

## Chapter 2

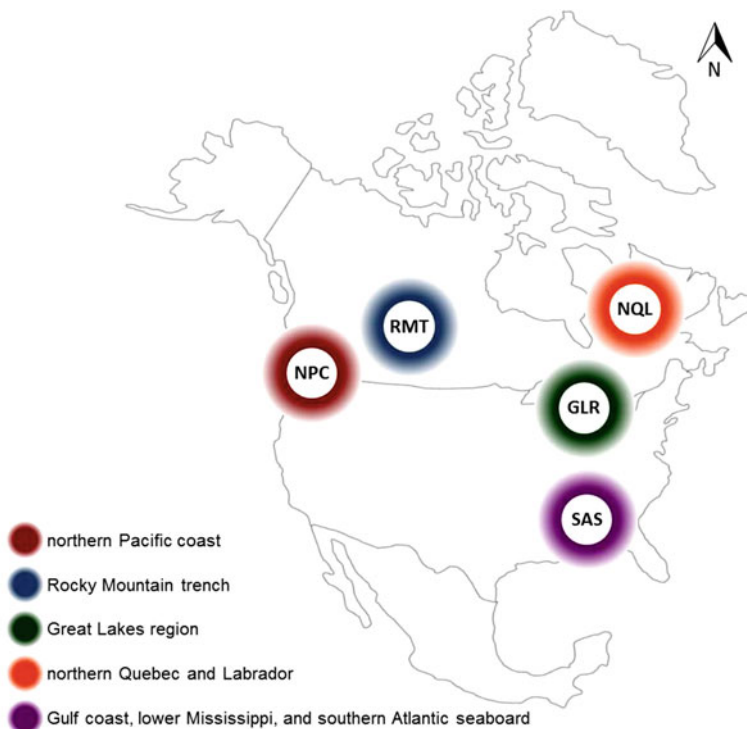
# Distribution of *Fascioloides magna*

**Abstract** Giant liver fluke has established permanent natural foci on two continents. North America represents the original continent of the parasite occurrence, while Europe is the continent where *F. magna* was introduced along with its cervid hosts. In North America, *F. magna* occurs in five enzootic regions across the United States and southern Canada: (1) the northern Pacific coast; (2) the Rocky Mountain trench; (3) the Great Lakes region; (4) northern Quebec and Labrador; and (5) Gulf coast, lower Mississippi, and southern Atlantic seaboard. In Europe, giant liver fluke has established three permanent natural foci: (1) La Mandria Regional Park in the northern Italy; (2) Czech Republic and southwestern Poland; and (3) Danube floodplain forests, involving Austria, Slovakia, Hungary, Croatia and Serbia. This chapter summarizes details on *F. magna* distribution in all North American enzootic regions and European natural foci. Besides permanent foci, sporadic findings of the parasite have been reported throughout the world. Occasional findings very probably represented only single detection of the parasite introduced to the particular region without further establishment of the permanent focus.

**Keywords** Giant liver fluke • Distribution • Biological invasion • North America • Europe • Enzootic region • Natural focus

## 2.1 North America

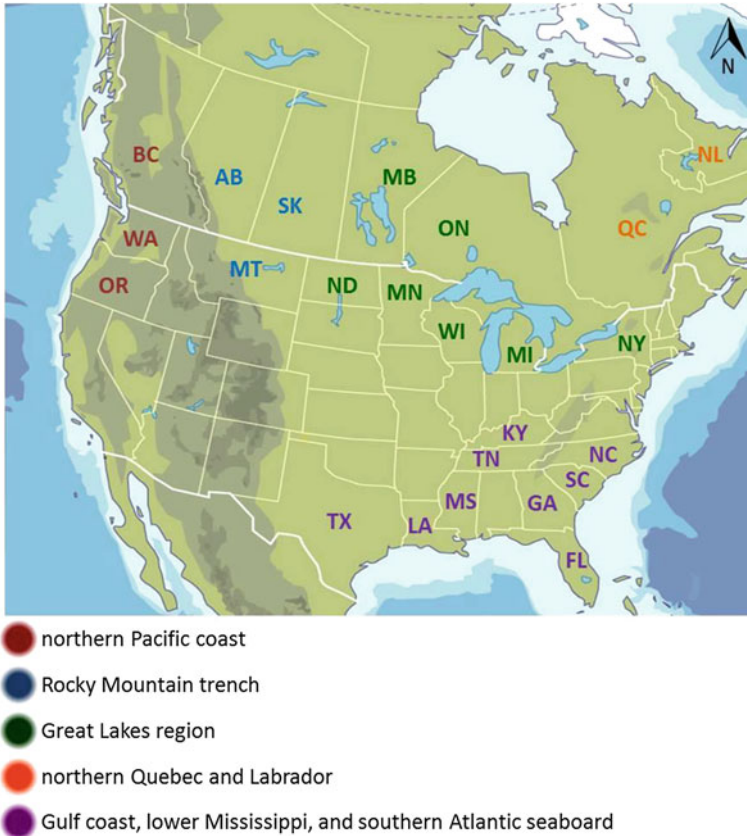
North America has been recognized as the original continent of giant liver fluke. To date, *F. magna* occurs in five enzootic regions across the United States and southern Canada: (1) the northern Pacific coast (NPC); (2) the Rocky Mountain trench (RMT); (3) the Great Lakes region (GLR); (4) northern Quebec and Labrador (NQL); and (5) Gulf coast, lower Mississippi, and southern Atlantic seaboard (SAS) (Fig. 2.1; Pybus 2001). The US states and Canadian provinces with confirmed natural infections of free-living and domestic ruminants are illustrated on Fig. 2.2. Details on geographic localities, final hosts and prevalence of fascioloidosis in all North American enzootic regions are provided in Table 2.1.



**Fig. 2.1** Schematic presentation of North American enzootic regions of *F. magna*

Distribution of *F. magna* in North America has been influenced by a natural migration and human-directed translocations of cervids. Definitive hosts, such as white-tailed deer, wapiti and caribou, have played major role in maintaining fascioloidosis in the natural environment and its further spread into currently recognized enzootic regions. It is generally accepted that *F. magna* have co-evolved with ancestral *Odocoileus* sp. and was originally widespread in white-tailed deer in major wetland habitats throughout North America (Pybus 2001). Interrelationships between white-tailed deer and *F. magna* are finely tuned; the number of flukes within an individual deer is usually limited, allowing maintenance of the parasite population, but not dispersing it beyond its foci. Wapiti and caribou, sympatric with white-tailed deer, encountered *F. magna* in overlapping contaminated wetland habitats. In contrast to the situation in white-tailed deer, potential translocation of liver flukes in wapiti is higher due to increased *F. magna* eggs production and subsequent release into the environment (Pybus 2001).

The population of white-tailed deer declined steadily in 16th and 20th centuries; this process proceeded from the east towards the west of North America and resulted in the disappearance of the giant liver fluke over much of its former range (Pybus 2001 and references therein). However, as claimed by Pybus (2001),



**Fig. 2.2** Details on US states and Canadian provinces with confirmed natural infections of *F. magna* in free-living and domestic ruminants (codes are explained in Table 2.1; map downloaded from [www.johomaps.com](http://www.johomaps.com))

populations of the fluke may have remained in three primary refuge areas, particularly in: (i) RMT region in persistent wapiti populations; (ii) SAS region with continued occurrence of white-tailed deer; and (iii) NQL region, where caribou remained unavailable for harvest. The spread of *F. magna* into its contemporary North American distribution was dependent on opportunities for infected cervids enter new regions, either via natural migration or via human-related translocation. At present, North American populations of *F. magna* are separated in detached pockets across the continent, in five enzootic regions that possess diverse ecological conditions (Pybus 2001).

*The northern Pacific coast (NPC)* is westernmost enzootic region of coastal Canadian province British Columbia (BC), and US states Oregon (OR) and Washington (WA) (Fig. 2.2), where diverse spectrum of naturally infected final hosts was found out. *Fascioloides magna* was detected in many definitive hosts

**Table 2.1** Spectrum of localities and final hosts of natural *F. magna* infections in North America

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
Northern Pacific coast (NPC)	CA/British Columbia/BC	Kootenay NP	White-tailed deer	28	1984–1991	Pybus et al. (2015)
	CA/British Columbia/BC	Kootenay NP	Wapiti	n.i.	n.i.	Flook and Stenton (1969)
	CA/British Columbia/BC	Kootenay NP	Wapiti	77–100	1985–1989	Pybus et al. (2015)
	CA/British Columbia/BC	Vancouver Island	Roosevelt elk	n.i.	n.i.	Bazsalovicsová et al. (2015)
	CA/British Columbia/BC	n.i.	Black-tailed deer	n.i.	n.i.	Hadwen (1916) c.i. Pybus (2001)
	CA/British Columbia/BC	n.i.	Black-tailed deer	n.i.	n.i.	Cowan (1946)
	CA/British Columbia/BC	Kootenay NP	Mule deer	4	1984–1991	Pybus et al. (2015)
	CA/British Columbia/BC	n.i.	Moose	n.i.	n.i.	Hilton (1930) c.i. Pybus (2001)
	CA/British Columbia/BC	n.i.	Moose	n.i.	n.i.	Cowan (1951)
	CA/British Columbia/BC	Kootenay NP	Moose	63	1984–1991	Pybus et al. (2015)
	CA/British Columbia/BC	n.i.	Cattle	n.i.	n.i.	Hilton (1930) c.i. Pybus (2001)
	US/Oregon/OR	Western Oregon	Wapiti	n.i.	n.i.	Dutton et al. (1967)
	US/Oregon/OR	Salem	Black-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)
	US/Oregon/OR	n.i.	Sheep	34,3	n.i.	Foreyt and Hunter (1980)
	US/Washington/WA	Olympic Peninsula	Roosevelt elk	n.i.	1935–1938	Schwartz and Mitchell (1945)

(continued)

**Table 2.1** (continued)

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
Rocky Mountain trench (RMT)	CA/Alberta/AB	n.i.	White-tailed deer	n.i.	n.i.	Swales (1935)
	CA/Alberta/AB	SW Alberta, Cypress Hills	White-tailed deer	2	1988	Pybus (1990)
	CA/Alberta/AB	Banff NP	White-tailed deer	44	1984–1991	Pybus et al. (2015)
	CA/Alberta/AB	n.i.	Wapiti	n.i.	n.i.	Swales (1935)
	CA/Alberta/AB	Banff NP	Wapiti	n.i.	n.i.	Flook and Stenton (1969)
	CA/Alberta/AB	SW Alberta	Wapiti	50	1984	Kingscote et al. (1987)
	CA/Alberta/AB	S Alberta	Wapiti	80	1990	Whiting and Tessaro (1994)
	CA/Alberta/AB	North Saskatchewan River	Wapiti	3–33	1997	Kennedy et al. (1999)
	CA/Alberta/AB	Banff NP	Wapiti	53–79	1984–1991	Pybus et al. (2015)
	CA/Alberta/AB	Banff NP	Wapiti	n.i.	n.i.	Bazsalovicsová et al. (2015)
	CA/Alberta/AB	SW Alberta, Cypress Hills	Rocky Moun. elk	29	1988	Pybus (1990)
	CA/Alberta/AB	Banff NP	Rocky Moun. elk	93	1989	Pybus et al. (1991)
	CA/Alberta/AB	SW Alberta, Cypress Hills	Mule deer	0	1988	Pybus (1990)
	CA/Alberta/AB	Banff NP	Mule deer	6	1985–1989	Pybus et al. (2015)
	CA/Alberta/AB	SW Alberta, Cypress Hills	Moose	4	1988	Pybus (1990)
	CA/Alberta/AB	Banff NP	Moose	52	1984–1991	Pybus et al. (2015)
	CA/Alberta/AB	n.i.	Cattle	n.i.	n.i.	Swales (1935)

(continued)

Table 2.1 (continued)

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
	CA/Alberta/AB	n.i.	Bison	n.i.	n.i.	Cameron (1923) c.i. Pybus (2001)
	CA/Alberta/AB	n.i.	Bison	n.i.	n.i.	Swales (1935)
	CA/Alberta/AB	n.i.	Yak	n.i.	n.i.	Swales (1935)
	CA/Saskatchewan/SK	Central SK, Prince Albert NP	Wapiti	n.i.	1982–1983	Wobeser et al. (1985)
	CA/Saskatchewan/SK	Central SK, Prince Albert NP	Moose	n.i.	1982–1983	Wobeser et al. (1985)
	US/Montana/MT	n.i.	White-tailed deer	n.i.	n.i.	Aiton (1938) c.i. Pybus (2001)
	US/Montana/MT	n.i.	Wapiti	n.i.	n.i.	Butler (1938) c.i. Pybus (2001)
	US/Montana/MT	Flathead, McCone, Cascade, Lincoln	Wapiti	4–100	1995–1996	Hood et al. (1997)
	US/Montana/MT	n.i.	Mule deer	n.i.	n.i.	Senger (1963)
	US/Montana/MT	SW Montana	Cattle	17.2	1989–1990	Knapp et al. (1992)
	US/Montana/MT	n.i.	Sheep	n.i.	n.i.	Hall (1914) c.i. Pybus (2001)
	CA/Manitoba/MB	SE Manitoba	Moose	n.i.	n.i.	Lankester (1974)
	CA/Manitoba/MB	n.i.	Cattle	n.i.	1912	Wobeser and Schumann (2014)
	CA/Ontario/ON	n.i.	Moose	n.i.	n.i.	Kingscote (1950)
	US/Michigan/MI	S and N Michigan	Cattle	0.4–14	1977–1981	Schillhorn van Veen (1987)
	US/Minnesota/MN	n.i.	White-tailed deer	n.i.	n.i.	Fenstermacher et al. (1943)

(continued)

Table 2.1 (continued)

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
Northern Quebec and Labrador (NQL)	US/Minnesota/MN	Erskine, Hibbing	White-tailed deer	n.i.	n.i.	Bazsalovicová et al. (2015)
	US/Minnesota/MN	n.i.	Moose	n.i.	n.i.	Fenstermacher (1934) c.i. Pybus (2001)
	US/Minnesota/MN	NW Minnesota	Moose	n.i.	n.i.	Murray et al. (2006)
	US/Minnesota/MN	NE Minnesota	Moose	17; 5	1972–2000	Peterson et al. (2013)
	US/Minnesota/MN	Central Minnesota	Horse	n.i.	n.i.	McClanahan et al. (2005)
	US/Minnesota/MN	n.i.	Llama	n.i.	n.i.	Conboy et al. (1988)
	US/New York/NY	n.i.	White-tailed deer	n.i.	n.i.	Stiles and Hassall (1894) c.i. Pybus (2001)
	US/North Dakota/ND	n.i.	Moose	19.6	1977–1992	Maskey (2011)
	US/North Dakota/ND	n.i.	Moose	0	2002–2003	Maskey (2011)
	US/Wisconsin/WI	n.i.	Sheep	n.i.	n.i.	Campbell and Todd (1954)
	CA/Quebec/QC	Eastern Ungava	Caribou	n.i.	n.i.	Choquette et al. (1971)
	CA/Quebec/QC	Kuujuuaq, Tasijuaq	Muskox	n.i.	n.i.	Bazsalovicová et al. (2015)
	CA/Labrador/NL	n.i.	Caribou	58	n.i.	Lankester and Lutich (1988)
	CA/Labrador/NL	Southcentral, coastal N Labrador	Caribou	78	2001	Pollock et al. (2009)
	CA/Labrador/NL	N Labrador at Nashuapi River	Caribou	n.i.	n.i.	Bazsalovicová et al. (2015)

(continued)

**Table 2.1** (continued)

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
Gulf coast, lower Mississippi, and southern Atlantic seaboard (SAS)	13 southeastern US states	n.i.	White-tailed deer	12.8	n.i.	Pursglove et al. (1977)
	US/Florida/FL	n.i.	White-tailed deer	n.i.	n.i.	Dinaburg (1939) c.i. Pybus (2001)
	US/Florida/FL	White Oak plantation	White-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)
	US/Georgia/GA	Wilkinson	White-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)
	US/Kentucky/KY	Fulton County	White-tailed deer	n.i.	1986	Lydeard et al. (1989)
	US/Louisiana/LA	Tensas NWR	White-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)
	US/Mississippi/MS	St. Catherine NWR	White-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)
	US/North Carolina/NC	Halifax County	White-tailed deer	73	1993–1994	Flowers (1996)
	US/South Carolina/SC	n.i.	White-tailed deer	n.i.	n.i.	Dinaburg (1939) c.i. Pybus (2001)
	US/South Carolina/SC	SRP, Aiken and Barnwell	White-tailed deer	30	1986	Lydeard et al. (1989)
	US/South Carolina/SC	WWC, Hampton County	White-tailed deer	25.6	1986	Lydeard et al. (1989)
	US/South Carolina/SC	25 SC Counties	White-tailed deer	11.7	2002–2006	Steele (2008)
	US/South Carolina/SC	Savannah River Site	White-tailed deer	n.i.	n.i.	Bazsalovicsová et al. (2015)

(continued)



**Table 2.1** (continued)

Enzootic region <sup>a</sup>	CA province/US state <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
	US/Tennessee/TN	Reelfoot NWR, Obion County	White-tailed deer	41.9	1986	Lydeard et al. (1989)
	US/Tennessee/TN	SFWMA, Shelby County	White-tailed deer	53.3	1986	Lydeard et al. (1989)
	US/Texas/TX	n.i.	White-tailed deer	n.i.	n.i.	Olsen (1949)
	US/Texas/TX	n.i.	White-tailed deer	69.7	n.i.	Foreyt and Todd (1972)
	US/Texas/TX	Southern Texas	White-tailed deer	64–84	1971–1975	Foreyt et al. (1977)
	US/Texas/TX	n.i.	Cattle	n.i.	n.i.	Francis (1891) c.i. Pybus (2001)
	US/Texas/TX	n.i.	Cattle	38.3	n.i.	Foreyt and Todd (1972)
	US/Texas/TX	n.i.	Wild boar	51.7	n.i.	Foreyt and Todd (1972)
	US/Texas/TX	San Patricio and Victoria Counties	Wild boar	69	1971–1975	Foreyt et al. (1975)
	US/Texas/TX	Dimmitt County	Wild boar	n.i.	n.i.	Schwartz et al. (1993)
	US/Texas/TX	Southern Texas	Collared peccary	1	n.i.	Samuel and Low (1970)
	US/Texas/TX	n.i.	Sheep	n.i.	n.i.	Olsen (1949)
	US/Texas/TX	n.i.	Goat	n.i.	n.i.	Olsen (1949)

CA Canada, US United States, P prevalence, n.i. not indicated in the respective literature, c.i. cited in, NP National Park, SW southwestern, S southern, Rocky Moun. elk Rocky Mountain elk, SE southeastern, N northern, NW northwestern, NE northeastern, NWR National Wildlife Refuge, SRP Savannah River Plant, WWC Webb Wildlife Center, SFWMA Shelby Forest Wildlife Management Area

<sup>a</sup>Order of enzootic regions follows direction from west to east and from north to south

<sup>b</sup>CA provinces and US states within respective enzootic region are listed alphabetically

<sup>c</sup>Final hosts (Latin names provided in Chap. 3) within respective CA provinces/US states are listed in order as indicated in Chap. 3

species (white-tailed deer, wapiti, Roosevelt elk, black-tailed deer and mule deer), but also in moose, cattle and sheep (see Table 2.1 and references therein). The highest prevalence was documented in wapiti (77–100 %) and moose (63 %) from Kootenay National Park (BC) (Pybus et al. 2015).

*The Rocky Mountain trench (RMT)* includes Canadian provinces Alberta (AB) and adjacent Saskatchewan (SK), and US state Montana (MT) (Fig. 2.2). The majority of giant liver fluke findings originated from the Banff National Park (NP) and southwestern Alberta. *Fascioloides magna* was determined in white-tailed deer, wapiti, Rocky Mountain elk, mule deer (definitive hosts), but also in moose, cattle, bison, yak and sheep (see Table 2.1 and references therein). The highest prevalence (up to 80 %) was determined in wapiti from southern Alberta and Banff NP (Whiting and Tessaro 1994; Pybus et al. 2015) and in Rocky Mountain elk in Banff NP (93 %; Pybus et al. 1991). Hood et al. (1997) detected 4–100 % prevalence of fascioloidosis in wapiti from Montana.

*The Great Lakes region (GLR)* involves US states surrounding the Great Lakes, e.g. Minnesota (MN), Wisconsin (WI), Michigan (MI) and New York (NY), and Canadian province Ontario (ON). Adjacent Canadian province Manitoba (MB) and US state North Dakota (ND) are considered to be within GLR (Fig. 2.2). Contrary to NPC and RMT, the white-tailed deer was the only definitive host in GLR region. Majority of natural *F. magna* infections were detected in moose, cattle, llama, horse (dead-end hosts) and sheep (aberrant host) (see Table 2.1 and references therein). The highest prevalence (up to 20 %) was documented during the long term surveys in moose from Minnesota (Peterson et al. 2013) and North Dakota (Maskey 2011).

The Saskatchewan and Manitoba/North Dakota are not directly located in the Rocky Mountains and Great Lakes regions, respectively. Their classification into RMT and GLR enzootic regions is due to their location neighbouring the respective regions.

*Northern Quebec and Labrador (NQL)* is the northernmost enzootic region with Canadian provinces Quebec (QC) and Labrador (NL). The dominant definitive host is caribou (Table 2.1); *F. magna* was also found in muskox (Bazsalovicsová et al. 2015). The highest prevalence (78 %) was determined in caribou from southcentral and coastal northern Labrador in 2001 (Pollock et al. 2009).

*Gulf coast, lower Mississippi, and southern Atlantic seaboard (SAS)* offers for giant liver fluke and its hosts suitable ecological conditions, in particular moist lowlands or swamps along major drainage systems (Pursglove et al. 1977). This enzootic region includes southeastern US states Georgia (GA), Florida (FL), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), South Carolina (SC), Tennessee (TN) and Texas (TX) (Fig. 2.2). The dominant definitive host is white-tailed deer (see Table 2.1 and references therein). Out of dead-end hosts, *F. magna* infection was found in cattle, collared peccary and wild boar. Infection in goat and sheep (aberrant hosts) was documented in Texas (Olsen 1949). The highest prevalence (over 64 %) was documented in white-tailed deer and wild boar from Texas (Foreyt and Todd 1972; Foreyt et al. 1975, 1977).

Genetic interrelationships among populations of giant liver fluke from all enzootic regions were studied by Bazsalovicsová et al. (2015) using short variable

regions of mitochondrial *cox1* and *nad1* markers designed by Králová-Hromadová et al. (2008). The principal outcome was detection of two separate lineages of *F. magna* in North American continent. The western lineage was formed by individuals from RMT region (in particular Alberta) and NPC region (British Columbia and Oregon). The eastern lineage was formed by samples from GLR region (Minnesota), SAS region (Mississippi, Louisiana, South Carolina, Georgia and Florida) and NQL region (Quebec and Labrador). More details on mitochondrial markers and their application in *F. magna* studies are provided in Sect. 5.2.

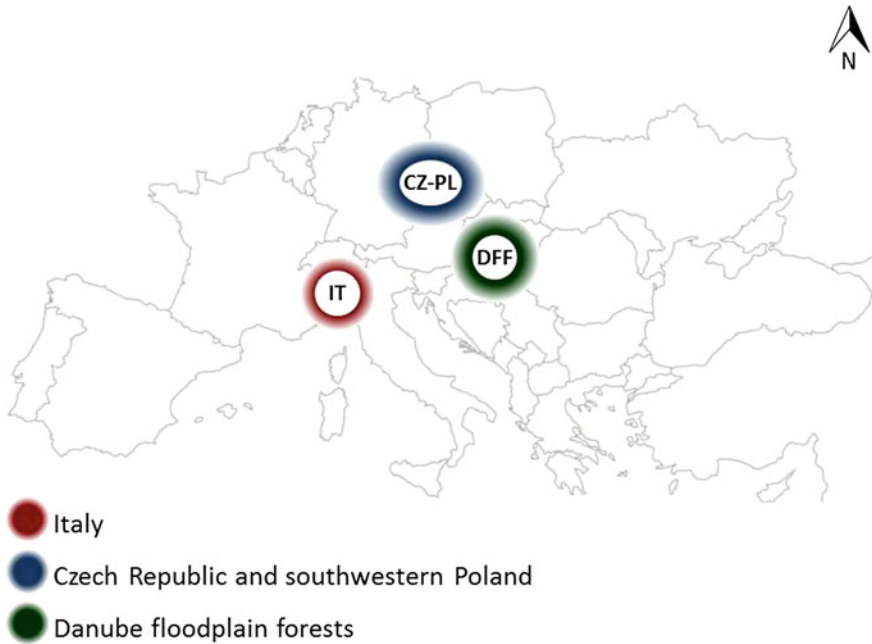
## 2.2 Europe

As a result of popular commercialized hunting in Europe of the 19th and 20th centuries, wapiti and white-tailed deer were imported from North America to European parks, zoological gardens and reservations (Ślusarski 1955; Bojović and Halls 1984). Together with the introduction of the game animals, *F. magna* was transferred as an undesirable side-effect from the Nearctic zone to the Palearctic, where it established local populations (Erhardová-Kotrlá 1971; Pybus 2001).

Contrary to native North America, Europe represents the continent where *F. magna* was introduced along with its cervid hosts and established three permanent natural foci: (1) La Mandria Regional Park in the northern Italy (IT); (2) Czech Republic and southwestern Poland (CZ-PL); and (3) Danube floodplain forests (DFF) (Fig. 2.3). The particular European countries with confirmed natural infections of final hosts are illustrated on Fig. 2.4. Details on geographic localities, final hosts and prevalence of fascioloidosis in all European natural foci are provided in Table 2.2.

*Italy (IT)* *Fascioloides magna* was introduced to the Royal Park La Mandria (now La Mandria Regional Park) near Turin in northern Italy in 1865, as was recorded and originally described by Bassi (1875). The Savoy King Vittorio Emanuele II directed import of 60 wapiti from Wyoming (USA), of which 47 reached La Mandria Regional Park (Apostolo 1996). The Regional Park represents first stable and isolated natural focus of fascioloidosis in Europe (Fig. 2.3) with occurrence of giant liver fluke mainly in red deer (see Table 2.2 and references therein). Besides, *F. magna* was also found in introduced Rocky Mountain elk and Sambar deer (Bassi 1875 c.i. Pybus 2001). A very high prevalence (up to 100 %) was recorded in red deer in a period of 1979–1980 (Balbo et al. 1987). Fascioloidosis was determined in the Italian focus in rather broad spectrum of dead-end hosts, mainly in cattle, blue bull, horse and wild boar and in sheep and goat (aberrant hosts) (see Table 2.2 and references therein).

*Czech Republic and southwestern Poland (CZ-PL)* The second European focus of fascioloidosis was determined in the Czech Republic by Ullrich (1930), who published the first occurrence of *F. magna* in fallow deer in 1910. The Czech focus was established mainly in the southern and central parts of the country, where *F. magna* was found in definitive hosts, such as red deer, fallow deer, or

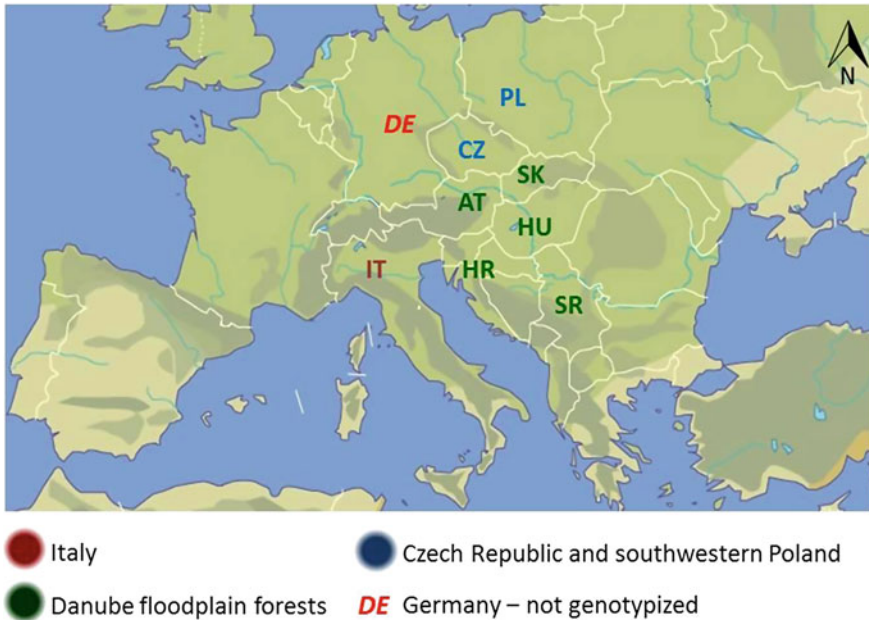


**Fig. 2.3** Schematic presentation of European natural foci of *F. magna*

white-tailed deer, also in sika deer and cattle (dead-end hosts), and roe deer (aberrant host) (see Table 2.2 and references therein). The highest prevalence was detected in red deer (81–100 %) and roe deer (70–80 %; Erhardová-Kotrlá 1971), and later on in red deer and fallow deer (up to 90 %; Novobilský et al. 2007).

The Czech focus of fascioloidosis was restricted to the southern and central parts of the Czech Republic for more than 100 years. Recently, *F. magna* was documented in the northern Czech-Polish border, what indicated a possible spread of fascioloidosis from Czech Republic to Poland (Kašný et al. 2012). Indeed, parasitological survey of cervids of the Lower Silesian Wilderness and Bory Zielonogórskie (southwestern Poland) performed in the period of 2012–2013 and in 2015, respectively, confirmed presence of *F. magna* in red deer, roe deer and fallow deer (Pyziel et al. 2014; Demiaszkiewicz et al. 2015). Molecular genotypization of Polish flukes using mitochondrial markers revealed close genetic interrelationships between Czech and Polish parasites (Králová-Hromadová et al. 2015). These findings indicate that giant liver fluke has spread to Lower Silesian Wilderness from well-established Czech focus, and common name “the Czech Republic and southwestern Poland” was suggested (Králová-Hromadová et al. 2015).

It is important to mention, that the first record on fascioloidosis in Poland originated from red deer from the Lower Silesian Forest in the southwestern Poland in 1953 (Ślusarski 1955). Since then, the occurrence of *F. magna* in Poland has not been documented for almost 60 years. Was the parasite present in the southwestern



**Fig. 2.4** Details on European natural foci with confirmed natural infections of *F. magna* (codes are explained in Table 2.2; map downloaded from [www.johomaps.com](http://www.johomaps.com))

Poland during the whole period from its first discovery in 1953 till present? Or does the recent detection of *F. magna* represent a new finding of the fluke in that region? Since fascioloidosis causes macroscopically visible pathological changes in livers of infected animals, it is difficult to imagine how giant liver fluke could escape from an attention of veterinarians and hunters for such a long time (Králová-Hromadová et al. 2015). More probable explanation is that *F. magna* was in 50s of the 20th century detected as a sporadic finding, but did not establish permanent focus.

The recent results of Karamon et al. (2015) confirmed that a spread of fascioloidosis is still ongoing and dynamic process which requires permanent monitoring. Giant liver fluke was found in fallow deer in southeastern region of Poland (Podkarpackie Province), neighbouring with Slovakia. The ribosomal ITS2 markers were applied for verification of the taxonomy of the fluke (Karamon et al. 2015). Since the Polish population of *F. magna* from Podkarpackie Province was not genotyped with mitochondrial markers, it can not be concluded where it originates from. It is evident that *F. magna* is expanding to novel territories, what represents potential threat for susceptible free-living and domestic ruminants.

*Danube floodplain forests (DFF)* The third European focus of fascioloidosis is Danube floodplain forests (Fig. 2.3). The first finding of *F. magna* was documented in fallow deer from game husbandry in Lower Austria in 1982 (Pfeiffer 1983). The infected animal apparently originated from the Netherlands; however, the infection did not result in establishment of the permanent focus and can be considered as a

sporadic finding. The real outbreak of fascioloidosis in Danube region was documented in 90s of the 20th century, when giant liver fluke was detected in red deer in southwestern Slovakia (Rajský et al. 1994), across the Slovak-Hungarian border, in the northwestern region of Hungary named Szigetköz (Majoros and Sztojkov 1994), in Fischamend area in Austria (Winkelmayer and Prosl 2001), Baranja region of eastern Croatia (Marinculić et al. 2002) and recently in Serbia (Marinković et al. 2013). Since the first findings of the parasite in the respective countries, *F. magna* has been regularly and repeatedly detected in the Danube floodplain forests (see Table 2.2 and references therein), which represents a unique biotope located on islands of the inland delta of the Danube River. The large trans-border wetland area lacks ecological or human barriers for the movement of cervids and dispersal of the infective stages of their parasites (Králová-Hromadová et al. 2011). This natural focus of fascioloidosis is still expanding and there is a high risk that the parasite will be determined in further countries down the Danube River (e.g. Romania), or neighbouring countries, such as Bosna and Hercegovina (Sinanović et al. 2013).

Red deer represent the most frequent and dominant definitive host in Danube floodplain forests. Besides, fascioloidosis was detected also in fallow deer and roe deer (see Table 2.2 and references therein). Danube floodplain forests represent so far the only European natural focus with no documented *F. magna* infection in domestic ruminants. High prevalence (over 60 %) was repeatedly detected in red deer in southwestern Slovakia (Rajský et al. 1994, 1995, 1996, 2002; Špakulová et al. 1997), Fischamend in Austria (Winkelmayer and Prosl 2001; Ursprung and Prosl 2011), in northwestern Hungary (Giczi 2008) and Baranja region in eastern Croatia (Slavica et al. 2006).

Genetic interrelationships among *F. magna* populations from all European foci using short variable fragments of mitochondrial *cox1* and *nad1* revealed two independent phylogenetic lineages (Králová-Hromadová et al. 2011). The Italian population represented one phylogenetic lineage, while the second one included populations from the Czech focus and the Danube floodplain forests. Molecular data did not show any genetic relationships between flukes from Italy and other European foci. It was confirmed that *F. magna* did not spread further to Europe from Italy and this focus remained rather isolated. On the other hand, the results indicated multiple introductions of *F. magna* to Europe (Králová-Hromadová et al. 2011). More details on mitochondrial markers and their application in *F. magna* studies are provided in Sect. 5.2.

*Germany (DE)* The first record on fascioloidosis in Germany originated from 1930, when *F. magna* was found in red deer in Lower Silesia, region neighbouring Poland (Salomon 1932). This finding may be closely related with detection of *F. magna* in red deer in the Lower Silesian Forest (southwestern Poland) in 1953 (Ślusarski 1955). Similarly to the history of *F. magna* occurrence in Poland, it can be hypothesized that after introduction of giant liver fluke to Germany, the permanent focus was not established maybe due to lack of some ecological factors.

More than seven decades later, Novobilský et al. (2007) detected *F. magna* in the southwestern border of the Czech Republic indicating a threat of its possible

Table 2.2 Spectrum of localities and final hosts of natural *F. magna* infections in Europe

Natural focus <sup>a</sup>	Country <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
Italy (IT)	Italy/IT	La Mandria Regional Park, northern Italy	Red deer	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Red deer	51.8	1980–1983	Lanfranchi et al. (1984/85)
			Red deer	50–100	1979–1980	Balbo et al. (1987)
			Red deer	n.i.	1977–1978	Balbo et al. (1989)
			Red deer	n.i.	n.i.	Králová-Hromadová et al. (2011)
			RM elk	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Fallow deer	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Sambar deer	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Cattle	3.4	1980–1983	Lanfranchi et al. (1984/85)
			Cattle	3.7	1979–1980	Balbo et al. (1987)
			Blue bull	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Horse	5.7	1979–1980	Balbo et al. (1987)
			Wild boar	n.i.	1979–1980	Balbo et al. (1987)
			Wild boar	n.i.	1979	Balbo et al. (1989)
			Sheep	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
			Goat	n.i.	<b>1875</b>	Bassi (1875) c.i. Pybus (2001)
Czech Republic and southwestern Poland (CZ-PL)	Czech Republic/CZ	Southern Bohemia	WT deer	n.i.	1966–1967	Erhardová-Kotrlá (1971)
			Red deer	81–100	n.i.	Erhardová-Kotrlá (1971)
			Red deer	n.i.	n.i.	Kolář (1978)
			Red deer	4–95	2003–2005	Novobilský et al. (2007)

(continued)

Table 2.2 (continued)

Natural focus <sup>a</sup>	Country <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
		Southern and central Bohemia	Red deer	n.i.	n.i.	Králová-Hromadová et al. (2011)
		Southern Bohemia	Fallow deer	n.i.	<b>1910</b>	Ullrich (1930)
		Southern Bohemia	Fallow deer	21.6–31.9	n.i.	Erhardová-Kotrlá (1971)
		Southern Bohemia	Fallow deer	15.8	2002–2003	Chroust and Chroustová (2004)
		Western, southern, central Bohemia	Fallow deer	28–90	2003–2005	Novobilský et al. (2007)
		Southern Bohemia	Sika deer	4	n.i.	Erhardová-Kotrlá (1971)
		Southern Bohemia	Cattle	n.i.	1965	Záhoř et al. (1966)
		Southern Bohemia	Cattle	9.1–21.1	1976–1977	Chroustová et al. (1980)
		Southern Bohemia	Cattle	n.i.	2011–2012	Leontovýč et al. (2014)
		Southern Bohemia	Roe deer	n.i.	n.i.	Záhoř (1965)
		Southern Bohemia	Roe deer	70–80	n.i.	Erhardová-Kotrlá (1971)
		Southern Bohemia	Roe deer	9.1	2002–2003	Chroust and Chroustová (2004)
	Poland/PL	Lower Silesian Wilderness	Red deer	n.i.	<b>1953</b>	Ślusarski (1955)
		Lower Silesian Wilderness	Red deer	n.i.	2012–2013	Pyziel et al. (2014); Králová-Hromadová et al. (2015)
		Bory Zielonogórskie	Red deer	n.i.	2015	Demiaszkiewicz et al. (2015)
		Bory Zielonogórskie	Fallow deer	n.i.	2015	Demiaszkiewicz et al. (2015)
		Podkarpackie Province*	Fallow deer	n.i.	2015	Karamon et al. (2015)
		Bory Zielonogórskie	Roe deer	n.i.	2015	Demiaszkiewicz et al. (2015)
	Austria/AT	Game husbandry, Lower Austria	Fallow deer	n.i.	<b>1982</b>	Pfeiffer (1983)
Danube floodplain forests (DFF)		Fischamend	Red deer	66.7	2000	Winkelmayr and Prosl (2001)
		Fischamend	Red deer	15.8	2000–2005	Ursprung et al. (2006)

(continued)



Table 2.2 (continued)

Natural focus <sup>a</sup>	Country <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References
		Fischamend	Red deer	13–100	2000–2010	Ursprung and Prosl (2011)
		Fischamend	Roe deer	n.i.	2000	Winkelmayr and Prosl (2001)
		Fischamend	Roe deer	n.i.	2000–2005	Ursprung et al. (2006)
	Hungary/HU	NW Hungary, Szigetköz	Red deer	n.i.	<b>1991</b>	Majeros and Sztajkov (1994)
		NW Hungary, Szigetköz	Red deer	21.1–65.1	1999–2006	Giezi (2008)
		NW Hungary, Szigetköz	Red deer	n.i.	n.i.	Králová-Hromadová et al. (2011)
		NW Hungary, Szigetköz	Roe deer	3.7	1999–2006	Giezi (2008)
	Slovakia/SK	SW Slovakia, Gabčíkovo	Red deer	100	<b>1993</b>	Rajský et al. (1994)
		SW Slovakia	Red deer	70–80	1991–1995	Rajský et al. (1995)
		SW Slovakia, Gabčíkovo	Red deer	90	n.i.	Rajský et al. (1996)
		SW Slovakia	Red deer	70	n.i.	Špakulová et al. (1997)
		SW Slovakia, Dunajská Streda	Red deer	91.3	1993–2001	Rajský et al. (2002)
		SW Slovakia	Red deer	17.39	2005	Rajský et al. (2006)
		SW Slovakia	Red deer	n.i.	n.i.	Králová-Hromadová et al. (2011)
		SW Slovakia, Dunajská Streda	Roe deer	60	1993–2001	Rajský et al. (2002)
		SW Slovakia	Roe deer	n.i.	2005	Rajský et al. (2006)

(continued)

Table 2.2 (continued)

Natural focus <sup>a</sup>	Country <sup>b</sup>	Locality	Final host <sup>c</sup>	P (%)	Period of examination	References	
	Croatia/HR	E Croatia, Baranja region	Red deer	n.i.	<b>2000</b>	Marinculić et al. (2002)	
		E Croatia, Baranja region	Red deer	54.1	2000–2001	Janicki et al. (2005)	
		E Croatia, Baranja region	Red deer	20–80	2001–2003	Slavica et al. (2006)	
		E Croatia, Baranja region	Red deer	53.3	2002–2003	Rajković-Janje et al. (2008)	
		Central, littoral, W Croatia	Red deer	4.05	2002–2003	Rajković-Janje et al. (2008)	
		E Croatia, Baranja region	Red deer	0–48	2001–2004	Florijančić et al. (2010)	
		E Croatia, Baranja region	Red deer	n.i.	n.i.	Kralová-Hromadová et al. (2011)	
		E Croatia	Red deer	57.4	2006–2008	Severin et al. (2012)	
		Serbia/SR	Northern Serbia	Fallow deer	52.2	n.i.	Marinković et al. (2013)
		Germany/DE*	Lower Silesia	Red deer	n.i.	<b>1930</b>	Salomon (1932)
		Northeastern Bavaria	Red deer	70	2011–2012	Rehbein et al. (2012)	
		Northeastern Bavaria	Red deer	4.9	2012–2013	Plötz et al. (2015)	
		Northeastern Bavaria	Fallow deer	10.2	2012–2013	Plötz et al. (2015)	
	Northeastern Bavaria	Sika deer	37.5	2011–2012	Rehbein et al. (2012)		
	Northeastern Bavaria	Roe deer	20	2011–2012	Rehbein et al. (2012)		

n.i. not indicated in the respective literature, c.i. cited in, P prevalence, RM elk Rocky Mountain elk, WT deer white-tailed deer, NW northwestern, SW southwestern, E eastern, W western

\*German population and Polish population from Podkarpackie Province have not been genotyped yet, therefore, the exact natural focus is not known, years in bold indicate the first finding of *F. magna* in the respective country

<sup>a</sup>Chronological order of natural foci

<sup>b</sup>Chronological order of European countries within respective focus

<sup>c</sup>Species of final hosts (Latin names provided in Chap. 3) within respective countries are listed in order as indicated in Chap. 3

spread into Germany. This suspicion was proved to be correct, since fascioloidosis in red deer, roe deer, sika deer, and fallow deer was reported in northeastern Bavaria (Rehbein et al. 2012; Plötz et al. 2015). *Fascioloides magna* specimens from Germany have not been genotyped, hence their exact origin is not known. Giant liver fluke in Bavaria very probably originates from the Czech focus; however, molecular characterization and studies on population genetics of the parasite in this region need to be performed in order to determine its origin.

## 2.3 Sporadic Reports

In Europe, the occasional finding of fascioloidosis was reported from Spain (Almarza 1935). In a global scale, fascioloidosis was documented in Brahman heifer in the South Africa (Boomker and Dale-Kuys 1977), ox in Australia (Arundel and Hamir 1982), and from wapiti in Cuba (Lorenzo et al. 1989). The giant liver fluke was imported to these localities mainly from North America. Probably due to unsuitable environmental and climate conditions, the life cycle of the parasite could not be completed and permanent foci were not established (Pybus 2001).

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