, 1994).

In Central Europe, on the territory of seven countries (Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Poland, Slovakia and Slovenia), national control programmes against bovine tuberculosis in cattle were carried out in the second half of the last century. As a consequence of these, the incidence of *M. bovis* in cattle (Pavlik *et al.*, 2001b, 2002a,d) and consequently in other domestic and wild animals (Pavlik *et al.*, 2002d) decreased. By studying the molecular epidemiology of bovine tuberculosis in animals and people in the Czech Republic and Slovakia, it was discovered that *M. bovis* had been isolated in a red deer living in the wild of a spoligotype which had not been found in any domestic animal or animal held in captivity (Pavlik *et al.*, 2002c). From this it may be assumed that animals living in the wild can represent a dangerous source of infection. In other parts of the world, infected animals living in the wild became a big problem for the successful completion of national programmes for the control of cattle herds from bovine tuberculosis. These animals were not only the vectors, but moreover also reservoirs of this infection.

The Eurasian badger and red deer living in the wild in Great Britain and Ireland, brushtail possum and ferret (*Mustela putorius* f. *furo*) in New Zealand and wild buffalo in Australia belong among the already known reservoirs and vectors of bovine tuberculosis (Cheeseman *et al.*, 1989; Tweddle and Livingstone, 1994). Therefore, the question arose whether, on the territory of the 7 above-mentioned countries of Central Europe, the favourable epidemiological and epizootiological situation in the field of bovine tuberculosis and possibly other mycobacterial infections of animals could be threatened by infected animals living in the wild. Of these, a considerable increase in particular in the numbers of wild boar, which are susceptible to mycobacterial infections, has presently been recorded in Central Europe.

The objective of our review was therefore to analyse, from available literary and statistical data, the identification of mycobacterial infection in wild boar and the spectrum of isolated mycobacterial species, in co-ordination with the directors of Reference Laboratories for Tuberculosis in Animals in the above-mentioned countries of Central Europe. Another objective of our work was to assess the current risks of the spread of the mycobacterial infections in Central Europe, on the basis of the occurrence of mycobacteria in wild boar in other parts of the world and the anticipated pathogenesis of mycobacterial infection in pigs.

The occurrence of mycobacteria in wild boar in Central Europe

The occurrence of bovine tuberculosis in wild boar was monitored in 7 countries of Central Europe in the years 1983 to 2001. These countries are situated between the Baltic and Adriatic seas, covering an area of 661 635 km^2 with 72.030 million inhabitants. Until 1995, a total of 13.040 million head of cattle were kept in this area, of which 6.001 million were cows (FAO-OIE-WHO, 1997; OIE, 1999, 2000). Statistical and anamnestic data were provided by Reference Laboratories for Mycobacterial Infections in Animals in six countries (Croatia, Czech Republic, Hungary, Poland, Slovakia and Slovenia). Only published data were available from Bosnia and Herzegovina (Ivetic and Sudaric, 1987).

On the basis of the analysis of literary data and own results it was found that a total of 431 wild boar were examined for mycobacterial infections. These wild boar originated from five countries: Bosnia and Herzegovina, Croatia, Czech Republic, Hungary and Slovakia. From the summarised analysis of all available examinations of 431 wild boar, tuberculous lesions in parenchymatous organs of wild boar were found in 43 (10.0%) animals, *M. bovis* was identified in 22 (5.1%) animals, *M. a. avium* in two (0.4%), *M. a. paratuberculosis* in one (0.2%) and atypical mycobacteria in 27 (6.3%) animals (Table 1).

Bosnia and Herzegovina. In 1987, a case of tuberculosis in one wild boar was described in Bosnia and Herzegovina. Pleuritis (*pleuritis parietalis tuberosa*) and miliary nodules in the liver were found by pathological anatomical examination. Langhan's cells including acid fast rods (AFR) were found by histological examination of tuberculous lesions. Cultural examination was not carried out therefore infection by the *M. bovis* species can be only presumed (Ivetic and Sudaric, 1987).

Croatia. In Croatia in 1992 the *M. bovis* infection was diagnosed in one wild boar, in which no pathological anatomical changes were found (Table 1) and for which the source of infection was not discovered (Pavlik *et al.*, 2002c). Therefore, for preventative reasons, in the years 1992 to 1999 a total of 69 wild boar were examined for mycobacteria, in none of which were tuberculous lesions found. Atypical mycobacteria of the following species were isolated from eight animals: *M. a. avium* genotype IS*901*– and IS*1245*+ currently called *M. a. hominissuis* (six animals), *M. fortuitum* (one animal) and *M. vaccae* (one animal) according to Mijs *et al.* (2002).

Czech Republic. First monitoring. The first monitoring of the occurrence of mycobacteria in hunt animals living in the wild including wild boar was realised in areas used for military exercises in the years 1986 to 1990 (Hejlicek *et al.*, 1994; Treml and Hejlicek, 1998). Tuberculous lesions were not found in any of the 165 wild boar examined and atypical mycobacteria of the *M. terrae* and *M. gordonae* species (Table 1) were isolated from only 7 of these wild boar.

Second monitoring. Following the social changes in 1989, rearing of cattle in pasture began to be more widely introduced in foothill regions. Since a mixed mycobacterial infection *M. bovis* and *M. a. avium* (genotype IS*901*+ and IS*1245*+ virulent for birds) currently called *M. a. avium* "bird type" (Mijs *et al.*, 2002) was identified in one red deer living in the wild in the north of the Czech Republic in 1991 (Pavlik *et al.*, 1998a,b; 2002a,b,c), a second monitoring was carried out in the years 1996 to 2001. From the culturally examined parenchymatous organs of 139 wild boar, tuberculous lesions were found in only six (4.3%) of them, of which *M. a. avium* genotype IS*901*+ and IS*1245*– (Pavlik *et al.*, 2000) was isolated in only one wild boar. The source of infection for this wild boar was probably pheasants (*Phasianus colchicus*) originating from a flock infected by avian tuberculosis from the same locality. Miliary tuberculous lesions of another five pigs were culturally negative, which could point to the tuberculous lesions being caused by a different causal agent (Table 1).

In 2000, mycobacteria were isolated from six (9.2%) of the 65 wild boar examined. An isolate of atypical mycobacteria was detected in two wild boar from the intestinal mucous membrane. *M. a. avium* (genotype IS*901*– and IS*1245*+, non-virulent for birds) was isolated from three wild boar (in one animal from the liver, one animal from a mesenteric lymph node and one animal from the mucous membrane of the small intestine). The iso-

Table 1. Bovine tuberculosis and other mycobacterial infections in wild pig (Sus scrofa) in five Central European countries

Country	Year	No. of animals	PA positive	Isolation of Mycobacterium			Atypical mycobacteria	Notes
				bovis	avium	paratuberculosis		
Bosnia and Herzegovina	1987	1	1	1	0	0	0	Bovine tuberculosis was diagnosed only by histological examination[1], epizootiological situation non-known
Croatia	1992	21	0	1	0	0	2	2x *M. intracellulare*[4], epizootiological situation non-known
	1993	10	0	0	0	0	1	*M. intracellulare*, epizootiological situation non-known
			0	0	0	0	1	*M. fortuitum*, epizootiological situation non-known
	1994	10	0	0	0	0	2	*M. intracellulare*, epizootiological situation non-known
	1995	6	0	0	0	0	1	*M. vaccae*, epizootiological situation non-known
	1996	14	0	0	0	0	1	*M. intracellulare*, epizootiological situation non-known
	1997	1	0	0	0	0	0	Epizootiological situation non-known
	1998	2	0	0	0	0	0	Epizootiological situation non-known
	1999	5	0	0	0	0	0	Epizootiological situation non-known
Czech Republic	1986–1990	165	0	0	0	0	1	*M. gordonae*, military training areas without BTB in cattle[2,3]
			0	0	0	0	6	*M. terrae*, military training areas without BTB in cattle[2,3]
	1996	1	1	0	1	0	0	Avian tuberculosis in pheasant farm in the same area
	1997	6	5	0	0	0	0	Epizootiological situation non-known
	1998	4	0	0	0	0	0	Epizootiological situation non-known
	1999	3	0	0	0	0	0	Epizootiological situation non-known
	2000	1	0	0	0	1	0	Outbreak of paratuberculosis in cattle
		64	0	0	0	0	3	*M. intracellulare*, epizootiological situation non-known
			0	0	0	0	2	Non-identified atypical mycobacteria, epizootiological situation non-known
	2001	60	0	0	0	0	1	*M. chelonae*, epizootiological situation non-known
			0	0	0	0	3	Non-identified atypical mycobacteria, epizootiological situation non-known

Hungary	1996	1	1	1	0	0	0	Area with BTB in cattle[7]
	2000	4	4	4	0	0	0	Area with BTB in cattle and area without BTB in cattle
	2001	6	6	6	0	0	0	Epizootiological situation non-known
Slovakia	1983	1	1	1	0	0	0	Area 1 with BTB in cattle and sheep[4,5,6]
	1987	1	1	1	0	0	0	Area 1 with BTB in cattle and sheep[4,5,6]
		1	1	1	0	0	0	Area 2 with BTB in cattle[4,5,6]
	1988	2	2	2	0	0	0	Area 1 with BTB in cattle and sheep[4,5,6]
		11	5	1	0	0	1	Area 2 with BTB in cattle; mycobacteria of Runyon's group IV; epizootiological situation non-known [4,5,6]
	1989	19	7	0	1	0	1	Area 2 with BTB in cattle; *M. fortuitum*[4]
	1990–1991	8	5	0	0	0	1	Area 2 with BTB in cattle; *M. intracellulare*[4]
	1992	3	3	3	0	0	0	Area 2 with BTB in cattle[6]
Total		431	43	22	2	1	27	
%		100	10.0	5.1	0.4	0.2	6.3	

BTBC = bovine tuberculosis
Area 1 = district Topolcany
Area 2 = district Presov
PA positive = positive pathological-anatomic finding (tuberculous lesions)
[1]Ivetic and Sudaric (1987)
[2]Hejlicek *et al*. (1994)
[3]Treml and Hejlicek (1998)
[4]Kalensky (1992)
[5]Hanzlikova and Vilimek (1992)
[6]Badalik *et al*. (1997)
[7]Pavlik *et al*. (2002a)

lation of *M. a. paratuberculosis* from a mediastinal lymph node of a wild boar which came from a district where paratuberculosis had been diagnosed in cattle, the roe deer living in the wild and farmed red deer (Table 1) was of great interest. In 2001, three isolates of atypical mycobacteria and the *M. chelonae* (6.6%) isolate were detected in the liver, lymph node and intestinal mucous membrane of 60 wild boar examined without pathological anatomical changes.

Hungary. In Hungary, *M. bovis* was isolated in 1996 in one wild boar in which large-node tuberculosis of the liver was found (Table 1, Pavlik *et al.*, 2002c). In January 2000, generalized bovine tuberculosis was identified in another four wild boar. The first wild boar with tuberculous lesions of the liver and lungs was found dead in the same area where a herd of cattle infected with tuberculosis could be found. Another three wild boar infected with *M. bovis* with tuberculous lesions were shot in a district 200 km away and free of tuberculosis. Consequently, in 2001, bovine tuberculosis was identified in six wild boar with tuberculous lesions in various parts of Hungary.

Slovakia. Over the whole territory of Slovakia between 1983 and 2001, 46 wild boar were examined. Infection caused by *M. bovis* was diagnosed in 9 (19.6%) animals in two areas (Figure 1), situated in the western (Figure 2) and eastern (Figure 3) parts of the country (Hanzlikova and Vilimek, 1992; Kalensky, 1992; Badalik *et al.*, 1997). Apart from the mycobacterial species *M. bovis*, other species of mycobacteria were isolated from 4 (10.2%) wild boar examined in the years 1987 to 1991 at the State Veterinary Institute in Presov. These were *M. a. avium* (one animal), *M. fortuitum* (one animal), *M. intracellulare* (one animal) and fast-growing mycobacteria (one animal) (Kalensky, 1992).

<u>Area 1</u> (Figure 2). In the years 1983 to 1988 *M. bovis* was isolated from four wild boar in the western Slovak region of Topolcany. The first wild boar infected with *M. bovis* was found in 1983 in a location NS about 10 km from a cattle farm (KNV) where bovine tuberculosis had already been diagnosed in the previous year (1982). Next, in 1987, *M. bovis* was isolated from one and a year later, in 1988, from the second wild boar in location C. This location bordered in a 10 to 30 km radius with areas where four farms were situated with cattle infected with bovine tuberculosis in 1984 (farm KNV), 1985 (farm BO), 1988 (farms KL and JV). In 1988, the infection was detected in the fourth wild boar captured in location P where the *M. bovis* infection had been diagnosed in 1987 in one herd of cattle and sheep (farm VU) kept in pasture (Hanzlikova and Vilimek, 1992). At the same time, bovine tuberculosis occurred on another two cattle farms nearby in 1985 (farm BR) and 1987 (farm CHY).

<u>Area 2</u> (Figure 3). In 1987, *M. bovis* was identified in the second area in eastern Slovakia in the Presov region in location HH in one approximately one-and-a-half year old emaciated wild sow, in which pearl disease of the peritoneum, purulent splenitis and pleuritis were found during pathological anatomical autopsy. A year later (1988) a large-node form of lung tuberculosis with the isolation of *M. bovis* (Kalensky, 1992) was found during a pathological anatomical autopsy in a second wild boar originating from location DU. In previous years (1980, 1982 to 1986) bovine tuberculosis was diagnosed in the neighbouring two regions on six cattle farms which, however, were more than

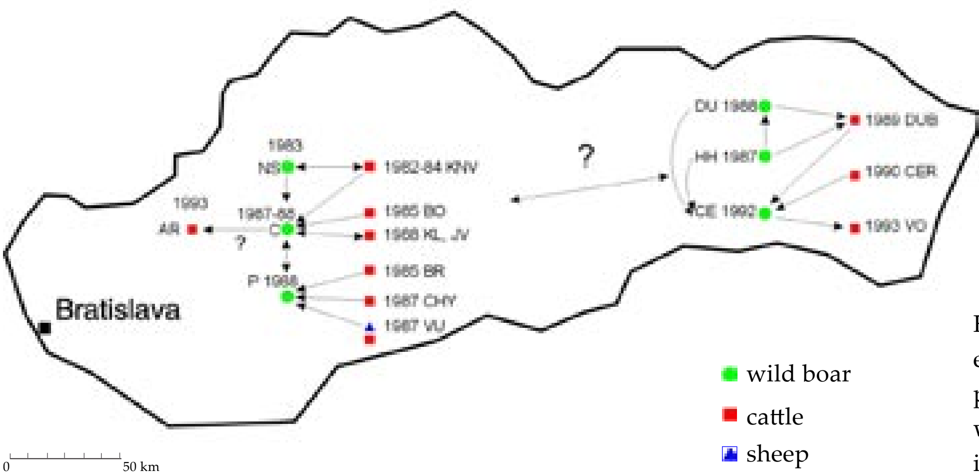

Figure 1. Two areas (western part – Area 1, eastern part – Area 2) in Slovakia with bovine tuberculosis in wild boar (*Sus scrofa*)

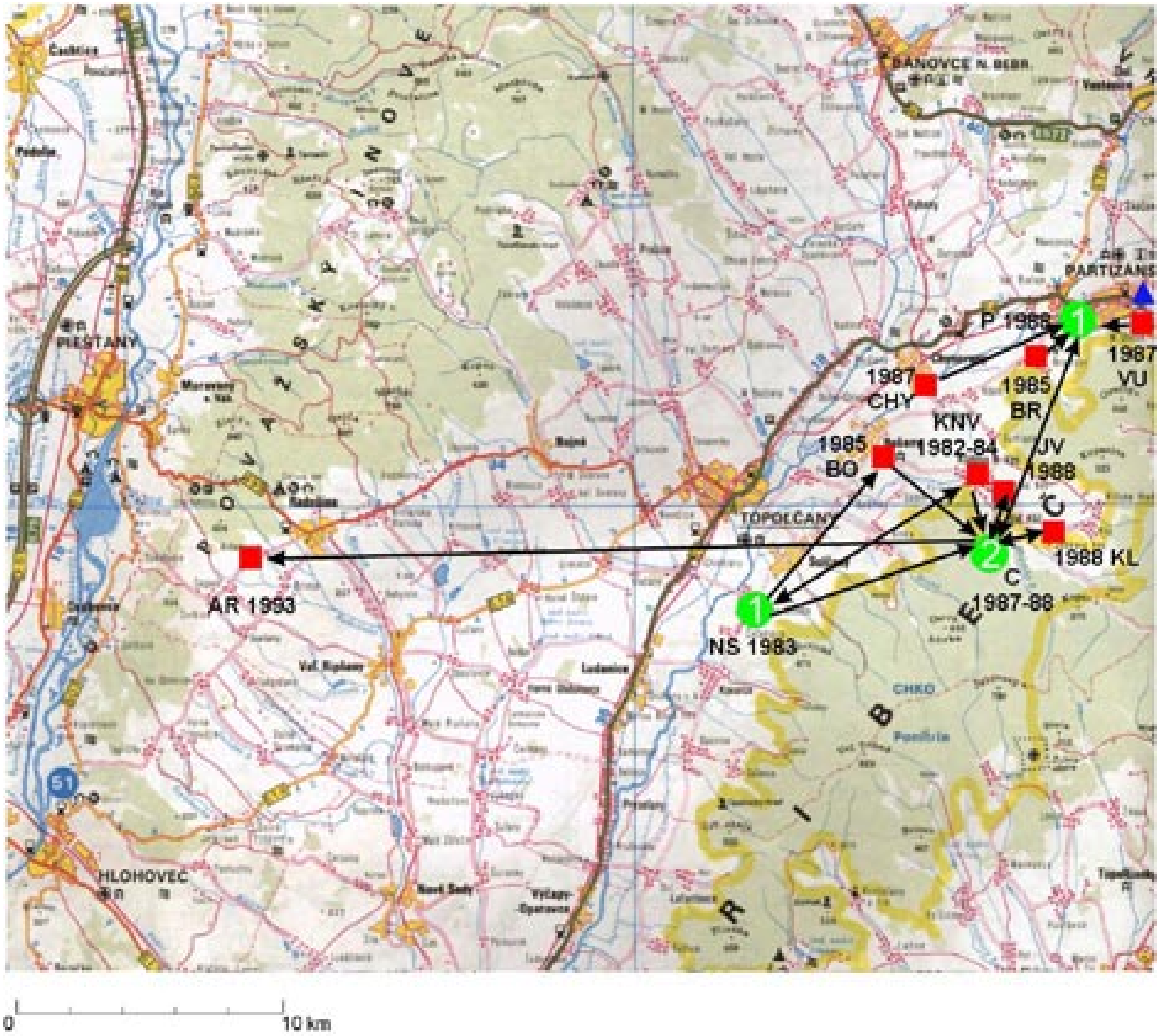

Figure 2. *Mycobacterium bovis* isolation from wild boar (*Sus scrofa*) in Area 1 (region of Topolcany)

● wild boar (1983–1988) ■ cattle (1982–1993) ▲ sheep (1987)

50 km away from the place where the wild boar were captured. In the following period in 1989 a new outbreak of bovine tuberculosis in cattle was found in the Presov district on farm DUB, located 20 km from locations HH and DU with occurrence of tuberculosis in wild boar. The last recorded finding of *M. bovis* in wild boar was noted in location CE in three individuals in 1992 (Badalik *et al.*, 1997). Certain epizootiological connection could point to locations HH, DU, DUB and also to locations in the neighbouring region, where bovine tuberculosis was diagnosed on two further cattle farms CER (1990) and VO (1993).

The occurrence of mycobacterial infections in wild boar in other countries

The tuberculous process was described in wild boar as early as 1930 (Kindinger, 1934). From literary data it emerges that bovine tuberculosis has been diagnosed since the 1970s in Australia, Bulgaria, Germany, the Hawaiian island of Molokai, Italy and Spain (Table 2). 361 mycobacterial isolates were detected in biological material (droppings and/or organs) from wild boar in the six above-mentioned countries. Most frequently, isolates of the *M. tuberculosis* complex were detected, of

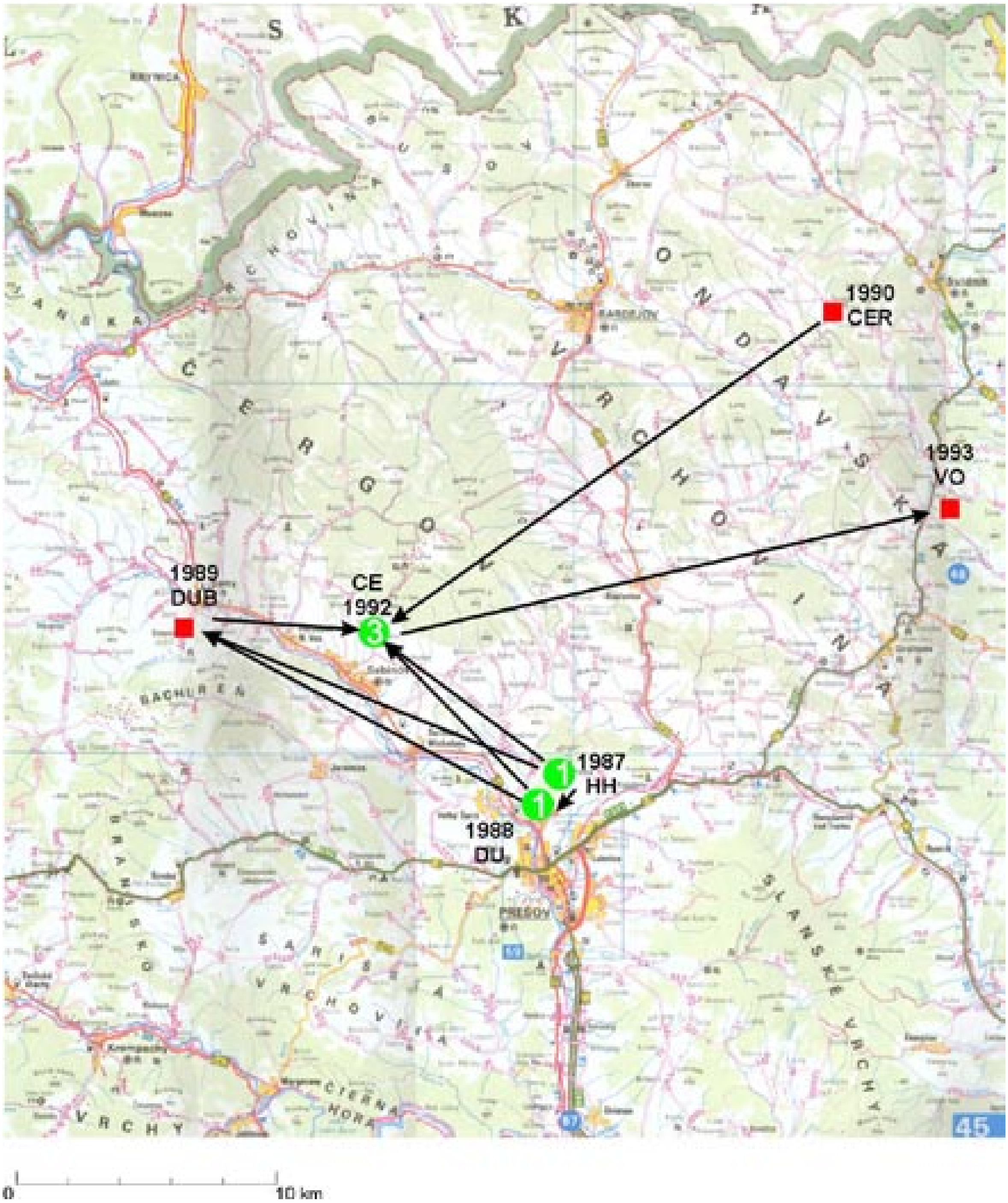

Figure 3. *Mycobacterium bovis* isolation from wild boar (*Sus scrofa*) in Area 2 (region of Presov)

wild boar (1987–1992) cattle (1989–1993)

which 33.9% were not more closely specified and 39.8% were identified as *M. bovis*. Of other mycobacterial species, the following were isolated: *M. intracellulare* (3.8%), *M. a. avium* (3.8%), *M. terrae* (2.4%), *M. fortuitum* (2.2%), *M. scrofulaceum* (2.2%), *M. gordonae* (0.8%), *M. simiae* (0.5%), *M. szulgai* (0.5%), *M. xenopi* (0.5%), *M. smegmatis* (0.2%), *M. vaccae* (0.2%), fast-growing further unspecified species (0.2%) and unidentified mycobacteria (8.8%).

Australia. The prevalence of mycobacterial infections in wild boar may be, depending on specific

Table 2. Mycobacteria isolated from wild pig (*Sus scrofa*) – review of literature from all countries except of Central Europe

Mycobacterial species	Total No. of isolates	%	Country	No. of isolates	PA positive	Reference
M. a. avium	14	3.8	Australia	1	1[2]	Corner *et al*., 1981
			Italy	5	5	Serraino *et al*., 1999
			Germany	2[1]	n	Weber, 1982
			Spain	6	6	Tato *et al*., 2001
M. bovis	144	39.8	Australia	39	37[2]	Corner *et al*., 1981; McInerney *et al*., 1995
			Bulgaria	7	7	Bachvarova *et al*., 1996
			Hawaiian island of Molokai	12	12	Thoen *et al*., 1981; Essey *et al*., 1983
			Italy	25	25	Mignone *et al*., 1991; Biolatti *et al*., 1992; Serraino *et al*., 1999
			Germany	57	57	Schulz *et al*., 1992
			Spain	4	4	Aranaz *et al*., 1996
M. fortuitum	8	2.2	Italy	5	5	Serraino *et al*., 1999
			Spain	3	3	Tato *et al*., 2001
M. gordonae	3	0.8	Australia	2	2[2]	Corner *et al*., 1981
			Germany	1[1]	n	Weber, 1982
M. intracellulare	14	3.8	Australia	14	14[2]	Corner *et al*., 1981
M. kansasii	1	0.2	Australia	1	1[2]	Corner *et al*., 1981
M. scrofulaceum	8	2.2	Australia	8	8[2]	Corner *et al*., 1981
M. simiae	2	0.5	Australia	2	2[2]	Corner *et al*., 1981
M. smegmatis	1	0.2	Spain	1	1	Tato *et al*., 2001
M. szulgai	2	0.5	Australia	2	2[2]	Corner *et al*., 1981
M. terrae	9	2.4	Germany	7[1]	n	Weber, 1982
			Spain	2	2	Tato *et al*., 2001
M. tuberculosis complex	119	33.9	Italy	119	119	Mignone *et al*., 1991; Biolatti *et al*., 1992; Serraino *et al*., 1999; Bollo *et al*., 2000
M. vaccae	1	0.2	Australia	1	1[2]	Corner *et al*., 1981
M. xenopi	2	0.5	Australia	2	2[2]	Corner *et al*., 1981
Runyon's group IV	1	0.2	Australia	1	1[2]	Corner *et al*., 1981
Non-identified atypical mycobacteria	32	8.8	Australia	18	18[2]	Corner *et al*., 1981
			Germany	14	14	Schulz *et al*., 1992
Total	361	100		361	349	

PA positive = pathological anatomic examination of parenchymatous organs
n = non-tested
[1]isolates from faeces
[2]isolates from tuberculoid lesions histologically negative for typical tuberculous granulom
[3]tuberculous changed organs examined histological only with the demonstration of typical tuberculous granulom

conditions (the epizootiological situation in the region, the size of the wild boar population, climatic conditions, feed availability etc.) considerably high. In the northern part of Australia the organs of 193 wild boar from six areas were examined between 1973 and 1976 for mycobacteria, with a positive result in 88 (45.6%) wild boar (Corner *et al.*, 1981). Of the 93 mycobacterial isolates, *M. bovis* was the most frequently isolated species from tuberculous and tuberculoid lesions (37 isolates). *M. a. avium* was isolated only once, 33 isolates belonged to species of atypical mycobacteria and 18 mycobacterial isolates were not specified (Table 2). Apart from mycobacteria, four isolates of the *Rhodococcus* sp. were detected, as happened, for example, from the lymph nodes of domestic pigs in the Czech Republic (Dvorska *et al.*, 1999). The higher incidence of *M. bovis* in wild boar was caused in the period monitored by a high prevalence of bovine tuberculosis in cattle reared in pasture and in Indian buffalo. After the depopulation of infected herds of cattle and Indian buffalo in the area monitored, the incidence of *M. bovis* in the population of wild boar was monitored again in 1992 (McInerney *et al.*, 1995). The prevalence of bovine tuberculosis in wild boar living in the wild had decreased significantly. Of 790 wild boar examined, *M. bovis* was found in only 2 (0.3%).

The Hawaiian island of Molokai. A similar development in the epizootiological situation to that in Australia was recorded on the Hawaiian island of Molokai. Of 68 wild boar examined in 1980, *M. bovis* was isolated from the tuberculous tissue of 17.7% of animals, in which a positive serological reaction was also discovered using the ELISA method (Thoen *et al.*, 1981; Essey *et al.*, 1983). In 1981 bovine tuberculosis was eliminated in cattle in this area and in subsequent years the prevalence of bovine tuberculosis in wild boar living in the wild was gradually reduced until in 1983 it fell to only 3% (Essey *et al.*, 1983).

New Zealand. In New Zealand, unlike Australia, the wild boar is not an ultimate host of *M. bovis*. Endemic areas with an incidence of bovine tuberculosis there are constantly expanding and, apart from the above-mentioned brushtail possum, red deer and ferrets, wild boar also contribute to the spread of *M. bovis* (Tweddle and Livingstone, 1994).

Germany. In Germany in the 1980s, as part of the screening of the occurrence of atypical mycobacterioses, various species of mycobacteria were isolated from 50 wild boar examined from 20% of the samples of droppings: *M. a. avium*, *M. gordonae* and *M. terrae* (Weber, 1982). In the years 1982 to 1988, 7 419 wild boar were examined in the region of Mecklenburg-Vorpommern (Schulz *et al.*, 1992). Tuberculous lesions were found in 102 (1.4%) animals. From the lesions found, it proved possible to isolate *M. bovis* in 57 (55.6%) cases and atypical mycobacteria in 14 (13.7%) cases. It is interesting that in the region mentioned no tuberculous findings were made in 263 wild ruminants examined. The source of *M. bovis* was most probably a herd of cattle infected by bovine tuberculosis.

Italy. In one region of Italy the incidence of *M. bovis* in wild boar was monitored in two time periods. In 1989 almost 300 wild boar were examined, of which *M. bovis* was isolated from 10 (3.3%) and *M. tuberculosis* from 6 (2.0%) wild boar. In only two wild boar infected with *M. bovis* it was found that wild boar were caught in a region where cattle infected with bovine tuberculosis had grazed (Mignone *et al.*, 1991; Biolatti *et al.*, 1992). In the same region, 63 wild boar were subsequently examined in the years 1993 to 1995 (Serraino *et al.*, 1999). Out of 42 microscopically positive samples for AFR, 26 isolates emerged which were biochemically identified as *M. bovis*, *M. tuberculosis*, *M. a. avium* and *M. fortuitum*. As part of epizootiological studies the isolates of *M. bovis* were further identified using molecular methods: spoligotyping and RFLP (Restriction Fragment Length Polymorphism). It was found that 60% *M. bovis* isolates from wild boar had the same DNA profile as *M. bovis* isolates from cattle reared in pasture in the same region. In the latest study, conducted in the years 1995 to 1996 in 2 488 wild boar, tuberculous lesions were found in the submandibular lymph nodes of 285 (11.5%). *M. tuberculosis* complex isolates were detected in 112 (4.5%) wild boar (Bollo *et al.*, 2000).

Spain. In western Spain in the region of Extramadura, screening of the occurrence of atypical mycobacteria in wild and domestic animals was carried out to assess the health risks for the human population. In this study 3 510 wild boar were examined over a six year period (1992 to 1998), of which in 40 (1.1%) tuberculous findings were made (above all in the lungs and retropharyngeal lymph nodes). Mycobacteria of the species *M. a. avium*, *M. fortuitum*, *M. terrae* and *M. smegmatis* were isolated from only 12 lymph nodes with tuberculous lesions (Tato *et al.*, 2001 – pers. commun.). In South-western Spain *M. bovis* was isolated from 4 wild boar in which granulomatous lesions were found in the lymph nodes, lungs, livers and in one animal in the area of the ulnar joint (Aranaz *et al.*, 1996). The DNA types of isolates from these wild boar were identical (using the RFLP method and spoligotyping) to those isolates from cattle. The authors presume that wild boar may be a reservoir of bovine tuberculosis for domestic ruminants (cattle, sheep, and goats) in Spain. In this country a control programme has been in progress since 1965, but the disease has still not been successfully eradicated. Since 1994 the prevalence of this infection in herds of domestic ruminants has remained constant at about 5% (Aranaz *et al.*, 1996).

Russia. According to the literature available, the incidence of tuberculosis in the wild boar population was also monitored in Russia in the Moscow area in the 1970s. Tuberculous lesions were found in approximately 5% of an unspecified number of wild boar examined (Starodynowa, 1974).

Bulgaria. In the mid-1990s the incidence of tuberculosis in wild boar in Bulgaria was monitored (Bachvarova *et al.*, 1996). Tuberculous lesions in organs were found in seven of the 29 animals examined with the isolation of *M. bovis.*

The pathogenesis and clinical symptoms of mycobacterial infections in wild boar

The low prevalence of the pleural and generalised form of bovine tuberculosis in wild boar may be explained by a certain species resistance to *M. bovis* (Serraino *et al.*, 1999). The low isolation of mycobacteria from tuberculous lesions also indicates a certain degree of resistance of this species of animals to mycobacterial infection (Corner *et al.*, 1981). Mycobacterioses in wild boar caused by other species of mycobacteria (*M. a. avium*, *M. intracellulare* and others) are not a cause of increased mortality, but cause increased morbidity (Corner *et al.*, 1981; Tweddle and Livingstone, 1994; Serraino *et al.*, 1999). According to Tato *et al.* (2001 – pers. commun.), atypical mycobacteria contribute to the emergence of tuberculous lesions especially in a stressful period as a consequence of a shortage of food or overpopulation of wild boar in a specific location.

At the same time the dependence of the prevalence of infection on the age of the animals has been proven. The youngest wild boar from which the *M. avium* complex isolate was received was only one month old. As age increased, the number of wild boar with tuberculous lesions increased, while the number of tuberculous lesions from which mycobacteria were isolated fell (Corner *et al.*, 1981). Ray *et al.* (1972) also describe the more frequent isolation of mycobacteria from the tissue of wild boar without tuberculous lesions. This was the same in domestic pigs as in wild boar, because the inflammatory granulomatous process was capable in a certain way of devitalising mycobacteria and their incidence in microscopically positive tuberculous lesions declined with age (Pavlas *et al.*, 1984).

Clinically the disease (above all bovine tuberculosis) in pigs manifests itself only in swelling of the mandibular lymph nodes. Pathological and anatomical changes are mostly represented only by yellowish tuberculous nodules with central necrosis and calcification above all in the submandibular and retropharyngeal lymph nodes, and also on the pleura and sometimes on the peritoneum (Corner *et al.*, 1981; Serraino *et al.*, 1999; Bollo *et al.* 2000). Ray *et al.* (1972) followed the dependence of the emergence of a certain form of tuberculome in pigs on an isolated mycobacterial species. *M. avium* was isolated more often from the proliferative form of tuberculome half the size of the exsudative tuberculous lesions caused by *M. bovis*. Ray *et al.* (1972) also suggest that in the case of *M. bovis* infection it was a question of generalised tuberculosis. In contrast, *M. avium* and atypical mycobacteria caused tuberculous lesions only in the mesenteric lymph nodes.

Wild boar – a reservoir or only a vector of mycobacterial infections?

The wild boar is an omnivore which in the wild catches small vertebrates, and occasionally small animals: hare (*Lepus europeus*), pheasants, partridges (*Perdix perdix*) and others, or weak ruminant game (e.g. young of deer). Wild boar also eat dead wild or inappropriately disposed of domestic animals or their remains not intended for kitchen use: poultry, rabbits and others (Bouchner and Berger, 1991).

From the epizootiological perspective a major risk factor is the high migration radius of wild boar and also their capacity to overcome natural barriers. Pigs overcome without difficulty the major water barrier represented by the River Danube near Komarno (Navratil *et al.*, 2002). Wild boar migrate outside the hunting season up to 20 km within the territory they inhabit. During the hunting season, however, they can cover more than 50 km a day (Serraino *et al.*, 1999), which can lead to the relatively fast spread of infection over great distances (Holejsovsky *et al.*, 1998).

Wild boar could have become a reservoir of bovine tuberculosis in Central Europe. Control programmes against bovine tuberculosis in cattle and other domestic animals had been virtually ended (Pavlik *et al.*, 2002d). In some of those states the *M. bovis* infection was identified in the wild boar populations. In Slovakia, Hungary and Croatia the incidence of *M. bovis* in wild boar was found to correspond to outbreaks of bovine tuberculosis in cattle as in Spain, Italy and Germany.

The spectrum of mycobacterial species isolated from wild boar was very wide (Tables 1 and 2). Apart from obligatorily pathogenic species, of the other potentially pathogenic mycobacterial species the following were found: *M. intracellulare*, *M. scrofulaceum, M. terrae, M. gordonae, M. fortuitum, M. kansasii, M. simiae, M. szulgai, M. vaccae, M. xenopi* and *M. smegmatis* (Corner *et al.*, 1981; Mignone *et al.*, 1991; Biolatti *et al.*, 1992; Kalensky, 1992; Schulz *et al.*, 1992; Treml and Hejlicek, 1998; Tato *et al.*, 2001 – pers. commun.). Nevertheless several epizootiological studies agree that wild boar are final hosts of bovine tuberculosis and other mycobacterial infections (Corner *et al.*, 1981; Tweddle and Livingstone, 1994; Serraino *et al.*, 1999).

The isolation of *M. a. paratuberculosis* from a wild boar originating in a district in the Czech Republic with diagnosed paratuberculosis in domestic and wild ruminants may be considered serious (Table 1). For a small number of animals examined, the risk of transferring causal agents of paratuberculosis, also an important disease in other countries of Central Europe, through wild boar in the Czech Republic cannot yet be assessed (Pavlik *et al.*, 1998a, 2001a; Kennedy and Benedictus, 2001; Pavlik *et al.*, 2002a).

Given the differing biorhythms of wild boar and domestic animals, we may assume that wild boar may be infected by *M. bovis* in pasture from infected livestock only indirectly by swallowing their faeces or puddles left by cows after giving birth in pasture, or while digging earth in contact with grass tainted with cow urine or sputum. Wild boar may also be infected in the wild by swallowing tissue (especially from parenchymatous organs and the digestive tract) of infected dead wild animals. It is therefore very dangerous for the spread of this infection to leave carcases of wild animals or the entrails of any animal caught in feeding areas in hunting grounds or reserves. The hunting of small vertebrates also carries risks of possible infection with various species of mycobacteria (Fischer *et al.*, 2000) including *M. bovis* (Little *et al.*, 1982a,b).

In view of the nocturnal activity of wild boar, the transmission of bovine tuberculosis in particular through direct contact (aerosol) with domestic animals is not very likely (Serraino *et al.*, 1999). Livestock reared in pasture may be infected by infected wild boar indirectly through contact with their faeces or excrets. Another risk is presented by the infected tissue of wild boar caught while hunting inappropriately disposed of, because under certain circumstances *M. bovis* can survive, for example, in manure for several months (Little *et al.*, 1982a; Duffield and Young, 1985).

In Slovakia in Area 1, bovine tuberculosis was found in wild boar in a relatively small area, given their migrational capabilities (Figures 1 and 2). In suitable geographical conditions, wild boar could migrate without restriction between all the localities mentioned in which bovine tuberculosis in domestic ruminants occurred. For this reason we suppose that the infection could also have been brought onto farms free of tuberculosis. For example, in 1988 infected wild boar from locality C could have been the source of infection for farms KL and JV. The wild boar from locality C could also have been the source of infection for farm AR, where an outbreak of bovine tuberculosis occurred in 1993, since they could easily cover a distance of 50 km on the flattish terrain of this area.

A similar situation occurred in Slovakia in Area 2 (Figures 1 and 3). Infected wild boar from localities DU and HH could have been the source of infection for cattle farm DUB given the distance of up to 20 km and the chronology. Wild boar from the above-mentioned localities HH and DU could spread the *M. bovis* infection into locality CE, where tuberculosis was found as late as 1992 in three wild boar (Badalik *et al.*, 1997). Wild boar could, however, have also been infected in pastures by cattle infected with bovine tuberculosis on farm DUB. After geographical assessment of the region and given the migrational capabilities of wild boar, it may be assumed that that these wild boar from locality CE could have been infected in pastures of farm CER and could have been a potential source of infection for farm VO.

However, in the wild other animals may act as a vector or even as a reservoir of *M. bovis*. In Poland, bovine tuberculosis was diagnosed between 1997 and 1999 in 12 European bison living in the wild. In this case, this was an area in which an outbreak of bovine tuberculosis in cattle was situated (Zorawski and Lipiec, 1997, 1998; Pavlik *et al.*, 2002c). The question therefore arises, whether the wild boar, which also occurs widely in Poland and which consumes carcases including bison, could also become a vector or even a reservoir of *M. bovis* for wild and domestic animals there.

CONCLUSION

Results published up until now support assumptions about the danger represented by wild boar, which may, given their substantial migrational capabilities, spread bovine tuberculosis and other mycobacterial infections relatively quickly, not only in Europe. However, the way in which the infection is transmitted and the size of the infection dose which is necessary to cause disease in susceptible animals remains an open question. Moreover, not all the risks connected with the transmission of *M. bovis* to the human population have been clarified.

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