*Rev. Sci. Tech. Off. Int. Epiz.*, 2021, **39** (3), ... – ...

# Integrated management of blood-feeding arthropods in veterinary teaching facilities – Part 1: overview of haematophagous arthropods of interest in North-western Europe

This paper (No. 06122021-00190-EN) has been peer-reviewed, accepted, edited, and corrected by authors. It has not yet been formatted for printing. It will be published in issue **39** (3) of the *Scientific and Technical Review*, in 2021.

M.-F. Humblet [(1)*], B. Losson [(2)] & C. Saegerman [(3)]

(1) Unit Biosafety, Biosecurity and Environmental Licences, Department for Occupational Protection and Hygiene, University of Liège, Quartier Vallée 2, Avenue de Cureghem 7A, B42, B-4000 Liège, Belgium

(2) Laboratory of Parasitology and Parasitic Diseases, Fundamental and Applied Research for Animals and Health Unit (FARAH), Faculty of Veterinary Medicine, University of Liège, Quartier Vallée 2, Avenue de Cureghem 6, B43, B-4000 Liège, Belgium

(3) Veterinary Science Epidemiology and Risk Analysis Research Unit (UREAR-ULiège), Fundamental and Applied Research for Animals and Health Unit (FARAH), Department of Infectious and Parasitic Diseases, Faculty of Veterinary Medicine, University of Liège, Quartier Vallée 2, Avenue de Cureghem 7A, B42, B-4000 Liège, Belgium

*Corresponding author: mfhumblet@uliege.be

**Summary**

Numerous arthropod species negatively affect animal and human health through physical attacks, by generating allergic reactions and as potential vectors of pathogens. Their control is essential to prevent vector-borne diseases and reduce their negative direct effect. Climate change militates for appropriate preparedness towards invasive

species, their establishment and their involvement in new potential vector–pathogen–host cycles. This paper reviews the main blood-feeding arthropods of veterinary/zoonotic interest and their role in the transmission of infections in North-western Europe. It is the first part of an approach aimed at proposing a coherent and affordable vector control programme for facilities housing healthy and sick animals in a veterinary faculty, from a global health point of view. It is the first review focusing on this topic in such a specific and at-risk environment. Indeed, considering its multi-disciplinary and multi-species context and the importance of animal welfare, a veterinary faculty should attach great importance to vector control.

**Keywords**

Companion animal – Haematophagous arthropod – Horse – Livestock – North-western Europe – Vector.

## Introduction

Several arthropods are involved in the transmission of pathogens to animals and/or humans. Vector-borne diseases are causing a great deal of concern in Western Europe (1) because the geographical distributions of their vectors, such as mosquitoes and ticks, are expanding in Europe (2). Climate change is partly responsible for the expansion of important disease vectors in Europe, such as *Aedes albopictus* (the Asian tiger mosquito), which can transmit, among others, Zika, dengue and chikungunya viruses, and *Phlebotomus* sandflies, the main vectors of leishmaniosis (1). Numerous vector-borne diseases pose an additional threat to public health if they are zoonotic. The protection of human health thus implies the protection of animal health and the environment in a One Health approach (3).

A wide variety of haematophagous arthropods exists in North-western Europe, and it is essential to consider all of them in order to implement preventive and control measures to reduce the risk of transmission of pathogens (4). The authors' area of interest includes eight European countries, as previously considered by Martinet *et al.* in 2019 (5) in their meta-analysis of mosquitoes' vector competence:

Belgium, continental France (Corsica excluded), Germany, Ireland, Luxembourg, the Netherlands, Switzerland and the United Kingdom. These countries fall into the temperate oceanic climate (Cfb) of the Köppen–Geiger climate classification, mainly characterised by a dry season and a warm summer (6).

Veterinary teaching facilities house a variety of animal species, with individuals sick and often debilitated as a result of concomitant infections or infestations. Their immune systems may therefore be less resistant to new infections or infestations, among them those transmitted by haematophagous arthropods. The implementation of an efficient control plan is an essential component of biosecurity in such an environment. The authors present a series of three papers dealing with vectors of infectious pathogens and suggestions for control methods combined in an integrated management plan. Part 1 will review the main haematophagous arthropods of veterinary/zoonotic interest in North-western Europe, which is the preliminary step in understanding the issue. Part 2 will describe general and vector-specific control measures. An affordable and practical 'arthropod vector integrated control plan', at the scale of a veterinary faculty (especially clinics housing small and large animals, and an educational farm), will be developed in Part 3.

## Haematophagous arthropods of concern

The transmission of pathogens by arthropods can be either mechanical or biological (7). Flies mostly act as mechanical vectors: they 'transport' the pathogen from one host to another (7). Ticks and mosquitoes are biological vectors: the pathogen undergoes replication and/or transformation inside the vector before transmission through subsequent blood meals (7). The potential of a vector will also depend on its extrinsic incubation period, which corresponds to the days before which an infected insect becomes infective, or to a tick's interstadial development period (8). Haematophagous behaviour makes these arthropods excellent vectors (9). The main vectors of interest from a medical and/or veterinary point of view belong to two classes: Insecta and Arachnida (10). The present review will focus on

the main haematophagous arthropods endemic to and/or reported in North-western Europe.

## Insects

### Mosquitoes (family Culicidae)

Mosquitoes are the major vectors of pathogens, especially the sub-families Culicinae and Anophelinae (11).

#### Subfamily Culicinae

*Culex* species (spp.) are vectors of several pathogens (Tables I, II and III). Their eggs are laid as floating rafts on water surface, and hatch two to three days later (73). *Culex* spp. breed in natural or artificial still waters (11). Several *Culex* species, e.g. *Cx. pipiens* (Fig. 1), are endemic to North-western Europe (74).

**Fig. 1**

**Female *Culex pipiens* mosquito** (courtesy of Nil Rahola, French National Research Institute for Development, Montpellier, France)

**Table I**

**Non-exhaustive list of viruses causing diseases affecting domestic species of concern (domestic livestock and companion animals such as dogs, cats and rabbits) and zoonoses transmitted by targeted haematophagous arthropods**

| Pathogen | Animal hosts | Mosquitoes | *Culicoides* biting midges | Horse flies | Sand-flies | Black flies | Stable flies | Ticks | Lice | Fleas | Louse flies | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| African horse sickness virus | Equids | | | | | | | | | | | 12 |
| African swine fever virus | Pigs, wild boar | | | | | | | | | | | 13, 14 |
| Akabane virus | Ruminants | | | | | | | | | | | 12 |
| Bluetongue virus | Ruminants | | | | | | | | | | M | 12, 15 |
| Border disease virus | Small ruminants | | | | | | | | | | M | 16 |
| Bovine ephemeral fever virus | Cattle | | | | | | | | | | | 17 |
| Crimean–Congo haemorrhagic fever virus* | Ruminants, dogs | | | | | | | | | | | 18 |
| Eastern equine encephalomyelitis virus* | Equids, wild birds | *Culiseta* spp. > *Culex* spp., etc. | | | | M | | | | | | 19 |
| Epizootic haemorrhagic disease virus | Ruminants | | | | | | | | | | | 12, 20 |
| Equine infectious anaemia virus | Equids | | | | | | M | | | | | 21 |
| Japanese encephalitis virus* | Ruminants | *Culex* spp., *Aedes* spp. (*A. koreicus*) | | | | | | | | | | 22, 23 |
| La Crosse encephalitis virus* | Small mammals | *Ochlerotatus* spp., *Aedes triseriatus* | | | | | | | | | | 24 |
| Louping ill virus* | Sheep (mainly), equids, pigs, dogs | | | | | | | | | | | 25 |
| Lumpy skin disease virus | Cattle | M | M | | | | M | M | | | | 26, 27, 28 |
| Myxoma virus | Rabbits | *Culex* spp., *Anopheles* spp. | | | | | | | | | | 29 |
| Rift Valley fever virus* | Ruminants, rodents | *Culex* spp., *Aedes* spp., *Anopheles* spp. | | | | | M | | | | | 30 |
| St. Louis encephalitis virus* | Equids, birds | *Culex* spp. | | | | | | | | | | 24 |
| Schmallenberg virus | Ruminants | | | | | | | | | | | 31 |
| Swine pox virus | Pigs | | | | | M | M | | | | | 32, 33 |
| Tick-borne encephalitis virus (European subtype)* | Dogs | | | | | | | | | | | 34 |
| Venezuelan equine encephalomyelitis virus* | Equids, rodents | *Culex* spp., *Aedes* spp., *Anopheles* spp., etc. | | | | M | | | | | | 35 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vesicular stomatitis virus* | Equids, cattle, pigs | *Aedes* spp. (M?) | | | | | 36 |
| Wesselsbron disease virus* | Sheep, goats > cattle, equids | *Aedes* spp. > *Culex* spp., *Anopheles* spp., *Mansonia* spp. | | | | | 24 |
| West Nile virus* | Equids, birds | *Culex* spp. | | | | M | 37, 38 |
| Western equine encephalomyelitis virus* | Equids, birds | *Culex* spp. > *Aedes* spp. | | | | | 35 |

* zoonotic viruses
M: mechanical transmission
main vector(s) involved in transmission of the pathogen
other vector(s) reported as involved in transmission of the pathogen
secondary vector (mainly mechanical)
virus isolated from the arthropod, but role in transmission of the pathogen not confirmed
suggested as a potential vector but not assessed in the field

**Table II**

**Non-exhaustive list of bacteria and rickettsia causing diseases affecting domestic species of concern (domestic livestock and companion animals such as dogs, cats and rabbits) and zoonoses transmitted by targeted haematophagous arthropods**

| Pathogen | Disease | Animal hosts | Mosquitoes | *Culicoides* biting midges | Horse flies | Sand-flies | Black flies | Stable flies | Ticks | Lice | Fleas | Louse flies | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anaplasma bovis* | Bovine monocytic anaplasmosis | Ruminants | | | | | | | | | | | 39, 40 |
| *Anaplasma marginale* | Bovine anaplasmosis | Cattle | | | M | | | | | | | | 41, 42 |
| *Anaplasma ovis* | Ovine anaplasmosis | Small ruminants | | | | | | | | | | M | 43 |
| *Anaplasma phagocytophilum** | Granulocytic anaplasmosis | Ruminants, equids, dogs, cats | | | | | | | | | | | 44, 45 |
| *Bacillus anthracis** | Anthrax | Mammals | M | | M | | | M | | | | | 42, 46 |
| *Bartonella henselae** | Cat-scratch disease | Cats | | | | | | | | | | | 47 |
| *Borrelia burgdorferi s.l.** | Lyme disease | Dogs, equids, cattle | | | | | | | | | | | 25 |
| *Coxiella burnetii** | Q fever | Ruminants, small animals, equids, etc. | | | | | | | | | | | 48, 49 |
| *Dermatophilus congolensis** | Dermatophilosis | Equids, ruminants > small animals, pigs | | | M | | | M | M | | | | 50, 51, 52 |
| *Ehrlichia canis** | Canine monocytic ehrlichiosis | Domestic dogs and wild carnivores | | | | | | | | | | | 53 |
| *Erysipelothrix rhusiopathiae** | Porcine erysipelas | Pigs > sheep, poultry | | | | | | M | | | | | 37, 54 |
| *Francisella tularensis** | Tularaemia | Rabbits, cats, dogs, sheep > equids, pigs | M | M | M | | M | M | | | | | 7, 37, 55 |
| *Mycoplasma* (= *Haemobartonella*) *haemofelis* | Feline infectious anaemia | Cats | | | | | | | | | | | 56 |
| *Pasteurella multocida** | Haemorrhagic septicaemia (ruminants) / Pasteurellosis (dogs, cats and rabbits) | Ruminants, equids, small animals, pigs, rabbits, etc. | | | | | | M | | | | | 37, 57 |
| *Rickettsia felis** | Flea-borne spotted fever | Rodents, cats | | | | | | | | | | | 58, 59, 60 |
| *Rickettsia typhi** | Murine typhus | Rodents, cats | | | | | | | | | | | 61 |
| *Yersinia pestis** | Plague | Rodents, cats | | | | | | | | | | | 62, 63 |

* zoonotic pathogen
M: mechanical transmission
main vector(s) involved in transmission of the pathogen
other vector(s) reported as involved in transmission of the pathogen
secondary vector (mainly mechanical)
virus isolated from the arthropod, but role in transmission of the pathogen not confirmed
suggested as a potential vector but not assessed in the field

**Table III**

**Non-exhaustive list of protozoans and helminths causing diseases affecting domestic species of concern (domestic livestock and companion animals such as dogs, cats and rabbits) and zoonoses transmitted by targeted haematophagous arthropods**

| Pathogen | Disease | Animal hosts | Mosquitoes | *Culicoides* biting midges | Horse flies | Sand-flies | Black flies | Stable flies | Ticks | Lice | Fleas | Louse flies | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Babesia caballi* | Equine babesiosis | Equids | | | | | | | | | | | 64 |
| *Babesia canis* | Canine babesiosis | Dogs | | | | | | | | | | | 41 |
| *Babesia* spp. in ruminants * | Bovine babesiosis | Ruminants | | | | | | | | | | | 14 |
| *Besnoitia besnoiti* | Besnoitiosis | Cattle | | | | | | | | | | | 65 |
| *Dirofilaria immitis** | Heartworm disease | Dogs | *Culex* spp. *Aedes* spp., *Anopheles* spp., etc. | | | | | | | | | | 66 |
| *Dirofilaria repens** | Subcutaneous filariasis | Dogs, cats | *Culex* spp. *Aedes* spp., *Anopheles* spp., etc. | | | | | | | | | | 67 |
| *Habronema microstoma* | Horse stomach worm | Equids | | | | | | | | | | | 68 |
| *Leishmania infantum** | Canine leishmaniosis | Dogs > cats, equids | | | | | | | | | | | 69 |
| *Onchocerca cervicalis* | Onchocercosis | Equids | | | | | | | | | | | 10 |
| *Theileria equi* (formerly *Babesia equi*) | Equine piroplasmosis | Equids | | | | | | | | | | | 41 |
| *Trypanosoma evansi* * | Surra | Equids, cattle | | | M | | | M | | | | | 70, 71 |
| *Trypanosoma vivax* | Nagana | Ruminants, equids, dogs | | | M | | | M | | | | | 72 |

* zoonotic pathogen
M: mechanical transmission
main vector(s) involved in transmission of the pathogen
suggested as a potential vector but not assessed in the field

*Aedes* spp. are well-assessed vectors of several pathogens (Tables I, II and III). The invasive *Aedes albopictus*, *Ae. japonicus* and *Ae. koreicus* have been spotted occasionally in North-western Europe, following the importation of egg-contaminated tyres and lucky bamboo as early as 2002 (22, 75). Since then, the areas of establishment of *Ae. albopictus* have been progressing northwards, as shown in Figure 2. *Aedes* spp. lay single eggs on damp surfaces in areas where the water level is variable (77); the eggs hatch when immersed in water (78). *Aedes* mosquitoes bite throughout the day, with peaks of activity in early morning and late afternoon (11).

- *Ae. albopictus* (the tiger mosquito) breeds outdoors in natural temporary containers such as tree holes or leaf axils (79);

- *Ae. japonicus* develops in natural and artificial water containers (flower vases and saucers, watering cans, buckets, tyres, bird baths, buckets, tree holes, etc.) (80);

- *Ae. aegypti* is a vector of several viruses (Table I). Its current distribution in Europe is limited, but extending (not observed in Belgium to date [81]);

- The potential role of *Ae. koreicus* as a vector has not been assessed in North-western Europe to date (82). Nevertheless, it is competent for the transmission of Japanese encephalitis virus and *Dirofilaria immitis* (83, 84, 85).

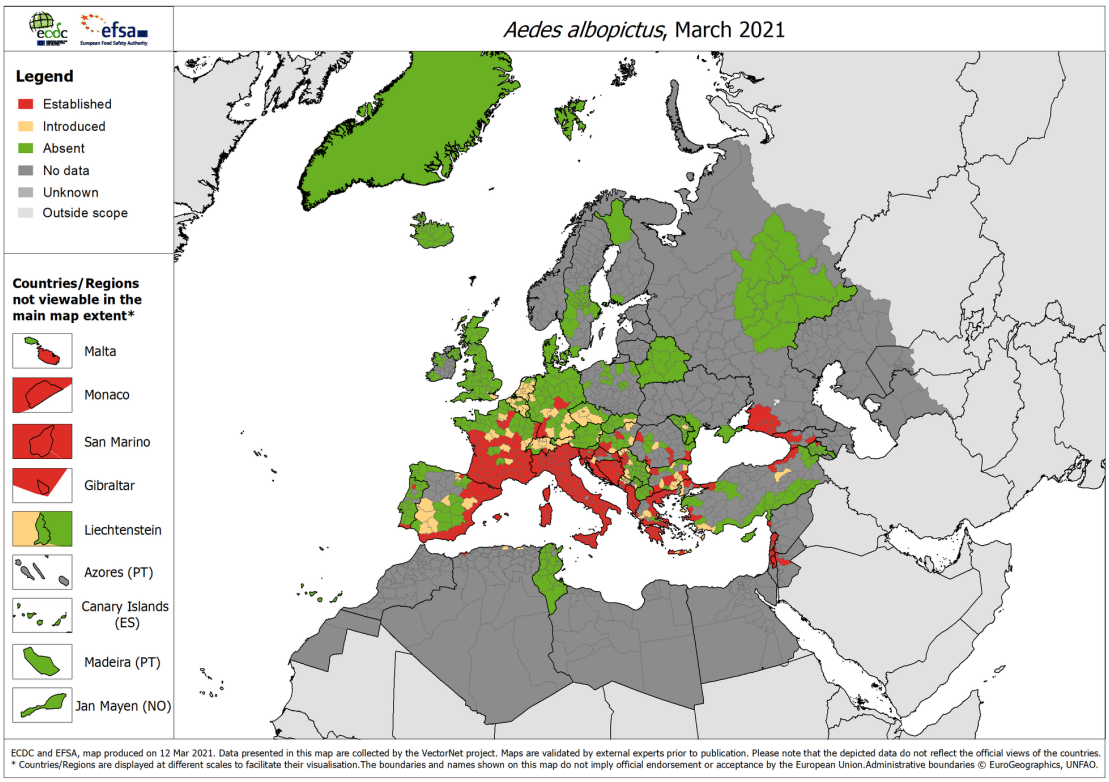


**Fig. 2**

**Current known distribution of invasive mosquito *Aedes albopictus* in Europe, as of 12 March 2021** (76). The invasive mosquito *A. albopictus* has been expanding northwards since its first introduction to North-western Europe in 2002. It is now established in France and Germany, among other countries.

## Subfamily Anophelinae

Several *Anopheles* spp., potential vectors of *Plasmodium* spp., are endemic to Europe, e.g. *An. atroparvus*, *An. labranchiae*, *An. plumbeus* and *An. sacharovi* (Table III) (86, 87). Their larval habitat is associated with vegetation protruding from the water (11).

*Anopheles plumbeus* lay eggs in water-filled tree holes and artificial containers (tyres, rainwater-collecting pits, liquid manure, abandoned manure tanks and uncleaned stables with broken roofing [88]). Fresh and saline water are appropriate environments for larvae of *An. atroparvus* (86).

## Biting midges (family Ceratopogonidae – genus *Culicoides*)

Biting midges are insects measuring 1 to 4 millimetres (mm), mostly active near sunrise and sunset, with activity peaks in early evening (11). Figure 3 illustrates *Culicoides dewulfi*. They bite outdoors, but also possibly indoors (11). Larvae develop in warm semi-aquatic microhabitats, especially around facilities housing ruminants (89). Adults fly only a few hundred metres (m) away from their emergence site, but can be dispersed passively over long distances by winds, up to 700 kilometres (km) from infected areas (90). *Culicoides* spp. transmit several viruses and nematodes (Tables I and III).

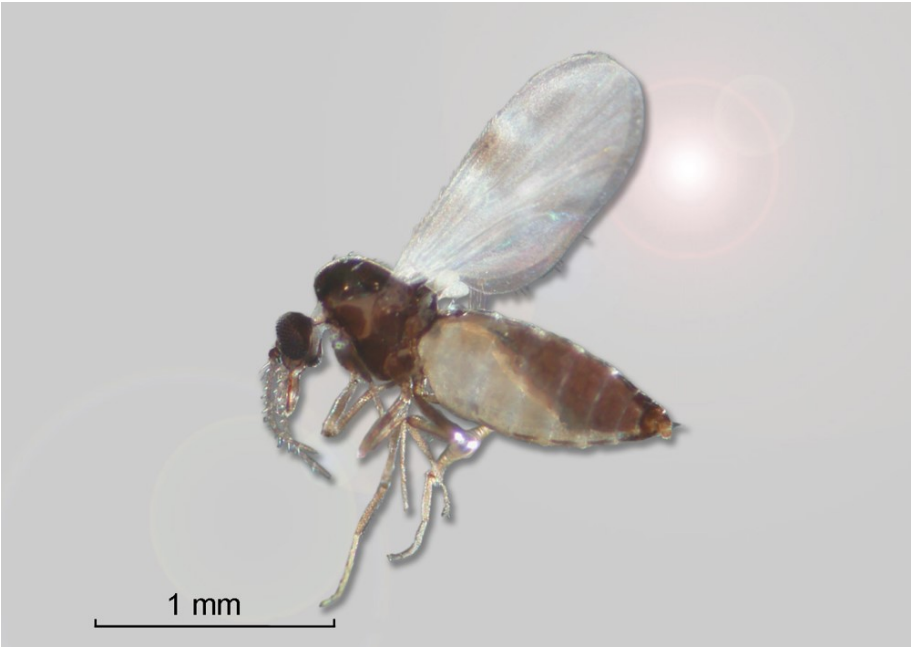


**Fig. 3**

**A gravid female *Culicoides dewulfi* collected from a location near bluetongue outbreaks in Belgium in 2006** (courtesy of Profs Reginald De Deken & Maxime Madder, Institute of Tropical Medicine, Antwerp, Belgium)

### Sandflies (family Psychodidae – subfamily Phlebotominae – genus *Phlebotomus*)

Sandflies or phlebotomines are insects, 1.5–4 mm long (Fig. 4), that usually bite after dark, mostly outdoors (11). They lay eggs on damp soil rich in organic matter (91). Breeding sites include small cracks and holes, animal burrows and cracks among tree roots (92). During the day, adults rest in cool, dark and humid corners, cracks and holes, especially in stone walls, wood piles and animal stables (11). Sandflies are weak fliers and adults usually stay close to emergence sites (93). Sandflies are the main vectors of leishmaniosis (69).

**Fig. 4**

**A male sandfly** (courtesy of Dr Emilie Bouhsira, Parasitology Department, National Veterinary School of Toulouse, France)

### Black flies (family Simuliidae – genus *Simulium*)

Black flies are biting insects (1–5 mm long) that are active only during daylight and outdoors, especially along riverbanks (94). They deposit eggs in fast-flowing, oxygen-rich water (11). After hatching, larvae feed on water nutrients, attached to solid supports (95). Adults prefer

low wind conditions (95). Black flies are distributed worldwide and can transmit several pathogens (Tables I, II and III). A toxic reaction to salivary compounds, simuliotoxicosis, observed in cases after massive attacks, has been reported in Belgian cattle, for example (96).

### Horse flies (family Tabanidae)

Horse flies are especially active in bright sunshine, mostly in woods and forests (11). They are effective mechanical vectors of several pathogens (Tables I, II and III): because of their painful bite they are frequently interrupted while feeding, and therefore take multiple small meals from the same or from different hosts (7, 11). Tabanids lay eggs under leaves, plant stems and small branches above water; emerged larvae develop in mud and rotting vegetation (11) (Fig. 5).

**Fig. 5**

***Philipomyia aprica*, a species of tabanid** (courtesy of Dr Frederic Baldacchino, Head of Missions 'Abattoirs', Departmental Directorate of Protection of northern Populations, Lille, France)

### Flies (family Muscidae – subfamily Stomoxyinae)

Adult flies are mostly involved in the mechanical transmission of pathogens (Tables I, II and III) (7). As non-biting insects, common houseflies and face flies will not be discussed.

#### Stable flies (*Stomoxys calcitrans*)

Larvae of stable flies develop in accumulating and undisturbed fermenting organic matter (manure, bedding and wet feed) (97). Adults usually feed in daytime and mostly outdoors (11, 98). Their bites are painful and a massive infestation has an impact on an animal's productivity (99). They are mechanical vectors of several pathogens (Tables I, II and III).

#### Horn flies (*Haematobia irritans*)

Horn flies require fresh, undisturbed cattle faecal pats to complete their immature development. They spend most of their time resting or feeding on cattle or horses (100). Their painful bites have a negative impact on milk production in cattle (101).

### Fleas (family Pulicidae)

Besides being vectors of pathogens (Tables I, II and III), *Ctenocephalides canis* and *C. felis*, the dog and cat flea, respectively, are stationary parasites and a source of nuisance for their primary hosts and humans, being responsible for allergy and anaemia (102). Adults live permanently on their hosts. Through their bites, fleas potentially transmit *Mycoplasma haemofelis* (formerly *Haemobartonella felis*) to cats, which is responsible for a disease called feline haemoplasmosis (103, 104).

### Haematophagous lice (order Phthiraptera – suborder Anoplura)

Host-specific, haematophagous lice infest both small and large animals (105). As they live in the hair or feathers, they are spread through direct contact and sharing of lice- and nit-infested

equipment (106). Severe infestations are rare, and mostly observed in debilitated or neglected animals (107).

### Keds or louse flies (family Hippoboscidae)

Keds or louse flies are blood-feeding ectoparasites of mammals and birds. These larviparous insects drop their third-stage larva on the ground, deposit them in a preferred site or attach them to hosts or substrate (108). Adults measure between 1.4 and 12 mm (108). There is still a lack of knowledge about their vector role, but their biology and blood-feeding behaviour could be factors favouring such a role (108). Canids are the main hosts of *Hippobosca longipennis Fabricius* (the dog louse fly) (109), a vector of *Acanthocheilonema reconditum*, a non-pathogenic filarial nematode existing in Southern Europe that may be confused, in blood smears, with *D. immitis* (109, 110). The sheep ked *Melophagus ovinus* is widely distributed in Europe (111). Being wingless, adults spend most of their lifespan on their hosts, mainly sheep, but can also infest goats (109). The sheep ked is a mechanical vector for bluetongue and border disease viruses, but also for *Anaplasma ovis* and *Bartonella* spp. (15, 16, 112, 113). They are also vectors of *Trypanosoma melophagium*, which has been reported in the United Kingdom (114).

## Hard ticks (order Acari – family Ixodidae)

To date, the main species of ticks found in North-western Europe are *Ixodes ricinus*, *I. hexagonus* and *Dermacentor reticulatus*, while the distribution of *Rhipicephalus sanguineus* and *Hyalomma marginatum* is expanding, as shown in Figure 6 and Figure 7, respectively (115, 116, 117).

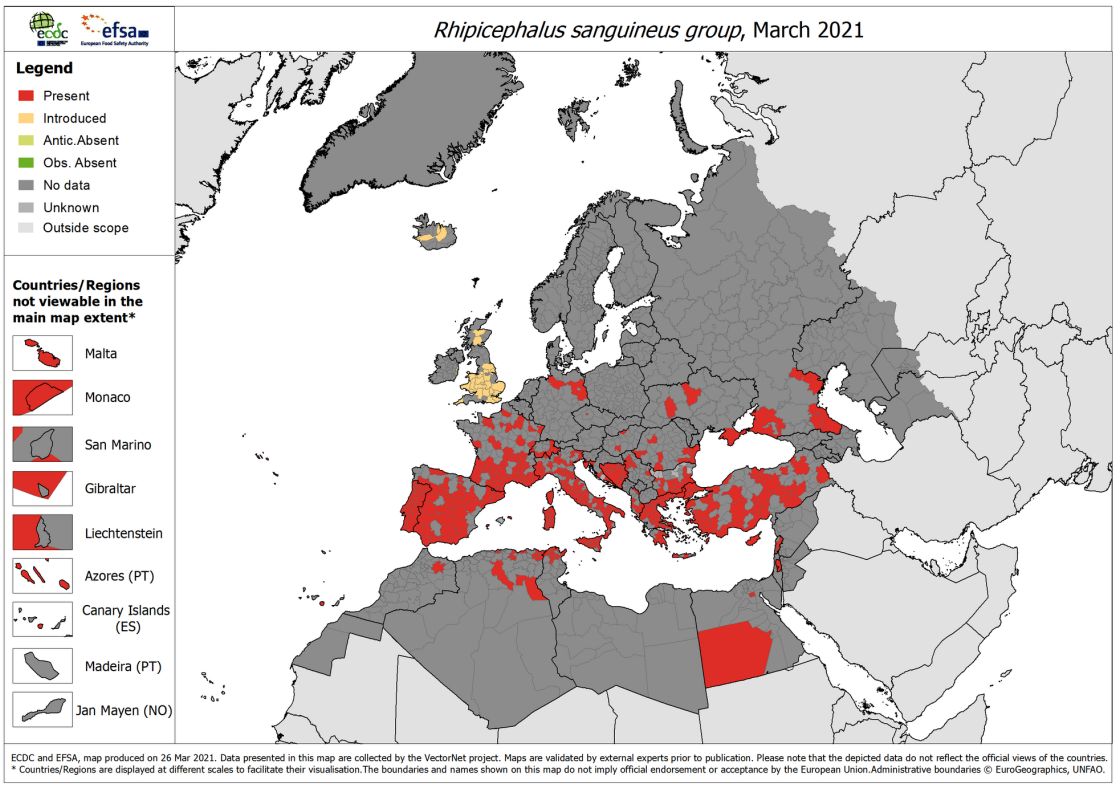


**Fig. 6**

**Current known distribution of the tick species *Rhipicephalus sanguineus* in Europe, updated on 12 March 2021** (115). The tick species *Rhipicephalus sanguineus* is expanding northwards. It is now established in France, Switzerland and Germany and introductions have been reported in the United Kingdom since 2012.

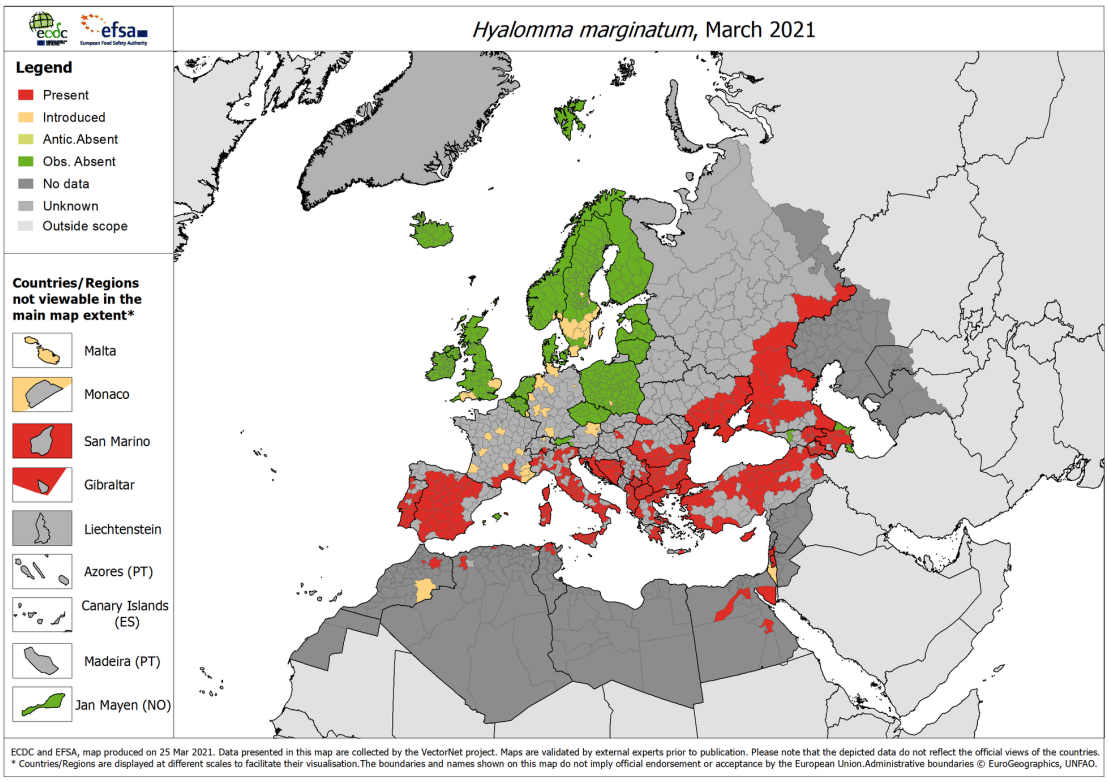


**Fig. 7**

**Current known distribution of the tick species *Hyalomma marginatum* in Europe, updated on 12 March 2021** (116). The tick species *Hyalomma marginatum* is expanding northwards. It has been established in southern France since 2015 and its distribution seems to be expanding northwards. Furthermore, some introductions have been reported in the United Kingdom since 2010–2011.

Infestation by ticks is seasonal, as temperature and humidity influence both tick activity and survival. The three stages of their life cycle are obligate haematophages; these species are therefore biological vectors of several pathogens all around the world (Tables I, II and III).

## Genus *Ixodes*

The main *Ixodes* species present in North-western Europe are *I. ricinus* and *I. hexagonus* (the hedgehog tick) (118). The geographical distribution of *I. ricinus* has expanded in recent years, as it is now found at higher altitudes and latitudes (2). After egg hatching, both *Ixodes* species go through three life stages (larva, nymph and adult); they are three-host ticks.

*Ixodes ricinus* is a telotropic tick species, which means it can feed on a wide variety of vertebrate hosts (119): larvae and nymphs feed on small to medium-sized animals such as rodents, birds and reptiles (e.g. lizards), while adults are more selective and feed on large animals including deer, sheep and cattle (120, 121). This tick species often feeds on humans (122). *Ixodes ricinus*, illustrated in Figure 8, is exophilic and prefers habitats with vegetation and a high relative humidity, for example deciduous woodland and mixed forests (123). All stages of *I. hexagonus* feed mainly on hedgehogs, abundant in (sub)urban areas, and therefore are often found on dogs and cats (118, 124); they can also feed accidentally on humans (125).

**Fig. 8**

**A female *Ixodes ricinus* tick** (courtesy of Dr Sarah Bonnet, National Veterinary School of Alfort, Maisons-Alfort, France)

Host infestation by *I. hexagonus* peaks during summer (118). Seasonal fluctuations in numbers of ticks collected from dogs and hedgehogs were generally weaker compared with *I. ricinus*, although a previous study performed in Belgium reported a peak of collection during spring (117, 126).

*Ixodes ricinus* transmits a large variety of pathogens of medical and veterinary importance (Tables I, II and III). It is a biological vector of the European subtype of the tick-borne encephalitis (TBE) and louping ill viruses (25). Canine cases of TBE have been reported in Switzerland, Germany and eastern France, among others (34). It can also transmit bacteria such as *Francisella tularensis* and *Borrelia burgdorferi* (causing Lyme borreliosis), but also *Babesia* spp., *Anaplasma* spp. and *Rickettsia* spp. (25).

In addition to *Anaplasma phagocytophilum*, *I. hexagonus* is a vector of *Borrelia burgdorferi*, *Babesia* spp. and TBE virus (44). *Rickettsia* spp. have been isolated from *I. hexagonus* (117, 118). Although it is very host-specific, the role of *I. hexagonus* in the transmission of the above-mentioned pathogens to companion animals is still unclear (118).

### Genus *Dermacentor*

The two main *Dermacentor* ticks present in North-western Europe are *D. reticulatus* and *D. marginatus*. They are ditropic ticks: between meals, endophilic immature stages live inside burrows while exophilic and hydrophilic adults generally stay on forest edges and meadows, or on wastelands (127). *Dermacentor reticulatus* is more frequently observed in regions with continental climates, and is commonly found on dogs, ungulates and humans (127). *Dermacentor marginatus* is more prevalent in European Mediterranean countries; these ticks are commonly found in clearings, but also in forests (127).

*Babesia canis* is the most significant animal pathogen transmitted by *D. reticulatus* (41). This tick species is also a vector of *Theileria equi* (also transmitted by *D. marginatus*) and *Anaplasma marginale* (41). Both *Dermacentor* ticks transmit causative agents of equine

piroplasmosis (41, 128) and are relevant in central Europe as vectors of *Francisella tularensis* (129) and *Rickettsia* spp. (41, 130). Furthermore, they are involved in the transmission of TBE virus (127, 131) and may contribute to the transmission of *Coxiella burnetii*, which causes Q fever (41).

### *Rhipicephalus sanguineus*

Owing to its ability to survive in dry conditions, *Rhipicephalus sanguineus* is especially abundant in Mediterranean countries, but it is spreading to northern France and Germany with occasional introductions to the United Kingdom (115, 132). This endophilic tick is found in dog housing, kennels and even inside houses and may be active throughout the year inside houses (127, 132). *Rhipicephalus sanguineus* is a three-host species, but all stages feed on dogs (133).

It is an important vector of, among others, *Ehrlichia canis*, *Anaplasma platys* (which causes canine anaplasmosis) and *Babesia* spp. (132, 134). A dog can become infected with *Hepatozoon canis* (the agent of canine hepatozoonosis) after ingestion of an infected tick (135).

### Genus *Hyalomma*

*Hyalomma marginatum* is the main species of this genus encountered in North-western Europe. It prefers a climate with low to moderate levels of humidity and a long dry summer (136). In North-western Europe, it became established in southern France in 2015, and has been sporadically reported in southern Switzerland, Germany (since 2006) and the United Kingdom (since 2010–2011) (116, 137, 138). Vertebrate hosts such as migratory birds can transport it over long distances (137, 139).

*Hyalomma marginatum* and *H. lusitanicum* prefer steppe, savannah and scrubland hill and valley biotypes (136). Both species are diphasic: larvae and nymphs remain on the same host (small mammals and birds) and adults feed on a second host (136). Endophilic immature stages remain in the nests of their hosts, while adults are

exophilic (136, 138). In the Iberian Peninsula, *H. marginatum* is more active in the summer and autumn (136).

*Hyalomma* spp. are involved in the transmission of several human and animal pathogens in Eurasia and Africa, such as *Theileria* spp., *Babesia* spp., *Coxiella burnetii*, *Anaplasma* spp. and *Rickettsia* spp., as well as several viruses (136, 140). *Hyalomma marginatum* is the main vector of the Crimean–Congo haemorrhagic fever (CCHF) virus in Eurasia that is expanding to Central and Western Europe (18). The CCFH virus was also isolated from another species that has not been observed in North-western Europe to date, *H. lusitanicum* (139). Occasional introductions of the latter have been reported in southern France and in the United Kingdom (141).

## Conclusions

This review illustrates the wide variety of potential haematophagous arthropod vectors in North-western Europe. Several interesting and pertinent free access tools provide useful information on vectors and the pathogens they transmit. The World Animal Health Information System (WAHIS) portal of the World Organisation for Animal Health (OIE) (https://wahis.oie.int/#/home) gives an overview of spatio-temporal distributions of the main animal and zoonotic vector-borne diseases. Useful information is also available in the OIE publication *Atlas of transboundary animal diseases*, written by Peter J. Fernández and William R. White, revised edition published in 2016 (https://oiebulletin.com/?panorama=atlas-of-transboundary-animal-diseases). The European Food Safety Authority (EFSA)'s vector-borne disease map journals (https://efsa.maps.arcgis.com/apps/PublicGallery/index.html?appid=dfbeac92aea944599ed1eb754aa5e6d1) provide interesting information on several vector-borne diseases, along with vector geographical distribution. A special version of the Method for Integrated Risk assessment for infectious diseases in animals (MINTRISK), which was developed jointly by Wageningen BioVeterinary Research and Wageningen Economic Research, both part of Wageningen University and Research, upon the request of EFSA, helps in assessing and

ranking the risk of a large number of vector-borne diseases (www.wecr.wur.nl/mintrisk/Default.aspx). Through the VectorNet initiative (www.ecdc.europa.eu/en/about-us/partnerships-and-networks/disease-and-laboratory-networks/vector-net), the European Centre for Disease Prevention and Control also makes available up-to-date information on vector distribution in Europe. A wide variety of tools is therefore available to collect as much data as possible on vector-borne diseases and their respective arthropod vectors. This is the preliminary step towards the understanding and selection of appropriate control measures, to be included under an affordable and practical 'arthropod vector integrated control plan', at the scale of a veterinary faculty (especially clinics housing small and large animals, and an educational farm).

## References

1. Semenza J.C. & Suk J.E. (2018). – Vector-borne diseases and climate change: a European perspective. *FEMS Microbiol. Lett.*, **365** (2), fnx244. https://doi.org/10.1093/femsle/fnx244.

2. Medlock J.M., Hansford K.M. […] & Van Bortel W. (2013). – Driving forces for changes in geographical distribution of *Ixodes ricinus* ticks in Europe. *Parasit. Vectors*, **6**, 1. https://doi.org/10.1186/1756-3305-6-1.

3. Ruy S., Kim B.I., Lim J.S., Tan C.S. & Chun B.C. (2017). – One Health perspectives on emerging public health threats. *J. Prev. Med. Public Health*, **50** (6), 411–414. https://doi.org/10.3961/jpmph.17.097.

4. Gossner C.M., Ducheyne D. & Schaffner F. (2018). – Increased risk for autochthonous vector-borne infections transmitted by *Aedes albopictus* in continental Europe. *Eurosurveillance*, **23** (24), 1800268. https://doi.org/10.2807/1560-7917.ES.2018.23.24.1800268.

5. Martinet J.-P., Ferté H., Failloux A.-B., Schaffner F. & Depaquit J. (2019). – Mosquitoes of North-western Europe as potential vectors of arboviruses: a review. *Viruses*, **11** (11), 1059. https://doi.org/10.3390/v11111059.

6. Peel M.C., Finlayson B.L. & McMahon T.A. (2007). – Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.*, **11** (5), 1633–1644. https://doi.org/10.5194/hess-11-1633-2007.

7. Gubler D.J. (2009). – Vector-borne diseases. *In* Veterinary education for global animal and public health (D.A. Walsh, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **28** (2), 583–588. https://doi.org/10.20506/rst.28.2.1904.

8. Randolph S.E. (1998). – Ticks are not insects: consequences of contrasting vector biology for transmission potential. *Trends Parasitol.*, **14** (5), 186–192. https://doi.org/10.1016/S0169-4758(98)01224-1.

9. Benelli G. & Duggan M.F. (2018). – Management of arthropod vector data: social and ecological dynamics facing the One Health perspective. *Acta Trop.*, **182**, 80–91. https://doi.org/10.1016/j.actatropica.2018.02.015.

10. Mullen G.R. & Durden L.A. (2002). – Medical and Veterinary Entomology. 1st Ed. Academic Press, San Francisco, United States of America, 597 pp. https://doi.org/10.1016/B978-012510451-7/50003-7.

11. Rozendaal J.A. (1997). – Chapter 1: Mosquitoes and other biting Diptera. *In* Vector control: methods for use by individuals and communities. World Health Organization, Geneva, Switzerland, 6–177. Available at: https://apps.who.int/iris/handle/10665/41968 (accessed on 30 April 2021).

12. Sick F., Beer M., Kampen H. & Wernike K. (2019). – *Culicoides* biting midges – underestimated vectors for arboviruses of public health and veterinary importance. *Viruses*, **11** (4), 376. https://doi.org/10.3390/v11040376.

13. Olesen A.S., Lohse L., Hansen M.F., Boklund A., Halasa T., Belsham G.J., Rasmussen T.B., Bøtner A. & Bødker R. (2018). – Infection of pigs with African swine fever virus via ingestion of stable flies (*Stomoxys calcitrans*). *Transbound. Emerg. Dis.*, **65** (5), 1152–1157. https://doi.org/10.1111/tbed.12918.

14. Nicholson W.L., Sonenshine D.E., Noden B.H. & Brown R.N. (2019). – Chapter 27: Ticks (Ixodida). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 603–672. https://doi.org/10.1016/B978-0-12-814043-7.00027-3.

15. Luedke A.J., Jochim M.M. & Bowne J.G. (1965). – Preliminary bluetongue transmission with the sheep ked *Melophagus ovinus* (L.). *Can. J. Comp. Med. Vet. Sci*., **29** (9), 229–231. Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC1494446/ (accessed on 26 July 2021).

16. Liu Y.-H., He B., Li K.-R., Li F., Zhang L.-Y., Li X.-Q. & Zhao L. (2019). – First report of border disease virus in *Melophagus ovinus* (sheep ked) collected in Xinjiang, China. *PLoS ONE*, **14** (8), e0221435. https://doi.org/10.1371/journal.pone.0221435.

17. Walker P.J. & Klement E. (2015). – Epidemiology and control of bovine ephemeral fever. *Vet. Res.*, **46**, 124. https://doi.org/10.1186/s13567-015-0262-4.

18. Gargili A., Estrada-Peña A., Spengler J.R., Lukashev A., Nuttall P.A. & Bente D.A. (2017). – The role of ticks in the maintenance and transmission of Crimean-Congo hemorrhagic fever virus: a review of published field and laboratory studies. *Antiviral Res.*, **144**, 93–119. https://doi.org/10.1016/j.antiviral.2017.05.010.

19. Adler P.H. & McCreadie J.W. (2019). – Chapter 14: Black flies (Simuliidae). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 237–259. https://doi.org/10.1016/B978-0-12-814043-7.00014-5.

20. Brown S.E., Gorman B.M., Tesh R.B. & Knudson D.L. (1992). – Isolation of bluetongue and epizootic haemorrhagic disease viruses from mosquitoes collected in Indonesia. *Vet. Microbiol.*, **32** (3–4), 241–252. https://doi.org/10.1016/0378-1135(92)90147-l.

21. Zimmerli U. & Thür B. (2019). – Equine infectious anaemia: a review from an official veterinary perspective [in German]. *Schweiz Arch. Tierheilkd*, **161** (11), 725–738. https://doi.org/10.17236/sat00232.

22. Medlock J.M., Hansford K.M., Schaffner F., Versteirt V., Hendrickx G., Zeller H. & Van Bortel W. (2012). – A review of the invasive mosquitoes in Europe: ecology, public health risks, and control options. *Vector Borne Zoonotic Dis.*, **12** (6), 435–447. https://doi.org/10.1089/vbz.2011.0814.

23. Mullen G.R. & Murphree C.S. (2019). – Chapter 13: Biting midges (Ceratopogonidae). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 213–236. https://doi.org/10.1016/B978-0-12-814043-7.00013-3.

24. Foster W.A. & Walker E.D. (2019). – Chapter 15: Mosquitoes (Culicidae). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 261–325. https://doi.org/10.1016/B978-0-12-814043-7.00015-7.

25. Sprong H., Azagi T., Hoornstra D., Nijhof A.M., Knorr S., Baarsma M.E. & Hovius J.W. (2018). – Control of Lyme borreliosis and other *Ixodes ricinus*-borne diseases. *Parasit. Vectors*, **11**, 145. https://doi.org/10.1186/s13071-018-2744-5.

26. Chihota C.M., Rennie L.F., Kitching R.P. & Mellor P.S. (2001). – Mechanical transmission of lumpy skin disease virus by *Aedes aegypti* (Diptera: Culicidae). *Epidemiol. Infect.*, **126** (2), 317–321. https://doi.org/10.1017/s0950268801005179.

27. Tuppurainen E.S., Stoltsz W.H., Troskie M., Wallace D.B., Oura C.A.L., Mellor P.S., Coetzer J.A.W. & Venter E.H. (2011). – A potential role for ixodid (hard) tick vectors in the transmission of lumpy skin disease virus in cattle. *Transbound. Emerg. Dis.*, **58** (2), 93–104. https://doi.org/10.1111/j.1865-1682.2010.01184.x.

28. Kahana-Sutin E., Klement E., Lensky I. & Gottlieb Y. (2017). – High relative abundance of the stable fly *Stomoxys calcitrans* is associated with lumpy skin disease outbreaks in Israeli dairy farms. *Med. Vet. Entomol.*, **31** (2), 150–160. https://doi.org/10.1111/mve.12217.

29. Hess L. & Tater K. (2012). – Chapter 18: Dermatologic diseases. *In* Ferrets, rabbits, and rodents: clinical medicine and surgery (K.E. Quesenberry & J.W. Carpenter, eds), 3rd Ed. Elsevier Saunders, St. Louis, United States of America, 232–244. https://doi.org/10.1016/B978-1-4160-6621-7.00018-X.

30. Paweska J.T. & van Vuren P.J. (2014). – Chapter 8: Rift Valley fever, a virus with potential for global emergence. *In* The role of animals in emerging viral diseases (N. Johnson, ed.). Academic Press, London, United Kingdom, 169–200. https://doi.org/10.1016/B978-0-12-405191-1.01001-2.

31. Rasmussen L.D., Kristensen B., Kirkeby C., Rasmussen T.B., Belsham G.J., Bødker R. & Bøtner A. (2012). – Culicoids as vectors of Schmallenberg virus. *Emerg. Infect. Dis.*, **18** (7), 1204–1206. https://doi.org/10.3201/eid1807.120385.

32. Laber K.E., Whary M.T., Bingel S.A., Goodrich J.A., Smith A.C. & Swindle M.M. (2002). – Chapter 15: Biology and diseases of swine. *In* Laboratory Animal Medicine (J.G. Fox, L.C. Anderson, F.M. Loew & F.W. Quimby, eds), 2nd Ed. Academic Press, London, United Kingdom, 615–673. https://doi.org/10.1016/B978-012263951-7/50018-1.

33. Proletto S., Killoran K. & Leedom Larson K.R. (2016). – Swinepox virus. Swine Health Information Center and Center for Food Security and Public Health (CFSPH), Iowa State University, Ames, United States of America, 9 pp. Available at: www.cfsph.iastate.edu/pdf/shic-factsheet-swinepox-virus (accessed on 8 April 2020).

34. Pfeffer M. & Dobler G. (2011). – Tick-borne encephalitis in dogs: is this an issue? *Parasit. Vectors*, **4**, 59. https://doi.org/10.1186/1756-3305-4-59.

35. Aréchiga-Ceballos N. & Aguilar-Setién A. (2015). – Alphaviral equine encephalomyelitis (Eastern, Western and Venezuelan). *In* New developments in major vector-borne diseases. Part II: Important diseases for veterinarians (S. Zientara, D. Verwoerd & P.-P. Pastoret, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **34** (2), 491–501. https://doi.org/10.20506/rst.34.2.2374.

36. Rozo-Lopez P., Drolet B.S. & Londoño-Renteria B. (2018). – Vesicular stomatitis virus transmission: a comparison of incriminated vectors. *Insects*, **9** (4), 190. https://doi.org/10.3390/insects9040190.

37. Krinsky W.L. (1976). – Animal disease agents transmitted by horse flies and deer flies (Diptera: Tabanidae). *J. Med. Entomol.*, **13** (3), 225–275. https://doi.org/10.1093/jmedent/13.3.225.

38. Doyle M.S., Swope B.N., Hogsette J.A., Burkhalter K.L., Savage H.M. & Nasci R.S. (2011). – Vector competence of the stable fly (Diptera: Muscidae) for West Nile virus. *J. Med. Entomol.*, **48** (3), 656–668. https://doi.org/10.1603/me10167.

39. Atif F.A. (2016). – Alpha proteobacteria of genus *Anaplasma* (Rickettsiales: Anaplasmataceae): epidemiology and characteristics of *Anaplasma* species related to veterinary and public health importance. *Parasitology*, **143** (6), 659–685. https://doi.org/10.1017/S0031182016000238.

40. Jurković D., Mihaljević Z., Duvnjak S., Silaghi C. & Beck R. (2020). – First reports of indigenous lethal infection with *Anaplasma marginale*, *Anaplasma bovis* and *Theileria orientalis* in Croatian cattle. *Ticks Tick Borne Dis.*, **11** (5), 101469. https://doi.org/10.1016/j.ttbdis.2020.101469.

41. Földvári G., Široký P., Szekeres S., Majoros G. & Sprong H. (2016). – *Dermacentor reticulatus*: a vector on the rise. *Parasit. Vectors*, **9**, 314. https://doi.org/10.1186/s13071-016-1599-x.

42. Mullens B.A. (2019). – Chapter 16: Horse flies and deer flies (Tabanidae). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 327–343. https://doi.org/10.1016/B978-0-12-814043-7.00016-9.

43. Torina A. & Caracappa S. (2012). – Tick-borne diseases in sheep and goats: clinical and diagnostic aspects. *Small Rum. Res.*, **106** (Suppl.), S6–S11. https://doi.org/10.1016/j.smallrumres.2012.04.026.

44. Jahfari S., Coipan E.C. […] & Sprong H. (2014). – Circulation of four *Anaplasma phagocytophilum* ecotypes in Europe. *Parasit. Vectors*, **7**, 365. https://doi.org/10.1186/1756-3305-7-365.

45. Pennisi M.G., Hofmann-Lehmann R. […] & Möstl K. (2017). – *Anaplasma*, *Ehrlichia* and *Rickettsia* species infections in cats: European guidelines from the ABCD on prevention and management. *J. Feline Med. Surg.*, **19** (5), 542–548. https://doi.org/10.1177/1098612X17706462.

46. Turell M.J. & Knudson G.B. (1987). – Mechanical transmission of *Bacillus anthracis* by stable flies (*Stomoxys calcitrans*) and mosquitoes (*Aedes aegypti* and *Aedes taeniorhynchus*). *Infect. Immun.*, **55** (8), 1859–1861. https://doi.org/10.1128/iai.55.8.1859-1861.1987.

47. Pennisi M.G., Marsilio F. […] & Horzinek M.C. (2013). – *Bartonella* species infection in cats: ABCD guidelines on prevention and management. *J. Feline Med. Surg.*, **15** (7), 563–569. https://doi.org/10.1177/1098612X13489214.

48. Psaroulaki A., Chochlakis D., Ioannou I., Angelakis E. & Tselentis Y. (2014). – Presence of *Coxiella burnetii* in fleas in Cyprus. *Vector Borne Zoonotic Dis.*, **14** (9), 685–687. https://doi.org/10.1089/vbz.2013.1399.

49. Körner S., Makert G.R., Mertens-Scholz K., Henning K., Pfeffer M., Starke A., Nijhof A.M. & Ulbert S. (2020). – Uptake and fecal excretion of *Coxiella burnetii* by *Ixodes ricinus* and *Dermacentor marginatus* ticks. *Parasit. Vectors*, **13**, 75. https://doi.org/10.1186/s13071-020-3956-z.

50. Richard J.L. & Pier A.C. (1966). – Transmission of *Dermatophilus congolensis* by *Stomoxys calcitrans* and *Musca domestica*. *Am. J. Vet. Res.*, **27** (117), 419–423. PMID 5959398.

51. Zaria L.T. (1993). – *Dermatophilus congolensis* infection (dermatophilosis) in animals and man! An update. *Comp. Immun. Microbiol. Infect. Dis.*, **16** (3), 179–222. https://doi.org/10.1016/0147-9571(93)90148-X.

52. Mauldin E.A. & Peters-Kennedy J. (2016). – Chapter 6: Integumentary system. *In* Jubb, Kennedy & Palmer's pathology of domestic animals: Volume 1 (M. Grant Maxie, ed.), 6th Ed. Elsevier, St. Louis, United States of America, 509–736. https://doi.org/10.1016/B978-0-7020-5317-7.00006-0.

53. Stich R.W., Schaefer J.J., Bremer W.G., Needham G.R. & Jittapalapong S. (2008). – Host surveys, ixodid tick biology and transmission scenarios as related to the tick-borne pathogen, *Ehrlichia canis*. *Vet. Parasitol.*, **158** (4), 256–273. https://doi.org/10.1016/j.vetpar.2008.09.013.

54. Wang Q., Change B.J. & Riley T.V. (2010). – *Eryispelothrix rhusiopathiae*. *Vet Microbiol.*, **140** (3–4), 405–417. https://doi.org/10.1016/j.vetmic.2009.08.012.

55. Petersen J.M., Mead P.S. & Schriefer M.E. (2009). – *Francisella tularensis*: an arthropod-borne pathogen. *Vet Res.*, **40** (2), 7. https://doi.org/10.1051/vetres:2008045.

56. Tasker S., Hofmann-Lehmann R. […] & Möstl K. (2018). – Haemoplasmosis in cats: European guidelines from the ABCD on prevention and management. *J. Feline Med. Surg.*, **20** (3), 256–261. https://doi.org/10.1177/1098612X18758594.

57. Williams C.J., Scheftel J.M., Elchos B.L., Hopkins S.G. & Levine J.F. (2015). – Compendium of veterinary standard precautions for zoonotic disease prevention in veterinary personnel: National Association of State Public Health Veterinarians: Veterinary Infection Control Committee 2015. *J. Am. Vet. Med. Assoc.*, **247** (11), 1252–1277. https://doi.org/10.2460/javma.247.11.1252.

58. Oliveira K.A., Oliveira L.S., Dias C.C., Silva Jr A., Almeida M.R., Almada G., Bouyer D.H., Galvão M.A. & Mafra C. (2008). – Molecular identification of *Rickettsia felis* in ticks and fleas from an endemic area for Brazilian spotted fever. *Mem. Inst. Oswaldo Cruz*, **103** (2), 191–194. https://doi.org/10.1590/s0074-02762008000200011.

59. Abdad M.Y., Stenos J. & Graves S. (2011). – *Rickettsia felis*, an emerging flea-transmitted human pathogen. *Emerg. Health Threats J.*, **4** (1), 7168. https://doi.org/10.3402/ehtj.v4i0.7168.

60. Dieme C., Bechah Y., Socolovschi C., Audoly G., Berenger J.M., Faye O., Raoult D. & Parola P. (2015). – Transmission potential of *Rickettsia felis* infection by *Anopheles gambiae* mosquitoes. *Proc. Natl. Acad. Sci. USA*, **112** (26), 8088–8093. https://doi.org/10.1073/pnas.1413835112.

61. Traub R. & Wisseman C.L. (1978). – The ecology of murine typhus: a critical review. *Trop. Dis. Bull.*, **75** (4), 237–317.

62. Perry R.D. & Fetherston J.D. (1997). – *Yersinia pestis*: etiologic agent of plague. *Clin. Microbiol. Rev.*, **10** (1), 35–66. https://doi.org/10.1128/CMR.10.1.35-66.1997.

63. Durden L.A. & Hinkle N.C. (2019). – Chapter 10: Fleas (Siphonaptera). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 145–169. https://doi.org/10.1016/B978-0-12-814043-7.00010-8.

64. Onyiche T.E., Suganuma K., Igarashi I., Yokoyama N., Xuan X. & Thekisoe O. (2019). – A review on equine piroplasmosis: epidemiology, vector ecology, risk factors, host immunity, diagnosis and control. *Int. J. Environ. Res. Public Health*, **16** (10), 1736. https://doi.org/10.3390/ijerph16101736.

65. Cortes H., Leitão A., Gottstein B. & Hemphill A. (2014). – A review on bovine besnoitiosis: a disease with economic impact in herd health management, caused by *Besnoitia besnoiti* (Franco and Borges, 1916). *Parasitology*, **141** (11), 1406–1417. https://doi.org/10.1017/S0031182014000262.

66. Morchón R., Carretón E., González-Miguel J. & Mellado-Hernández I. (2012). – Heartworm disease (*Dirofilaria immitis*) and their vectors in Europe: new distribution trends. *Front. Physiol.*, **3**, 196. https://doi.org/10.3389/fphys.2012.00196.

67. Capelli G., Genchi C. […] & Silaghi C. (2018). – Recent advances on *Dirofilaria repens* in dogs and humans in Europe. *Parasit. Vectors*, **11**, 663. https://doi.org/10.1186/s13071-018-3205-x.

68. Traversa D., Otranto D., Iorio R., Carluccio A., Contri A., Paoletti B., Bartolini R. & Giangaspero A. (2008). – Identification of the intermediate hosts of *Habronema microstoma* and *Habronema muscae* under field conditions. *Med. Vet. Entomol.*, **22** (3), 283–287. https://doi.org/10.1111/j.1365-2915.2008.00737.x.

69. Munstermann L.E. (2019). – Chapter 12: Phlebotomine sand flies and moth flies (Psychodidae). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 191–211. https://doi.org/10.1016/B978-0-12-814043-7.00012-1.

70. Truc P., Büscher P. […] & Desquesnes M. (2013). – Atypical human infections by animal trypanosomes. *PLoS Negl. Trop. Dis.*, **7** (9), e2256. https://doi.org/10.1371/journal.pntd.0002256.

71. Rovid-Spickler A. (2015). – Surra. Center for Food Security and Public Health, Iowa State University, Ames, United States of America, 7 pp. Available at: www.cfsph.iastate.edu/Factsheets/pdfs/surra.pdf (accessed on 8 April 2020).

72. Rovid-Spickler A. (2018). – African animal trypanosomiasis. Center for Food Security and Public Health, Iowa State University, Ames, United States of America, 8 pp. Available at: www.cfsph.iastate.edu/Factsheets/pdfs/trypanosomiasis_african.pdf (accessed on 8 April 2020).

73. Blosser E.M. & Burkett-Cadena N.D. (2017). – Oviposition strategies of Florida *Culex* (*Melanoconion*) mosquitoes. *J. Med. Entomol.*, **54** (4), 812–820. https://doi.org/10.1093/jme/tjx052.

74. European Centre for Disease Prevention and Control (ECDC) (2021). – *Culex pipiens* group: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/culex-pipiens-group-current-known-distribution-march-2021 (accessed on 20 April 2021).

75. Medlock J.M., Hansford K.M., Versteirt V., Cull B., Kampen H., Fontenille D., Hendrickx G., Zeller H., Van Bortel W. & Schaffner F. (2015). – An entomological review of invasive mosquitoes in Europe. *Bull. Entomol. Res.*, **105** (6), 637–663. https://doi.org/10.1017/S0007485315000103.

76. European Centre for Disease Prevention and Control (ECDC) (2021). – *Aedes albopictus*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/aedes-albopictus-current-known-distribution-march-2021 (accessed on 2 May 2021).

77. Kauffman E., Payne A., Franke M.A., Schmid M.A., Harris E. & Kramer L.D. (2017). – Rearing of *Culex* spp. and *Aedes* spp. mosquitoes. *Bio. Protoc.*, **7** (17), e2542. https://doi.org/10.21769/BioProtoc.2542.

78. Faraone J., Fischer S., Aponte C.A., Etchepare E., Stechina O.S. & Stein M. (2021). – Hatching pattern and coexistence of *Aedes aegypti* and *Aedes albopictus* (Culicidae) in a subtropical city, Argentina, after three decades of coexistence. *Acta Trop.*, **218**, 105885. https://doi.org/10.1016/j.actatropica.2021.105885.

79. Delatte H., Dehecq J.S., Thiria J., Domerg C., Paupy C. & Fontenille D. (2008). – Geographic distribution and developmental sites of *Aedes albopictus* (Diptera: Culicidae) during a chikungunya epidemic event. *Vector Borne Zoonotic Dis.*, **8** (1), 25–34. https://doi.org/10.1089/vbz.2007.0649.

80. Kampen H., Zielke D. & Werner D. (2012). – A new focus of *Aedes japonicus japonicus* (Theobald, 1901) (Diptera: Culicidae) distribution in western Germany: rapid spread or a further introduction event? *Parasit. Vectors*, **5**, 284. https://doi.org/10.1186/1756-3305-5-284.

81. European Centre for Disease Prevention and Control (ECDC) (2021). – *Aedes aegypti*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/aedes-aegypti-current-known-distribution-march-2021 (accessed on 2 May 2021).

82. Schaffner F., Medlock J.M. & Van Bortel W. (2013). – Public health significance of invasive mosquitoes in Europe. *Clin. Microbiol. Infect.*, **19** (8), 685–692. https://doi.org/10.1111/1469-0691.12189.

83. Capelli G., Drago A. […] & Russo F. (2011). – First report in Italy of the exotic mosquito species *Aedes (Finlaya) koreicus*, a potential vector of arboviruses and filariae. *Parasit. Vectors*, **4**, 188. https://doi.org/10.1186/1756-3305-4-188.

84. Miles J.A.R. (1964). – Some ecological aspects of the problem of arthropod-borne animal viruses in the Western Pacific and South-East Asia regions. *Bull. World Health Organ.*, **30** (2), 197–210. Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC2554795/ (accessed on 1 April 2021).

85. Shestakov V.I. & Mikheeva A.I. (1966). – Study of vectors of Japanese encephalitis in the maritime territory [in Russian]. *Med. Parazitol. (Mosk.)*, **35** (5), 545–550.

86. Sinka M.E., Bangs M.J. […] & Hay S.I. (2010). – The dominant *Anopheles* vectors of human malaria in Africa, Europe and the Middle East: occurrence data, distribution maps and bionomic précis. *Parasit. Vectors*, **3**, 117. https://doi.org/10.1186/1756-3305-3-117.

87. European Centre for Disease Prevention and Control (ECDC) (2021). – *Anopheles plumbeus*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/anopheles-plumbeus-current-known-distribution-march-2021 (accessed on 20 April 2021).

88. Schaffner F., Thiery I., Kaufmann C., Zettor A., Lengeler C., Mathis A. & Bourgouin C. (2012). – *Anopheles plumbeus* (Diptera: Culicidae) in Europe: a mere nuisance mosquito or potential malaria vector? *Malar. J.*, **11**, 393. https://doi.org/10.1186/1475-2875-11-393.

89. Zimmer J.Y., Losson B., Saegerman C., Haubruge E. & Francis F. (2013). – Breeding sites and species association of the main Bluetongue and Schmallenberg virus vectors, the *Culicoides* species (Diptera: Ceratopogonidae) in northern Europe. *Ann. Soc. Entomol. France*, **49** (3), 335–344. https://doi.org/10.1080/00379271.2013.854100.

90. Braverman Y. & Chechik F. (1996). – Air streams and the introduction of animal diseases borne on *Culicoides* (Diptera: Ceratopogonidae) into Israel. *Rev. Sci. Tech. Off. Int. Epiz.*, **15** (3), 1037–1052. https://doi.org/10.20506/rst.15.3.968.

91. Maroli M.D., Feliciangeli M.D., Bichaud L., Charrel R.N. & Gradoni L. (2013). – Phlebotomine sandflies and the spreading of leishmaniases and other diseases of public health concern. *Med. Vet. Entomol.*, **27** (2), 123–147. https://doi.org/10.1111/j.1365-2915.2012.01034.x.

92. Gálvez R., Montoya A., Fontal F., Martínez De Murguía L. & Miró G. (2018). – Controlling phlebotomine sand flies to prevent canine *Leishmania infantum* infection: a case of knowing your enemy. *Res. Vet. Sci.*, **121**, 94–103. https://doi.org/10.1016/j.rvsc.2018.10.008.

93. Hendrix C.M. (2013). – Sand flies. Merck Sharp & Dohme Corp., Kenilworth, United States of America. Available at: www.msdvetmanual.com/integumentary-system/flies/sand-flies (accessed on 31 March 2020).

94. Apperson C. & Waldvogel M. (2005). – Black flies and their control: biting and stinging pests. North Carolina State Extension, Raleigh, United States of America. Available at: https://content.ces.ncsu.edu/black-flies-and-their-control (accessed on 31 March 2020).

95. Butler J.F. & Hogsette J.A. (2020). – Featured creatures: entomology & nematology: black flies (*Simulium* spp. [Insecta: Diptera: Simuliidae]). Institute of Food and Agricultural Sciences, University of Florida, Gainesville, United States of America. Available at: http://entnemdept.ufl.edu/creatures/livestock/bfly.htm (accessed on 31 March 2020).

96. Caron Y. & Losson B. (2014). – Attaques massives de simulies et mort brutale. *Veterinaria*, **2014** (3), 34–36. Available at: http://hdl.handle.net/2268/168635 (accessed on 12 April 2021).

97. Townsend L. (2007). – Fly control around horse barns and stables. ENTFACT-514. Cooperative Extension Service, College of Agriculture, University of Kentucky, Lexington, United States of America, 2 pp. Available at: https://entomology.ca.uky.edu/files/efpdf3/ef514.pdf (accessed on 31 March 2020).

98. Mullens B.A., Lii K.-S., Mao Y., Meyer J.A., Peterson N.G. & Szijj C.E. (2006). – Behavioural responses of dairy cattle to the stable fly, *Stomoxys calcitrans*, in an open field environment. *Med. Vet. Entomol.*, **20** (1), 122–137. https://doi.org/10.1111/j.1365-2915.2006.00608.x.

99. Taylor D.B., Moon R.D. & Mark D.R. (2012). – Economic impact of stable flies (Diptera: Muscidae) on dairy and beef cattle production. *J. Med. Entomol.*, **49** (1), 198–209. https://doi.org/10.1603/ME10050.

100. Cupp E.W., Cupp M.S., Ribeiro J.M.C. & Kunz S.E. (1998). – Blood-feeding strategy of *Haematobia irritans* (Diptera: Muscidae). *J. Med. Entomol.*, **35** (4), 591–595. https://doi.org/10.1093/jmedent/35.4.591.

101. Minár J., Kostenko L.A. & Ríha J. (1987). – Decrease in the milk yield in cows caused by dipterous blood-sucking insects and the protection of heifers with Oxamate, a repellent, in the area of Leningrad [in Czech]. *Vet. Med. (Praha)*, **32** (6), 355–363. Summary available at: https://pubmed.ncbi.nlm.nih.gov/3113032/ (accessed on 28 October 2021).

102. Iannino F., Sulli N., Maitino A., Pascucci I., Pampiglione G. & Salucci S. (2017). – Fleas of dog and cat: species, biology and flea-borne diseases. *Vet. Ital.*, **53** (4), 277–288. https://doi.org/10.12834/VetIt.109.303.3.

103. Barker E.N. (2019). – Update on feline hemoplasmosis. *Vet. Clin. North Am. Small Anim. Pract.*, **49** (4), 733–743. https://doi.org/10.1016/j.cvsm.2019.02.009.

104. Bitam I., Dittmar K., Parola P., Whiting M.F. & Raoult D. (2010). – Fleas and flea-borne diseases. *Int. J. Infect. Dis.*, **14** (8), E667–E676. https://doi.org/10.1016/j.ijid.2009.11.011.

105. Thomas J.E. (2018). – Lice of dogs. Merck Sharp & Dohme Corp., Kenilworth, United States of America. Available at: www.msdvetmanual.com/dog-owners/skin-disorders-of-dogs/lice-of-dogs (accessed on 31 March 2020).

106. Durden L.A. (2002). – Chapter 4: Lice (Phthiraptera). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 1st Ed. Academic Press, San Francisco, United States of America, 45–65. https://doi.org/10.1016/B978-012510451-7/50006-2.

107. Sanchez Londoño A. (2012). – Pediculosis. *In* Clinical Veterinary Advisor: The Horse (D.A. Wilson, ed.), 1st Ed. Elsevier Saunders, St. Louis, United States of America, 430–431. Available at: https://books-library.net/files/download-pdf-ebooks.org-kupd-1276.pdf (accessed on 27 July 2021).

108. Reeves W.K. & Lloyd J.E. (2019). – Chapter 20: Louse flies, keds, and bat flies (Hippoboscoidea). *In* Medical and Veterinary Entomology (G.R. Mullen & L.A. Durden, eds), 3rd Ed. Academic Press, London, United Kingdom, 421–438. https://doi.org/10.1016/B978-0-12-814043-7.00020-0.

109. Berthet-Beaufils A. (2010). – Manifestations dermatologiques associées aux diptères chez le chien et le chat. Doctoral thesis. National Veterinary School of Alfort, Maisons-Alfort, France, 185 pp. Available at: http://theses.vet-alfort.fr/telecharger.php?id=1340 (accessed on 21 April 2021).

110. Abd Rani P.A.M., Coleman G.T., Irwin P.J. & Traub R.J. (2011). – *Hippobosca longipennis*: a potential intermediate host of a species of *Acanthocheilonema* in dogs in northern India. *Parasit. Vectors*, **4**, 143. https://doi.org/10.1186/1756-3305-4-143.

111. Oboňa J., Sychra O., Greš S., Heřman P., Manko P., Roháček J., Šestáková A., Šlapák J. & Hromada M. (2019). – A revised annotated checklist of louse flies (Diptera: Hippoboscidae) from Slovakia. *ZooKeys*, **862**, 129–152. https://doi.org/10.3897/zookeys.862.25992.

112. Zhao L., He B., Li K.-R., Li F., Zhang L.-Y., Li X.-Q. & Liu Y.-H. (2018). – First report of *Anaplasma ovis* in pupal and adult *Melophagus ovinus* (sheep ked) collected in South Xinjiang, China. *Parasit. Vectors*, **11**, 258. https://doi.org/10.1186/s13071-018-2788-6.

113. Bezerra-Santos M.A. & Otranto D. (2020). – Keds, the enigmatic flies and their role as vectors of pathogens. *Acta Trop.*, **209**, 105521. https://doi.org/10.1016/j.actatropica.2020.105521.

114. Gibson W., Pilkington J.G. & Pemberton J.M. (2010). – *Trypanosoma melophagium* from the sheep ked *Melophagus ovinus* on the island of St Kilda. *Parasitology*, **137** (12), 1799–1804. https://doi.org/10.1017/S0031182010000752.

115. European Centre for Disease Prevention and Control (ECDC) (2021). – *Rhipicephalus sanguineus*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/rhipicephalus-sanguineus-current-known-distribution-march-2021 (accessed on 20 April 2021).

116. European Centre for Disease Prevention and Control (ECDC) (2021). – *Hyalomma marginatum*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/hyalomma-marginatum-current-known-distribution-march-2021 (accessed on 20 April 2021).

117. Claerebout E., Losson B., Cochez C., Casaert S., Dalemans A.-C., De Cat A., Madder M., Saegerman C., Heyman P. & Lempereur L. (2013). – Ticks and associated pathogens collected from dogs and cats in Belgium. *Parasit. Vectors*, **6**, 183. https://doi.org/10.1186/1756-3305-6-183.

118. Walker M.D. (2018). – The hedgehog tick, *Ixodes hexagonus* (Leach, 1815) (Acari: Ixodidae): the natural history and ecology of a nest ectoparasite. *Syst. Appl. Acarol.*, **23** (4), 680–714. https://doi.org/10.11158/saa.23.4.9.

119. Boyard C. (2007). – Facteurs environnementaux de variation de l'abondance des tiques *Ixodes ricinus* dans des zones d'étude modèles en Auvergne. Doctoral thesis. Blaise Pascal University, Clermont-Ferrand, France, 233 pp. Available at: https://tel.archives-ouvertes.fr/tel-00930307/document (accessed on 10 August 2021).

120. Gray J., Kahl O. & Zintl A. (2021). – What do we still need to know about *Ixodes ricinus*? *Ticks Tick Borne Dis.*, **12** (3), 101682. https://doi.org/10.1016/j.ttbdis.2021.101682.

121. Rizzoli A., Silaghi C., Obiegala A., Rudolf I., Hubálek Z., Földvári G., Plantard O., Vayssier-Taussat M., Bonnet S., Špitalská E. & Kazimírová M. (2014). – *Ixodes ricinus* and its transmitted pathogens in urban and peri-urban areas in Europe: new hazards and relevance for public health. *Front. Public Health*, **2**, 251. https://doi.org/10.3389/fpubh.2014.00251.

122. Wilhelmsson P., Lindblom P., Fryland L., Nyman D., Jaenson T.G.T., Forsberg P. & Lindgren P.-E. (2013). – *Ixodes ricinus* ticks removed from humans in Northern Europe: seasonal pattern of infestation, attachment sites and duration of feedings. *Parasit. Vectors*, **6**, 362. https://doi.org/10.1186/1756-3305-6-362.

123. Horobik V., Keesing F. & Ostfeld R.S. (2006). – Abundance and *Borrelia burgdorferi*-infection prevalence of nymphal *Ixodes scapularis* ticks along forest–field edges. *EcoHealth*, **3**, 262–268. https://doi.org/10.1007/s10393-006-0065-1.

124. Dziemian S., Sikora B., Piłacińska B., Michalik J. & Zwolak R. (2015). – Ectoparasite loads in sympatric urban populations of the northern white-breasted and the European hedgehog. *Parasitol. Res.*, **114**, 2317–2323. https://doi.org/10.1007/s00436-015-4427-x.

125. Lernout T., De Regge N., Tersago K., Fonville M., Suin V. & Sprong H. (2019). – Prevalence of pathogens in ticks collected from humans through citizen science in Belgium. *Parasit. Vectors*, **12**, 550. https://doi.org/10.1186/s13071-019-3806-z.

126. Pfäffle M., Petney T., Skuballa J. & Taraschewski H. (2011). – Comparative population dynamics of a generalist (*Ixodes ricinus*) and specialist tick (*I. hexagonus*) species from European hedgehogs. *Exp. Appl. Acarol.*, **54** (2), 151–164. https://doi.org/10.1007/s10493-011-9432-x.

127. Boulanger N., Boyer P., Talagrand-Reboul E. & Hansmann Y. (2019). – Ticks and tick-borne diseases. *Med. Mal. Infect.*, **49** (2), 87–97. https://doi.org/10.1016/j.medmal.2019.01.007.

128. Rothschild C.M. (2013). – Equine piroplasmosis. *J. Equine Vet. Sci.*, **33** (7), 497–508. https://doi.org/10.1016/j.jevs.2013.03.189.

129. Telford S.R. & Goethert H.K. (2011). – Toward an understanding of the perpetuation of the agent of tularemia. *Front. Microbiol.*, **1**, 150. https://doi.org/10.3389/fmicb.2010.00150.

130. Garcia-Vozmediano A., Krawczyk A.I., Sprong H., Rossi L., Ramassa E. & Tomassone L. (2020). – Ticks climb the mountains: Ixodid tick infestation and infection by tickborne pathogens in the Western Alps. *Ticks Tick Borne Dis.*, **11** (5), 101489. https://doi.org/10.1016/j.ttbdis.2020.101489.

131. Buczek W., Koman-Iżko A., Buczek A.M., Buczek A., Bartosik K., Kulina D. & Ciura D. (2020). – Spotted fever group rickettsiae transmitted by *Dermacentor* ticks and determinants of their spread in Europe. *Ann. Agric. Environ. Med.*, **27** (4), 505–511. https://doi.org/10.26444/aaem/120602.

132. Saari S., Näreaho A. & Nikander S. (2019). – Chapter 9: Arachnida. *In* Canine Parasites and Parasitic Diseases. 1st Ed. Academic Press, London, United Kingdom, 187–228. https://doi.org/10.1016/B978-0-12-814112-0.00009-X.

133. Little S.E., Hostetler J. & Kocan K.M. (2007). – Movement of *Rhipicephalus sanguineus* adults between co-housed dogs during active feeding. *Vet. Parasitol.*, **150** (1–2), 139–145. https://doi.org/10.1016/j.vetpar.2007.08.029.

134. Uspensky I. (2014). – Tick pests and vectors (Acari: Ixodoidea) in European towns: introduction, persistence and management. *Ticks Tick Borne Dis.*, **5** (1), 41–47. https://doi.org/10.1016/j.ttbdis.2013.07.011.

135. Baneth G., Samish M. & Shkap V. (2007). – Life cycle of *Hepatozoon canis* (Apicomplexa: Adeleorina: Hepatozoidae) in the tick *Rhipicephalus sanguineus* and domestic dogs (*Canis familiaris*). *J. Parasitol.*, **93** (2), 283–299. https://doi.org/10.1645/GE-494R.1.

136. Valcárcel F., González J., González M.G., Sánchez M., Tercero J.M., Elhachimi L., Carbonell J.D. & Olmeda A.S. (2020). – Comparative ecology of *Hyalomma lusitanicum* and *Hyalomma marginatum* Koch, 1844 (Acarina: Ixodidae). *Insects*, **11** (5), 303. https://doi.org/10.3390/insects11050303.

137. Jameson L.J., Morgan P.J., Medlock J.M., Watola G. & Vaux A.G.C. (2012). – Importation of *Hyalomma marginatum*, vector of Crimean-Congo haemorrhagic fever virus, into the United Kingdom by migratory birds. *Ticks Tick Borne Dis.*, **3** (2), 95–99. https://doi.org/10.1016/j.ttbdis.2011.12.002.

138. Stachurski F. & Vial L. (2018). – Installation de la tique *Hyalomma marginatum*, vectrice du virus de la fièvre hémorragique de Crimée-Congo, en France continentale. *Bull. Épidémiol. Santé Anim. Alim.*, **84** (8), 8. Available at: https://be.anses.fr/sites/default/files/O-005_2018-07-23_Hyalomna-Stachurski_VF.pdf (accessed on 20 April 2021).

139. Estrada-Peña A., Palomar A.M., Santibáñez P., Sánchez N., Habela M.A., Portillo A., Romero L. & Oteo J.A. (2012). – Crimean-Congo hemorrhagic fever virus in ticks, Southwestern Europe, 2010. *Emerg. Infect. Dis.*, **18** (1), 179–180. https://doi.org/10.3201/eid1801.111040.

140. Bakheit M.A., Latif A.A., Vatansever Z., Seitzer U. & Ahmed J. (2012). – Chapter 8. The huge risks due to *Hyalomma* ticks. *In* Arthropods as Vectors of Emerging Diseases (H. Mehlhorn, ed.). Springer-Verlag, Berlin, Germany, 167–194. https://doi.org/10.1007/978-3-642-28842-5.

141. European Centre for Disease Prevention and Control (ECDC) (2021). – *Hyalomma lusitanicum*: current known distribution: March 2021. ECDC, Stockholm, Sweden. Available at: www.ecdc.europa.eu/en/publications-data/hyalomma-lusitanicum-current-known-distribution-march-2021 (accessed on 20 April 2021).