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Review

The Expanding Threat of Crimean-Congo Haemorrhagic Fever Virus: Role of Migratory Birds and Climate Change as Drivers of *Hyalomma* spp. Dispersal in Europe

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Simple Summary: The Crimean-Congo Haemorrhagic Fever Virus (CCHFV) is a deadly pathogen transmitted primarily by *Hyalomma* spp. ticks, which are expanding their range in Europe. Migratory birds play a key role in transporting immature ticks over long distances. Moreover, climate change is making new areas suitable for these ticks, increasing the risk of infection and disease spread. This review highlights how bird migration and climate change determine the spread of *Hyalomma* spp. and CCHFV in Europe.

Abstract: The Crimean-Congo Haemorrhagic Fever Virus (CCHFV) is an emerging zoonotic pathogen with a high case fatality risk. Its primary vectors, *Hyalomma* spp. ticks, are expanding their geographic range, raising concerns about the increasing risk of Crimean-Congo Haemorrhagic Fever (CCHF) outbreaks in Europe. Migratory birds contribute considerably to the spread of *Hyalomma* ticks, transporting immature forms over long distances during spring migrations. Additionally, climate change plays a crucial role in this expansion by creating favorable conditions for *Hyalomma* spp. survival and dispersal. This review explores the interplay between *Hyalomma* spp. ecology as vectors of CCHFV, the role of migratory birds and the impact of climate change on the dispersal of CCHFV across Europe. Understanding these dynamics is essential for assessing future risks, improving surveillance strategies, and implementing effective public health interventions

Keywords: crimean-congo haemorrhagic fever; crimean-congo haemorrhagic fever virus; *Hyalomma* spp.; migratory birds; public health; zoonosis; Climate change

1. Introduction

The Crimean-Congo Haemorrhagic Fever Virus (CCHFV) is an emerging zoonotic pathogen. Crimean-Congo Haemorrhagic Fever (CCHF) is an expanding public health concern, classified as a priority disease by the World Health Organisation (WHO) since the disease is associated with high case fatality risk and the absence of effective vaccines and a specific treatment [1–3]. Historically concentrated in Africa, Asia, and parts of Eastern and Southern Europe [4], CCHFV has been

progressively expanding into new areas, raising awareness about potential establishment in previously unaffected regions of Europe [5–8].

Humans may be exposed to CCHFV either through tick bites or by direct contact with infected animal tissues and fluids [9]. Livestock handlers, slaughterhouse workers, and agricultural and healthcare workers are at higher risk of CCHFV infection [10].

Although infection is usually asymptomatic and may circulate unnoticed in wild and domestic animals, the case fatality risk may range from 5% to 40% in humans, with the possibility of reaching 80% in some nosocomial settings [2,11,12]. The incubation period lasts from 2 to 14 days, varying depending on the mode of viral transmission and load, with the possibility of lasting between 2 and 7 days after tick-bite and 10 to 14 days if the infection occurs by blood transfusion [13]. Symptoms and clinical signs include, among other, high fever, nausea, vomiting, headache, diarrhoea, myalgia, hypotension, haemorrhage (petechiae, ecchymoses, epistaxis, hematuria, melena) and, ultimately, multiorgan failure [2,11]. As previously mentioned, no vaccine or specific effective antiviral treatment is available [1]. As a tick-borne disease, with *Hyalomma* spp. as main vectors, its distribution is closely linked to the ecology and dispersal of the latter. Ground-feeding migratory birds play an essential role in the dispersal and importation of *Hyalomma* spp. ticks, especially *Hyalomma marginatum* complex, into Europe during their migration season [12]. This phenomenon facilitates the introduction of *Hyalomma* spp. into new environments, potentially accelerating the spread of CCHFV in Europe [14]. Moreover, it is expected that climatic factors, such as temperature and precipitation, may be helpful predictors of CCHF once climatic variability influences the distribution of ticks [10,15].

This review investigates the expansion of CCHF in Europe, highlighting the role of *Hyalomma* spp. as vectors of CCHFV and the contribution of migratory birds to their introduction and dispersal across the continent. It also provides a descriptive inventory of bird species previously reported as hosts of *Hyalomma* spp. in Europe and explores the role of climate change in the dispersal of *Hyalomma* ticks in this region.

2. Materials and Methods

A rapid literature search was conducted from January to March 2025 across the PubMed, Google Scholar, CAB Abstracts, and ScienceDirect databases.

The inclusion of articles was limited to those published in peer-reviewed/academic journals or conference proceedings, written in English or Spanish, and that addressed the following topics: (1) the occurrence of CCHFV and CCHF in Europe; (2) the life cycle and ecology of *Hyalomma* ticks as vectors of CCHFV in Europe; (3) the occurrence of *Hyalomma* spp. and CCHFV-positive *Hyalomma* ticks in migratory birds in Europe over the last 17 years (studies with data collection starting in 2008); and (4) the impact of climate change on the expansion of *Hyalomma* spp. in Europe were included. Additionally, studies describing migratory patterns of bird species known to host *Hyalomma* spp., as identified in the selected literature, were included.

Search keywords included, among other variations, “Crimean-Congo Haemorrhagic Fever Virus” OR “CCHFV” OR “CCHF”; “Crimean-Congo Haemorrhagic Fever Virus” OR “CCHFV” AND “Europe”; “Hyalomma” AND “Europe”; “Migratory birds” AND “CCHFV” AND “Hyalomma”; “Crimean-Congo Haemorrhagic Fever Virus” AND “Hyalomma”; “Climate change” AND “Hyalomma” OR “CCHFV” were considered as search terms. The removal of duplicates across journals and databases was then carried out.

A total of 290 articles were initially selected based on their titles and abstracts. After full-text screening, 18 studies assessing the occurrence of *Hyalomma* species in migratory birds and the detection of CCHFV-positive ticks on these hosts in Europe were retained. All these studies were published after 2012 and covered sampling periods ranging from 2008 to 2022. In this selection, studies were excluded if they were not conducted in Europe, lacked a clear distinction of European findings, or failed to specify the bird species reported to be infested with *Hyalomma*.

Furthermore, noting that some articles were selected simultaneously to discuss different topics, 25 articles were included to provide an overview of the migratory patterns of bird species reported to have been infested by *Hyalomma* spp. in Europe, and 16 articles were included to discuss the impact of climate change on *Hyalomma* spp. expansion; 14 articles were included to examine the occurrence of CCHFV and CCHF in Europe; 13 articles were included to discuss the role of *Hyalomma* spp. as vectors of CCHFV and the occurrence of *Hyalomma* species in Europe; and 7 articles were included to provide an introduction to the theme regarding the role of migratory birds in the dispersal of *Hyalomma* spp. in Europe. Complementary data from the European Centre for Disease Prevention and Control (ECDC) and BirdLife Datazone were also consulted.

3. Crimean-Congo Haemorrhagic Fever Virus (CCHFV) and its evidence in Europe

The CCHFV belongs to the genus *Orthonairovirus* of the family *Nairoviridae* and order *Bunyavirales* [1,2]. The emergence of CCHF in new non-endemic regions is primarily attributed to international animal trade, human travel, the transportation of infected ticks by migratory birds, and climate change [16].

Hyalomma spp. ticks are the primary vectors of CCHFV, and their distribution correlates with the global distribution of CCHF [11]. Although evidence for active CCHFV transmission by non-*Hyalomma* ticks is limited, the virus has also been detected in non-*Hyalomma* ticks of the genera *Amblyomma*, *Boophilus*, *Dermacentor*, *Haemaphysalis*, and *Rhipicephalus*. However, their role in natural transmission cycles or in maintaining CCHFV foci remains uncertain [17].

According to the model developed by Okely et al. [18], CCHFV exhibited high environmental suitability across Southern and Central Europe, namely in Western Mediterranean countries.

Currently, CCHF is considered endemic in Southwestern Europe [3]. Since 2013, human cases have been detected in Bulgaria (n = 41 cases), Spain (n = 17 cases), Greece (n = 1 case), Portugal (n = 1 case), and the United Kingdom (n = 1 case) [19] (Figure 1). From these cases, seven and six deaths were registered in Bulgaria and Spain, respectively [19]. In Portugal, the only reported death since 2013 associated with CCHF occurred in 2024 [20]. Moreover, CCHF is endemic in Turkey, particularly in the Central Anatolian region [11].

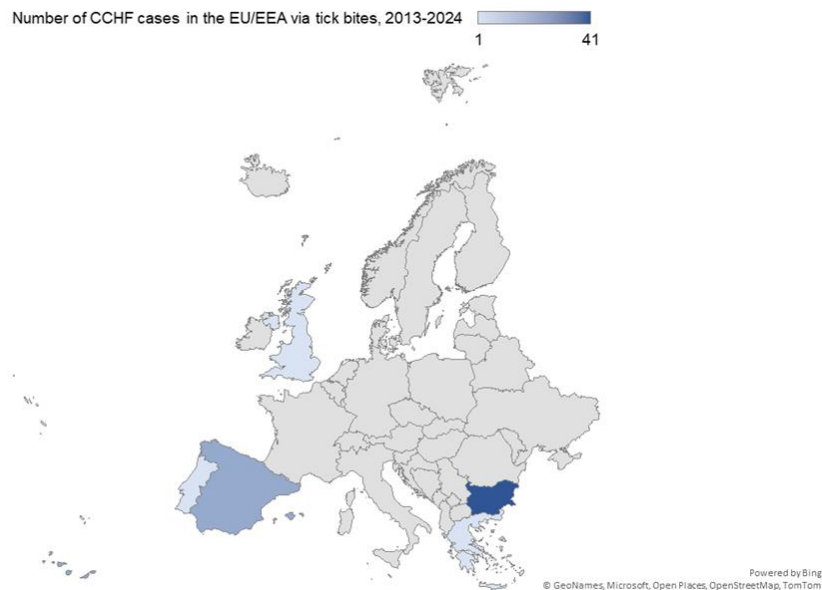


Figure 1. Distribution of Crimean-Congo Haemorrhagic Fever (CCHF) cases in the EU/EEA in years 2013-2024. Adapted from ECDC, 2024 (<https://www.ecdc.europa.eu/en/crimean-congo-haemorrhagic-fever/surveillance/cases-eu-since-2013>, last updated on 24 August 2024).

Good indicators of CCHFV occurrence in specific areas comprise the status of antibodies to CCHFV in the animal populations of the corresponding region [21]. For instance, sheep seroconvert to CCHFV and are considered suitable sentinels for monitoring the virus and its circulation in new non-endemic regions [22]. Additionally, antibodies against CCHFV have been detected in several wild and domestic animals, such as cattle, swine, horses, donkeys, lagomorphs, and rodents [22]. Moreover, to assess the risk of exposure to CCHFV in the Iberian Peninsula, the seroprevalence of CCHFV has already been studied in populations of red deer (*Cervus elaphus*), wild boar (*Sus scrofa*), and roe deer (*Capreolus capreolus*) [1,23,24]. Furthermore, unlike most avian species, magpies (*Pica pica*) and ostriches (*Struthio camelus*) display CCHFV antibodies [9].

Given that the distribution of CCHFV closely follows that of its primary vector, *Hyalomma* spp., understanding their ecology, dispersal patterns, and role in viral transmission is essential for assessing the risk of CCHF expansion in Europe.

4. *Hyalomma* ticks in Europe

The genus *Hyalomma* comprises more than 20 species [7]. The natural distribution of *Hyalomma* species is confined to the continents of Asia, Africa, and Europe [25]. The distribution of *Hyalomma* spp. has been expanding since the first recorded evidence of *Hyalomma marginatum* into Europe in the late 20th century [26].

The majority of *Hyalomma* spp. have a three-host cycle, with the exception of *H. marginatum* complex, which are diphasic, with the larvae and nymph taking their meals on the same host [26,27]. *Hyalomma marginatum sensu lato* (s.l.) includes, among other species, *Hyalomma marginatum sensu stricto* (s.s.) and *Hyalomma rufipes* [14].

Hyalomma ticks can become infected by CCHFV when feeding on an infected host (Figure 2). Immature ticks prefer to feed on rodentia, lagomorpha, and aves, while adults infest large ungulates, with a lower yet notable preference for lagomorpha and suidae [28].

Regarding the mechanism of CCHFV infection of *Hyalomma marginatum*, initial viral replication occurs in the intestinal epithelium following ingestion, with subsequent dissemination to other tissues. The highest viral loads are typically observed in the reproductive organs and salivary glands [29]. Following replication and dissemination, the virus can be transmitted both vertically and horizontally, including via co-feeding [29]. Co-feeding transmission occurs when infected ticks introduce the virus into the host's skin or bloodstream during feeding, enabling non-infected ticks feeding in close proximity on the same host to acquire the virus, thereby increasing the overall probability of transmission [28,29]. Given that small mammals tend to develop prolonged viremia, the feeding preference of *Hyalomma* spp. for these hosts may result in high tick burdens on key reservoir species, facilitating sustained viral circulation [28].

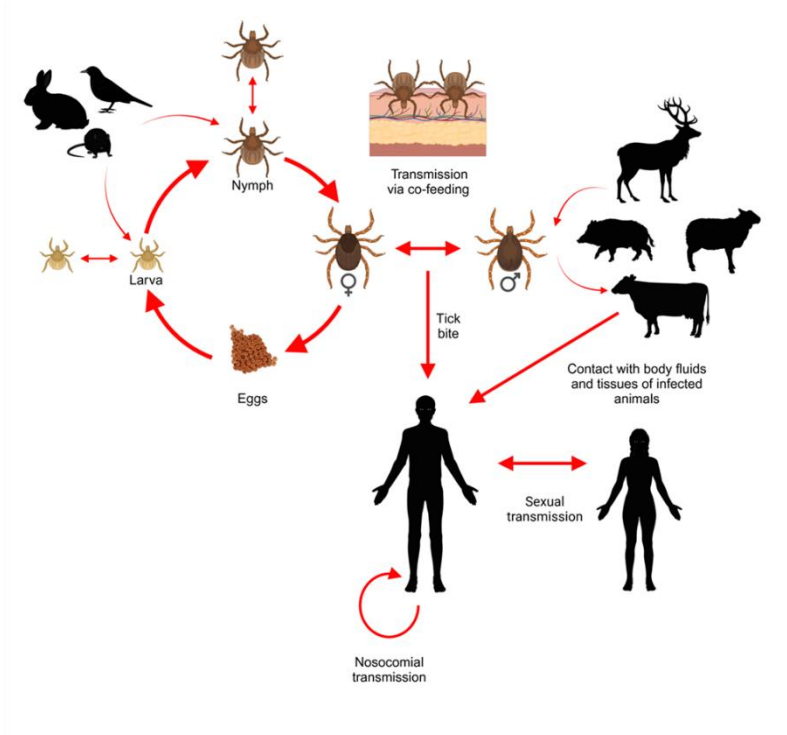


Figure 2. Routes of CCHFV transmission between *Hyalomma* spp. ticks, small vertebrates, ungulates and humans. Created in BioRender®.

Hyalomma marginatum s.s. may pose a natural reservoir of CCHFV once ticks carry the virus throughout the life stages [29]. *Hyalomma marginatum* is primarily distributed in Southern Europe, Northern Africa and parts of Asia [30]. In Europe, *H. marginatum* is endemic in the Mediterranean regions and Balkan countries, where established populations are present. However, it is also occasionally found in Central Europe [14]. Besides CCHFV, *H. marginatum* can transmit diverse tick-borne pathogens, such as spotted fever rickettsiae to humans [14], *Anaplasma* spp. [31] and *Theileria annulata* to cattle, and *Babesia caballi* and *Theileria equi* to horses [14].

Immature *H. marginatum* ticks feed on the same host, such as hares, hedgehogs, rodents, and ground-resident birds, in contrast with adult forms, which prefer large hosts like cattle, horses, and, sometimes, humans [14,32].

Hyalomma marginatum is commonly found in passerine migratory birds. Jameson et al. [33] reported that up to 21% of birds migrating from Africa to the United Kingdom were infested with *H. marginatum* nymphs. Consequently, it is predicted that every year a high number of immature ticks are passively transported by migrating birds from Africa and Southern Europe into or over Central Europe [34].

Hyalomma rufipes is also one of the vectors of CCHFV [26]. In April 2020, Rudolf et al. [35] obtained one live specimen of an adult *Hyalomma rufipes* tick in the Czech Republic that might have moulted during the autumn-spring period and overwintered in an adult stage, a circumstance which can support the assumption of a future establishment of *Hyalomma* spp. ticks in Central Europe.

Along with *H. marginatum*, *Hyalomma lusitanicum* is endemic in the Iberian Peninsula [36]. *Hyalomma lusitanicum* is a vector of CCHFV, but it is also suspected to transmit *Theileria equi*, *T. annulata*, *Babesia pecorum*, *Anaplasma phagocytophilum*, *Borrelia burgdorferi*, *B. lusitaniae*, and *Coxiella burnetii*, although these species remain poorly understood in terms of their vectorial ability for these pathogens [26]. The detection of CCHFV genetic material in adult *H. lusitanicum* ticks collected from red deer in Spain may suggest the possibility of the virus circulating in this country [5].

5. The Role of Migratory Birds in the Dispersal of Hyalomma spp. in Europe

Migratory birds play a key role in the passive transport of *Hyalomma* spp. from Africa and Southern Europe to the northern breeding areas, as millions of birds migrate between these continents, breeding in the northern hemisphere during summer and returning to warmer regions of Africa in autumn to the wintering locations, thus contributing to intercontinental dispersal of several pathogens and vectors [9,37,38]. The role of migratory birds in the spread of tick-borne pathogens, including CCHFV, has been studied and highlighted [39,40]. In stopover sites, engorged ticks can detach from their bird host and, under favourable conditions, colonise new habitats [39].

Immature *Hyalomma* ticks can remain attached to the primary host for up to 26 days, enabling migratory birds to transport ticks over long distances [22,32,40].

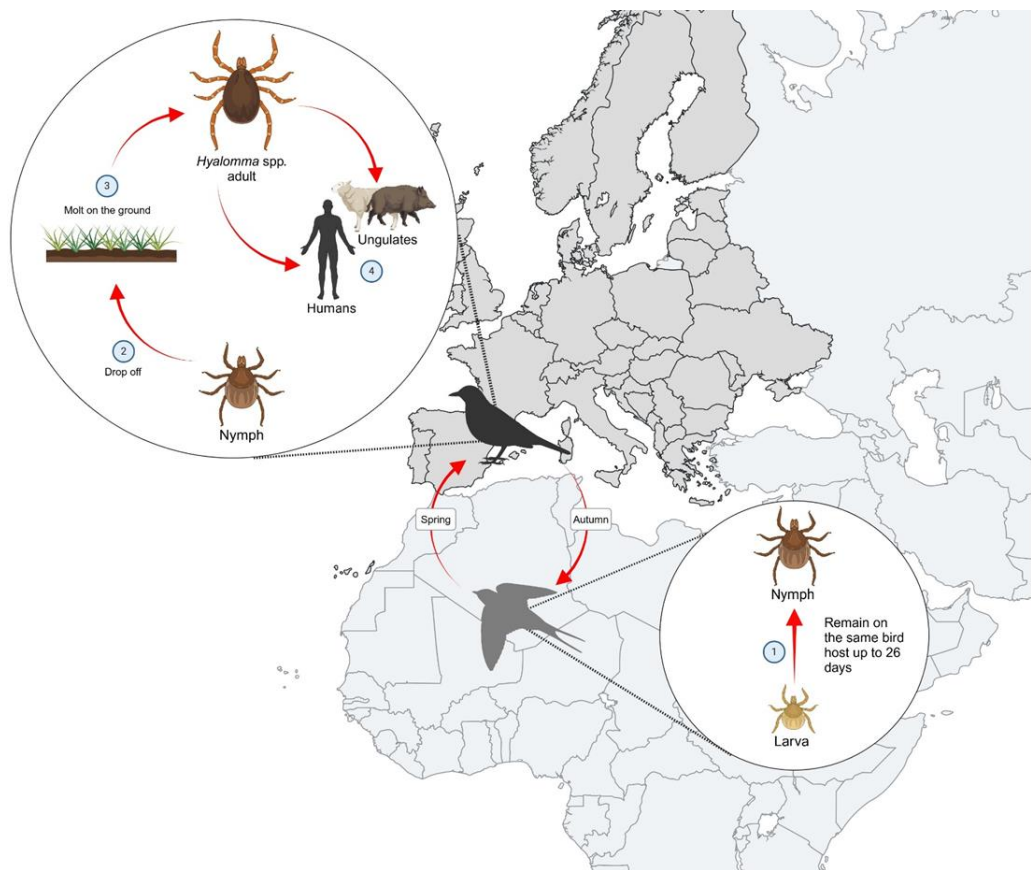


Figure 3. Life cycle of *Hyalomma* ticks in migratory birds and their role in tick dispersal to Europe. Created in BioRender®.

Viremia does not develop in most passerine birds [40]. Understanding the contribution of migratory birds in the dispersal of pathogens plays a crucial part in assessing the risk of spread and introducing emerging diseases and pathogens [40]. Findings of ticks belonging to *Hyalomma* spp., *H. marginatum*, and *H. rufipes*, from migratory birds in the last seventeen years, are shown in Tables 1, 2, and 3.

Table 1. Detection of ticks of *Hyalomma* spp. on migratory birds since 2008, according to host species.

Ticks	Bird species	Country or region	References
<i>Hyalomma</i> spp.	Great reed-warbler (<i>Acrocephalus arundinaceus</i>)	Italy, Turkey	[22,41]
	Sedge warbler (<i>Acrocephalus schoenobaenus</i>)	Italy, United Kingdom, Hungary, Spain	[22,33,40,42,43]
	Common reed-warbler (<i>Acrocephalus scirpaceus</i>)	Italy, Netherlands	[40,44];
	Tree pipit (<i>Anthus trivialis</i>)	African-Western Palaearctic region, Italy	[5,22,40,45,46]
	Eurasian buzzard (<i>Buteo buteo</i>)	Italy	[45]
	European nightjar (<i>Caprimulgus europaeus</i>)	Italy	[40]
	European goldfinch (<i>Carduelis carduelis</i>)	Italy	[40]
	Common cuckoo (<i>Cuculus canoru</i>)	Italy	[22]
	Subalpine Warbler (<i>Curruca cantillans</i>)	Italy	[22,46]
	Common whitethroat (<i>Curruca communis</i>)	Italy, United Kingdom, Hungary, Spain	[22,33,40,42,43,45,46]
	European robin (<i>Erithacus rubecula</i>)	Italy	[40]
	Collared flycatcher (<i>Ficedula albicollis</i>)	Italy	[40]
	European opied flycatcher (<i>Ficedula hypoleuca</i>)	Italy, Hungary	[22,40,42,45,46]
	Icterine warbler (<i>Hippolais icterina</i>)	Italy	[22,40,46]
	Melodious warbler (<i>Hippolais polyglotta</i>)	Italy	[45]
	Barn swallow (<i>Hirundo rustica</i>)	Italy	[46]
	Western olivaceous warbler (<i>Iduna opaca</i>)	Spain	[43,47]
	Red-backed shrike (<i>Lanius collurio</i>)	Turkey	[41]
	Woodchat shrike (<i>Lanius senator</i>)	Italy	[22,40,45]
	Thrush nightingale (<i>Luscinia luscinia</i>)	Turkey	[41]
	Common nightingale (<i>Luscinia megarhynchos</i>)	Italy	[22,40,45]

Western yellow wagtail (<i>Motacilla flava</i>)	Italy	[22,40,45]
Spotted flycatcher (<i>Muscicapa striata</i>)	Italy	[22,40,45]
Black-eared wheatear (<i>Oenanthe hispanica</i>)	Italy	[22,40,45]
Northern wheatear (<i>Oenanthe oenanthe</i>)	Italy, United Kingdom	[22,33,40,46]
Eurasian golden oriole (<i>Oriolus oriolus</i>)	Italy	[22,40]
Eurasian scops-owl (<i>Otus scops</i>)	Italy	[22,40]
Great tit (<i>Parus major</i>)	Italy	[40]
European honey-buzzard (<i>Pernis apivorus</i>)	Italy	[45]
Common redstart (<i>Phoenicurus phoenicurus</i>)	Italy, United Kingdom, Turkey	[22,33,40,41,45,46]
Black redstart (<i>Phoenicurus ochruros</i>)	Italy	[46]
Common chiffchaff (<i>Phylloscopus collybita</i>)	Italy	[40]
Wood warbler (<i>Phylloscopus sibilatrix</i>)	Italy	[22,40,46,48]
Willow warbler (<i>Phylloscopus trochilus</i>)	Italy, Spain	[22,40,43,45,46]
Dunnock (<i>Prunella modularis</i>)	Italy	[46]
Whinchat (<i>Saxicola rubetra</i>)	African-Western Palaearctic region, Italy	[5,22,40,45,46]
Eurasian blackcap (<i>Sylvia atricapilla</i>)	Italy	[45]
Garden warbler (<i>Sylvia borin</i>)	Italy, Netherlands	[22,40,49]
Eurasian blackbird (<i>Turdus merula</i>)	Italy	[45]
Song thrush (<i>Turdus philomelos</i>)	Italy	[40,46]
Common hoopoe (<i>Upupa epops</i>)	Italy	[22,40]

Table 2. Detection of ticks of *Hyalomma marginatum*, on migratory birds since 2008, according to species.

Ticks	Bird species	Regions	References
<i>Hyalomma marginatum</i>	Great reed-warbler (<i>Acrocephalus arundinaceus</i>)	Greece, Slovakia, Czech Republic, Spain	[27,32,50]
	Marsh Warbler (<i>Acrocephalus palustris</i>)	Czech Republic	[32]
	Sedge warbler (<i>Acrocephalus schoenobaenus</i>)	Greece, Slovakia, Malta	[27,32,51]
	Common reed-warbler (<i>Acrocephalus scirpaceus</i>)	Slovakia, Czech Republic, Spain	[32,50]
	Long-tailed tit (<i>Aegithalos caudatus</i>)	Spain	[50]
	Common kingfisher (<i>Alcedo atthis</i>)	Malta	[51]
	Eurasian buzzard (<i>Buteo buteo</i>)	Spain	[50]
	European goldfinch (<i>Carduelis carduelis</i>)	Italy	[40]
	Citrl finch (<i>Carduelis citrinella</i>)	Spain	[50]
	Kentish plover (<i>Charadrius alexandrinus</i>)	African-Western Palaearctic region	[5]
	European Greenfinch (<i>Chloris chloris</i>)	Spain	[50]
	Common whitethroat (<i>Curruca communis</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,51]
	Eurasian blue tit (<i>Cyanistes caeruleus</i>)	Spain	[50]
	Rock bunting (<i>Emberiza cia</i>)	Spain	[50]
	Ortolan bunting (<i>Emberiza hortulana</i>)	Spain	[50]
	European robin (<i>Erithacus rubecula</i>)	African-Western Palaearctic region, Italy, France	[5,40,52]
	Common kestrel (<i>Falco tinnunculus</i>)	Spain, Malta	[50,51]
	European pied flycatcher (<i>Ficedula hypoleuca</i>)	Spain	[50]
	Common chaffinch (<i>Fringilla coelebs</i>)	Spain	[50]
	Icterine warbler (<i>Hippolais icterina</i>)	Italy	[40]
	Woodchat shrike (<i>Lanius senator</i>)	African-Western Palaearctic region	[5]
	Common linnet (<i>Linaria cannabina</i>)	Spain	[50]
	Savi’s warbler (<i>Locustella luscinioides</i>)	Slovakia	[32]
	Woodlark (<i>Lullula arborea</i>)	Spain	[50]
	Common nightingale (<i>Luscinia megarhynchos</i>)	African-Western Palaearctic region, Czech Republic, Italy, Spain,	[5,32,40,50]
	Spotted flycatcher (<i>Muscicapa striata</i>)	Italy	[40]
	Northern wheatear (<i>Oenanthe oenanthe</i>)	African-Western Palaearctic region	[5]

Eurasian golden oriole (<i>Oriolus oriolus</i>)	Greece, Italy, Spain	[27,40,50]
Eurasian scops-owl (<i>Otus scops</i>)	Italy	[40]
Great tit (<i>Parus major</i>)	Spain	[50]
House sparrow (<i>Passer domesticus</i>)	Spain	[50]
Rock sparrow (<i>Petronia petronia</i>)	Spain	[50]
Black redstart (<i>Phoenicurus ochruros</i>)	Spain	[50]
Common redstart (<i>Phoenicurus phoenicurus</i>)	African-Western Palaearctic region, Greece, Italy	[5,27,40]
Wood warbler (<i>Phylloscopus sibilatrix</i>)	Italy	[40]
Willow warbler (<i>Phylloscopus trochilus</i>)	Malta	[51]
Dunnock (<i>Prunella modularis</i>)	Italy, France	[40,52]
Eurasian siskin (<i>Spinus spinus</i>)	Greece	[27]
Eurasian blackbird (<i>Turdus merula</i>)	Spain	[50]
Song thrush (<i>Turdus philomelos</i>)	Greece, Italy	[27,40]

Table 3. Detection of ticks of *Hyalomma rufipes*, on migratory birds since the year 2008, according to species.

Ticks	Bird species	Regions	References
<i>Hyalomma rufipes</i>	Great reed-warbler (<i>Acrocephalus arundinaceus</i>)	Italy, Malta	[40,51];
	Sedge warbler (<i>Acrocephalus schoenobaenus</i>)	African-Western Palaearctic region, Greece, Italy, Malta	[5,27,40,51]
	Common reed-warbler (<i>Acrocephalus scirpaceus</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,51]
	Tree pipit (<i>Anthus trivialis</i>)	African-Western Palaearctic region, Italy	[5,40]
	European Nightjar (<i>Caprimulgus europaeus</i>)	African-Western Palaearctic region, Italy	[5,40]
	Subalpine Warbler (<i>Curruca cantillans</i>)	Italy	[40]
	Common whitethroat (<i>Curruca communis</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,46,51]
	Western subalpine warbler (<i>Curruca iberiae</i>)	Malta	[51]
	European robin (<i>Erithacus rubecula</i>)	Italy	[46]
	Collared flycatcher (<i>Ficedula albicollis</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,46,51]
	European pied flycatcher (<i>Ficedula hypoleuca</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,51]

Icterine warbler (<i>Hippolais icterina</i>)	African-Western Palaearctic region, Italy	[5,40]
Barn swallow (<i>Hirundo rustica</i>)	Italy, Malta	[40,51]
Woodchat shrike (<i>Lanius senator</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,48,51]
Common nightingale (<i>Luscinia megarhynchos</i>)	African-Western Palaearctic region, Italy	[5,40]
Rufous-tailed rock-thrush (<i>Monticola saxatilis</i>)	African-Western Palaearctic region	[5]
Western yellow wagtail (<i>Motacilla flava</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,51]
Spotted flycatcher (<i>Muscicapa striata</i>)	African-Western Palaearctic region, Italy	[5,40,46]
Black-eared wheatear (<i>Oenanthe hispanica</i>)	Italy	[40]
Northern wheatear (<i>Oenanthe oenanthe</i>)	African-Western Palaearctic region, Italy	[5,40,46]
Eurasian golden oriole (<i>Oriolus oriolus</i>)	African-Western Palaearctic region, Italy	[5,40]
Black redstart (<i>Phoenicurus ochruros</i>)	Italy	[40,46]
Common redstart (<i>Phoenicurus phoenicurus</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,46,48,51]
Wood warbler (<i>Phylloscopus sibilatrix</i>)	African-Western Palaearctic region, Italy, Malta	[5,40,46,51]
Willow warbler (<i>Phylloscopus trochilus</i>)	Italy, Malta	[40,51]
Whinchat (<i>Saxicola rubetra</i>)	African-Western Palaearctic region, Italy	[5,40,46,48]
European turtle-dove (<i>Streptopelia turtur</i>)	African-Western Palaearctic region	[5]
Eurasian blackcap (<i>Sylvia atricapilla</i>)	African-Western Palaearctic region, France	[5,52]
Garden warbler (<i>Sylvia borin</i>)	African-Western Palaearctic region, Italy	[5,40]
Song thrush (<i>Turdus philomelos</i>)	Italy	[40,46]
Common hoopoe (<i>Upupa epops</i>)	African-Western Palaearctic region	[5,51]

5.1. *Acrocephalus* spp.

The great reed warbler (*Acrocephalus arundinaceus*), the Sedge Warbler (*Acrocephalus schoenobaenus*), and the common reed warbler (*Acrocephalus scirpaceus*) are migratory birds that prefer wet habitats, travelling between their European breeding grounds and African wintering quarters [53].

The great reed warbler inhabits reed vegetation habitats with water in Europe and Western Palearctic, preferring canals, ponds, shallow lakes and fish ponds [54]. Individuals of the great reed warbler were previously reported as carriers of *Hyalomma* spp. ticks in Turkey (n = 6 ticks in 3 birds) [41] and in Italy (n = 1 tick in a bird) [22]. More specifically, *H. marginatum* was recovered from a great reed warbler in Czech Republic (n = 8 ticks) [32], in Spain (n = 7 ticks) [50], in Greece (n = 1 tick) [27], and in Slovakia (n = 1 tick) [32]. More recently, 14 *H. rufipes* ticks were sampled from two great reed warblers in Malta [51] and in Italy (n = 3 ticks) [40]. Furthermore, a Turkish study already reported a CCHFV-positive *Hyalomma* spp. nymph collected from a great reed warbler [41].

The sedge warbler (*Acrocephalus schoenobaenus*) is found in diverse types of low, dense vegetation, often near to water or moist depressions and in Western Europe, its egg-laying mainly begins in late April, while in Central Europe it starts from early May [55]. Nonspecific species of *Hyalomma* spp. ticks were previously recovered from sedge warblers in Italy by Mancuso et al. [40] (n = 20 ticks) and by De Liberato et al. [22] (n = 7 ticks), in Spain (n = 5 ticks) [43], in Hungary (n = 3 infested birds) [42], and in the United Kingdom (n = 1 tick in a bird) [33]. In contrast, *H. marginatum* have been reported in sedge warblers in Slovakia (n = 10 ticks in 7 birds) [32], in Malta (n = 2 ticks in a bird) [51], and in Greece (n = 1 tick in a bird) [27]. Individuals of sedge warbler were also found to be infested by *H. rufipes* in the African-Western Palearctic region (n = 53 ticks) [5], in Malta (n = 12 ticks in 6 birds) [51], in Italy (n = 2 ticks) [40], and in Greece (n = 1 tick) [27]. In a Maltese study, the infestation of *Hyalomma* spp. was detected in three sedge warblers (n = 4 ticks), but it was not possible to determine whether the tick species was *H. marginatum* or *H. rufipes* [51].

The Eurasian reed warbler (*Acrocephalus scirpaceus*) is a trans Saharan migratory species that breeds from May until August or September in Central and Western Europe, and winters in Africa, primarily in tropical Africa [56,57]. Previous monitoring suggests that their migratory behaviour may be changing, and some birds now remain on the Iberian Peninsula over winter instead of crossing the Sahara [58].

Fourteen ticks of *Hyalomma* spp. were previously sampled from an Eurasian reed warbler in the Netherlands [44]. Also, in Italy, *Hyalomma* spp. (n = 2 ticks) were collected from an individual of this species [40]. *H. marginatum* ticks were found to be infesting Eurasian reed warblers in Spain (n = 10 ticks in 5 birds) [50], in Slovakia (n = 3 ticks in 2 birds) [32], and in Czech Republic (n = 1 tick in a bird) [32]. In Italy (n = 5 ticks) [40], in Malta (n = 3 ticks in a bird) [51], and in a study carried out in the African-Western Palearctic region (n = 1 tick) [5], *H. rufipes* was collected from Eurasian reed warblers.

Like other *Acrocephalus* warblers, the marsh warbler (*Acrocephalus palustris*) is among the most frequent long-distance passerine migrants along the eastern route [53]. Their breeding season takes place between the second half of May and July [55]. In the spring migratory season of 2012, a study carried out in Czech Republic found a bird belonging to *Acrocephalus palustris* infested by *H. marginatum* [32].

5.2. *Anthus trivialis*

The tree pipit (*Anthus trivialis*) is a migratory bird inhabiting predominantly the temperate regions of Eurasia [59].

Individuals of tree pipit have been previously reported to be infested by nonspecific *Hyalomma* spp. in a research study conducted in the African-Western Palearctic region (n = 3 ticks) [5] and in four Italian studies. In Italy, a study published in 2013 found six *Hyalomma* spp. ticks in three birds [45]. Other Italian studies detected *Hyalomma* spp. ticks in tree pipits sampled in the period between

2013-2014 (n = 8 ticks in 4 birds) [22], between 2016-2017 (n = 3 ticks) [46], and in the period between 2017 and 2019 (n = 34 ticks) [40].

Hyalomma rufipes ticks were recovered from tree pipit birds in a study carried out in the African-Western Palearctic region (n = 4 ticks) [5] and in Italy (n = 3 ticks) [40].

5.3. *Carduelis* spp.

The European goldfinches (*Carduelis carduelis*) are widely distributed across Europe, Central Asia and the Northern tip of Africa, inhabiting diverse habitats, from forests and wetlands to grasslands and urban areas, breeding between April and early August [55].

Hyalomma marginatum was reportedly collected from a European goldfinch bird (n = 1 tick) in Italy [40]. Non-defined species of *Hyalomma* spp. were identified in a European goldfinch (n = 1 tick) in Italy [40].

Furthermore, *H. marginatum* was recovered from a citril finch (*Carduelis citronella*) (n = 2 ticks), a partial short-distance migrant and an altitudinal migrant, in Spain [50,55].

5.4. *Curruca* spp.

Common whitethroat (*Curruca communis*) is a long-distance migrant that overwinters in sub-Saharan Africa, breeding primarily from April to July [55,60].

The occurrence of non-defined *Hyalomma* spp. ticks in common whitethroat individuals have been significant. In Italy, Mancini et al. [45], De Liberato et al. [22] and Battisti et al. [46] collected 18, 55 and 24 ticks, respectively. Another Italian study highlighted the infestation of common whitethroats by undefined *Hyalomma* spp. ticks (n = 109 ticks) [40]. In Spain, England et al. [43] recovered five. In the United Kingdom, four ticks were detected by Jameson et al. [33]. Also, in Hungary, Keve et al. [42] found a bird infested by *Hyalomma* spp.

Mancuso et al. [40] also recovered *H. marginatum* (n = 2 ticks) and *H. rufipes* (n = 52 ticks) from common whitethroats. Hoffman et al. [5] found six *H. marginatum* in a sampling from the common whitethroat. *Hyalomma marginatum* was also described in Malta (n = 1 tick) [51]. Similarly, the latter two mentioned studies also identified *H. rufipes* as infesting ticks of common whitethroats (n = 56 ticks and n = 19 ticks, respectively) [5,51]. Additionally, Battisti et al. [46], in Italy, also obtained five *Hyalomma rufipes* ticks from common whitethroats.

Additionally, *H. rufipes* was collected from eastern subalpine warblers (*Curruca cantillans*) (n = 5 ticks) in Italy [40] and from a western subalpine warbler (*Curruca iberiae*) (n = 1 tick) bird in Malta [51]. *Hyalomma* spp. ticks were also reported in eastern subalpine warbler (*Curruca cantillans*) birds in Italy by De Liberato et al. [22] and by Battisti et al. [46].

5.5. *Erithacus rubecula*

The European robin (*Erithacus rubecula*) (Figure 4) is a widespread migrating songbird species, breeding from April to July in Eurasia, varying by region [61]. The species inhabits forests, thickets, and urban areas, requiring shade, cover, and bare ground [55].

European robins were classified as vectors of *Hyalomma* spp. ticks in studies carried out in France [52], in Italy [40], and in the African-Western Palearctic region, more specifically in Greece [5].

Mancuso et al. [40], Vial et al. [52], and Hoffman et al. [5] identified *H. marginatum* obtained from European robins (n = 22 ticks, n = 2 ticks in 2 birds, and n = 2 ticks in a bird, respectively). Mancuso et al. [40] also recovered three non-defined *Hyalomma* spp.. Additionally, in Italy, ten ticks of *H. rufipes* were collected from European robins [46].

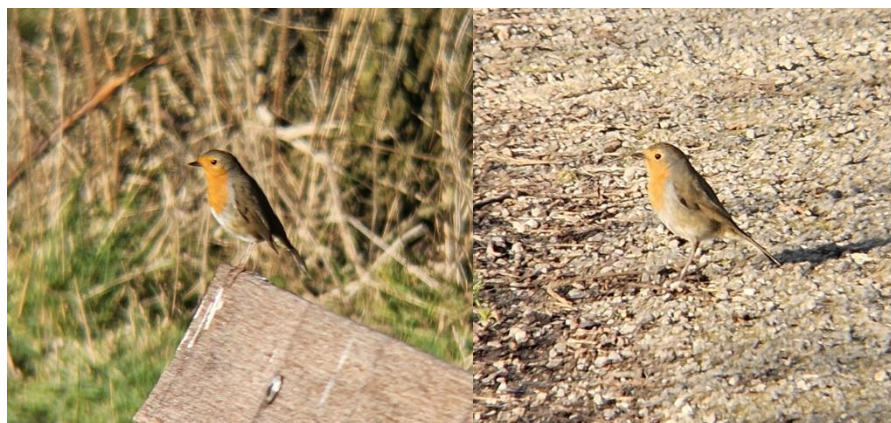


Figure 4. European robin (*Erithacus rubecula*). Photographed by Melissa Alves Rodrigues.

5.6. *Ficedula* spp.

Pied flycatcher (*Ficedula hypoleuca*) inhabits semi-open areas, breeding across a vast area of the Western Palearctic region and wintering in West Africa [62].

In a Spanish study published in 2016, *H. marginatum* was reported as being recovered from a pied flycatcher bird (n = 1 tick) [50]. Meanwhile, *H. rufipes* ticks were collected from pied flycatchers in Italy (n = 52 ticks) [40], in a study carried out in the African-Western Palearctic region (n = 19 ticks) [5], and in Malta (n = 6 ticks in 2 birds) [51]. In Italy, four studies have described nonspecific *Hyalomma* spp. ticks collected from pied flycatchers. Mancini et al. [45] have recovered two ticks in two birds, De Liberato et al. [22] have recovered eight ticks, and, more recently, Battisti et al. [46] obtained six ticks, and Mancuso et al. [40] have collected 138 ticks from pied flycatchers. Also in Hungary, *Hyalomma* spp. were detected in an infested bird [42].

Meanwhile, individuals of collared flycatcher (*Ficedula albicollis*) are migratory birds previously identified as carriers of *H. rufipes* in a study conducted in the African-Western Palearctic region (n = 8 ticks) [5], in two Italian studies (n = 1 ticks and n = 4 ticks, respectively) [40,46], and in a Maltese study (n = 1 tick) [51]. Nonspecific *Hyalomma* spp. ticks were also detected in pied flycatcher birds in Italy (n = 27 ticks) [40].

5.7. *Hippolais* spp.

Icterine warbler (*Hippolais icterina*) is a migratory bird, breeding from the end of May to July, wintering in Africa [55].

Hyalomma marginatum was obtained from an icterine warbler in a previous study conducted in Italy (n = 1 tick) [40]. Meanwhile, in the same study, 25 *H. rufipes* ticks were recovered from icterine warblers [40]. Hoffman et al. [5] also detected five *H. rufipes* ticks from the icterine warbler. Moreover, non-defined *Hyalomma* spp. were described as infesting icterine warblers in three Italian studies. The first of the studies sampled three ticks [22]. Later, Battisti et al. [46] obtained two *Hyalomma* spp. ticks and, more recently, Mancuso et al. [40] recovered sixty-seven.

Additionally, the melodious warbler (*Hippolais polyglottal*) (n = 1 bird) was also described as carrier of *Hyalomma* spp. (n = 2 ticks) in Italy [45].

5.8. *Hirundo rustica*

The barn swallow (*Hirundo rustica*) is migratory, breeding from May to August, with the European birds wintering in sub-Saharan Africa and in southern and western Europe [55].

Barn swallows were previously reported as carriers of *H. rufipes* in Italy by Mancuso et al. [40] and in Malta by Hornok et al. [51] (n = 1 tick and n = 1 tick, respectively). Also in Italy, Battisti et al. [46] obtained an indistinguishable *Hyalomma* spp. tick from a barn swallow individual.

5.9. *Lanius* spp.

Three CCHFV-positive *H. marginatum* nymphs were already obtained from woodchat shrike (*Lanius senator*) in a Greek study [4].

Woodchat shrike (*Lanius senator*) is adapted to open landscapes, widely distributed from the Iberian Peninsula to Western Turkey, preferring to breed in semi-open, dry grassland habitats with scattered shrubs [63,64].

Non-specified *Hyalomma* spp. were previously reported in woodchat shrikes in three Italian studies (n = 1 tick [45], n = 2 ticks [22], and n = 12 ticks [40]).

Hoffman et al. [5] described the occurrence of *H. marginatum* (n = 2 ticks) and *H. rufipes* (n = 45 ticks) in woodchat shrikes. Other studies also collected *H. rufipes* from woodchat shrikes. Among them, two Italian studies [40,48]. Mancuso et al. [40] identified ten ticks. A Maltese study [51] found two ticks collected from a woodchat shrike.

Furthermore, in Turkey, a red-backed shrike (*Lanius collurio*) was reported by Leblebicioglu et al. [41] to carry *Hyalomma* spp. (n = 1 tick).

5.10. *Luscinia megarhynchos*

The common nightingale (*Luscinia megarhynchos*) is a migratory bird that winters in Africa [65].

Hyalomma marginatum ticks were recovered from common nightingales in Czech Republic in 2010 (n = 4 ticks in a bird) and in 2012 (n = 1 tick in a bird) [32]. Also, a Spanish study [50], a study in the African-Western Palearctic region [5], and an Italian one [40] sampled *H. marginatum* from common nightingale (n = 8 ticks, n = 5 ticks, n = 2 ticks, respectively). Regarding the occurrence of *H. rufipes* in individuals of common nightingale, it was reported the sampling of 14 ticks collected in a study carried out in the African-Western Palearctic region [5] and 10 ticks in Italy [40].

Furthermore, non-defined *Hyalomma* spp. were sampled in three Italian studies. Mancini et al. [45] detected 25 ticks in a total of six birds, De Liberato et al. [22] identified six ticks in two birds, and, more recently, Mancuso et al. [40] collected 15 ticks from common nightingale individuals.

Also, a thrush nightingale (*Luscinia luscinia*) individual was reported in Turkey as carrying an undefined *Hyalomma* spp. [41].

5.11. *Motacilla flava*

The western yellow wagtail (*Motacilla flava*) is a common Palearctic passerine, breeding in this region between March and May, and wintering in Africa and Southern Asia [66].

Western yellow wagtails were described carrying *H. rufipes* in Italy (n = 11 ticks) [40], in a study in the African-Western Palearctic region (n = 2 ticks) [5], and in Malta (n = 1 tick in a bird) [51]. In Italy, three studies detected *Hyalomma* spp., although not defining the species. Mancini et al. [45] recovered two *Hyalomma* spp. ticks in a western yellow wagtail, De Liberato et al. [22] collected nine ticks in two birds, and Mancuso et al. [40] detected 13 *Hyalomma* spp. in the same bird species.

5.12. *Muscicapa striata*

The spotted flycatcher (*Muscicapa striata*) is a migratory bird, breeding in Europe from mid-May to mid-August and wintering in sub-Saharan Africa [55].

Mancuso et al. [40] identified a *H. marginatum* infesting a spotted flycatcher bird in Italy. Meanwhile, the same study also recovered 39 *H. rufipes* ticks from the same species of birds [40]. *Hyalomma rufipes* were also described by Battisti et al. [46] (n = 2 ticks) and by Hoffman et al. [5] (n = 4 ticks).

In Italy, Mancini et al. [45] have identified a *Hyalomma* spp. tick in a spotted flycatcher, similarly to De Liberato et al. [22]. Also in Italy, Mancuso et al. [40] recovered 83 ticks from spotted flycatchers.

5.13. *Oenanthe* spp.

The black-eared wheatear (*Oenanthe hispanica*) is a passerine species associated with warm areas in the Mediterranean region, where it breeds [67].

The black-eared wheatear has been described as a carrier of *Hyalomma* spp. in Italy. Mancini et al. [45] reported the occurrence of a tick in a bird of this species, similarly to the findings of De Liberato et al. [22]. Meanwhile, Mancuso et al. [40] found four ticks of *Hyalomma* spp. (the species was not defined) and, more specifically, two ticks of *H. rufipes* infesting black-eared wheatear. The same study recovered a CCHFV-positive larva of *H. rufipes* from a black-eared wheatear in May 2018 [40].

The northern wheatear (*Oenanthe oenanthe*) is a mountain generalist and open grassland species that primarily breeds in Southern Europe, migrating approximately 3500 km to its wintering grounds in sub-Saharan Africa [68].

Hoffman et al. [5] sampled six *H. marginatum* and 21 *H. rufipes* ticks from northern wheatear individuals. Also, two Italian studies reported the infestation of northern wheatear birds by *H. rufipes* (n = 1 tick and n = 7 ticks) [40,46]. In the same study, 59 ticks of *Hyalomma* spp., which species was not defined, were collected from these birds [40]. Similarly, De Liberato et al. [22] and Battisti et al. [46] found *Hyalomma* spp. in northern wheatears (n = 2 ticks in 2 birds and n = 1 tick, respectively).

5.14. *Oriolus oriolus*

The Eurasian golden oriole (*Oriolus oriolus*) is a long-distance migrant that winters on the south Sahara regions [69].

Hyalomma marginatum was previously described in Eurasian golden oriole birds in Spain [50], Greece [27], and Italy [40]. In Spain, Palomar et al. [50] reported two ticks in a bird, while Wallménus et al. [27] and Mancuso et al. [40] detected a tick, each (in Greece and in Italy, respectively).

Hyalomma rufipes ticks were also detected in Eurasian golden orioles by Hoffman et al. [5] (n = 30 ticks) and by Mancuso et al. [40] (n = 28 ticks). Eurasian golden orioles were also described as carriers of *Hyalomma* spp. (non-defined) in Italy by De Liberato et al. [22] (n = 6 ticks in 4 birds) and by Mancuso et al. [40] (n = 34 ticks).

5.15. *Otus scops*

The Eurasian scops-owl (*Otus scops*) is the only long-distance migrating European owl, wintering in south Sahara [70].

Mancuso et al. [40] have detected *H. marginatum* (n = 1 tick) in an Eurasian scops-owl in Italy. The same study also described another *Hyalomma* spp. tick, which species is not defined. Similarly, an Italian study [22] found two ticks of unspecific *Hyalomma* spp. in an Eurasian scops-owl.

5.16. *Parus major*

The great tit (*Parus major*) (Figure 5) is generally a resident bird, but with seasonal altitudinal movements and partial eruptions [55].

In Spain, Palomar et al. [50] reported the presence of four *H. marginatum* ticks in five great tit. Meanwhile, in Italy, a *Hyalomma* spp. tick was found infesting a great tit individual [40].



Figure 5. Great tit (*Parus major*). Photographed by Melissa Alves Rodrigues.

5.17. *Phoenicurus* spp.

The common redstart (*Phoenicurus phoenicurus*) is a migratory species that breeds from late-April to mid-July, with earlier breeding in Southern Europe and later May to late-June in northern Finland [55].

Common redstarts have been reported to be carriers of *H. marginatum* in studies carried out in Italy (n = 4 ticks) [40], in the African-Western Palearctic region (n = 2 ticks) [5], and in Greece (n = 1 tick) [27]. Also, *H. rufipes* ticks were sampled from this bird species by Mancuso et al. [40] (n = 65 ticks), by Hoffman et al. [5] (n = 29 ticks), by Battisti et al. [46] (n = 12 ticks), by Hornok et al. [51] (n = 5 ticks in 2 birds), and, more recently, by Mancuso et al. [40].

Non-specific *Hyalomma* spp. ticks were obtained from common redstarts in Turkey (n = 3 ticks) [41], in the United Kingdom (n = 1 tick) [33], and in Italy [22,40,45,46]. In Italy, more specifically, Mancini et al. [45] sampled two ticks, De Liberato et al. [22] detected 49, Battisti et al. [46] obtained nine ticks, and Mancuso et al. [40] recovered 122 ticks from *Phoenicurus phoenicurus* birds.

Additionally, two black redstarts (*Phoenicurus ochruros*) were also described as carrying *H. marginatum* in Spain [50] and *H. rufipes* in Italy [40], respectively. Also in Italy, *H. rufipes* (n = 1 tick) and non-defined *Hyalomma* spp. ticks (n = 3 ticks) were collected from black redstarts by Battisti et al. [46]. Their breeding populations in Iberia, southern and central France, Italy, the Balkans, and central Turkey are mostly sedentary, with mountain-dwelling individuals moving to lower elevations during winter. In contrast, populations from northern Europe migrate southwest towards, among others, the Balearic Islands and Spain [55].

5.18. *Phylloscopus* spp.

The wood warbler (*Phylloscopus sibilatrix*) is a migratory species which breeds in mid to high latitudes from Western Europe to Western Asia, wintering near the equator in Central and West Africa [71]. After leaving their wintering grounds in March, these bird species arrive at their breeding grounds in May [71].

Mancuso et al. [40] described the infestation of *H. marginatum* (n = 2 ticks) in Italy. Meanwhile, *H. rufipes* are more extensively reported as infesting ticks of wood warblers by Mancuso et al. [40] (n = 83 ticks), by Battisti et al. [46] (n = 1 tick), and by Mancuso et al. [40] in Italy. Hoffman et al. [5] collected *H. rufipes* from samples recovered from wood warblers in the African-Western Palearctic region (n = 21 ticks). Similar findings were obtained by Hornok et al. [51] in Malta (n = 9 ticks in 4 birds).

Moreover, De Liberato et al. [22] (n = 26 ticks in 17 birds), Battisti et al. [46] (n = 7 ticks), Mancuso et al. [40] (n = 159 ticks), and Mancuso et al. [48] reported indistinguishable *Hyalomma* spp. ticks sampled from wood warbler in Italy.

The willow warbler (*Phylloscopus trochilus*) is a migratory songbird, breeding in Northern Europe and Asia and wintering in sub-Saharan Africa [72]. Hornok et al. [51] collected *H. marginatum* (n = 2 ticks a bird) and *H. rufipes* (n = 4 ticks in 2 birds) from willow warblers in Malta [51]. Additionally, in

Italy, Mancuso et al. [40] identified 11 *H. rufipes*. Also, in Italy, Mancini et al. [40] sampled a tick of non-specific *Hyalomma* spp., similar to De Liberato et al. [22] and to Battisti et al. [46] findings. Moreover, Mancuso et al. [40] obtained 24 non-defined *Hyalomma* spp. ticks from willow warblers.

5.19. *Prunella modularis*

The dunnoek (*Prunella modularis*) breeds throughout the temperate zones and marginally in the subarctic and boreal regions of the Palearctic [73].

Dunnock birds were previously identified as carriers of *H. marginatum* and undistinguishable *Hyalomma* spp. in Italy and France [40,46,52]. Mancuso et al. [40] and Vial et al. [52] recovered four and two *H. marginatum* ticks, respectively. Additionally, Battisti et al. [46] obtained a non-defined *Hyalomma* spp. tick from this bird species.

5.20. *Saxicola rubetra*

In April 2017, an Italian study [40] found a *H. rufipes* nymph positive to CCHFV collected from a whinchat (*Saxicola rubetra*).

The whinchat breeds from Western Europe into Western Asia, spending the winter in the humid zone of sub-Saharan Africa [74]. The infestation of *Hyalomma* spp. ticks in these individuals is extensively reported. Hoffman et al. [5] revealed the infestation by 123 *H. rufipes* ticks. In Italy, 65 and seven *H. rufipes* ticks were sampled from whinchats by Battisti et al. [46] and by Mancuso et al. [40], respectively. Mancuso et al. [48] also detected *H. rufipes*.

Non-defined *Hyalomma* spp. ticks were sampled from whinchats by Mancuso et al. [40] (n = 214 ticks), by De Liberato et al. [22] (n = 41 ticks in 22 birds), by Mancini et al. [45] (n = 20 ticks), by Battisti et al. [46] (n = 13 ticks), and by Hoffman et al. [5] (n = 8 ticks).

5.21. *Sylvia* spp.

The Eurasian blackcap (*Sylvia atricapilla*) is sedentary on islands, partially migratory in the Mediterranean and Western Europe, and migrates long distances in the north and east [55].

Hyalomma rufipes were collected from Eurasian blackcaps by Hoffman et al. [5] (n = 4 ticks) in the African-Western Palearctic region, and by Vial et al. [52] (n = 2 ticks in 2 birds) in France. *Hyalomma* spp. (n = 2 ticks in 2 birds) were reported in Italy [45].

Individuals of garden warbler (*Sylvia borin*), a long-distance migrant, were previously described to be infested with *H. rufipes* by Mancuso et al. [40] (n = 10 ticks) and by Hoffman et al. [5] (n = 1 tick). Unspecific *Hyalomma* spp. ticks were sampled from garden warblers in Italy, by De Liberato et al. [22] (n = 1 tick) and Mancuso et al. [40] (n = 11 ticks), and in the Netherlands by Heylen et al. [49] (n = 1 tick).

5.22. *Turdus* spp.

The Eurasian blackbird (*Turdus merula*) (Figure 6) is a ubiquitous species and, depending on latitude, sedentary, partially and fully migratory [55,75]. Birds belonging to this species were found to be infested by *H. marginatum* (n = 31 ticks in 11 birds) [50]. In Italy, Mancini et al. [45] identified four *Hyalomma* spp. in four birds.

Song thrush (*Turdus philomelos*) breeds in Scandinavia and northwestern Russia and spends the winter in the Mediterranean basin [76]. A previous Italian study [40] sampled *H. marginatum* from song thrushes (n = 57 ticks). The same Italian study also detected *H. rufipes* (n = 2 ticks) and other *Hyalomma* spp. (n = 28 ticks) in this bird species [40]. Also, in Italy, Battisti et al. [46] obtained one *Hyalomma rufipes* and three *Hyalomma* spp. ticks from song thrushes.

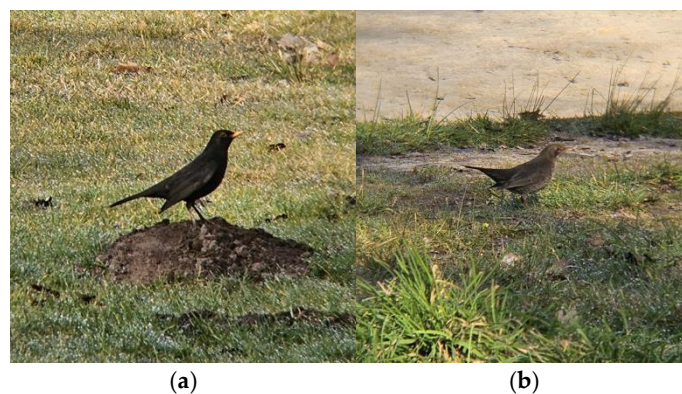


Figure 6. Male (a) and female (b) of Eurasian blackbird (*Turdus merula*). Photographed by Melissa Alves Rodrigues.

5.23. *Upupa epops*

Northern populations of the common hoopoe (*Upupa epops*) are fully migratory, while others are either only partially migratory or sedentary [55].

Hyalomma rufipes has been reported in common hoopoe birds in a study conducted in the African-Western Palearctic region [5] (n = 2 ticks) and in Malta [51] (n = 1 tick in a bird). De Liberato et al. [22] and Mancuso et al. [40] revealed the occurrence of *Hyalomma* spp. in common hoopoe individuals analysed in Italy (n = 1 tick and n = 2 ticks, respectively).

6. Climate Change and Its Effects on the Expansion of *Hyalomma* spp.

Climate change is considered the main factor behind the observed expansion of *Hyalomma marginatum*, [6].

Factors such as temperature, precipitation, and air currents influence the seasonal migration routes of migratory birds, as well as the time of attachment of ticks to birds and the distance over which the feeding immature ticks are transported [39]. Moreover, climate and weather changes determine the time of birds' stay in their wintering grounds and the course of seasonal migrations [39], and impact the moulting from nymphs to adults [44].

In several regions of Europe, spring temperatures are generally considered insufficient to support the moulting of *Hyalomma* spp. nymphs into adults [22]. Nevertheless, recent reports have documented successful moulting events in newly colonised areas, indicating that *Hyalomma* spp. may adapt to changing climatic conditions or benefit from localised microclimates [7]. In Southern Europe and Northern Africa, the summer rainfall and evapotranspiration regulate the *Hyalomma marginatum* populations [77]. In Eastern Europe and the Caucasus, warmer autumns are considered ideal conditions for *Hyalomma marginatum* and are associated with decreased mortality rates [77].

Areas where the annual cumulative temperatures reach between 3000-4000°C and the water vapour deficit is below 15 hPa are favorable for the distribution of *Hyalomma marginatum* [77,78]. Moreover, established populations of *Hyalomma marginatum* occur in areas where the average cumulative temperatures during September and December are around 800°C [77,79]. Thus, warm autumns can lead to nymph populations to moult into adults and taking into account that adults are more cold-resistant in comparison to nymphs, autumn temperatures are connected with lower winter mortality [77].

The timing of first arrival for many migratory bird species is closely linked to average monthly temperatures, with warmer conditions often associated with earlier arrivals. As temperatures rise, suitable breeding and stopover habitats are also expected to shift northward. Conversely, approximately one-eighth of bird species are projected to face a high risk of extinction in the coming decades [80].

There is growing interest in creating maps that delineate areas where the risk of ticks or tick-borne pathogens is likely to occur [81], with several studies modelling the distribution of *Hyalomma*

spp. and the potential expansion of CCHF under climate change scenarios. A retrospective study revealed changes in the life cycle of *Hyalomma marginatum* along a latitudinal gradient, with more significant changes between 1901–1922 and 1989–2009 [15]. Climate modelling carried out by Estrada-Peña et al. [15] showed that warmer temperatures and lower humidity have increased the tick's development and survival rates, particularly in regions where the tick has been historically present. Their model results [15] predicted that large regions in the Atlantic domain could experience a 60%–80% increase in development rates and over 80% in survival rates during the developmental and questing stages. In turn, Gale et al. [82] projected that, by 2075–2084, the number of European regions meeting the moulting threshold for *Hyalomma marginatum* nymphs ($\geq 8^\circ\text{C}$ for 15 consecutive days) will increase relative to 2005–2014, particularly in coastal areas during March and expanding inland by April. Despite this, the frequency of annual CCHFV incursions via immature ticks on migratory birds (e.g., Common Quail, Tree Pipit, Willow Warbler, Northern Wheatear) is expected to remain stable, with reduced risk in Central and Southern Europe but increased risk in the North [82]. More recent projections by Okely et al. [18] suggest a possible northward expansion of *Hyalomma rufipes* into Germany and the UK. Similarly, Gillingham et al. [77] identified regions in the UK with suitable temperatures for *H. marginatum* nymphal moulting between 2000–2019, although autumn conditions remain suboptimal for population establishment. The model developed by Fanelli et al. [83] predicts areas at risk of further CCHFV expansion, such as Italy and France, but highlights a still low risk of CCHFV entry and exposure in most Western European countries. Moreover, in comparison with Cuadrado-Matías et al. [23], the predictions carried out by Fanelli et al. [83] show a more expansive distribution of favourable CCHF occurrence conditions in the Iberian Peninsula.

As climate change persists, predictive models incorporating data regarding *Hyalomma* spp. habitat suitability, host distribution and temperature project a continued expansion of CCHFV into Central and Northern Europe, with a medium risk of CCHFV introduction in France, Italy and Germany [8].

7. Conclusions

The Crimean-Congo Hemorrhagic Fever (CCHF) poses a significant public health threat due to its high mortality rate, lack of effective treatments or vaccines, and expanding geographic distribution. Understanding the population dynamics of *Hyalomma* ticks and studying the eco-epidemiology of CCHF is crucial to preventing this emerging disease in Europe. Variation in the prevalence and intensity of *Hyalomma* spp. infestation among migratory bird species may indicate differential host susceptibility or distinct migratory strategies that modulate exposure timing and risk, as previously proposed by several authors. Additionally, identifying knowledge gaps, such as the specific influence of bird migration routes and the effectiveness of different surveillance strategies, is essential for controlling this underestimated disease in Europe. Moreover, it has been established that future climate change scenarios may contribute to habitat suitability and the spread of CCHFV northward. Furthermore, public awareness regarding CCHFV, mainly among healthcare workers, veterinarians, hunters, and farmers, should be promoted. The need for continuous projections and adaptation of monitoring strategies as the climate changes is highlighted. Monitoring vectors and suitable sentinels is crucial for assessing the risk of introducing CCHFV in non-endemic areas, predicting possible outbreaks, implementing complementary surveillance strategies, and designing action plans. To conclude, it is essential to strengthen collaboration between European countries for disease monitoring and response.

Supplementary Materials: The following supporting information can be downloaded at [x], Table S1: Detection of *Hyalomma* spp. in European migratory birds (2008–2025).

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