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World Health Organization
Regional Office for Europe
Scherfigsvej 8
DK-2100 Copenhagen Ø
Denmark
Tel.: +45 39 17 17 17. Fax: +45 39 17 18 18
E-mail: postmaster@euro.who.int
Web site: www.euro.who.int

ISBN 978-92-890-7188-8

Public Health Significance of Urban Pests

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Xavier Bonnefoy
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Keywords

PEST CONTROL - methods
INSECT CONTROL - methods
URBAN HEALTH
URBAN POPULATION
ENVIRONMENTAL EXPOSURE
CITY PLANNING
PUBLIC HEALTH
HEALTH POLICY

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ISBN 978-92-890-7188-8

Graphic design: Pierre Finot
Text editor: Jerome M. Rosen

Contents

10. Ticks

Howard S. Ginsberg and Michael K. Faulde

Summary

The most common vector-borne diseases in both Europe and North America are transmitted by ticks. Lyme borreliosis (LB), a tick-borne bacterial zoonosis, is the most highly prevalent. Other important tick-borne diseases include TBE (tick-borne encephalitis) and Crimean-Congo haemorrhagic fever in Europe, Rocky Mountain spotted fever (RMSF) in North America, and numerous less common tick-borne bacterial, viral, and protozoan diseases on both continents. The major etiological agent of LB is *Borrelia burgdorferi* in North America, while in Europe several related species of *Borrelia* can also cause human illness. These *Borrelia* genospecies differ in clinical manifestations, ecology (for example, some have primarily avian and others primarily mammalian reservoirs), and transmission cycles, so the epizootiology of LB is more complex in Europe than in North America.

Ticks dwell predominantly in woodlands and meadows, and in association with animal hosts, with only limited colonization of human dwellings by a few species. Therefore, suburbanization has contributed substantially to the increase in tick-borne disease transmission in North America by fostering increased exposure of humans to tick habitat. The current trend toward suburbanization in Europe could potentially result in similar increases in transmission of tick-borne diseases. Incidence of tick-borne diseases can be lowered by active public education campaigns, targeted at the times and places of greatest potential for encounter between humans and infected ticks. Similarly, vaccines (e.g., against TBE) are most effective when made available to people at greatest risk, and for high-prevalence diseases such as LB. Consultation with vector-borne disease experts during the planning stages of new human developments can minimize the potential for residents to encounter infected ticks (e.g., by appropriate dwelling and landscape design). Furthermore, research on tick vectors, pathogens, transmission ecology, and on geographic distribution, spread, and management of tick-borne diseases can lead to innovative and improved methods to lower the incidence of these diseases. Surveillance programs to monitor the distribution and spread of ticks, associated pathogens, and their reservoirs, can allow better-targeted management efforts, and provide data to assess effectiveness and to improve management programs.

10.1. Introduction

Ticks transmit more cases of human disease than any other arthropod vector in Europe and North America. They are also important worldwide as disease vectors to people and domestic animals, and they cause substantial economic losses, both by transmitting disease and by direct negative effects on cattle (Jongejan & Uilenberg, 2004). Lyme borreliosis (LB), in particular, is the most commonly reported vector-borne disease in both Europe and North America (Steere, Coburn & Glickstein, 2005). In Europe, Tick-Borne Encephalitis is also prevalent, especially in central and eastern Europe, while in North America, Rocky Mountain spotted fever (RMSF), caused by a rickettsial agent, is responsible for a few hundred to over a thousand cases a year. In addition to their importance as disease vectors, some hard tick species can directly cause adverse effects, such as tick paralysis, a toxicosis (systemic poisoning) due to toxic salivary proteins. Similarly, soft ticks can provoke severe allergenic bite reactions in people (IgE-mediated type-I allergy).

The response to tick-borne diseases (TBDs) in the United States has been substantial, including federally sponsored research programmes, public health programmes within individual states (partly funded by the CDC [United States Centers for Disease Control and Prevention]) and several smaller programmes funded by states, localities and non-profit-making organizations. States with a high incidence of disease have numerous public education programmes, and several novel methods of tick and disease management have been developed (Stafford & Kitron, 2002). However, coordination and evaluation of programmes is spotty, and the incidence of disease remains high in many locales and has increased nationwide (Piesman & Gern, 2004). Ecological differences in transmission dynamics from site to site mean that the approach to management needs to be tailored to conditions at each locale. Methods for developing effective IPM programmes and evaluations of efficacy remain high priorities (Ginsberg & Stafford, 2005).

The situation in Europe is different in that national reporting strategies differ among countries (Table 10.1), and little has been done to routinely implement measures that protect individuals against tick bites or TBDs. Some notable exceptions are vaccination against TBE (Nuttall & Labuda, 2005) and the use of skin repellents in some areas. Fabrics impregnated with acaricides (agents that kill ticks and mites), such as permethrin, are widely unknown and difficult to procure, even for personnel occupationally exposed to tick-infested areas of endemic TBDs. So far, few research efforts have been initiated to reduce tick populations by ecological changes, biological control or IPM.

10.2. Ticks of Europe and North America

Ticks are arachnids (the class Arachnida includes spiders, scorpions, ticks and mites) in the subclass Acari, which includes mites and ticks. There are three families of ticks (Barker & Murrell, 2004): the hard ticks, Ixodidae (713 species), which includes most ticks of medical importance to people; the soft ticks, Argasidae (185 species), which includes a few species that transmit diseases to humans; and Nuttalliellidae, which includes just one species from Africa with no known medical importance.

Table 10.1. TBDs in Europe to be notified to national health authorities, as of 2005

Country/locale	TBE/CEE	Lyme borreliosis	Other diseases
Albania	- (Endemic)	- (Endemic)	-
Austria	+	(+) Only meningoencephalitis caused by Lyme borreliosis	-
Belarus	+	+	Tularaemia, Q fever, tick-borne haemorrhagic fevers
Belgium	-	- (Endemic)	-
Bosnia and Herzegovina	-	+	CCHF
Bulgaria	- (Endemicity status unclear)	- (Endemic)	CCHF
Croatia	+	+	Tick-borne tularaemia, ehrlichiosis, human granulocytic anaplasmosis
Czech Republic	+	+	-
Denmark	- (Not endemic)	(+) Neuroborreliosis only	-
Estonia	+	+	Tick-borne tularaemia
Finland	+	+	
France	- (Endemic)	- (Endemic)	-
Germany	+	(+) Only the federal states of Brandenburg, Mecklenburg-Western Pomerania, Berlin, Lower Saxony, Saxony-Anhalt and Thuringia (about 25 % coverage of population)	-
Greece	- (Not endemic)	+	-
Hungary	+	+	-
Ireland	- (Not endemic)	- (Endemic)	Louping ill
Italy	+	+	-
Latvia	+	+	Tick-borne tularaemia
Lithuania	+	+	Tick-borne tularaemia
Luxembourg	- (Not endemic)	+	
Netherlands	-	- (Endemic)	-
Norway	+	+	-
Poland	+	+	-
Portugal	-	+	-
Republic of Moldova	- (Endemic)	- (Endemic)	-
Romania	+	+	MSF
Russian Federation	+	+	Tularaemia, Q fever, tick-borne haemorrhagic fevers
Serbia	+	+	-
Slovakia	+	+	-
Slovenia	+	+	HGE
Spain	-	- (Endemic)	-
Sweden	+	- (Endemic)	-
Switzerland	+	- (Endemic)	-
The former Yugoslav Republic of Macedonia	-	+	-
Ukraine	+	+	Tularaemia, Q fever, tick-borne haemorrhagic fevers
United Kingdom	-	(+) Scotland only	-

Note. -: not notifiable disease; +: disease notifiable by national health organisations.

Source: The information in this table has been provided by M.K. Faulde and is based on official civil and military country sources.

Table 10.2. Tick vectors of medical importance that are endemic in Europe

Species	Geographical distribution	Habitat	Host [a]	Remarks
Castor-bean tick *(Ixodes ricinus)*	North-western Europe (westwards to Baltic states)	Humid microhabitats in woodlands, rough grasslands and moorlands	Many different kinds of wild and domestic animals; readily feeds on man; three-host tick	Most common tick species in north-west Europe
Taiga tick *(Ixodes persulcatus)*	North-eastern Europe (eastwards to Baltic states)	Humid microhabitat in taiga woodlands, rough grasslands and moorlands	Many different kinds of wild and domestic animals; readily feeds on man; three-host tick	Most common tick species in north-east Europe and northern Asia
Ornate sheep tick *(Dermacentor marginatus)*	Southern Europe, southwards to 50th parallel	Scrub steppes, temperate forests, grasslands and sheep pastures	Larvae and nymphs feed on rabbits and small mammals, also on birds; adults feed on large mammals, such as deer, cattle and sheep; readily feeds on man; three-host tick	As many as 200 adult ticks can be found on one sheep
Marsh tick (also called the ornate cow tick; *Dermacentor reticulatus*)	Generally southern Europe southwards to 50th parallel; localized populations occur in north-western Europe in Belgium, south-west England and Wales	Grasslands, pastures and woodlands	Larvae and nymphs feed on small mammals, occasionally on birds; adults feed on wild and domestic mammals, such as deer, dogs, foxes, cattle and sheep; occasionally feeds on man; three-host tick	Spreading geographically in Germany
Brown dog tick *(Rhipicephalus sanguineus)*	Mediterranean Europe and Africa, with focal populations in Belgium, United Kingdom, France, Germany, Denmark, Norway	Arid microhabitat in scrub steppes, buildings and kennels	Larvae, nymphs and adults primarily feed on dogs (90%), but are also found on cattle, cats, foxes and human beings; three-host tick	Local populations may survive in kennels and other sheltered places with dogs in central and northern Europe; transported over longer distances by dogs
Bont-legged tick *(Hyalomma marginatum)*	Southern Europe (southwards to 40th parallel), southern Asia and most of Africa	Scrub steppes, temperate forests, grasslands and sheep pastures, and migrating birds	Larvae and nymphs feed on one bird host for 12–26 days; adults actively search for mammal hosts, such as cows, donkeys, dogs, foxes and human beings; two-host tick	Transported over longer distances by migrating birds and may sporadically appear in northern Europe (such as Denmark and Norway)
Coastal red tick *(Haemaphysalis punctata)*	Throughout Europe, except Ireland	Wide variety: from relatively cold and humid coasts (such as United Kingdom) to semi-desert zones of central Asia	Larvae and nymphs feed on small mammals and rarely birds; adults primarily feed on sheep and cattle, occasionally on human beings, three-host tick	Bite may cause tick paralysis

[a] Some ticks, called one-host ticks, feed on only one host throughout all three stages of life (larval, nymphal and adult). Other ticks, called two-host ticks, feed and remain on the first host during the larval and nymphal stages of life, and then drop off and attach to a different host as an adult. Finally, three-host ticks feed, drop off and reattach to progressively larger hosts subsequently to each moulting.

Source: Data presented have been collected by the authors from numerous sources.

Endemic tick species in Europe can be peridomestic or can be associated with pets and farm animals (Table 10.2). European ticks that can infest buildings in urban environments include: the ixodid brown dog tick, *Rhipicephalus sanguineus*, as far north as southern Germany; and the argasids: the European pigeon tick, *Argas reflexus* (associated with pigeons), and the fowl tick, *Argas persicus* (associated with poultry in south-eastern Europe). Long-term infestations with brown dog ticks can occur in human dwellings, if control efforts are neglected (Gothe, 1999). The only survey thus far for European pigeon ticks was performed in the city of Berlin, where more than 200 infested buildings were discovered between 1989 and 1998 (Dautel, Scheurer & Kahl, 1999). Most of the infestations were found in older buildings constructed before 1918. Control is difficult and requires professional expertise and time.

Recent studies in Germany have shown increases in urban and periurban collections of castor-bean ticks, *Ixodes ricinus* (Mehnert, 2004). According to studies conducted in north-eastern Germany, Lyme borreliosis (LB) is most often acquired in city parks and gardens near forests (Ammon, 2001; Anonymous, 2005a). Other ticks, such as the soft tick *Ornithodoros erraticus*, and the hard ticks *Dermacentor* spp., *Hyalomma* spp. and *Haemaphysalis* spp., are associated with pigs, sheep and cattle and are known vectors of both animal and human disease agents. They usually do not infest houses, but can be found in stables and in houses that incorporate stables.

The most common hard ticks that regularly bite people in North America (Table 10.3) include: the black-legged or deer tick, *Ixodes scapularis*, in eastern and central North America; the western black-legged tick, *Ixodes pacificus*, in west coastal areas; the American dog tick, *Dermacentor variabilis*, in the east and Midwest; the Rocky Mountain wood tick, *Dermacentor andersoni*, in the Rocky Mountain region; the Pacific Coast tick, *Dermacentor occidentalis*, on the Pacific coast; and the lone star tick, *Amblyomma americanum*, in eastern and central North America. The brown dog tick attaches to dogs and can be found in the home, but rarely attaches to people. The primary soft ticks that affect people are *Ornithodoros* spp. in western areas.

These ticks are found primarily in natural areas and are often encountered by recreational users of parks and woodlands (Ginsberg & Ewing, 1989). However, increasing suburbanization around major urban centres has resulted in substantial contact between people and ixodid ticks, and most disease transmission from ticks to people occurs in the peridomestic environment (Maupin et al., 1991). Some nidicolous species (including soft ticks, such as *Ornithodoros* spp.) are found in animal nests in rustic cabins and can transmit pathogens (such as relapsing fever borreliae) to recreational users of these dwellings (Barbour, 2005).

10.3. Tick-borne diseases

The epidemiology and distribution of TBDs in Europe and North America are generally similar, but differ in some important details. In Europe, 31 viral, 14 bacterial, and 5 *Babesia* species are known endemic tick-borne pathogens of people (Table 10.4). Among

Table 10.3. Tick vectors of medical importance that are endemic in North America

Species	Geographical distribution	Habitat	Host [a]	Remarks
Deer tick *(Ixodes scapularis)*	Eastern North America and northern Midwest	Closed-canopy woodlands; adults extend into open habitats	Broad range of hosts, including mammals, birds and reptiles; adults on large mammals, such as deer; three-host tick	Especially common in north-eastern United States
Western black-legged tick *(Ixodes pacificus)*	Western North America	Woodlands, scrub and open habitats	Broad range of hosts; adults on large mammals, such as deer; immatures on lizards, birds, and diverse mammals; three-host tick	Immatures more common on lizards than on rodents
American dog tick *(Dermacentor variabilis)*	Eastern and central North America, especially the Carolinas to Oklahoma	Woodlands, shrublands and grasslands, especially along animal trails	Adults on large mammals; immatures on small mammals, such as rodents; three-host tick	Can be found in urban parks as well as natural areas
Rocky Mountain wood tick *(Dermacentor andersoni)*	Rocky Mountain region	Woodlands, low shrub vegetation and grasslands	Adults on large mammals; immatures on small mammals; three-host tick	—
Pacific Coast tick *(Dermacentor occidentalis)*	Pacific region of North America	Woodlands	Adults on large mammals; immatures on small mammals; three-host tick	—
Lone star tick *(Amblyomma americanum)*	South-eastern and south-central North America, expanding northward	Woodlands, shrublands and grasslands	All three life stages attach readily to large mammals, especially deer; immatures also on birds; three-host tick	Extremely aggressive and fast-moving tick
Ornithodoros spp.	Western North America	Rodent nests	Generally rodents, but can attach to a variety of mammals	Can bite human beings who utilize rustic cabins with rodent nests

[a] Some ticks, called one-host ticks, feed on only one host throughout all three stages of life (larval, nymphal and adult). Other ticks, called two-host ticks, feed and remain on the first host during the larval and nymphal stages of life, and then drop off and attach to a different host as an adult. Finally, three-host ticks feed, drop off and reattach to progressively larger hosts subsequently to each moulting.

Note. —: no remarks.

Source: Data presented have been collected by the authors from numerous sources.

European TBDs, only TBE is a widely notifiable disease (Table 10.1), with more than 10 000 clinical cases annually. Detailed epidemiological information is not available on other TBDs, despite the fact that the most frequent TBD in Europe is LB (with possibly hundreds of thousands of clinical cases a year). Germany alone claims 20 000–60 000 cases a year (O'Connell et al., 1998; Wagner, 1999). Yearly rates of incidence in hyperendemic foci (sites where disease organisms exist in host populations at very high rates) can exceed 300 cases per 100 000 population, with average occupational seroprevalence rates of up to 48% in forest workers. Other TBDs occur, but their rates of incidence remain largely unknown.

Several isolated regional studies in Europe show that tick abundance is increasing regionally while TBDs are simultaneously emerging and spreading geographically. The changing urban landscape in Germany, specifically in the federal state of Brandenburg, where LB has been a notifiable disease since 1996, shows a steady increase in exposure to castor-bean ticks. Other studies have shown that urban parks in Berlin and Munich have growing tick populations and contribute to a growing number of cases of LB. In the Czech Republic, castor-bean tick populations spread an average of 161 meters into higher altitude sites (from about 780 m to 960 m above sea level) during the last 30 years. This resulted in exposure to ticks and TBDs in higher mountainous areas that were formerly not endemic for castor-bean ticks and diseases associated with them. Since the 1990s at least two TBDs, TBE and Mediterranean spotted fever (MSF), have been reported to be extending their geographical ranges. TBE is spreading geographically into the north-eastern parts of Germany. MSF, transmitted by the brown dog tick, is reportedly spreading northwards along the French Rhone Valley, as far north as Belgium, where the first autochthonous (locally acquired) human cases of MSF were recently reported. Data from the Baltic states show that landscape-level ecological changes (resulting from agricultural practices) have led to increases in ecotopes (the smallest ecologically distinct features in a landscape mapping and classification system) suitable for tick infestation. Finally, the reported increase in incidence of TBDs may in part result from increased awareness of TBDs, better diagnostic tools, and markedly higher leisure and sporting activities that result in increased exposure to endemic disease foci.

The most common TBD in North America, as in Europe, is Lyme borreliosis (also called Lyme disease). Other important TBDs (Sonenshine, Lane & Nicholson, 2002) include RMSF, human monocytic ehrlichiosis (HME), human granulocytic anaplasmosis (HGA), Q fever, and tularaemia (Table 10.5). All of these diseases are notifiable in the United States (Groseclose et al., 2004).

Less common or non-emerging TBDs in North America include such infections as babesiosis, which is caused by the protozoan *Babesia microti* and is transmitted by the black-legged tick, primarily in southern New England and mid-Atlantic coastal areas (Spielman, 1976; Spielman et al., 1979). Powassan encephalitis is a rarely reported viral disease related to European TBE (Ebel, Spielman & Telford, 2001). Colorado tick fever (CTF) is a viral disease transmitted by the Rocky Mountain wood tick in the Rocky Mountain region (McLean et al., 1981). The lone star tick transmits *Ehrlichia ewingi*, which causes human ehrlichiosis. Q fever, caused by *Coxiella burnetii*, is primarily a livestock disease (McQuiston & Childs, 2002). Tick-borne relapsing fever, caused by several *Borrelia* spp. and transmitted by associated *Ornithodoros* spp., is primarily contracted by people in intermittently used recreational cabins in wild areas in western North America. Important vectors include *Ornithodoros hermsi* (which transmits the spirochete *Borrelia hermsii*), *Ornithodoros parkeri* (which transmits *Borrelia parkerii*), and *Ornithodoros turicata* (which transmits *Borrelia turicatae*) (Barbour, 2005). Tularaemia, caused by the bacterium *Francisella tularensis*, is usually acquired by rabbit hunters that handle infected rabbits (especially in eastern North America), but is sometimes transmitted by ticks (especially in western states).

Table 10.4. Human pathogenic TBDs that are endemic in Europe

Tick genus	Tick species	Common name	Viral pathogens	Bacterial and parasitic pathogens
Hyalomma	*marginatum*	Bont-legged tick	SINV, WNV, TBEV, CCHFV, Dhorivirus	—
Ixodes	*ricinus*	Castor-bean tick	Louping-ill virus, TBEV, Negishi virus, Uukuniemi virus, Erve virus, Eyach virus, Tribec virus, Lipovnik virus, CCHFV, Bhanjavirus	*B. burgdorferi* s.l., *C. burnetii*, *A. phagocytophilum*, *R. slovaca*, *R. helvetica*, *B. divergens*, *B. bovis*, *B. microti*, *F. tularensis*, *E. chaffeensis*, *Ehrlichia equi*
	persulcatus	Taiga tick	TBEV, Negishi virus, Uukuniemi virus	*R. slovaca*, *E. equi*, *B. burgdorferi* s.l.
	gibbosus		TBEV	—
	hexagonus		TBEV, Erve virus	*B. burgdorferi* s.l.
	arboricola		TBEV	—
	uriae		Tyuleniy virus, Avalon virus	*B. burgdorferi* s.l.
	ventalloi		Erve virus, Eyach virus	—
Dermacentor	*marginatus*	Ornate sheep tick	TBEV, Bhanjavirus, Erve virus, Dhori virus, CCHFV, WNV, OHFV	*F. tularensis*, *B. bovis*, *R. slovaca*, *R. helvetica*, *C. burnetii*, *Ehrlichia canis*
	reticulatus	Marsh tick (also called the ornate cow tick)	TBEV, OHFV	*C. burnetii*, *R. slovaka*, *Rickettsia sibirica* strain 246
Haemaphysalis	*inermis*		TBEV	R. slovaka
	concinna		TBEV	*C. burnetii*
	punctata	Coastal red tick	TBEV, CCHFV, Bhanjavirus, Tribec virus, Lipovnik virus	*C. burnetii*, *B. microti*, *B. burgdorferi* s.l.
Rhipicephalus	*bursa*	Brown dog tick	CCHFV, Thogoto virus	—
	sanguineus		CCHFV, Lipovnik virus	*R. conori*, *Rickettsia massiliae* GS, *Rickettsia rhipicephali*, *A. phagocytophilum*, *C. burnetii*, *B. burgdorferi* s.l., *B. valaisiana*, *E. canis*
	turanicus		—	*Rickettsia massiliae* Mtu1
Ornithodoros	*coniceps*		WNV	—
	maritimus		Soldado virus	*Borrelia hispanica*
	erraticus		—	
Argas	*reflexus*		WNV	*C. burnetii*
	vespertilionis	—		*B. burgdorferi* s.l.

Note. —: no remark; SINV: Sindbis virus; WNV: West Nile virus; TBEV: tick-borne encephalitis virus; CCHFV: Crimean-Congo haemorrhagic fever virus; OHFV: Omsk haemorrhagic fever virus.

Source: Data presented have been collected by the authors from numerous sources.

Table 10.5. Human pathogenic TBDs that are endemic in North America

Tick genus	Tick species	Common name	Viral pathogens	Bacterial and parasitic pathogens
Ixodes	*scapularis*	Black-legged tick	Deer tick virus (Powassan encephalitis virus)	*B. burgdorferi* s.s., *Borrelia* sp. nov. (relapsing fever group), *A. phagocytophilum*, *B. microti*
	pacificus	Western black-legged tick	—	*B. burgdorferi* s.s.
Dermacentor	*variabilis*	American dog tick	—	*R. rickettsii*
	andersoni	Rocky Mountain wood tick	CTF	*R. rickettsii* (RMSF)
Amblyomma	*americanum*	Lone star tick	—	*E. chaffeensis*, *E. ewingii*, *Borrelia lonestari*
Various hard tick species (or contact with host fluids, aerosols, and the like)			—	*F. tularensis*
Ornithodoros	various species		—	*Borrelia* spp.

Note. —: no remark; CTF: Colorado tick fever; HGA: human granulocytic anaplasmosis; HME: human monocytic ehrlichiosis; RMSF: Rocky Mountain spotted fever.

Source: Data presented have been collected by the authors from numerous sources.

The following sections provide more comprehensive treatments of the most prevalent TBDs in Europe and North America: LB on both continents, TBE in Europe, and RMSF in North America.

10.4. Lyme borreliosis

The clinical features, diagnosis, treatment, pathology, microbiology, ecology, surveillance and management of LB have been extensively reviewed (Ginsberg, 1993; Gray et al., 2002; Piesman & Gern, 2004; Steere, Coburn & Glickstein, 2005). Features relevant to current trends in LB epidemiology in Europe and North America are summarized below.

10.4.1. Public health

LB is the most common TBD in both North America and northern Eurasia. The complex of related pathogenic species, *B. burgdorferi* s.l., the causative agents of LB, are Gram-negative, microaerophilic bacteria that belong to the family Spirochaetaceae. To date *B. burgdorferi* s.l. can be divided into at least 12 species (Fingerle et al., 2005), of which those with human-pathogenic significance are *Borrelia afzelii*, *Borrelia burgdorferi* sensu stricto, *B. garinii*, and *Borrelia spielmanii* (Richter et al., 2006). *B. valaisiana* and *Borrelia lusitaniae* may also be pathogenic to people (Ryffel et al., 1999; Collares-Pereira et al., 2004), but firm evidence is currently lacking.

B. burgdorferi s.l. infection can be subclinical or it can have a broad range of clinical presentations (Gern & Falco, 2000). Symptoms apparently depend on the *Borrelia* genospecies involved, the tissues affected, the duration of infection and individual human host factors, including genetic predisposition. There is considerable evidence that infection with different LB genospecies have different clinical outcomes (Gern & Falco, 2000; WHO Regional Office for Europe, 2004). Thus, *B. burgdorferi* s.s. is most often associated with arthritis, particularly in North America, where it is the only known cause of human LB; *B. garinii* is associated with neurological symptoms; and *B. afzelii* is associated with the chronic skin disease acrodermatitis chronica atrophicans (ACA). All four pathogenic *B. burgdorferi* s.l. genospecies, including *B. spielmanii* (formerly named A14S), have been isolated from erythema migrans (EM) lesions (Fingerle et al., 2005). There is evidence in Europe that EM occurs more frequently in *B. afzelii* infections than in those caused by *B. garinii*.

Generally, clinical presentations can be divided into three stages (Gern & Falco, 2000; Steere, Coburn & Glickstein, 2005).

1. The first stage, early localized LB, is characterized by an expanding red rash (EM, often with central clearing) and flu-like symptoms (such as headache and fever) 2–30 days after an infective tick bite, which occurs in about 60% of cases. The rash can be faint and difficult to notice and resolves even without treatment.

2. The second stage, early disseminated LB, varies from patient to patient and can include more severe flu-like illness, secondary skin lesions, facial palsy, aseptic meningitis, mild encephalitis and arthritis with effusion or carditis.

3. The third stage, late LB, is most commonly manifested as Lyme arthritis, typically affecting large joints, especially the knee. Other presentations are ACA, an unusual skin condition, and, rarely, chronic Lyme meningoencephalitis, where sporadic fatalities have been reported. Late stage central nervous system involvement can be severe and difficult to treat. Late LB symptoms can be nonspecific, difficult to diagnose, and can occur in other conditions.

According to treatment guidelines, LB treatment involves different antibiotic regimens in varying concentrations, adapted to specific clinical manifestation (Wormser et al., 2000). Doxycycline is effective in early LB. Amoxicillin and penicillin are also still drugs of choice. Treatment of late-stage disseminated LB requires higher doses, often of ceftriaxone or cefuroxime, and sometimes longer treatment periods. A specific vaccine for people, based on outer surface protein A (OspA), was temporarily available in the United States, but was withdrawn by the manufacturer in 2002. Due to the heterogenicity of *B. burgdorferi* s.l. genospecies in Europe and Asia, an effective vaccine for Europe would most probably require a defined so-called cocktail of immunogenic outer surface proteins.

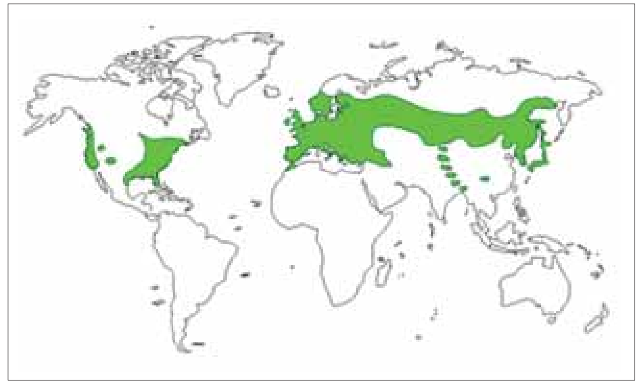

Fig. 10.1. Global distribution of Lyme borreliosis

Source: CDC (2006).

10.4.1.1. LB in Europe and North America

LB is broadly distributed in the northern hemisphere (Fig. 10.1). The prevalence of LB varies considerably among European countries, with estimated average rates between 0.3 case per 100000 population in the United Kingdom and up to 130 cases per 100000 population in parts of Austria. LB tends to be focal, with defined hot spots within countries. In Germany, for example, the average incidence in the Oder-Spree region in the federal state of Brandenburg was estimated to be 89.3 cases per 100000 population in 2003. Within this area, the local incidence of LB varied from 16 cases per 100000 population in Erkner county to 311 cases per 100000 population in Brieskow-Finkenheerd county (Talaska, 2005; Anonymous, 2005a). Therefore, mapping hot spots is an important tool for disease prevention.

Over 23000 cases of LB were reported to the CDC in 2002 (Groseclose et al., 2004), and it has been estimated that this is a small fraction (roughly 10%) of the actual total number of cases in the United States. In one study in Connecticut (Meek et al., 1996), about 16% of diagnosed cases had been reported. Cases follow the geographic distribution of the *Ixodes* vectors (the black-legged tick and the western black-legged tick) (Fig. 10.2), with most cases in the north-eastern, mid-Atlantic and northern Midwest regions (within the range of the black-legged tick), and with some hot spots in California (western black-legged tick) (Dennis et al., 1998; Dennis & Hayes, 2002). As in Europe, the distribution of LB tends to be highly focal, because of nonrandom distributions of tick vectors, reservoir hosts, appropriate habitat types and other ecological conditions. This focal pattern is illustrated by the distribution of cases in 1999, when the national incidence was 6.0 cases per 100 000 population (16273 cases). The number of cases in individual states varied dramatically, with a maximal incidence of 98.0 cases per 100000 population in Connecticut (Dennis & Hayes, 2002).

The costs associated with LB can be significant. Assuming a cost of about €10000 per case of so-called disseminated LB in Europe and, on average, 20–30% disseminated LBs per notified clinical case, with 1800–2000 cases a year in the federal state Brandenburg, an economic impact of €1 million a year can be easily exceeded for that state alone (Talaska, 2003). An economic burden of several €100 million up to 1 billion a year is plausible for Europe. Similarly, in the United States, Meltzer, Dennis & Orloski (1999) estimated costs (including treatment and lost work) of US$ 161 for early LB with no sequelae (previous diseases or injuries), US$ 34 354 for disseminated cases with arthritic symptoms, US$ 61243 for neurological cases and US$ 6845 for cardiac cases. Assuming 83% of cases with effective early treatment, and 17% with disseminated disease (12% with

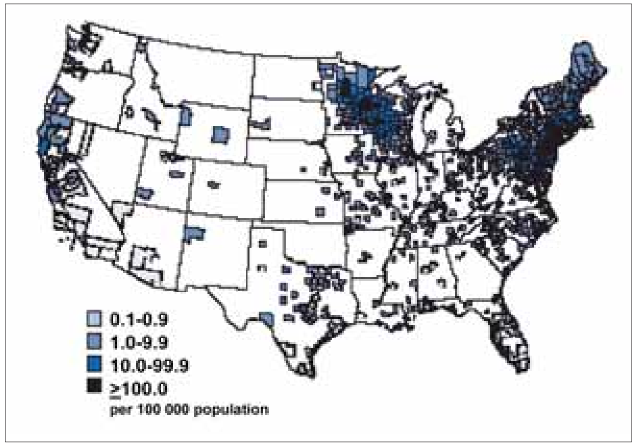

Fig. 10.2. Distribution of Lyme disease in the United States
A. Lyme disease cases

Source: Groseclose et al. (2004).

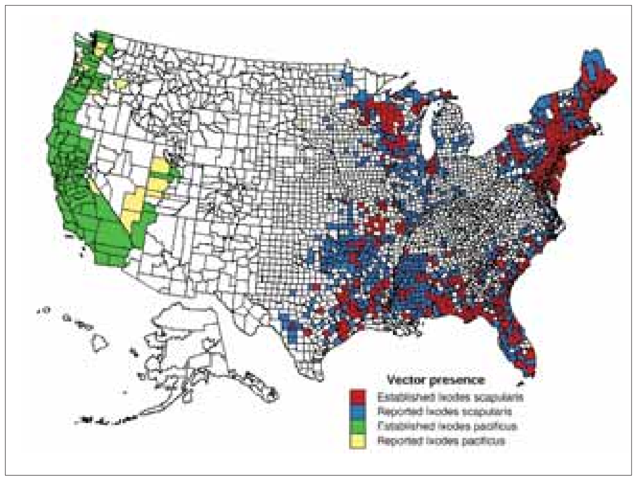

Fig. 10.2. Distribution of Lyme disease in the United States
B. Tick distribution *Source:* CDC (2006).

arthritic symptoms, 4% with neurological disease and 1% with cardiac disease), the total of about 23000 reported cases a year results in about US$150 million in costs. If the number of cases reported is only about 10% of the total number of cases, the actual costs are in US$ billions. These very rough estimates refer primarily to costs of medical treatment. Expenses associated with family accommodations for patients, lost work time and the like would greatly increase these estimates. Zhang and colleagues (2006) used actual cost data to estimate the economic impact of LB (including treatment and loss of productivity) in the Eastern Shore area of Maryland. They estimated a national cost of about US$ 203 million for the 23763 cases reported in 2002. Again, unreported cases (probably the vast majority of actual cases) would greatly inflate this estimate. Furthermore, the costs of prevention activities associated with LB (such as landscaping and pesticide applications) contribute further to the costs of this disease, including human, economic and environmental costs.

10.4.2. Geographical distribution

The global distribution of human pathogenic *B. burgdorferi* s.l. genospecies includes parts of North America and most of Europe and extends eastward in Asia to Japan (Fig. 10.1 and 10.2). In Europe, LB has been reported throughout the continent (including the European parts of the Russian Federation), except for the northernmost areas of Scandinavia. Taking the limitations of seroprevalence studies into account, LB in Europe shows a gradient of increasing incidence from west to east, with the highest rates of incidence in central-eastern Europe. Simultaneously, LB shows a gradient of decreasing incidence from south to north in Scandinavia and north to south in the European Mediterranean and Balkan countries (Lindgren, Talleklint & Polfeldt, 2000; Faulde et

al., 2002; WHO Regional Office for Europe, 2004). The incidence of LB is apparently also increasing eastward in Asia. Infection rates are highest in adult ticks and vary between 10% and 30% in Europe (5–10% in nymphs), reaching up to a 45% positivity rate in adult ticks in hot spots of LB in Germany and Croatia (Hubalek & Halouzka, 1998; Kimmig, Oehme & Backe, 1998; Golubic & Zember, 2001).

In the foreseeable future, the incidence of TBDs, especially LB, seem likely to increase, partly due to man-made environmental changes. For example, some current approaches to urban planning can provide additional ecotopes suitable for castor-bean tick and taiga tick, *Ixodes persulcatus*, infestations (Kriz et al., 2004). In North America, suburbanization has produced extensive suburban and periurban areas that provide an interface between urban and sylvan environments – a so-called border effect. Property sizes in these areas tend to be larger than in urban areas and therefore allow ready access to tick habitats that border infested natural ecosystems. This border effect is more pronounced in North America than in Europe. However, the European landscape is beginning to change. Increasing suburbanization can potentially create conditions similar to those in North America, as recently shown in the federal state of Mecklenburg-Western Pomerania, Germany (Talaska, 2003), potentially leading to greater human exposure to TBDs. Thus, the increase of LB is apparently related to that of urban sprawl, which often results in invasion of residential areas by deer and mice, providing reservoirs, tick hosts, and carriers for the spirochete (Matuschka et al., 1996). Moreover, some studies suggest that climate changes in Europe have resulted in a northern shift in the distributional limit of castor-bean ticks, an increase in their population density in Sweden and a shift into higher altitudes in mountainous areas in the Czech Republic (Lindgren, Talleklint & Polfeldt, 2000; Danielova, 2006). Castor-bean tick nymphs infected with *B. afzelii* were found at altitudes up to 1024 m, and tick populations reached up to 1250–1270 m. Thus, the range of LB is apparently increasing in Europe. The prevalence of ticks infected with *B. burgdorferi* s.l. has also increased at some sites (Kampen et al., 2004), possibly due to changes in climate or wildlife management.

In the United States, LB is most common in the north-eastern and mid-Atlantic states and in the northern Midwest, with scattered foci in the south-eastern states and in California (Fig. 10.2). Scattered foci also exist in the Great Lakes region in southern Ontario and possibly other parts of Canada (Barker & Lindsay, 2000). *Borrelia burgdorferi* s.l. has been present in North America at least since the 1800s (Marshall et al., 1994). The increase and expanding range of LB in North America apparently results from a combination of factors: increasing populations of white-tailed deer (*Odocoileus virginianus*), an important host for adult black-legged ticks; habitat modifications that favour dissected second-growth woodlands (following movement of eastern farmers to the Midwest); and suburbanization that has produced excellent tick habitats and brought residents close to ticks (Spielman, Telford & Pollack, 1993). Genetic evidence suggests recent expansion of black-legged tick and *B. burgdorferi* populations in the north-eastern United States (Qiu et al., 2002). *Borrelia burgdorferi* s.s. is a generalist in the north-east, with individual genotypes infecting a variety of mammalian hosts, which may have contributed to its rapid expansion (Hanincová et al., 2006). Its range continues to expand – for example, with the spread of tick populations and LB cases in New Jersey and up the Hudson Valley of New York (White et al., 1991; Schulze, Jordan & Hung, 1998).

10.4.3. Epizootiology and epidemiology

LB is a sylvatic zoonosis. Ticks that are generally associated with temperate deciduous woodlands that include patches of dense vegetation with little air movement and high humidity carry the infective agent. LB is also associated with some coniferous forests, when conditions are suitable for the ixodid tick vectors (Ginsberg et al., 2004). In open habitats in Europe, such as meadows and moorland, the main source of blood-meals is usually livestock, such as sheep and cows. With increasing frequency, ticks also occur in domestic settings when a moist microhabitat is provided by high grass, gardens and rough forest edges. Foliage, decomposing organic matter and litter can give shelter to both ticks and small mammals that act as hosts for immature ticks. Therefore, contemporary trends of suburbanization can potentially increase exposure in the peridomestic environment. Vector ticks are frequently encountered in residential areas (Maupin et al., 1991), and they are also encountered by people recreationally or occupationally exposed to forest habitats (Ginsberg & Ewing, 1989; Rath et al., 1996).

Closed enzootic cycles that involve reservoir-competent hosts and host-specific ticks also have a role in maintaining LB in nature, and the spirochete can be transmitted to people when a bridge vector, such as the castor-bean tick, intrudes into the cycle. An example of this in Europe is the circulation of borreliae between the European hedgehog (*Erinaceus europaeus*) and the hedgehog tick, *Ixodes hexagonus* (Gern & Falco, 2000). Since the castor-bean tick frequently feeds on hedgehogs, the potential is there for the hedgehog tick/hedgehog cycle to have a considerable impact on the eco-epidemiology (the specific association between an ecosystem or habitat and the enzootic transmission chain of reservoir hosts and vectors living therein) of LB in some areas. The widespread recommendation to encourage hedgehogs to live in home gardens, by preparing piles of leaf litter, may therefore contribute to the currently seen so-called urbanization cycle. Also, urban sprawl and invasion of commensal and non-commensal rodents can influence LB epidemiology. Norway rats, *Rattus norwegicus*, and garden dormice, *Eliomys quercinus*, can carry vector ticks and borreliae and can contribute to the urbanization of LB (Matuschka et al., 1996; Richter et al., 2004).

In Europe, the castor-bean tick and the taiga tick serve as vectors to people, while the hedgehog tick transmits spirochetes among medium-sized mammals, and the seabird tick, *Ixodes uriae*, transmits *B. garinii* among seabirds. The prevalence of infection in nymphal sheep ticks averages 10.8% in Europe, with considerable variation among locales (Hubálek & Halouzka, 1998). In North America, the black-legged tick and western black-legged tick act as vectors to people, while *Ixodes dentatus*, *Ixodes spinipalpus* and other species serve as enzootic vectors to small animals, such as rabbits and wood rats (Eisen & Lane, 2002). The prevalence of infection in nymphal black-legged ticks varies from about 15% to 30% in endemic areas of the north-east (Piesman, 2002). A variety of other tick species, as well as some haematophagous insects, have been found to carry borreliae, but are most probably not involved in disease transmission. *B. burgdorferi* s.l. is transmitted transstadially by vector ticks, but transovarial transmission, while it occurs, is relatively rare. Besides these tick-specific transmission modes, a co-feeding effect has been described, in which uninfected ticks can acquire spirochetes while feeding near infected ticks on an uninfected host (Ogden, Nuttall & Randolph, 1997).

Compared with North America, important differences in the ecology of LB in Europe result from the greater diversity of *Borrelia* spp. that cause human disease in Europe. Table 10.6 provides an overview of known genospecies of *B. burgdorferi* s.l., their primary vectors and reservoir hosts, geographical distribution, and virulence in people. In North America, *B. burgdorferi* s.s. is responsible for the vast majority of human cases, while in Europe, *B. afzelii*, *B. garinii* and *B. valaisiana* are most common. The most important reservoir in North America is the white-footed mouse, *Peromyscus leucopus* (Mather et al., 1989), and other rodents can also serve as major reservoirs, including voles (such as the meadow vole, *Microtus pennsylvanicus*), chipmunks (such as the eastern chipmunk, *Tamias striatus*) and rats (such as the Norway rat) (Smith et al., 1993; Markowski et al., 1998). Some North American birds, such as the American robin and the song sparrow, *Melospiza melodia*, can also serve as reservoirs (Richter et al., 2000; Ginsberg et al., 2005). In Europe, on the other hand, different species of *Borrelia* are associated with different wild hosts. The primary reservoirs of *B. afzelii* are rodents, including mice (*Apodemus* spp.) and voles (*Clethrionomys* spp.) (Kurtenbach et al., 2002a; Hanincová et al., 2003a). In contrast, the primary reservoirs of *B. garinii* and *B. valaisiana* are birds, including pheasants and songbirds (Humair et al., 1998; Kurtenbach et al., 1998, 2002b; Hanincová et al., 2003b).

Reservoir competence varies among hosts. Lagomorphs, such as hares (*Lepus* spp.) and rabbits (*Oryctolagus* spp. and *Sylvilagus* spp.), show varying degrees of reservoir capacity. Similarly, carnivorous mammals, such as foxes (the red fox, *Vulpes vulpes*, for example), dogs (the domestic dog, *Canis familiaris*, for example) and cats (the domestic cat, *Felis domesticus*, for example), vary considerably in competence as reservoirs. Borreliae, however, are eliminated in ticks attached to some lizard species (Lane & Quistad, 1998), which apparently limits the importance of LB in areas where ground-dwelling lizards are abundant, such as south-eastern North America. In addition to their roles as reservoirs of some borreliae, many birds can serve as carriers of attached infected ticks when migrating (see Chapter 8). Ungulates (such as deer, sheep, cattle, goats and pigs) feed large numbers of mainly adult ticks in nature and may influence the epidemiology of LB, by increasing tick numbers (and thus the number of ticks per individual reservoir host), even if they themselves are not competent reservoirs.

10.5. TBE

10.5.1. Public health

TBE is caused by the TBE virus (TBEV), a member of the RNA virus family Flaviviridae. Three subtypes can be differentiated. One of them causes central European encephalitis (CEE); this virus subtype was first isolated in 1937, and the castor-bean tick is the main vector. The Siberian and far-eastern subtypes (endemic in eastern Europe and throughout northern Asia) are the causative agents of Russian spring-summer encephalitis (RSSE), which is responsible for a disease similar to CEE, but with a more severe clinical course. The primary vector of RSSE is the taiga tick. Transmission can also occur on an epidemic scale after consumption of raw milk from TBE-infected goats, sheep or cows. Person-to-person transmission has not been reported. However, vertical virus transmission from an infected mother to her fœtus has been described (Hubálek & Halouzka, 1996).

Table 10.6. Overview of known genospecies of *B. burgdorferi* s.l.

***Borrelia* genospecies**	**Literature**	**Geographical distribution**	***Ixodes* tick vector**	**Primary vertebrate host**	**Primary symptoms**
B. burgdorferi s.s.	Baranton et al. (1992)	North America, Europe, N. Africa	*I. scapularis* *I. dammini* *I. pacificus* *I. ricinus* *I. dentatus*	Rodents, insectivores	Arthritis, neuropathy
B. garinii	Baranton et al. (1992)	Worldwide	*I. ricinus* *I. persulcatus* *I. uriae* *I. hexagonus* *I. trianguliceps*	Passerine birds, pheasants	Neuropathy
B. afzelii	Canica et al. (1993)	Eurasia	*I. ricinus* *I. persulcatus* *I. nipponensis*	Rodents	Erythema migrans, skin lesions
B. japonica	Kawabata, Masuzawa & Yanagihara (1993)	Japan	*I. ovatus*	Not determined	—
B. andersonii	Marconi, Liveris & Schwartz (1995)	United States	*I. dentatus*	Cottontail rabbit	—
B. tanukii	Fukunaga et al. (1996)	Japan	*I. tanuki*	Not determined	—
B. turdi	Fukunaga et al. (1996)	Japan	*I. turdus*	Not determined	—
B. lusitaniae	Le Fleche et al. (1997)	Europe, North Africa	*I. ricinus*	Birds	Unclear
B. valaisiana	Wang et al. (1997)	Eurasia	*I. ricinus* *I. columnae* *I. granulatus*	Passerine birds, pheasants	Unclear
B. bissettii	Postic et al. (1998)	United States, Europe	*I. scapularis* *I. pacificus* *I. spinipalpis*	Not determined	Not determined
B. sinica	Masuzawa et al. (2001)	China	*I. ovatus*	Rodents	Unclear
B. spielmanii	Richter et al. (2006)	Central Europe	*I. ricinus*	Garden dormice	Erythema migrans

[a] Because not all *Ixodes* ticks have common names, only the scientific names are given here.

Note. —: no remarks.

Source: CDC (2006).

The incubation period of TBE is usually between 7 and 14 days (sometimes shorter with milk-borne transmission). A characteristic biphasic febrile illness occurs in about 30% of cases, with an initial phase that lasts 2–4 days, which corresponds to the viraemic phase. Symptoms are nonspecific and may include fever, malaise, anorexia, headache, muscle aches and nausea or vomiting (or both). After a remission phase of about 8 days, up to 25% of the patients develop an infection of the central nervous system with symptoms of meningitis (50%), encephalitis or meningoencephalitis (40%) and myelitis (10%). Case fatality rates are generally below 5% in European TBE, but they are up to 50% in some outbreaks of Asian subtypes (Nuttall & Labuda, 2005). In up to 40% of cases, convalescence can be prolonged by sequelae (known as post-encephalitic syndrome), and about 4% of the CEE cases produce a residual paresis (slight or partial motor paralysis).

Treatment depends on the symptoms and often requires hospitalization and intensive care. Anti-inflammatory drugs are sometimes utilized, and intubation and ventilatory support are sometimes necessary. Licensed vaccines (active and passive) that neutralize all three virus subtypes (Rendi-Wagner, 2005) are commercially available, with protection rates exceeding 98%.

10.5.1.1. Public health impact of TBE in Europe

TBE is the most frequent viral TBD in central Europe. Overall, several thousand clinical cases a year occur in Europe: mainly in the Russian Federation (5000–7000 cases a year), the Czech Republic (400–800 cases a year), Latvia (400–800 cases a year), Lithuania (100–400 cases a year), Slovenia (200–300 cases a year), Germany (200–400 cases a year) and Hungary (50–250 cases a year). In 1997, 10 208 clinical cases of TBE (with 121 fatalities) were reported from all over Europe. In 2005, a sharp increase of 50% or more in notified clinical cases of TBE was seen in Switzerland (91 cases in 2004 versus 141 cases in 2005; weeks 1–33) (Anonymous, 2005b) and Germany (258 cases in 2004 versus 426 cases in 2005) (Anonymous, 2005b).

Since treatment of this potentially fatal disease depends on the symptoms, vaccination, prevention of infective tick-bite and pasteurization of contaminated milk constitute the first line of defense in preventing TBE. Due to the frequent need for hospitalization (often with intensive care), subsequent prolonged recovery time and neurotropic sequelae, the economic impact of this disease, in addition to its effect on health, is costly. As has been reported in Austria, vaccination programmes can substantially lower the annual incidence of TBE. Vaccination coverage of the Austrian population increased from 6% in 1980 to 86% in 2001, exceeding 90% in some hyperendemic areas (Kunz, 2003). This programme led to a steady decline in cases of TBE, drastically reducing the annual health impact for Austria to less than 10%. For example, in Carinthia, Austria, there were an average of 155 cases a year from 1973 to 1982, while from 1997 to 2001 there were only four cases a year (Kunz, 2003). In Hungary, 3–5% of the population were reported to be vaccinated, and in the southern Bohemia region of the Czech Republic it was 10% (WHO Regional Office for Europe, 2004). For other European countries, the vaccination status is unknown, but is probably low (Kunz, 2003).

10.5.2. Geographical distribution

The currently known geographical distribution of European TBE foci includes much of central and eastern Europe and extends broadly into Asia. Randolph (2001) predicted an eventual future decline in the distribution and incidence of TBE, due to global climate change, but currently both the geographical distribution and incidence of infection are increasing. Therefore, programmes that promote vaccination and prevention of tick bites are essential in highly affected areas. TBE has recently spread in a north-westerly direction from central Europe to western Germany and has moved north to Finland, Norway and Sweden, as well as to higher altitudes in mountainous areas in the Czech Republic (Hillyard, 1996). The north-westward spread of TBE might be explained by:

- the movement of wildlife, migrating birds and domestic animals together with their ticks across the continent;
- landscape changes, resulting from human activities; and
- the result of global warming.

Milder winter temperatures in particular have important effects on tick distribution and can foster shifts into higher latitudes and altitudes (Lindgren, Talleklint & Polfeldt, 2000).

10.5.3. Epizootiology and epidemiology

Ixodid ticks act as both the vector and reservoir for TBEV. This virus can chronically infect ticks and can be transmitted transstadially and transovarially. Small rodents are the main hosts, although viraemia has been reported from insectivores (representing an order of mammals whose members basically feed on insects and other arthropods), goats, sheep, cattle, canids (which include foxes, wolves, dogs, jackals and coyotes) and birds. People are an accidental host, and large mammals are feeding hosts for adult vector ticks, but do not play a significant role in maintaining the natural virus cycle. The infection rates in castor-bean ticks and taiga ticks in endemic foci usually vary from 0.1% to 5%, but can reach up to 10% in hyperendemic foci – for example, in Austria. The rate of infection increases steadily from the larval to the adult stage. Human TBE cases occur mainly during the highest period of vector tick activity, between April and November, peaking from mid-June to early August. Nevertheless, sheep ticks can be active at any temperatures above about 10 °C, even during winter. Thus sporadic clinical cases occur even during wintertime.

TBE is usually contracted in habitats suitable for the vector tick species and primary rodent reservoirs. These include mixed forest, pastoral and mountainous sylvan areas for castor-bean ticks and mixed taiga forest for taiga ticks. During recent years, man-made changes in natural areas have increased the periurban abundance of both tick species. This trend is associated with growing disease transmission, including a tendency towards urban transmission. Urban TBE transmission has been described in Europe and Asia – for example, in Novosibirsk, the Russian Federation (Hubalek & Halouzka, 1996). Commensal rodents, cats and dogs are known to carry host-seeking ticks into human dwellings in periurban and urban areas. *Ixodes* ticks can survive for several hours and bite humans, but they do not persist in houses or stables.

TBE is most likely to be acquired in forests rich in small mammals, so forest workers, hunters and others highly exposed to this ecotope are at high risk. The seroprevalence of this virus in foresters can reach 12–16% in hyperendemic foci – for example, in Austria and Switzerland. In Germany, seroprevalence rates exceeding 20% have been found in foresters in the Emmendingen and Ludwigsburg counties (Kimmig, Oehme & Backe, 1998). TBE morbidity rates in the Czech Republic and Slovakia averaged 4.2 (1.4–9.9) deaths per 100 000 population between 1955 and 2000. In Switzerland (Thurgau canton) a morbidity rate of 5.4 people per 100 000 population was estimated for 1995. The highest morbidity in Germany was estimated for the federal state of Baden-Württemberg, with 1.1 cases per 100 000 population. In some cases, up to 76% of human TBE infections can result from consumption of raw milk, as was reported in Belarus (Ivanova, 1984).

10.6. RMSF

10.6.1. Public health

RMSF was first recognized in an epidemic in the Bitterroot Valley of Montana, in the United States, in the late 1800s. The etiological agent is *Rickettsia rickettsii*, and the primary vectors are the American dog tick in eastern and central North America and the Rocky Mountain wood tick in the Rocky Mountain region (Sonenshine, Lane & Nicholson, 2002). The number of cases reported to the CDC varies from about 200 to about 1200 a year, with an average incidence from 1985 to 2002 of between 0.24 to 0.32 cases per 100 000 population (Schriefer & Azad, 1994).

RMSF is characterized by the sudden onset of high fever, headache and myalgia, often with nausea and other symptoms (Macaluso & Azad, 2005). A few days after the onset of symptoms, a rash generally appears, beginning as macropapular eruptions on the ankles and wrists that then spread to the entire body, producing a so-called spotted appearance. The rickettsiae are intracellular parasites that affect (in particular) cells of the capillaries and arterioles. Symptoms are often severe, and though early treatment (generally with tetracyclines) is effective, the disease is fatal in around 5% of cases.

10.6.2. Geographical distribution

The distribution of human cases of RMSF, or at least the distribution of recognized cases, has shifted from the Rocky Mountain region in the late 1800s to eastern and central North America today. The incidence of the disease is currently highest in the south-eastern and south-central states (such as the Carolinas and Oklahoma), but cases are scattered throughout the eastern and central regions of North America (Fig. 10.3), with relatively few cases in the Rocky Mountain and western states (Groseclose et al. 2004; Macaluso & Azad, 2005).

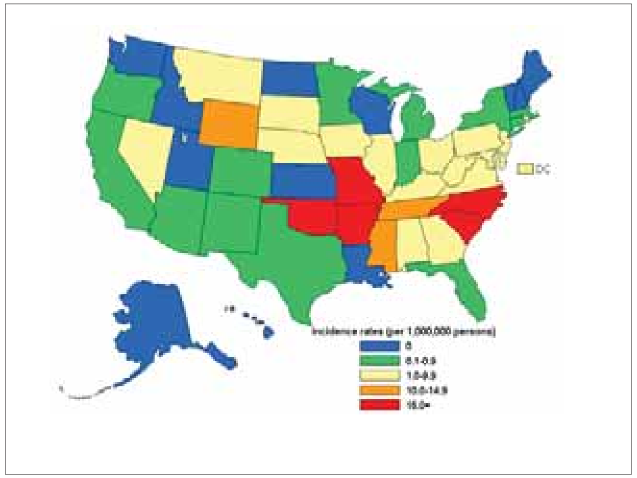

Fig. 10.3. Distribution of human cases of RMSF in the United States, 2002 *Source:* CDC (2006).

10.6.3. Epizootiology and epidemiology

RMSF is generally acquired in rural and suburban areas with woodland and associated open vegetation where the tick vectors are abundant (Sonenshine, Peters & Levy, 1972; Sonenshine, Lane & Nicholson, 2002). However, foci sometimes occur in appropriate habitats within large cities (Salgo et al., 1988). The pathogen is transmitted vertically in the tick (from mother to offspring) and is maintained transstadially, so the tick can act as both vector and reservoir. However, infection with nonpathogenic rickettsiae can interfere with transovarial transmission (Burgdorfer, Hayes & Mavros, 1981). Small mammals also can serve as reservoirs and apparently can contribute to amplification under appropriate circumstances, but occurrence of RMSF does not seem to depend on any particular vertebrate reservoir (Schriefer & Azad, 1994). Larvae and nymphs of American dog ticks and Rocky Mountain wood ticks attach to a variety of small and medium-sized mammals, including mice, voles, rats, ground squirrels, hares and rabbits, many of which can maintain infection with spotted fever group rickettsiae. Adults of these tick species generally attach to larger mammals, including human beings. Infection rates of adults vary considerably from site to site, ranging from less than 1% to about 10%.

10.7. Emerging TBDs

Several TBDs have recently been recognized in Europe and North America. Some of these might represent new introductions of the diseases to these continents, while others were undoubtedly already present, but were recognized recently because of the renewed attention to TBDs that resulted from the recent increase of LB. Also, some diseases that have been rare in the past are apparently expanding in range, along with expanding tick populations. Selected diseases that have recently been recognized in North America and Europe are discussed in this section.

10.7.1. Crimean-Congo haemorrhagic fever

Crimean-Congo haemorrhagic fever (CCHF) was first mentioned by the Tajik physician Abu-Ibrahim Djurdjani in the 12th century and has been extensively studied since the 1944/1945 epidemic in the Crimean Peninsula (Hubalek & Halouzka, 1996). This epidemic resulted in more than 200 human cases, with 10% of them fatal. The disease is cau-

sed by the CCHF virus (CCHFV), a *Nairovirus* (family Bunyaviridae) closely related to Dugbe and Nairobi sheep disease viruses and classified as a biosafety level-4 virus (the highest biological security level). The clinical course appears as a haemorrhagic fever with severe typhoid-like symptoms, including fever, chills, headache, myalgia, backache, anorexia, nausea, repeated vomiting, conjunctivitis, pharyngitis, bradycardia, meningitis and encephalitis. Haemorrhagic manifestations can vary from petechiae (pinpoint-sized haemorrhages of small capillaries in the skin) to large haematomas (solid swellings of clotted blood within tissues) on the mucous membranes and skin, and bleeding from the gums, nose and intestines and, less frequently, lungs and kidneys. Case fatality rates are usually between 8% and 30%, but may reach up to 50–60% in cases transmitted from person to person (Hubalek & Halouzka, 1996). Convalescence is slow, but usually without sequelae. Treatment of confirmed human cases requires barrier nursing and special hygienic care to prevent nosocomial infection.

Treatment usually depends on the symptoms, but treatment with ribavirin seems promising during the early stages of the disease (Ozkurt et al., 2006). An inactivated CCHF vaccine was administered to several hundred people in Bulgaria and Ukraine (Rostov oblast), but severe side-effects appeared. Specific immunoglobulins can also be used prophylactically or therapeutically. However, no licensed, safe vaccine is currently available.

CCHF is the most severe TBD in Europe and has the potential to spread quickly from person to person. The disease is probably underreported worldwide, so European and global incidences are unknown. Bulgaria, the southern part of the Russian Federation and Ukraine are among the most highly affected areas within Europe. Cases have also been reported from Bosnia and Herzegovina, Greece, Hungary, Montenegro, the Republic of Moldova, Serbia, and the former Yugoslav Republic of Macedonia. From 1952 to 1970, 865 cases of CCHF were recorded in Bulgaria alone, with a case fatality rate of 17%, and 6% of the cases of nosocomial origin (Vasilenko et al., 1971). In the Rostov region, 312 cases were registered between 1963 and 1969. Human cases sporadically occur in that region, with an outbreak occurring in 1999 (65 cases with 6 fatalities) (Onishchenko et al., 2000). The virus has been detected in almost all south-eastern districts of the Russian Federation, resulting in an additional regional budget of Rub 2.5 million (US$ 872 000) for diagnostic procedures and preventive measures (ProMED Mail, 2005). In 2002, eight cases clustered within families were observed in Albania (Papa et al., 2002). Although the overall incidence for Europe remains unclear, CCHF is a re-emerging disease with an estimated annual incidence far greater than100 cases, especially during outbreaks (Faulde et al., 2002).

The bont-legged tick, *Hyalomma marginatum*, is the principal vector and tick reservoir of CCHFV in Europe. Transstadial, transovarial and venereal transmission occur. This tick species inhabits pastoral steppe ecosystems, and the adult stage frequently feeds on sheep. CCHFV is highly contagious and transmission to people can occur by tick bite, by contact with infected animals (such as during sheep shearing and meat handling) and by person-to-person contact. Laboratory infections have also been reported.

10.7.2. Tick-borne rickettsioses

Several new human-pathogenic tick-borne rickettsioses of the spotted fever group have been reported from Europe during the last decade. Among them, *Rickettsia conorii* and *Rickettsia helvetica* are of greatest concern. *Rickettsia slovaca*, *Rickettsia aeschlimannii* and *Rickettsia mongolotimonae* are also endemic, although with very few human cases reported to date. Novel rickettsioses have recently been described in North America as well.

10.7.2.1. Boutonneuse fever

R. conorii is the causative agent of Boutonneuse fever (BF), also known as tick-borne typhus, Mediterranean spotted fever and South African tick bite fever. Patients usually present with fever, malaise, a generalized maculopapular erythematous rash and a typical black skin lesion, called *tache noir*, at the site of the infected-tick bite. While the disease is usually mild, severe forms, including encephalitis, occur occasionally. Overall, the case fatality rate in Europe is estimated to be less than 2.5%, even if untreated. Fever usually persists for a few days to two weeks, with a specific antibiotic treatment required for no more than two days. The seroprevalence rates in dogs, which are often infested with up to 100 adult brown dog ticks per animal, can be quite high in hyperendemic foci, varying between 35.5% in Italy and 93.3% in Portugal. The annual incidence rate in people has been estimated to be 48 cases per 100 000 population in Corsica, France, whereas 1000 cases have been reported annually from Portugal. Human seroprevalence rates can exceed 70% in hyperendemic foci in Spain (WHO Regional Office for Europe, 2004). However, the overall incidence of BF in Europe is unclear.

R. conorii is widely found in southern Europe and the Mediterranean countries. This disease is spreading northwards, reaching Belgium, Germany and the Netherlands, where antibodies were detected in dogs and people, and *R. conorii* has been isolated from sheep ticks and rodents in Belgium (Jardin, Giroud & LeRay, 1969; Gothe, 1999; WHO Regional Office for Europe, 2004).

The major tick vector of *R. conorii* in Europe is the brown dog tick. Other vectors include the castor-bean tick, the hedgehog tick, the marsh tick (also called the ornate cow tick), *Dermacentor reticulatus*, and the ornate sheep tick, *Dermacentor marginatus*. Besides vector ticks, the primary reservoirs are dogs, rabbits and rodents. Pet dogs can acquire infected ticks during family holidays, and they can carry *R. conorii* with them when they return home further north in Europe. Human infection with BF in urban areas, often in a person's own home, can be caused by skin or eye contamination from rickettsiae-infected dog ticks that are crushed while de-ticking infested dogs (Hillyard, 1996).

10.7.2.2. Rickettsia helvetica

First isolated in Switzerland in 1979, this agent was linked with human disease in 1999, when it was associated with two fatal Swedish cases of chronic perimyocarditis (Nilsson, Lindquist & Pahlson, 1999). *R. helvetica* is now known to have caused chronic interstitial inflammation and pericarditis in people in France, Sweden and Switzerland. A serosurvey of foresters conducted after seroconversion of a 37-year-old man in 1997 in eastern France revealed a seroprevalence rate of 9.2% (Fournier et al., 2000). The disease is transmitted by the castor-bean tick, and initial results show infection rates in ticks between 1.7% in Sweden and 8.2% in northern and central Italy (Nilsson et al., 1999; Beninati et al., 2002). Recent studies indicate that *R. helvetica* is widely distributed throughout Europe and might cause more clinical disease and (even) mortality than is currently recognized (WHO Regional Office for Europe, 2004).

10.7.2.3. HME

HME is caused by the rickettsial pathogen *Ehrlichia chaffeensis*. In North America, this pathogen exists in a tick–deer cycle, with the lone star tick serving as the primary vector (Ewing et al., 1995) and the white-tailed deer serving as the primary reservoir (Lockhart et al., 1997). Human cases are most common in the southern Midwest, with foci along the East Coast (Dawson et al., 2005). In 2001, 142 cases were reported in the United States; in 2002, 216 cases were reported; and in 2003, 321 cases were reported (CDC, 2003; Groseclose et al., 2004; Hopkins et al., 2005). *E. chaffeensis* has also been found to be endemic in Europe – in Belgium, the Czech Republic, Denmark, Greece, Italy and Sweden – but human cases of disease have not been described to date (WHO Regional Office for Europe, 2004; Oteo & Brouqui, 2005).

10.7.2.4. HGA

HGA is caused by the rickettsial pathogen *Anaplasma phagocytophilum* (formerly *Ehrlichia phagocytophila*). Patients present with an acute febrile illness, and most develop leukopenia or thrombocytopenia (or both), and elevated concentrations of C-reactive protein and transaminases, with occasional fatalities occurring. Treatment with tetracycline generally leads to full recovery. The pathogen was first isolated from ticks and people in northern Midwestern United States in the 1990s (Chen et al., 1994; Dumler et al., 2001). The black-legged tick is the vector in the United States, and its mammal hosts, especially the white-footed mouse, serve as reservoirs (Pancholi et al., 1995; Levin & Fish, 2001). The United States distribution includes the Atlantic coastal states, the northern Midwest and California (CDC, 2003; Maurin, Bakken & Dummler, 2003; Brown, Lane & Dennis, 2005). In 2001, 261 cases were reported to the CDC; in 2002, 511 cases were reported (CDC, 2003; Groseclose et al., 2004).

In Europe, HGA in people was first recognized in 1995, when serum antibodies against *A. phagocytophilum* were confirmed. In 1997, the first proven European case of human disease was reported from Slovenia. Through March 2003, about 65 patients with confirmed HGA (and several patients fulfilling criteria for probable HGA) had been reported in Europe (Strle, 2004). Seroprevalence rates in the WHO European Region range from 0% to 28%, and infection rates in adult castor-bean ticks (the recognized tick vector) range from 0% to more than 30%. The relatively high seroprevalence rates in people and the presence of *A. phagocytophilum* in vector ticks in many European countries are discordant with the rather low number of patients with proven HGA. This may be due to an inadequate awareness among European physicians and limited recording and reporting of the disease, or it may be due to the presence of nonpathogenic strains of *A. phagocytophilum* (Strle, 2004).

The castor-bean tick is probably the principal vector in Europe and the taiga tick in north-eastern Europe and Asia, although transmission studies have not been reported to date. HGA is known to cause febrile illness in several domestic animals, including sheep, goats, cattle and horses. A Swiss study stressed the importance of small mammals, with the bank vole, *Clethrionomys glareolus*, wood mouse, *Apodemus sylvaticus*, yellow-necked mouse, *Apodemus flavicollis*, and common shrew, *Sorex araneus*, as likely animal reservoirs in nature (Liz, 2002).

10.7.3. Babesiosis

Human babesiosis, first described in 1957, is a malaria-like illness caused by piroplasms (pear-shaped protozoan organisms that live in red blood cells of mammals), including *B. microti* in North America and *Babesia divergens* in Europe (Homer & Persing, 2005). The primary vectors are the black-legged tick in eastern North America and the castor-bean tick in Europe. Rodents, such as white-footed mice serve as reservoirs (Spielman, 1976; Spielman et al., 1979). Babesiosis is often mild and self-limiting, but can be severe and is undoubtedly underreported. Nevertheless, hundreds of cases have been reported in North America, and 29 in Europe (from England and France). In the United States, cases have been reported primarily in coastal areas of the north-eastern and mid-Atlantic states (Dammin et al., 1981; Spielman et al., 1985).

10.8. Ticks in human dwellings

In Europe, the brown dog tick can persist in long-term infestations of human dwellings with dogs. The European pigeon tick can also occur in dwellings with pigeon infestations or breeding. The fowl tick and *Ornithodoros erraticus* may also occur in houses close to poultry stables (*Argas* spp.) in south-east Europe and pig stables (*Ornithodoros* spp.) in Spain and Portugal.

Ticks found in human dwellings in North America are primarily soft ticks (of the genus *Ornithodoros*) associated with rodents that nest in buildings. The most important human disease transmitted by these ticks is tick-borne relapsing fever, which is caused by various species of the bacterial genus *Borrelia*. The most common pathogens in this group are *B. hermsi* (transmitted by *O. hermsi*) in mountainous areas of the western United States and Canada, and *B. turicatae* (transmitted by *O. turicata*) in desert and scrub habitats in the south-western United States and Mexico (Barbour, 2005). People generally encounter these pathogens recreationally, when occupying rustic cabins that are inhabited by tick-bearing rodents. Recently, specimens of the bat-associated soft tick, *Carios kelleyi* (collected from buildings in Iowa) were found to be infected with spotted fever group *Rickettsia*, relapsing fever group *Borrelia*, and *Bartonella henselae* (the etiological agent of cat scratch disease), but the role of these ticks as vectors of these bacterial pathogens has not been established (Loftis et al., 2005). Also, the brown dog tick can be found in homes, associated with dogs, but generally does not bite people.

10.9. Tick and tick-borne disease surveillance

TBDs that are reportable in the United States include LB, RMSF, HME, HGA, Q fever, and tularaemia (Hopkins et al. 2005). In Europe, where regulations differ among countries, only TBE is widely reportable.

Active surveillance for ticks or TBDs requires purposeful sampling of ticks or samples from wild or domestic hosts, or from people (Nicholson & Mather, 1996; Lindenmayer, Marshall & Onderdonk, 1991). Passive surveillance, on the other hand, utilizes information collected for other purposes, such as data collected from tick laboratories or hospital registries, to assess tick or disease distribution (White, 1993). Active surveillance tends to provide more accurate information, but is expensive and labour intensive. Passive surveillance is less expensive and requires less effort, and it can provide useful information of appropriate types, but the value of the results are sometimes limited by unidentifiable biases in data collection (Johnson et al., 2004). Most current tick surveillance programmes are of the passive type.

10.10. Tick and TBD management

Ticks are controlled for a variety of reasons, including nuisance prevention, commodity protection (to prevent cattle loss, for example) and protection against TBDs. This section briefly reviews tick control methods and then discusses IPM strategies that are appropriate for various purposes of tick control.

10.10.1. Self-protection

10.10.1.1. Avoidance

Ticks can be avoided by refraining from exposure to fields, forests and other hard tick-infested habitats, especially in known disease foci (Ginsberg & Stafford, 2005). Specific habitats to be avoided depend on tick distribution, which can differ for different species and for different stages of the same species. Use of clearly defined paths can help avoid contact with tick-infested vegetation. Bites of soft ticks can be prevented by avoiding old campsites, animal and poultry stables, and infested cabins and mud houses and by taking appropriate precautions when coming in contact with animals that are potentially infested with ticks.

10.10.1.2. Repellents

Effective repellents can prevent ticks from becoming attached to the body and can be applied to clothing or directly on the skin (some products are not labelled for use on skin). Effective skin repellents include N,N-diethyl-3-methylbenzamide (DEET), (N,N-butyl-N-acetyl)-aminopropionic acid-ethyl ester and 1-piperidinecarboxylic acid 2-(2-hydroxyethyl)-1-methylpropylester (picaridin). Depending on the active ingredient and formulation, skin repellents generally do not last longer than a few hours, because of absorption or abrasion.

10.10.1.3. Clothing

Individuals can protect themselves against tick attachment by tucking trousers into boots or socks and tucking shirts into trousers. Light-coloured clothing aids detection of dark-coloured ticks, which can be collected or removed with commercial tape. Most TBDs require a period of attachment (often several hours) before the pathogen is transmitted, so thorough body examination and prompt removal of attached ticks at the end of a day spent in tick-infested areas can minimize exposure to TBD agents.

10.10.1.4. Tick removal

Hard ticks should be removed by grasping the tick where the mouthparts are attached to the skin and then pulling it out slowly, but steadily (Needham, 1985); the use of pointed forceps is preferable, because it avoids contact with fingers and the tick's infective body fluid or excreta. The bite site should be cleansed with antiseptic before and after removal. Soft ticks withdraw their mouthparts when touched with a hot needle tip or when dabbed with chloroform, ether, alcohol or other anaesthetics (Gammons & Salam, 2002).

10.10.1.5. Clothing impregnation

A major advance in the protection of high-risk personnel, such as outdoor workers, hunters, travellers and soldiers, has been the development of residual insecticides that can impregnate clothing, tents and netting (WHO, 2001a, b). Permethrin, a synthetic pyrethroid insecticide, has been widely used for decades as an arthropod contact repellent in fabric impregnation, by spraying or soaking the fabric at final concentrations between 500 mg/m^2 and 1,300 mg/m^2 (Young & Evans, 1998; Faulde, Uedelhoven & Robbins, 2003). Recently, factory-based impregnation methods have been introduced, such as soaking the fabric or using a new polymer-coating technique for impregnating clothing and battle dress uniforms. The polymer coating is safe, and the impregnation lasts the life of the fabric (Faulde & Uedelhoven, 2006). Ticks crawling up impregnated fabric quickly fall off. The benefits to people are the bites prevented and the acaricidal activity. This method can also be used to protect against other haematophagous arthropod vectors of public health importance.

10.10.1.6. Vaccination

Of tick-borne diseases endemic in Europe and North America, only TBE can be prevented by the use of a vaccine. TBE vaccination is widely neglected as a public health tool for disease prevention (Austria is an exception). A vaccine for preventing LB was briefly available in North America, but this was specific to *B. burgdorferi* s.s. and would not be efficacious in Europe, where diverse *Borrelia* spp. are associated with LB in people. The manufacturer removed the vaccine from production in 2002, and no vaccine against LB is currently available.

10.10.2. Habitat manipulation and urban design

Ticks have species-specific habitat requirements, often associated with habitats of hosts and the need to avoid desiccation. Therefore, habitats can be manipulated to make them unsuitable for ticks or to minimize encounters between ticks and people (Stafford, 2004).

Suburban habitats associated with natural woodlands foster populations of black-legged ticks and castor-bean ticks, because these habitats are excellent for both immature and adult ticks and for vertebrate hosts suitable for all tick stages. Lawns that were cut short and were open to the sun had minimal numbers of deer ticks, while tick densities increased incrementally in gardens, wood edges and forests (Maupin et al., 1991). Therefore, maintaining a short-clipped lawn and establishing barriers to prevent access to the woods can minimize human exposure to ticks in this environment. Mowing and burning vegetation in natural areas lowers tick numbers temporarily, but ticks reinfest treated areas as the vegetation grows back (Wilson, 1986).

Most ticks that are important to human health are rare in highly urbanized environments, but parks with natural patches and appropriate host species, and natural habitats interspersed with human dwellings in suburban areas, foster encounters between ticks and people. These encounters can be minimized with appropriate design features, such as barriers between areas frequently used by people and natural patches, and pathways constructed through natural sites (boardwalks, for example). Medical entomologists and natural resource experts should be consulted, so that urban design appropriate for the local tick species of concern can be incorporated into the planning process. Unfortunately, in the past, TBDs have rarely been considered in urban or suburban design.

10.10.3. Host-centred methods

Domestic animals can be vaccinated to minimize tick attachment (de la Fuente, Rodriguez & Garcia-Garcia, 2000) or to protect them against TBDs (Kocan et al., 2001). House pets, especially dogs, are commonly vaccinated against LB in the United States. Vaccination of wild reservoir species of animals (Tsao et al., 2001) could theoretically interrupt enzootic transmission cycles of tick-borne zoonoses and, in field trials, it has reduced the prevalence of Lyme spirochetes in questing ticks (Tsao et al., 2004), but this approach has not yet been applied to manage the risk of disease.

Manipulation of host populations can also lower tick populations. Excluding deer can lower populations of deer ticks, and deer-proof fencing can contribute to a tick management programme (Daniels, Fish & Schwartz, 1993). Although lowering deer populations by hunting can also lower tick numbers, this approach is not generally practical, because deer populations must be reduced to extremely low levels to have a reliable effect on the transmission of LB (Ginsberg & Stafford, 2005).

10.10.4. Biological control

Ticks have numerous natural enemies, including predators, parasites and pathogens. In the northern hemisphere, predators are generally not specific to ticks. In contrast, wasps of the genus *Ixodiphagus* parasitize ticks, and the most widespread species, *Ixodiphagus hookeri*, has been studied as a possible biocontrol agent. This species was released on an island off the New England coast in the early 1900s, resulting in establishment of the wasp, but no tick control. Inundative releases have shown some promise of efficacy in agricultural settings (Mwangi et al., 1997), and theoretical analyses suggest that with additional research and development widespread releases might eventually be effective in North America (Knipling & Steelman, 2000). However, considerable problems remain to be overcome before this approach becomes practical.

Numerous pathogens attack ticks, including bacteria, fungi, and nematodes (Samish, Ginsberg & Glazer, 2004). At present, one of the best candidates for tick biocontrol is the entomopathogenic fungus, *Metarhizium anisopliae* (Zhioua et al., 1997; Samish et al., 2001). Preliminary field trials have had modest results; but enhanced tick mortality, from the use of an oil-based carrier solution, compared with a water-based solution (Kaaya & Hassan, 2000), suggests that improved formulations may provide effective control. The pathogens that affect ticks typically also affect other arthropods (Ginsberg et al., 2002), so effects on non-target arthropods must be considered in application strategies of biocontrol materials.

10.10.5. Pesticide applications

Numerous pesticides are effective against ticks, and they are widely used to control ticks and TBDs. Acaricides can be broadcast for area control of ticks or can be targeted at host animals used by the ticks. Broadcast applications have the advantage that they can rapidly lower tick numbers, but timing, chemical distribution and formulation can profoundly influence the effectiveness of treatment. For example, broadcast applications for controlling nymphal deer ticks (the primary vector stage of LB in North America) need to penetrate the leaf litter where the nymphs dwell, while other ticks are better targeted by area sprays. Schulze, Jordan & Hung (2000) found that granular formulations of carbaryl effectively controlled deer tick nymphs (which quest down in the leaf litter where the heavy granules were deposited), but they did not control lone star tick nymphs (which quest up in the shrub layer). Also, most materials used for tick control are broadly toxic to arthropods, so broadcast applications can have substantial effects on non-target species (Ginsberg, 1994). Pesticide applications that are carefully targeted can help minimize these non-target effects. Application concentrations for tick control vary with materials and formulations, but examples of label application concentrations include: carbaryl (43% by weight, 0.17–0.34 g/m^2); cyfluthrin (11.8% by weight, 0.04–0.065 ml/m^2); and permethrin (36.8% by weight, 0.12–0.24 g/m^2).

Pesticides can be targeted at host animals by attracting the hosts (using feed, nesting materials or other attractants) to devices that apply the pesticide to them. Examples include bait boxes, permethrin-treated cotton balls and so-called four-poster devices (Stafford & Kitron, 2002). Four-poster devices, which coat the heads and necks of animals with a pesticide that kills the ticks, have the advantage of well-targeted applications, allowing far lower amounts of pesticide to be applied than in broadcast applications. The effectiveness of the approach taken tends to depend on ecological conditions at the application site. These methods can be important tools in IPM programmes, especially when integrated with other management techniques appropriate for local conditions of tick distribution and transmission dynamics.

Permanent infestations in houses and stables – for example by the brown dog tick or the

pigeon tick – require the professional use of acaricides. Governmental European authorities – for example, in Germany – recommend the use of formulations that contain popoxur (1% by weight, 200 ml/m^2) and diazinon (2% by weight, 50–100 ml/m^2) (Anonymous, 2000). Besides the application of acaricides, dog hosts have to be treated with tick-repelling or -controlling spot-on or dipping formulations, and construction modifications of infested houses and stables are needed to prevent further infestations of pigeons, which are natural hosts of pigeon ticks (Uspensky & Ioffe-Uspensky, 2002).

10.11. IPM

IPM is an approach to the management of arthropod pests that fosters the integration of various pest control methods, so as to minimize reliance on individual environmentally damaging approaches and to provide sustained management of pest populations. IPM was developed for agriculture, where decisions are based on cost–benefit analyses that compare the cost of control with the economic value of crops protected. For vector-borne diseases, decisions are more appropriately based on cost–effectiveness (or cost–efficiency) analyses that integrate management methods, so as to prevent the greatest number of possible human cases of disease at a given cost (Phillips, Mills & Dye, 1993; Ginsberg & Stafford, 2005). Efficient management of TBDs maximizes the number of human cases prevented with available resources and minimizes dependence on broad-spectrum approaches to control that tend to be environmentally damaging. However, these analyses require information from field trials of various management methods and from models of transmission dynamics that use each potential combination of techniques to estimate the costs and the number of cases prevented (Mount, Haile & Daniels, 1997). Given the many tick control techniques currently available and the numerous novel techniques being developed, it is important to develop the theory and practice of efficient integration of methods, so that these techniques can be applied in such a manner as to most effectively prevent human disease.

10.12. Conclusions

The following conclusions can be drawn about public activities, surveillance and management, and research.

10.12.1. Public activities

Conclusions that relate to public activities cover three areas, as follows.

1. Accurate and practical information about ticks and TBDs should be made readily and widely available to health professionals, pest management professionals and the general public. Printed and online information about the effects on health, personal protection and preventive measures would be especially useful, as would information on tick biology and behaviour and on effective control strategies.

2. Specific education and health promotion programmes should be provided for people with occupational and recreational exposure to ticks and TBDs. These programmes should emphasize the threat of ticks, TBDs of public health importance, personal protection measures against tick bites, tick avoidance, tick removal, available control measures and medical follow-up in case of exposure.

3. Development and design of human residential and recreational areas should routinely consider TBDs as part of the planning effort. Public health experts (including specialists on TBDs) should be consulted early in the planning process.

10.12.2. Surveillance and management

Conclusions that relate to surveillance and management cover two areas, as follows.

1. Reporting programmes should be developed for major endemic TBDs, where these currently do not exist. These programmes can include passive or active disease surveillance, or both.

2. Management programmes should be implemented for TBDs. Such programmes should efficiently target the sites where encounter rates between people and infected ticks are greatest. Surveillance and specific public education should be part of these programmes.

10.12.3. Research

Conclusions that relate to research cover three main areas, as follows.

1. Research is needed on new, emerging, and resurging TBDs, including: epidemiology, vector biology, disease-transmission competence of potential vector and reservoir species, transmission dynamics and geographical distribution; and anthropogenic, environmental, and climatic factors that affect emergence, re-emergence and geographical spread of ticks and TBDs.

2. Research is also needed on principles and strategies of tick and TBD management, including least toxic approaches, strategies for well-targeted integrated tick management and optimal approaches in urban, periurban and rural areas, especially in hyperendemic disease foci.

3. Research should be encouraged and carried out on new vaccination strategies, chemoprophylaxis and treatment regimens for TBDs of public health importance.

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