A survey of the transmission of infectious diseases/infections between wild and domestic ungulates in Europe

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Abstract

The domestic animals/wildlife interface is becoming a global issue of growing interest. However, despite studies on wildlife diseases being in expansion, the epidemiological role of wild animals in the transmission of infectious diseases remains unclear most of the time. Multiple diseases affecting livestock have already been identified in wildlife, especially in wild ungulates. The first objective of this paper was to establish a list of infections already reported in European wild ungulates. For each disease/infection, three additional materials develop examples already published, specifying the epidemiological role of the species as assigned by the authors. Furthermore, risk factors associated with interactions between wild and domestic animals and regarding emerging infectious diseases are summarized. Finally, the wildlife surveillance measures implemented in different European countries are presented. New research areas are proposed in order to provide efficient tools to prevent the transmission of diseases between wild ungulates and livestock.

Keywords: Animal diseases; Domestic ungulates; Wild ungulates; Interspecies transmission; Europe.

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1. INTRODUCTION

1.1. General introduction

The transmission of infectious diseases between wild and domestic animals is becoming an issue of major interest [1]. Scientists still lack of knowledge concerning the means and ways a large majority of infectious agents are transmitted. Wildlife can be exposed to domestic animal diseases resulting in severe consequences on their populations. On the other hand, numerous emerging infectious diseases (EIDs), including zoonoses, were shown to originate from wildlife [2,3]. Multiple publications dealing with wildlife diseases focus on zoonoses, while the present review targets the wild ungulates present in Europe (focussing on *suinae* and ruminants[1]), considering their close ecological and phylogenic relationship with livestock. The main objectives of this review are (i) for the first time, to establish a list as complete as possible of infectious agents already reported in European wild ungulates, (ii) to evaluate the possible role of both wild and domestic ungulates in the transmission of infectious diseases (iii) to emphasize the importance of considering wildlife when studying the epidemiology of infectious diseases. Indeed, wild species may be infected by livestock pathogens and, at the same time, be a risk for the re-infection of livestock [4]. Thus, their importance in global animal health and in farming economy must be taken into account. This review is the first to list so exhaustively infectious diseases/infections already reported in European wild ungulates and, above all, to address their potential epidemiological role (e.g. reservoir, spillover, dead-end host and asymptomatic excretory animal). Bacterial, parasitic, viral and prion diseases are listed in three supplement materials (S1, S2 and S3). In order to better understand the epidemiology of diseases/infections at the domestic animals/wildlife interface, global risk factors associated with the transmission of infectious diseases are reviewed. Finally, the different measures implemented by European countries regarding wildlife diseases/infections are summarized and new areas of research are suggested.

[1] According to the new phylogenic classification of living world.

1.2. Methodology of bibliographic research

A list of bacterial, viral and parasitic diseases known to affect wild ungulates or livestock in Europe was established. The starting point was the list of diseases reportable to the World Organization for Animal Health (OIE). A bibliographical research was performed, combining the [name of pathogens] or the [name of the disease associated] with [ungulate] or [wildlife] or [wild ungulate] on web medical servers and databases (Medline, Pubmed, CAB abstracts and ISI Web of Knowledge). Researches on prevalence or seroprevalence studies were mostly carried out from October 2008 to March 2009. No time limits of publication were imposed. For each pathogen, the most recent publications covering a maximum of European countries were selected. Furthermore, for each risk factor or perspective considered, a bibliographic review was launched in both Pubmed and ISI Web of Knowledge databases to identify the most suitable publications (fitting with keywords introduced, and illustrating problematic of concerns).

2. CURRENT SITUATION/STATUS OF EUROPEAN WILD UNGULATES

2.1. Species and countries of concerns

This review targets wild ungulates present in the European continent (not only the European Union). They are listed in Table I according to their phylogenic relationship. Data about the origin of populations (natural *vs*. introduced) as well as their geographical distribution are adapted from a recently edited book [5].

2.2. Definition of important concepts

2.2.1. Definition of an infectious disease/infection

The definition of an infectious disease/infection is the first step towards understanding the mechanisms involved in the transmission of a pathogen between animals. The first definition was given by Koch in four postulates at the end of the 19th century. However, they are stated in a “one disease-one agent” model and are almost exclusively based on laboratory considerations. Several characteristics such as carrier state, opportunistic agents or predisposing factors are not taken into account with this definition. A disease may be currently defined as ‘any perturbation, not balanced, of one or more body function(s)’ [6], which includes responses to infectious as well as non infectious agents [7]. In wild animals, characterized by feeding, reproduction and movements are mostly independent from human activities (in opposition to domestic animals) [8], disease is strongly associated with environmental factors. Ecological factors are of major importance in the dynamics of wild populations as their survival rate and fecundity may be influenced by diseases [7]. A new concept of disease ecology recently emerged. For a well defined target population, the study of a disease/infection should be related to the study of interactions between the environment, pathogens and human activities [1,9]. For practical reasons, in this review, the term disease will be used to design both disease and infection.

2.2.2. Definitions of epidemiological roles

Studying and controlling an infectious disease implies the knowledge of all actors involved in its transmission. A reservoir, or maintenance host, ‘is able to maintain an infection in a given area, in the absence of cross-contamination from other domestic or wild animals’ [10]. Some authors distinguish different types of reservoirs (1) true reservoir (the species alone maintains the infection), (2) accessory reservoir (maintains the infection secondarily to the main reservoir), (3) opportunistic reservoir (accidentally infected, but without serious consequences) and (4) potential reservoir (can be a reservoir for biological or ecological reasons, but, to date, has not been identified as such under field conditions) [6]. For each category, the reservoir is related to a target population [11]. Spillover hosts can maintain the infection after recurrent contacts with an external source [10]. However, the categorisation of a species is not definite and may be a question of time: the integration in the maintenance or spillover categories of hosts is dynamic as a spillover species may become a reservoir as suspected in the French Brotonne forest [12, 13]: cervids were initially spillover hosts for *Mycobacterium bovis* but because of a high density of animals, the infection spread among them and they now act like maintenance hosts [12]. Wildlife pathogens can also spill back to domestic animals [3]. A dead-end host may be infected by a pathogen but does not allow its transmission in natural conditions; such status may be lost by a species under modified environmental conditions [6]. Finally, an infected animal can excrete a pathogen without showing obvious clinical signs. It is important to mention that the environmental survival of pathogens may also determine wether or not an asymptomatic excretory animal may be considered as reservoir.

Although definitions seem to be clearly delimited, it is not so easy to determine the particular role of a species. Indeed, out of 295 descriptions of wildlife infections reported in the supplementary tables, their epidemiological role is only suggested by the authors in 34.2% of cases (N = 101). Authors often lack of data concerning species interactions as well as the infection status in other species. Besides, to determine the epidemiological role of a wild species towards domestic animals, it is required to assess the real status of livestock, which might not be always the case [13].

2.3. Review of some infectious diseases already reported in European wild ungulates

A global view of infectious diseases affecting domestic animals but already reported in European wild ungulates is presented in Supplement materials S1 (bacteria), S2 (viruses and prions) and S3 (parasites). The epidemiological role of each species with respect to the pathological agent is specified. Nevertheless, it is not an exhaustive list of all diseases affecting wild ungulates as these studies only focused on pathogens affecting domestic animals. Pathogens were generally characterized by laboratory tests developed for domestic livestock. Some results such as apparent prevalence may therefore be biased [13]. In addition, the achievement of studies will also largely depend on the geographical accessibility of the region [14].

3. RISKS FACTORS ASSOCIATED WITH THE TRANSMISSION OF DISEASES

A wide range of factors related to the ecology of diseases, e.g. environmental and ecological parameters, are constantly changing and will subsequently induce modifications in the transmission of pathogens. According to the OIE *Terrestrial Animal Health Code*, an EID is 'a new infection resulting from the evolution or change of an existing pathogenic agent, a known infection spreading to a new geographic area or population, or a previously unrecognised pathogenic agent or disease diagnosed for the first time and which has a significant impact on animal or public health'[2]. Approximately 75% of the pathogens having affected or affecting humans for the last 20 years originate from animals[3]. Moreover, 72% of human EIDs reported between 1940 and 2004 find their origin in wildlife [15]. The role of wild ungulates as a reservoir of infectious diseases, for both humans and livestock, is now well established [16]. Over 250 species of human pathogens have been isolated from ungulates [17]. The main factors affecting the transmission of pathogens among populations of wild ungulates are listed hereafter. Factors related to the host, the pathogen and the environmental changes are considered separately [18]. Most environmental modifications are

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[2] OIE, Glossary, in: *Terrestrial Animal Health Code*, [on line] (2008) http://www.oie.int/eng/normes/Mcode/en_glossaire.htm#terme_maladie_emergente [consulted 16 December 2009]

[3] Vallat B., Surveiller la faune sauvage pour mieux la protéger et pour nous prémunir contre les maladies qu'elle nous transmet, in: Editorial du Bulletin de l'OIE [on line] (2008) http://www.oie.int/fr/edito/fr_edito_juil08.htm [consulted 22 july 2009].

anthropogenic because directly or indirectly linked to human activities, thus, they are expected to change with time [3]. A spatial classification (local *vs*. global) of the main factors involved in the transmission of pathogens between wild and domestic ungulates are illustrated in Figure 1**.**

3.1. Global level (national or European level)

3.1.1. Environmental changes

3.1.1.1. Distribution of geographical spaces

Different factors can explain the constantly increasing interactions between wild and domestic animals. A major parameter is the growing human population, which increased four times during the previous century to now reach 6.9 billion people[4]. Such human population involves a huge and diversified protein demand constantly increasing [19]. In most European countries, large populations of wild ungulates are concentrated in small delimited areas because of high human distribution and densities. Degradation and fragmentation of wild spaces are the main anthropogenic factors associated with the emergence of diseases in wildlife [9,20]. The Food and Agricultural Organization (FAO) website[5] provides surface areas of the different type of land cover (agricultural, forestry, crops, meadows, etc.) since 1961 for almost all European countries: their evolution rates in Europe are summarized in Table II. Until the nineties, areas dedicated to permanent crops and permanent pastures were increasing, leading to a diminution of natural landscape available for wild animals. However, a recent increase in forests areas as well as a global reduction of agricultural areas are observed, reflecting a decreasing importance of agriculture in the economy and additional space for wild populations (positive for wildlife conservation). What will be the real impact on the transmission on infectious diseases between wild animals is still to be assessed.

[4] World population [on line] (2010) http://www.worldometers.info/ [consulted on 16 December 2010]
[5] FAO STAT (2010) http://faostat.fao.org/site/377/default.aspx#ancor [consulted on 19 December 2010]

3.1.1.2. Chemical pollution

Chemical pollution may have a negative impact on wildlife demography or disease suceptibility. Direct impact on reproductive parameters and sex ration has been described [20]. Immunodepression can directly result from a toxic accumulation of chemicals at subclinical levels and increase the susceptibility to infectious diseases [21]. Several studies targeting the consequences of chemical pollution on wildlife reported a direct negative impact on birds and rodents but only few studies focused on wild ungulates [22]. In France, wildlife intoxication reports are registered by the SAGIR Network, in charge of the wildlife health surveillance [23]**.** Twenty five percent of mammalian intoxication reports concerned ungulates, but only 2.1% of cases were confirmed by positive findings [22]. Scientists reported a biomagnification of chemical concentrations via a food-chain transfer: for instance, liver concentrations of chlordecone, a carcinogenic insecticide, were lower in herbivores (bottom of the food chain) than in carnivores, and concentrations in scavengers were still more elevated (top of the food chain) [24]. The season of sampling should be considered whenever using wildlife as an accumulative bioindicator of environmental pollution. Indeed, seasonal variability in metal levels measured in roe deer kidneys found its origin in the difference of nutrition, both quantitative and qualitative. Seasonal peaks for the majority of metals are observed in a very narrow period (summer-autumn). Some plant taxons, such as fungi, are an important pathway for heavy metal intake into the mammalian organism [25]. In addition, consequences and interactions of chemicals on the expression of a disease are not entirely elucidated yet.

3.1.2. Global agricultural practices

The last century was marked by an evolution of agricultural practices especially through industrialisation. Until the nineties, populations of “European classic livestock species” (cattle, sheep, goat, pig) were globally increasing (Table III), along with an increase of areas dedicated to farming (Table II). In such systems, domestic animals were genetically selected for a specific production, and as a result, they are less hardy and resistant to a high exposure rate of pathogens. However, since a few years, everywhere in Europe, public opinion is getting worried about the environment: people are in favour of an agriculture respectful of the environment. Development of organic farming is thus gaining much interest: areas dedicated to such farming were occupying more than 6% of the total agricultural areas in 2008 in Europe[6]. In opposite to the global intensification of agricultural practices, extensive farming systems regain interest, facilitating contacts between livestock and wildlife.

3.1.3. Microbial evolution and adaptation

Pathogens lacking intermediate stages such as viruses, bacteria or protozoans are the main recently emerged pathogens of wildlife [14]. Out of 31 pathogens identified as having a real impact on the dynamics of mammals, 41% are viruses [26]. Because of their high mutational rate, RNA viruses are perfect candidates for emergence. However, even if the evolution of pathogens plays a key role in the emergence of diseases, the ecological factors described below also favour their emergence [21].

3.1.4. Climate change

According to the last report of the Intergovernmental Panel on Climate Change (IPCC), the earth's surface and oceans temperatures are increasing by leading to the constant reduction of land snow cover and the melting of sea ice and glaciers [27]. The global mean surface air temperature increased of an average of 0.75°C since the mid-twentieth century and climate experts expect this increase to continue during the 21th century [28]. As a result, changes in

[6] http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor [consulted on 19 December 2010]

ecosystems are occurring in many parts of the world: the distribution of species and timing of events in some seasonal cycles are affected [29]. In Europe, changes are less obvious than in other sensible parts of the world such as arctic or tropical ecosystems. However, epidemiological cycles are affected since the temperature threshold may modulate the cycle of vector-borne microorganisms [30]. Climate changes might favour the emergence of vector-borne diseases and be responsible of outbreaks of known diseases in regions where they were never reported before. The prevalence and distribution of well-known vector-borne diseases have already increased during the last decade [28]. In the Mediterranean region, bluetongue virus (BTV) recently emerged and became enzootic in livestock [31]. Wild ungulates were proved to be receptive to the virus in all European regions [32,33]. In southern Spain, BTV antibodies were detected in wild ruminants in areas where no outbreak had been reported in livestock, suggesting their potential role of reservoir for BTV, but this statement requires further confirmation [34]. The distribution of ticks is evolving along with climate changes. Indeed, during the last 20 years, the upper limit of tick distributions shifted from 700-800m to 1200-1300 m above the sea level [35]. Consequences on wildlife infections were immediate: in 2005, tick-borne babesiosis was reported for the first time in chamois (*Rupicapra rupicapra*) in Switzerland [36].

3.1.5. Global increased mobility and trade

The last decades were marked by an increased human and animal mobility as well as a constantly evolving animal trade. The translocation of wild or domestic animals is one of the major factors responsible for the introduction of diseases. The trade of living animals was multiplied by a factor 10 between 1995 and 2005: global imports and exports were respectively 8.8 and 13.5 times more important in 2005 than in 1995[7]. Transports are often carried out under very poor conditions because animals are piled up and stressed. Their susceptibility to infections increases. Even if it mainly concerns species other than ungulates, wildlife trade is one of the main problems in a potential cross-species transmission of infectious agents [37]. One should also consider (re)introduction of wild animals for hunting purpose when focusing on wildlife trade. The presence in Europe of most non-native species of ungulates may be explained by such practices. It is currently almost impossible to quantify the global wildlife trade as it is mostly illegal. However, the economic impact resulting from outbreaks caused by wildlife trade has globally reached hundreds of billions dollars to date [19]. Spatial mobility of humans was multiplied by more than 1000 since 1800. A 222% increase is expected for the number of passenger per km by 2035[8]. As the incubation period of most infections exceeds the time necessary to transfer an animal from a country to another[9], the propagation of pathogens and vectors has reached an unprecedented rate.

3.2. Local level (regional or district)

3.2.1. Natural dynamics of populations

The social organisation of populations impacts the transmission rate of infections: the probability of contacts is higher for gregarious animals than for solitary species. Besides, the reproduction period is characterised by increased contacts between individuals [8]. Furthermore, the exposure to pathogens depends on the presence/absence of migratory flows

[7] Food and Agriculture Organization. Data relatives of trade, given in FAOSTAT, [on line] http://faostat.fao.org/site/604/DesktopDefault.aspx?PageID=604#ancor [Consulted 18 November 2008].

[8] United Nation Environment Programme. Climate Neutral Network, [On line] (2008) http://www.climateneutral.unep.org/cnn_contentdetail.aspx?m=224&amid=1018. [Consulted 18 November 2008].

[9] King L.J. Maladies zoonotiques et ré-émergentes: défis et opportunités. 72° Session Générale de l’Organisation mondiale de la santé animale, Comité international, Paris, 23-28 mai 2004.

[3]. European wild ungulates are not migratory animals as such, except reindeer (*Rangifer tarandus*). Nevertheless, once wild populations colonize and occupy a given area, some animals might later radially disperse to close areas and be at risk for contamination [4]. Natural and artificial barriers are likely to limit animal movements and may thus reduce the transmission of pathogens.

3.2.2. Human behaviours

Contacts between wildlife and livestock are also increasing because behaviours of farmers, hunters, scientists and the general public are changing.

3.2.2.1. Farmers

Along with a global change of agricultural practices at the European scale, it is important to consider local agricultural practices. Changes of farmers' behaviours mostly impact contact rates between wild and domestic ungulates. Pastures are places where the transmission rate of infectious diseases is the highest [38]. Farmers' management of pastures are thus of major importance. Some practices such as salt deposits in alpine pastures enhance the risk of indirect transmission of pathogens, like *Pasteurella* for example [39]. Mountain transhumance (summer moving of domestic flocks to alpine meadows) was initially performed at walking-distance. Nowadays, flocks are moved by cattle-trucks, allowing long-distance transportations of more animals; alpine meadows are overgrazed and the probability of contacts with wildlife increases. Besides, whereas initially created to protect biodiversity, national parks allow domestic flocks to graze inside their central part in some countries, which may have detrimental effects for both sides.

3.2.2.2. Hunters

Hunting behaviours may play a major role in the transmission of diseases between or among wild populations. Food supplementation programs implemented to increase the number of hunting bags have drastically disturbed the natural regulation and spatial distribution of populations. Various wild populations, e.g. wild boar [40] or red deer [41], are constantly growing. For example, in Wallonia (Belgium), red deer and roe deer populations have increased twofold while wild boar populations have more than tripled between 1980 and 2005[10]. In some other European areas, populations are overabundant. The hunting of predators led to their extinction and a subsequent imbalance of interactions between species. Offals of dead wild ungulates are generally left in the field, which may reach at the European scale thousands of tons of potentially infected materials in free access to other species. When an infectious disease is prevalent in wild populations, directed shots of sick animals are often applied. However, during a recent outbreak of infectious keratoconjonctivitis in Alpine wild ungulates, such measure seems to have prevented the natural immunisation of populations (Gauthier, personnal communication). A global reduction in hunting pressure may therefore be preferred, especially to protect reproductive adults.

3.2.2.3. General public

For many city dwellers, contacts with nature are limited to controlled areas such as national parks or wildlife game parks. National/regional natural areas are government parks, of which the first objective is to protect natural lands (ecosystems). Wild ungulates may or may not be hunted in function of local legislation. In these opened parks, public frequentation is constantly increasing, as people are in search of a closer contact with nature under protected conditions. The frequency of contacts between wild species and humans increases as a consequence of natural tourism [42]. Wildlife game parks could be associated to ‘game zoos’: species belonging to the native European wild fauna are parked in closed areas. Densities of populations are often high and animals are frequently translocated between different parks. The high density rate can be implicated in the transmission of diseases [43]. Deer farming is

[10] Data provided by the Nature and Forests Division, Ministry of Agriculture, Wallonia.

promoted by several European governments like Switzerland [44]. In France, 400 deer farms are inventoried[11]. The proximity of several species (including humans) will subsequently play a key role in the contact rate.

3.2.2.4. Scientists

More and more scientific studies focus on monitoring of wild populations. Even if carefully controlled, the intrusions of scientists may be a risk of disease transmission. Even if some introduction programs prevent animal transfers from one region to another, or between different countries, some wounded animals are brought to health cares and released after successful treatment. While it mainly concerns wild species other than ungulates, such practices can also increase the risk of disease transmission.

4. CONTROL MEASURES OF INFECTIOUS DISEASES ALREADY IMPLEMENTED IN EUROPEAN WILDLIFE

The section below develops the measures already implemented or to be implemented by European countries to control the transmission of diseases between wild and domestic animals, at three different levels: (i) European; (ii) national, (iii) regional (local).

4.1. At European level

The continuity between all living beings involved in the transmission of infectious diseases must be treated from an international point of view.

4.1.1. Wildlife-livestock-human continuum

[11] Brelurut A., Chardonnet P., Benoît M. Deer farming in mainland France and french overseas territories. 1997. In: *Quatrièmes rencontres autour des recherches sur les ruminants*. Paris: Institut de l'elevage, p. 31-38. Rencontres autour des recherches sur les ruminants. (Paris, France).

As previously described, the importance of contacts between wildlife, livestock and humans is such that some authors suggested a “wildlife-livestock-human continuum” [45]. In 2008, King suggested to use the term ‘interdependence’ instead of ‘independence’ of these three compartments[12]. As a consequence, a new concept of conservation medicine emerged for the protection of animal, human and ecosystem healths [48]. The main goals are to promote the development of scientific studies for problems occurring at the interface between environmental and health (human and animal) sciences [46]. In this context, studies of the community ecology should be performed, in order to better understand the epidemiological links between all actors of the wildlife-livestock- human-continuum [47].

4.1.2 Biodiversity and wild heritage

As already mentioned before, infectious diseases affecting wildlife have several impacts such as depletion of populations and rare species (on their own or in concert with other factors) but management actions also have an environmental impact [48]. Nevertheless, if diseases are a risk for wildlife conservation, preserving biodiversity helps also avoiding their emergence. For example, the prevalence of vector-borne diseases will decrease if the variety of food sources (native hosts) increases, as the infestation rate within each species will be reduced [49].

4.1.2.1. Wild mammals

The first modern complete inventory of mammals was established in 1982, with a list of 4,170 species identified (cited in [50]). The 1993-inventory included 4,629 different species[13]. In 2005, the complete list of mammals indexed 5,416 species the total number beingestimated at

[12] King L.J., Understanding the factors of animal disease emergence: a world of one health, in: Emerging animal Diseases: from science to policy, Proc. Int. Colloquium Belgian Federal Agency for the Safety Food Chain, Brussel, 2008, pp. 15-18.

[13] Mammal Species of the World. http://www.bucknell.edu/msw3/ (database) Wilson and Reeder’s. – 3rd edition

around 5,500: 99% of mammalian species are thus probably already known [51]. Such increasing number of identified species is due to the separate listing of newly discovered phenotypes and genotyping through molecular biology (taxonomic revision). Two hundred and forty species of *Artiodactyla* pertaining to 89 genera are described, most of them living in the biodiversity 'hot spots' located in Sub-Saharan Africa. European species of *Artiodactyla* are by contrast less numerous (see **Table I**).

4.1.2.2. Domestic species

Through selection, man created numerous breeds of domestic animals, e.g. there are approximately 700 breeds of cattle identified worldwide [52]. Nevertheless, many of them are on the verge of extinction, decreasing the genetic variability of cattle.

4.1.2.3. Role of biodiversity in disease ecology

The influence of human activities on endangered and unmanaged wild fauna is of major concern. Out of 31 cases of disease emergence in wildlife, only 6 were not influenced by humans [14]. Eighty-eight percent of mammals at risk for severe infections and listed by the International Union for Conservation of Nature (IUCN) Red List of Threatened and Endangered Species are carnivores or artiodactyls [26]. Most livestock and companion animals belong to these categories. The degradation of ecosystems, the loss of habitats and diminishing food resources force some species to use alternative alimentary sources [1]. Biodiversity acts as a primordial barrier against infectious pathogens. Besides, anthropogenic factors causing losses of biodiversity increase the risk of disease emergence [21] by modifying the abundance, the behaviour or the condition of hosts or vectors [53]. It is then crucial to preserve biodiversity in an integrated and sustainable manner [54].

4.1.3. OIE working group on wildlife diseases

In order to develop specific surveillance guidelines for wildlife diseases, the OIE recently created a Working Group on Wildlife Diseases[14]. It provides information on the wild animal health status, either in the wild or in captivity. Its most important missions are: (i) the elaboration of recommendations and the reviewing process of scientific publications on wildlife diseases; (ii) the implementation of surveillance systems of the wildlife-domestic animals- human continuum; (iii) the control of emerging and re-emerging zoonoses.

4.1.4. Prioritization of wildlife diseases

Based on an OIE imported framework, a method of 'rapid risk analysis' was developed in New Zealand with the aim to prioritize pathogens for the wildlife disease surveillance strategy [55]. Authors first listed all wildlife pathogens likely to interfere with animal or human health. They selected the pathogens likely to have a serious impact on wildlife, livestock and/or humans, after consulting experts of each sector. The risk estimate for each pathogen was scored on a semi-quantitative scale (from 1 to 4). The likelihood and consequences of spread were assessed for free-living and captive wildlife, livestock (distinction between consequences on productivity, welfare and trade), humans and companion animals. The risk of introduction in New Zealand was also assessed (scores: 0 or 1). Finally, pathogens were ranked and authors listed the top exotic and endemic dangerous wildlife pathogens for each population of interest (wildlife, domestic animals or human). Summing the risk estimate for each population gave a 'total risk estimate' [55]. In Europe, the French agency for food, environmental and occupational health safety (ANSES) multidisciplinary working group also elaborated a two-phase risk prioritization method [30]: (i) identification of diseases of which the incidence or geographical distribution could be affected by climate change, (ii) the risk assessment for each disease. Twenty diseases likely to be influenced by climate changes were

[14] Planté C., Current position of the OIE on the approach of emerging animal diseases, in: Emerging animal Diseases: from science to policy, Proc. Int. Colloquium Belgian Federal Agency for the Safety Food Chain, Brussel, 2008, pp. 11-13.

selected. The authors qualitatively assessed the risk of each disease for its impact on human and animal health and on economy, considering the likelihood of disease evolution and the impact level. Three diseases affecting ungulates were selected for which some measures needed to be implemented (BTV, Rift Valley Fever and African horse sickness).

The prioritisation of diseases is useful to (re)-direct and target funds allocated to diseases surveillance and research. Organisms involved in wildlife conservation will be more inclined to financially support the control of wildlife diseases [55]. However, several current EIDs should in fact be considered as re-emerging [56]. To focus wildlife surveillance on prioritized agents could lead to a reduced vigilance/surveillance of 'old' diseases. Their implementation in a global surveillance of wildlife diseases should be conducted carefully.

4.2. At country level

Some decisions will depend on the organization of national governments and bodies in charge of sanitary surveillance.

4.2.1. Surveillance programs

Disease surveillance is defined by the World Health Organization (WHO) as 'the ongoing systematic collection, analysis and interpretation of data but also the dissemination of information to the different actors involved in wildlife management'[15]. For the OIE, surveillance is 'aimed at demonstrating the absence of disease / infection, determining the occurrence or distribution of disease / infection, while also detecting as early as possible exotic or emerging diseases'[16]. Several European Member States (MSs) have already implemented a health monitoring of their main wild populations. Surveillance systems of

[15] World Health Organization, Protocol for the evaluation of epidemiological surveillance systems WHO/EMC/DIS/97.2 [on line] (2001) http://www.who.int/vaccines-documents/DocsWord/word577.doc [Consulted 19 November 2008].

[16] World Organization for Animal Health, Animal Health surveillance, in: *Terrestrial Animal Health Code* [on line] (2008) http://www.oie.int/eng/normes/Mcode/en_chapitre_1.1.4.htm [Consulted 8 December 2008].

wildlife diseases are usually declined in passive surveillance, which consists in reports and necropsies of all animals found dead, and active surveillance, declined as the sampling of some populations in order to assess the (sero)-prevalence of infections. Such systems are now well developed in Belgium [32], Spain (Gortazar, personal communication), France (SAGIR Network) [57] and Switzerland (Ryser-Degiorgis, personal communication). A National Health Surveillance Program for cervids (HOP) was implemented in Norway in 2001 [58]. In Sweden, a monitoring of wildlife health exists since 1945 and became an integrated part of the National Environmental Monitoring Programs[17].

Such systems should be developed at a larger scale. Each State should be able to provide relevant information on the health status of its wild populations. To help other countries developing surveillance systems, it may be interesting to provide guidelines with different modalities in function of the specific epidemiological situation. Standardization of protocols between the different countries would permit a better global and harmonized evaluation of diseases status, and would allow the implementation of an efficient surveillance system. Moreover, the implementation of epidemiological surveillance should be based on both epidemiological (regular collection and analysis of epidemiological information and early warning systems for animal diseases) and ecological monitoring (surveillance of vectors and wild reservoirs) [30].

4.2.2. Vaccination programs

Several reasons may justify the implementation of vaccination programs in wild animals: (i) conservation of endangered species, (ii) reduction of disease impacts, (iii) protection of human health (zoonotic agents) and (iv) prevention of transmission to domestic animals (and

[17] Mörner T., The domestic animal/wildlife interface: issues for disease control, conservation, sustainable food production, and emerging diseases, in: Wildlife and Livestock, Disease and Sustainability: What makes sense? Conference of the Soc. Trop. Vet. Med. And Wildl. Dis. Assoc. Pilanesberg National Park, 2001, pp.34-38.

subsequent economic losses) [46]. Besides, vaccination is an alternative to global culling of wild reservoirs. However, it is important to keep in mind the goals of a vaccination programme. Indeed, a safe and effective vaccine can be used in restricted threatened populations and provide expected results. To eliminate a pathogen in a large area or in large populations, vaccination programs may be used in a multiple-hosts system or at a too-large scale and be unsuccessful. The majority of available vaccines have been developed for domestic animals, and their efficacy and safety are in most cases unknown for wildlife. An ideal vaccine for wildlife should be (i) administered *per os*, (ii) mono-dose (iii) safe for target and non-target species and, if possible, (iv) inexpensive to produce [59]. For example, in Europe, vaccination programs have been implemented in wild boar for classical swine fever (CSF). In France, a quantitative and retrospective study showed that a preventive vaccination (using oral baits) in a determined region improved the control of CSF, but did not eradicate the disease [60]. For multi-hosts pathogens such as *Mycobacterium bovis*, vaccination programs may be more difficult to implement [61], the previous identification of reservoir(s) being essential. Vaccination programs against *M. bovis* were recently started in the UK for badgers [59] or in Spain for wild boar [62]. In conclusion, vaccination programs can be used in wildlife under specific conditions, especially for small populations or in restricted areas [46].

4.2.3. Sentinel animals

A sentinel species is an animal/species different from the target animal/species. The use of sentinel animals may be applied in three main situations: when adequate sampling of the target species is difficult (e.g. rare or endangered species), when the sentinel species is more abundant (e.g. use of sentinel chickens instead of wild birds for West Nile virus monitoring) and finally, when the species provides useful information on lower trophic level (e.g. the study of scavengers or carnivores) [65,66]. The place a species occupies in the food chain determines its probability of contamination [63]. The target and the sentinel population must be epidemiologically linked, at least spatially and the response of sentinel animals against a particular pathogen must be demonstrable [64]. For example, red deer are used as a sentinel species for the surveillance of BTV in Spain [33].

4.3. At Local level (district or region)

(Inter)-national regulations must be implemented at local levels also, involving the participation of local structures, such as farmers groups or hunter organisations.

4.3.1. Adaptation of livestock farming

Wild animals are often considered as reservoir of infectious diseases [16]. However, in many cases, infections originate from domestic animals. For instance, bovine herpesvirus 1 (BoHV-1) can induce a moderate infection in deer, whereas cattle is not at risk for the cervid herpesvirus 1 [66]. Thus, contacts should be limited but, at best, avoided between wild fauna and livestock [54]. In some regions of North America, brucellosis became endemic among wapitis (*Cervus elaphus*) and bisons (*Bison bison*). Bisons were infected by cattle around 1900, and the disease became endemic in those wild populations after their release. Although this example concerns non-European wild populations, the measures implemented are interesting to develop in this review. Despite the implementation of feedgrounds and vaccination, habitat improvement and prevention of commingling, livestock still remains infected. Other management options were then proposed: (i) removing cattle from public lands, (ii) developing and implementing brucellosis vaccines more effective for elks and bisons, (iii) managing cattle through vaccination and physical separation from elks and bisons and (iv) using contraceptives in elks to reduce pregnancies and abortions[18]. In the U.S. Sierra

[18] Kreeger T.J., Brucellosis in wapiti (*Cervus elaphus*) and bison (*Bison bison*) in the United States: a classic wildlife-human-livestock problem, in: Proc. 8th Conference of the European Wildlife Disease Association, Rovinj, 2008, pp. 31.

Nevada, a model assessing the impact of different management strategies of domestic sheep (grazing allotment closure, grazing time reductions and reduced probability of contact with stray domestic animals) on the transmission of respiratory diseases from domestic herds to endangered bighorn sheep was built [67]. In order to reduce the risk of disease transmission, the best solution was to avoid an overlapping between domestic sheep and bighorn sheep grazing areas.

Such epidemiologic studies show the importance of identifying and assessing the risks in order to implement preventive measures. Efforts should be devoted towards avoiding contacts between wild and domestic animals. Compartmentalisation and zoning are biosecurity measures advised by the OIE *Terrestrial animal health code* to avoid contacts between domestic and wild animals. However, such measures are often impossible to achieve in field conditions. The total surface area of the European continent occupied by national parks, protected zones where grazing is forbidden, is in fact very limited [66]. Efforts should be devoted to improve biosecurity in farms. In the UK, cattle often contract *Mycobacterium bovis* tuberculosis in pasture contaminated by badger excreta [68]. In order to reduce the risk of contamination in pasture, different practices such as the presence of ungrazed wildlife strips, and the greater availability, width and continuity of hedgerow may be proposed. The management of grazing has shown to reduce the risk of contamination. Here are other examples of efficient measures: rotational grazing system, off-fencing of setts and latrines, the avoidance of grazing pasture too short, the non-introduction of cattle to recently cut fields, the moving of cattle to fresh pasture in the afternoon and the absence of supplementary feeding on pasture [69].

4.3.2. Specific hunting measures

While hunters may play an important role in the transmission of diseases, they can also be important for their control. Indeed, most scientific studies dealing with infectious pathogens in wildlife require an effective collaboration with hunters, as sampling is facilitated on carcasses of hunted animals. Such collaborations should be promoted at a larger scale. Besides, the establishment of controlled management plans for different known diseases should be promoted.

5. PERSPECTIVES

Interdisciplinary collaboration is a requisite to the success of management programs. Studies involving biologists, ecologists, veterinariy epidemiologists and medical doctors should then be promoted. Nevertheless, further research is needed to clearly assess all consequences of the diseases transmitted between wildlife, livestock and humans. A better knowledge of wild populations (size and distribution) of each species should be promoted by applying harmonized methods among the different regions and/or countries. Besides, more studies could be performed in order to understand and analyse the infectious strains circulating among wild animals, but, above all, to compare them to strains isolated from domestic livestock. In most cases, researchers ignore if strains circulating among domestic and wild populations are similar. The epidemiological cycles of infectious diseases in all populations of concern are not well assessed to date. Then, it would be interesting to study methods of space sharing between wild and domestic animals. Costs associated as well as benefits for biodiversity and economical incentives for livestock farming should be evaluated. Because of numerous factors such as globalisation or climate changes, the threat of EIDs is clearly present. The impact of EIDs on economy and public health is not always easily predictable, and should receive more attention, through prioritization procedures for example. Awareness campaigns of politics *via* a direct estimation of costs generated by EIDs would allow funding research projects for wildlife health surveillance. Ecology and protection of the environment should also be integrated in research programmes without neglecting the surveillance of already known ‘old’ diseases.

To focus wildlife surveillance on prioritized agents could lead to a reduced vigilance/surveillance of ‘old’ diseases. Their implementation in a global surveillance of wildlife diseases should be conducted carefully. The implementation of surveillance programs and research studies is not achievable without the involvement of local partners. However, the latter often complain about significant discordances between research (most of the time carried out at the European Union level) and field conditions (regional level). Awareness campaigns and a better communication between all sectors would ensure a better involvement of all surveillance actors and thus benefit to the global system. For example, the attribution of definite roles at the different levels would provide a more efficient distribution of work. Futhermore, information provided by the surveillance of wildlife should be available for the whole scientific community, in order to facilitate the development of spatio-temporal epidemiological methodologies to improve and refine it. Such approach would encourage interdisciplinary collaborations by involving all partners. Surveillance programs have already been implemented in wildlife such as the PREDICT project[19] developed by the Davis University of California: it uses a risk-based approach focused in areas where zoonotic diseases are most likely to emerge and where host species are likely to have significant interaction with domestic animals and high density human populations[20]. This proactive novel approach should be adapted to the specific EU situation. For some domestic species, epidemiologic networks are already in place, such as the RESPE network (Epidemiosurveillance Network of Equine diseases) in France[21]. This network is based on the existence of different specialized networks. It involves owners/farmers, veterinarians and laboratories. The role of each member is well definite, which comes out onto a well-working

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[19] http://www.vetmed.ucdavis.edu/ohi/predict/index.cfm [consulted on 15 February 2011]
[20] http://www.vetmed.ucdavis.edu/ohi/local-assets/pdfs/predict-summary.pdf [consulted on 15 February 2011]
[21] http://www.respe.net/ [consulted on 10 january 2011]

network. Besides, decisional trees may be suggested to local partners in order to adapt their management of wild populations and surveillance of diseases. These trees may propose different approaches for the populations' management in function of diseases or clinical signs reported. Such trees may simplify the decision making for local partners, when, for example, an epizooty starts in wildlife populations. Management plans will then be adapted more easily and more quickly.

A preliminary stage would be to categorise the diseases according to different parameters such as its mode of transmission, its pathogeny or the type of clinical signs it generates. Demographic specificities of the populations of interest (gregarious *vs*. solitary) must be taken into account also. According to the category of disease and the type of populations, management plans may be well adapted or not.

6. CONCLUSION

In 2004, King reminded that knowledge and strategy were still missing for the prevention and control of wild animal diseases. Nowadays, governments and scientists become aware of the necessity to provide means for research on wildlife; scientific studies focusing on wildlife ecology as well as surveillance programs are indeed in expansion [1]. Nevertheless, numerous factors influencing the transmission and ecology of diseases reached a threshold without precedent, and are of major concern for the control of wildlife diseases, such as increasing pressure of humans on natural ecosystems and rising interactions between the different species. A better surveillance of wildlife diseases implemented in an integrated system involving international, national and local actors would be of major relevance to understand the origin of diseases and subsequently to control them. Efforts are required to reduce disagreements and misunderstandings between all actors involved in sanitary surveillance of wildlife. The preservation of biodiversity is crucial for diminishing the risk of disease transmission, as well as the improvement of farm biosafety.

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Supplement material S1. Selected bacterial diseases reported in wild ungulates in Europe

Pathogen	***Ungulate specie (Latin name)***	**n**	**N**	**Prevalence**	**Sero-prevalence**	**Diagnostic method**	**Epidemiological role from author's opinion**	**Years**	**Country**	**Reference**
Anaplasma spp. (Anaplamosis)	*Capreolus capreolus*	14	17		X	ELISA	Reservoir	2005	Spain	[70,70]
Anaplasma ovis (Anaplasmosis)	*Capreolus capreolus*	9	17	X		PCR	Reservoir	2005	Spain	[70]
Anaplasma phagocytophilum (Anaplasmosis)	*Capreolus capreolus*	23	72	X		ELISA	Reservoir	2003	Poland	[71]
		18	132	X		PCR	Unspecified	2004	Italy	[72]
		?	56		94%	IFA	Unspecified	1998	Slovenia	[73]
		19	96	X		PCR	Reservoir	2001	Italy	[74]
		52	121	X		PCR	Reservoir	Unspecified	Austria	[75]
		217	227		X	IFA	Reservoir	2002-2003	Denmark	[76]
		101	237	X		PCR	Reservoir	2002-2003	Denmark	[76]
		1	-	(case report)		PCR	Unspecified	2004	Norway	[77]
	Cervus elaphus		32		35%	IFA	Unspecified	1998	Slovenia	[73]
		15	150		X	ELISA	Reservoir	2000-2003	Spain	[78]
		2	7	X		PCR	Unspecified	Unspecified	Austria	[75]
	Bison bonasus	5	8	X		Nested PCR	Reservoir	2003	Poland	[79]
	Dama dama	31	70		X	IFA	Unspecified	2004-2005	Italy	[80]
		21	29	X(µ)		PCR	Unspecified	2004-2005	Italy	[80]
Borrelia burgdorferi (Lyme disease)	*Capreolus capreolus*	83	227		X	IFA	Unspecified	2002-2003	Denmark	[76]
	Rangifer tanrandus(&)	1	13		X	ELISA	Unspecified	1969-1998	Germany	[81]
	Alces alces (&)	2	13		X	ELISA	Unspecified	1969-1998	Germany	[81]
	Ovis amnon (&)	3	18		X	ELISA	Unspecified	1969-1998	Germany	[81]
Brucella suis (Brucellosis)	*Sus scrofa*	168	763		X	ELISA	Zoonotic reservoir	1995-1996	Germany	[82]
		98	424		X	RBT+CFT ELISA	Possible reservoir	2003-2004	Croatia	[83]
Brucella suis biovar 2 (Brucellosis)	*Sus scrofa*	6	93	X		Isolation	Possible reservoir	2003-2004	Croatia	[83]
	Sus scrofa	198	1841	X		Bacteriology test	Unspecified	2001-2007	Italy	[84]
Brucella suis biovar 3	*Sus scrofa*	1	93	X		Isolation	Possible reservoir	2003-2004	Croatia	[83]
Brucella melitensis biotype 2	*Capra ibex*	1	7	(case report)		Isolation	High seroprevalence (4%) present among domestic animal in the area	1996	Italy	[85]
Brucella melitensis biotype 3	*Rupicapra rupicapra*	1		(case report)		Isolation	Sporadic case	1988	France	[86]

Brucella spp. (Brucellosis)	*Cervus elaphus*	2	54		X		Unspecified	Unspecified	France	[87]
			5821		0.4 [0.3-0.6]	ELISA	Not reservoir	1999-2009	Spain	[88]
	Rupicapra pyrenaica		1410		0.8 [0.4-1.4]	ELISA	Not reservoir	1999-2009	Spain	[88]
	Capra pyrenaica		1086		0.1 [0-0.6]	ELISA	Not reservoir	1999-2009	Spain	[88]
	Capreolus capreolus	0	696		X	Unspecified	Unspecified	Unspecified	France	[87]
	Sus scrofa	180	1821		X	ELISA	Unspecified	2001-2003	Switzerland	[89]
		15	342		X	ELISA	Unspecified	2005-2006	Italy	[90]
			4454		33 [31.6-34.4]	ELISA	Possible threat	1999-2009	Spain	[88]
		448	2267		X	RBT + CFT	Unspecified	2001-2007	Italy	[84]
		62	211		X	RBT + CFT	Unspecified	1996-2000	Croatia	[83]
Campylobacter jejuni	*Capreolus capreolus*	1	38	X		Culture	Unspecified	2002	Norway	[58]
Chlamydia spp.	*Capreolus capreolus*	5	155		X	Complement fixation	Unspecified	1979	France	[91]
	Bison bonasus	28	60		X	CFT	Unspecified	1980-1983	Poland	[92]
Chlamydia abortus	*Sus scrofa*	2	14	X		PCR + sequencing	Possible reservoir	2002	Germany	[93]
Chlamydia psittaci	*Sus scrofa*	4	14	X		PCR + sequencing	Possible reservoir	2002	Germany	[93]
Chlamydia suis	*Sus scrofa*	2	14	X		PCR + sequencing	Possible reservoir	2002	Germany	[93]
Chlamydophila pecorum	*Rupicapra rupicapra*	1	-	(case report)		Isolation	Unknown	Unspecified	Italy	[22]
Chlamydophila abortus	*Capra ibex*	3	306		X	ELISA	Unspecified	2006-2008	Switzerland	[23]
Coxiella burnetti (Q fever)	*Capreolus capreolus*	3	175		X	Complement fixation	Unspecified	1979	France	[91]
		4	78	X		PCR	Unspecified	2001-2006	Spain	[94]
		6	39		X	IFA	Possible reservoir	2004-2005	Spain	[95]
	Cervus elaphus	1	54		X	Unknown	Unspecified	1982-1985	France	[24]
		34	116		X	IFA	Possible reservoir	2004-2005	Spain	[95]
	Bison bonasus	7	60		X	CFT + MAT	Unspecified	1980-1983	Poland	[92]

[22] Gaffuri A., Monaci C., Vicari N., Paterlini F., Magnino S., Detection of *Chlamydophila pecorum* in the lung of an alpine chamois (*Rupicapra rupicapra*) in Northern Italy, in: Proc. 8th Conference of the European Wildlife Disease Association, Rovinj, 2008, pp.60.

[23] Marreros N., Albini S., Hüssy D., Frey C.F., Vogt R.R., Abril C., Holzwarth N., Borel N., Dittus S., Willisch C., Signer C., Ryser-Degiorgis M.P., Serological survey of infectious abortive agnets in free-ranging alpine ibex (*Capra ibex ibex*) in Switzerland, in: Proc. 8th Conference of the European Wildlife Disease Association, Rovinj, 2008, pp. 73.

[24] Barrat, J., Gerard, Y., Schwers, A., Thiry, E., Dubuisson, J., Blancou, J., Serological survey in free-living red deer (*Cervus elaphus*) in France, in: Kluwer Academic (Ed.), Proc. The Management and Health of Farmed Deer. Edinburgh, 1987, pp. 123-127.

		36	47		X	Unknown	Endemic disease	Unspecified	Poland	[96]
	Capra ibex	8	269		X	ELISA	Unspecified	2006-2008	Switzerland	[18]
	Sus scrofa	4	93	X		PCR	Unspecified	2001-2006	Spain	[94]
Escherichia coli	*Cervus elaphus*	3	206	X		PCR	Reservoir	2005-2006	Spain	[97]
Francisella tularensis (Yersiniosis)	*Sus scrofa*	24	763		X	ELISA	Zoonotic reservoir	1995-1996	Germany	[82]
Foot necrobacillosis complex (#)	*Rangifer tarandus tarandus*	100	3000	X		bacteriological examination + PCR	Independent cases	2007	Norway	[98]
Leptospira interrogans (Leptospirosis)	*Capra ibex*	2	153		X	MAT	Unspecified	2006-2008	Switzerland	[17]
	Sus scrofa	9	342		X	MAT	Unspecified	2005-2006	Italy	[90]
	Bison bonasus	35	60		X	MAT	Cross reaction	1980-1983	Poland	[92]
Mycobacterium bovis (Tuberculosis)	*Cervus elaphus*	9	72	X		Culture	Reservoir	2001-2002	France	[12]
		33	138	X		Culture	Reservoir	2005-2006	France	[12]
		86	543	X		Gross lesions	Spill over	1999-2004	Spain	[99]
		1		(case report)		Isolation	Unspecified	1991	Czech republic	[100]
		26	95	X		Culture	Unspecified	2006-2007	Spain	[101]
		33	121*	X		Culture	Unspecified	1996-2002	Spain	[102]
	Capreolus capreolus	1	53	X		Culture	Spillover		France	[12]
	Sus scrofa	25	85	X		Culture	(£)	2001-2002	France	[12]
		65	155	X		Culture	(£)	2005-2006	France	[12]
		269	474	X		Gross lesions	Spill over	1999-2004	Spain	[99]
		51	96*	X		Culture	Unspecified	1996-2002	Spain	[102]
		65	126	X		Culture	Reservoir	2006-2007	Spain	[101]
		3		(case report)		Isolation	Unspecified	1992	Slovakia	[100]
	Dama dama	60	89*	X		Culture	Unspecified	1996-2002	Spain	[102]
		18	97	X		Culture	Reservoir	2006-2007	Spain	[101]
	Bison bonasus	12		(case report)		Isolation	Unspecified	1997-1999	Poland	[100]
	*Capra aegragus**	1		(case report)		Isolation	Unspecified	1991	Czech republic	[100]
	Ammotragus lervia	33	67		X	ELISA	Possible reservoir	1999	Spain	[103]
Mycobacterium avium subsp paratuberculosis (Paratuberculosis)	*Alces alces*	10	537		X	ELISA	Unspecified	1992-1999	Norway	[104]
	Cervus elaphus	106	709*	X		RFLP	Unspecified	1999-2001	Czech Republic	[105]
			95	42.6 [95% CI :		PCR	Unspecified	2006-2007	Spain	[25]

[25] Carta T., Gortázar C., Vicente J., Reyes-Garcia R., Perez-de-la-lastra J.M., Torres Sanchez M.J., Negro J.J., Aznar Martin J. Prevalence of Mycobacterium avium paratuberculosis in wild ruminants (Cervus elaphus, Dama dama, and Sus srofa) from Doñana National Park. , in: Proc. 8th Conference of the European Wildlife Disease Association, Rovinj, 2008, pp. 29.

				32.6-52.6]						
		257	852		X	ELISA	Unspecified		Spain	[106]
		14	371		X	ELISA	Unspecified	1998	Norway	[104]
	Ammotragus lervia	13	67		X	ELISA	Possible reservoir	1999	Spain	[103]
	Dama dama	4	385*	X		RFLP	Unspecified	1999-2001	Czech Republic	[105]
			101	65.1 [95% CI : 55.1-75.1]		PCR	Unspecified	2006-2007	Spain	22
		1	94	X		PCR	Unspecified	2001-2003	Spain	[107]
		2	5	(case report)		PCR	Unspecified	1997-1998	Spain	[108]
	Ovis musimon	16	416*	X		RFLP	Unspecified	1999-2001	Czech Republic	[105]
	Capreolus capreolus	2	858	X		RFLP	Unspecified	1999-2001	Czech Republic	[105]
		6	49		X	ELISA	Unspecified	1997	Norway	[104]
	Rangifer tarandus	0	91		X	ELISA	Unspecified	1996	Norway	[104]
		11	325		X	ELISA	Unspecified	1994	Norway	[104]
	Sus scrofa	1	2	X		RFLP	Accidental host	1999-2001	Czech Republic	[105]
			127	25.7 [95% CI : 17.6-33.8]		ELISA	Unspecified	2006-2007	Spain	22
		1	65	X		PCR	Unspecified	2001-2003	Spain	[107]
Mycoplasma conjunctivae	*Capra ibex*	16	136	X		PCR	Possible carrier	2006-2007	Switzerland	[109]
Mycoplasma agalactiae	*Capra pyrenaica*	46	422	X		PCR	Unspecified	1996-2003	Spain	[110]
Mycoplasma suis (Porcine infectious anemia)	*Sus scrofa*	36	359	X		PCR	Possible reservoir	2007-2008	Germany	[111]
Mycoplasma hyopneumoniae	*Sus scrofa*	92	428		X	ELISA	Not a reservoir	2000-2008	Spain	[112]
Mannheimia sp (Pneumonia)	*Ovibos moschatus*	71	276	X		Isolation for some cases	Unspecified	2006	Norway	[113]
Salmonella spp.	*Ammotragus lervia*	9	67		X	Agglutination test	Unspecified	1999	Spain	[103]
	Sus scrofa	66	342		X	ELISA	Unspecified	2005-2006	Italy	[90]

Legend: n=number of positive animals; N=number of animals tested; CFT = Complement Fixation Test; IFA = Indirect immunofluorescence Assay; ELISA: Enzyme Linked Immuno Sorbent Assay; MAT= Microscopic Agglutination Test; PCR= Polymerase Chain Reaction; RBT =

Rose Bengal Test; RFLP = restriction fragment length polymorphism method; * = animal from game park (isolated from the wild) or extensives farms; (&) = zoo animals; (£) = no epidemiological conclusion possible because of the sampling was not done randomly; (µ): 29 PCR were done on sera with positive serology; *(#):* foot necrobacillosis complex= *Fusobacterium necrophorum, Arcanobacter pyogenes, Streptococcus agalactiae, Staphylococcus aureus.*

Supplement material S2. Selected viral diseases reported in wild ungulates in Europe.

Pathogen	Ungulate specie (latin name)	n	N	Prevalence	Sero-prevalence	Diagnostic method	Epidemiological role from author's opinion	Year	Country	Reference
Aujezsky's disease virus (Pseudo-rabies)	*Sus scrofa*	294	3143		X	ELISA	Endemic	1991-1994	Germany	[114]
		9	16		X	IFAT	Unspecified	2000	Spain	[115]
		101	338		X	ELISA	Reservoir	2004-2005	Czech Republic	[116]
		92	929		X	ELISA	Enzootic disease	1993-2000	Germany	[117]
			192	30,6 ±6,7%		PCR	Widespread infection	2004-2005	Spain	[118]
			185		45.9 ±7.8%	ELISA	Widespread infection	2004-2005	Spain	[118]
		111	427		X	ELISA	Reservoir	2003-2004	Slovenia	[119]
		63	1857		X	ELISA	Sporadic cases	2001-2003	Switzerland	[89]
		62	152	X		PCR	Reservoir	2002-2003	Italy	[120]
		306	693		X	ELISA	Unspecified	2000-2003	Spain	[121]
		0	24		X	ELISA	Unspecified	2004	Lithuania	[122]
		423	12025 *		X	ELISA	Reservoir	1991-1998	France	[123]
		24	44		X	ELISA	Reservoir	1999	Croatia	[124]
		105	342		X	ELISA	Unspecified	2005-2006	Italy	[90]
African swine fever virus (African swine fever)	*Sus scrofa*	14	147		X	ELISA	Not a reservoir	1991-1993	Spain	[125]
Border disease virus (Border disease)	*Sus scrofa*	240	12025 *		X	ELISA	Unspecified	1991-1998	France	[123]
	Rupicapra pyrenaica	227	323		X	ELISA	Unknown	1994-2005	France	[126]
		17	167	X		ELISA+RT-PCR	Unknown	1994-2005	France	[126]
		82	114		X	ELISA	Emerging disease	2002-2006	Spain	[127]
		10	10 (£)	X		RT-PCR	Emerging disease	2005-2006	Spain	[127]
Bovine herpes virus -1 (Infectious bovine rhinotracheitis)	*Rangifer tarandus*	237	831		X	VNT	Endemic disease	1993-2000	Norway	[128]
	Cervus elaphus	3	589		X	VNT	Unspecified	1993-2000	Norway	[128]
		17	73		X	VNT	Spill over	2000-2002	Germany	[129]
	Capreolus capreolus	18	602		X	VNT	Unspecified	1993-2000	Norway	[128]
		4	38		X	VNT	Spill over	2000-2002	Germany	[129]
	Dama dama	1	46		X	VNT	Unspecified	2000-2002	Germany	[129]
	Bison bonasus	5	60		X	ELISA	Unspecified	1980-1983	Poland	[92]
	Rupicapra pyrenaica ornata	7	27		X	Microseroneutralisatio n	Unspecified	1990-1993	Italy	[130]
Bluetongue virus (Blue Tongue)	*Cervus elaphus*		513		40.4%	ID Screen Bluetongue Competition assay	Unspecified	2007	Belgium	[32]
		309	1409		X	ELISA	Unspecified	2005-2007	Spain	[33]
	Capreolus capreolus	2	39		X	ELISA	Unspecified	2005-2007	Spain	[33]

	Dama dama	34	96		X	ELISA	Unspecified	2005-2007	Spain	[33]
	Ovis aries	9	68		X	ELISA	Unspecified	2005-2007	Spain	[33]
		4	6	X (BTV-1)		RT-PCR	Unspecified	2007	Spain	[131]
	Ammotragus lervia	1	4		X	ELISA	Unspecified	2005-2007	Spain	[33]
	*Lama pacos**	1		(Case report)		PCR	Unspecified	2007	Germany	[132]
Bovine viral diarrhea virus (Bovine viral diarrhea)	*Capra ibex*	13	273		X	ELISA	Unspecified	2006-2008	Switzerland	[26]
	Sus scrofa	2	352		X	ELISA	Rarely exposed	2004-2005	Czech Republic	[116]
		2	44		X	ELISA	Reservoir	1999	Croatia	[124]
	Rangifer tarandus	34	810		X	VNT	Endemic disease	1993-2000	Norway	[128]
	Capreolus capreolus	78	635		X	VNT	Endemic disease	1993-2000	Norway	[128]
		12	123		X	VNT	Unspecified	1990-1992	Germany	[133]
	Cervus elaphus	7	658		X	VNT	Unspecified	1993-2000	Norway	[128]
		2	20		X	VNT	Unspecified	1995-1996	Denmark	[134]
	Alces alces	35	1794		X	VNT	Unspecified	1994-1999	Norway	[128]
Caprine herpes virus -1 (Caprine herpesvirosis)	*Cervus elaphus*	10	75		X	VNT	Unspecified	2000-2002	Germany	[129]
	Capreolus capreolus	1	38		X	VNT	Unspecified	2000-2002	Germany	[129]
Classic swine fever virus (Classic swine fever)	*Sus scrofa*	0	6471		X	ELISA	Unspecified	1999-2005	Czech Republic	[116]
		28	1767		X	ELISA	Sporadic cases	2001-2003	Switzerland	[89]
		0	591		X	ELISA	Unspecified	2004	Lithuania	[120]
		585	5286		X	ELISA	Reservoir	2002-2004	France	[135]
		128	301		X	VNT	Reservoir	2002-2004	France	[135]
		96	2767	X		PCR	Reservoir	2002-2004	France	[135]
		80	12025 *		X	ELISA	Unspecified	1991-1998	France	[123]
		17	44		X	ELISA	Reservoir	1999	Croatia	[113]
Chronic wasting disease agent (Chronic wasting disease)	*Cervus elaphus*	0	739	X		ELISA	Unspecified	-	Italy	[27]
		0	674	X		ELISA	Unspecified	2001-2003	Belgium	[136]
	Capreolus capreolus	0	192	X		ELISA	Unspecified	2001-2003	Belgium	[136]
Encephalomyocarditis virus (Encephalomycar	*Sus scrofa*	13	20		X	VNT	Unspecified	1994-2006	Greece	[137]
	Rupicapra pyrenaica ornata	5	27		X	Microseroneutralization	Unspecified	1990-1993	Italy	[130]

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ditis)										
Foot and mouth disease virus (Foot and mouth disease)	*Sus scrofa*	0	504		X	ELISA	Unspecified	2004	Lithuania	[122]
		0	208		X	ELISA	Unspecified	2001	The Netherlands	[138]
Cervid herpes virus-1	*Cervus elaphus*	15	73		X	VNT	Unspecified	2000-2002	Germany	[129]
	Capreolus capreolus	2	38		X	VNT	Unspecified	2000-2002	Germany	[129]
Hepatite E virus (Hepatitis E)	*Sus scrofa*	143	676		X	ELISA	Possible reservoir	2001-2008	Spain	[28]
		9	74	X		RT-PCR	Possible reservoir	2001-2006	Hungary	[139]
		165	1039		X	ELISA	Unspecified	2005-2008	The Netherlands	[140]
		8	106	X		RT-PCR	Unspecified	2005-2008	The Netherlands	[140]
	Cervus elaphus	3	38		X	ELISA	Unspecified	2005-2008	The Netherlands	[140]
		6	39	X		RT-PCR	Unspecified	2005-2008	The Netherlands	[140]
	Capreolus capreolus	11	32	X		RT-PCR	Possible reservoir	2001-2006	Hungary	[139]
Orf virus	*Ovibos moschatus*	19	170	X		Characterization	Spill-over	2004	Norway	[141]
Parapox virus (Contagious echtyma)	*Rangifer tarandus**	48	6		X	Characterization	Unspecified	2000	Norway	[104]
Porcine circo virus -2 (Postweaning multisystemic wasting syndrome)	*Sus scrofa*	57	134		X	IFAT	Unspecified	2005	Czech Republic	[116]
		335	531	X		Nested PCR	Unspecified	2004-2007	Germany	[142]
		314	656		X	IPMA	Unspecified	2000-2003	Spain	[143]
Pestiviruses (unprecised) (Pestivirus infections)	*Rupicapra pyrenaica ornata*	6	35 *		X	ELISA	Unspecified	1990-1993	Italy	[130]
	Rupicapra rupicapra	28	110		X	ELISA	Unspecified	1999	Italy	[144]
		145	343		X	ELISA	Unspecified	2004-2007	France	[13]
	Cervus elaphus	8	136		X	ELISA	Unspecified	1999	Italy	[144]
	Ovis amon	11	18		X	ELISA	Unspecified	2006-2007	France	[13]
	Sus scrofa	7	56		X	ELISA	Unspecified	1999	Italy	[144]
Porcine parvovirus (Porcine parvovirus infection)	*Sus scrofa*	187	254		X	HIT	Unspecified	2004	Lithuania	[122]
		27	342		X	ELISA	Unspecified	2005-2006	Italy	[90]
Porcine	*Sus scrofa*	33	909 *		X	ELISA	Reservoir	1991-1998	France	[123]

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reproductive and respiratory syndrome virus (porcine reproductive and respiratory syndrome)		129	342		X	ELISA	Unspecified	2005-2006	Italy	[90]
Small ruminant lentivirus	*Capra ibex*	3		(case report)		PCR	Independant cases	2006	France	[145]
Swine vesicular disease virus (Swine vesicular disease)	*Sus scrofa*	0	12		X	ELISA	Unspecified	2004	Lithuania	[122]
Transmissible gastroenteritis virus(Transmissible Gastroenteritis)	*Sus scrofa*	1	134		X	IFAT	Sporadic case	2004-2005	Czech Republic	[116]

<u>Legend</u>: n: number of positive animals; N: number of animals tested; *: semi-domesticated animal or farmed animals; £: Only 10 animal tested, because were found sick or already dead in the field. Suspicion of the disease was present before doing the test; IFAT: Indirect Fluorescence Antibodies Test; ELISA: Enzyme Linked Immuno Sorbent Assay; HIT: Haemagglutination Inhibition Test; PCR: Polymerase Chain Reaction; RT-PCR: Reverse Transcriptase Polymerase Chain Reaction; VNT: Virus Neutralization Test.

Supplement material S3. Selected parasitic diseases reported in wild ungulates in Europe

Pathogen	*Ungulate specie (latin name)*	n	N	Prevalence	Serology	Diagnostic method	Epidemiological role from author's opinion	Year	Country	Reference
PROTOZOAN										
Babesia capreoli	*Rupicapra rupicapra*	6	7	(case report)		PCR	Emerging disease	2005	Switzerland	[36]
		1	48	X		PCR	Unspecified	2006-2007	Switzerland	[146]
	Cervus elaphus	1	9	X		PCR	Unspecified	2006-2007	Switzerland	[146]
	Capreolus capreolus	12	46	X		PCR	Reservoir	2006-2007	Switzerland	[146]
Babesia divergens	*Rupicapra pyrenaica*			15.79 [4.2-27.38]			Reservoir		Spain	[147]
	Capreolus capreolus	40	75		X	Indirect IF	Unspecified	1979	France	[91]
			51	54.9 %		PCR	Zoonotic reservoir	1996-2000	Slovenia	[148]
	Cervus elaphus		30	16.7%		PCR	Zoonotic reservoir	1996-2000	Slovenia	[148]
Babesia ovis	*Ovis musimon*	6	50		X	IFAT	Reservoir	1991-1996	Spain	[149]
	Capra pyrenaica	155	475		X	IFAT	Unspecified	1992-1995	Spain	[150]
Babesia spp	*Capra pyrenaica*	1	1	(case report)		Microscopic examination	Unspecified	1995	Spain	[151]
	Capreolus capreolus			53.3 [42.04-64.62]			Unspecified		France	[91]
		83	202	X		PCR	Unspecified	2004-2008	France	[29]
Babesia EU1	*Capreolus capreolus*		51	21.6%		PCR	Zoonotic reservoir	1996-2000	Slovenia	[148]
Cryptosporidium spp.	*Cervus elaphus*		118*	14,4		IFA+PCR	Unspecified	2003-2005	Poland	[152]
		1	289	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Capreolus capreolus		22	9.1		IFA+PCR	Unspecified	2003	Poland	[152]
		18	291	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Bison bonasus		55	29.1		IFA+PCR	Unspecified	2003-2005	Poland	[152]
	Alces alces	15	455	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Sus scrofa		5	0		IFA+PCR	Unspecified	2003	Poland	[152]
Cryptosporidium parvum	*Dama dama*	1	16	X		Fecal examination	Possible reservoir	1995-1998	England	[154]
	Muntiacus reevsi	4	42	X		Fecal examination	Possible reservoir	1995-1998	England	[154]
Dicrocoelium dendriticum	*Capreolus capreolus*	1	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	4	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Giardia spp.	*Cervus elaphus*		118*	1,7		IFA	Unspecified	2003-2005	Poland	[152]
			285	1		Fecal examination	Unspecified		Croatia	[30]

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		5	289	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Capreolus capreolus		22	4.5		IFA	Unspecified	2003	Poland	[152]
			14	27			Unspecified		Croatia	[29]
		45	291	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Bison bonasus		55	7.5		IFA	Unspecified	2003-2005	Poland	[152]
	Alces alces	56	455	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
		1	1	X		Fecal examination	Unspecified	2002-2008	Sweden	[156]
	Rangifer tarendus	11	155	X		Fecal examination	Reservoir	2001-2003	Norway	[153]
	Sus scrofa		144	1.7		Fecal examination	Unspecified		Croatia	[29]
Neospora caninum	*Ammotragus lervia*	1	13	X		ELISA + IFAT	Unspecified	1993-2005	Spain	[157]
	Capreolus capreolus	2	33	X		ELISA + IFAT	Unspecified	1993-2005	Spain	[157]
	Cervus elaphus	28	237	X		ELISA + IFAT	Unspecified	1993-2005	Spain	[157]
	Sus scrofa	1	298	X		ELISA + IFAT	Unspecified	1993-2005	Spain	[157]
		102	565	X		ELISA	Unspecified	1999-2005	Czech Republic	[158]
Toxoplasma gondii	*Alces alces*	270	2142	X		cDAT	Unspecified	1992, 1994-2000	Norway	[159]
	Cervus elaphus	1	67		X	ELISA	Possible reservoir	1999	Spain	[103]
		1	10	X		MAT	Unspecified	1993-2005	Spain	[160]
	Capra pyrenaica	1	3	X		MAT	Unspecified	1993-2005	Spain	[160]
	Dama dama *Ovis ammon*	12	32	X		Isolation	Possible reservoir	2003-2008	France	[94]
		258	760	X		cDAT	Unspecified	1994, 1999-2000	Norway	[159]
		7	33	X		MAT	Unspecified	1993-2005	Spain	[160]
	Cervus elaphus	1	4	X		Isolation	Possible reservoir	2003-2008	France	[94]
		69	441	X		MAT	Possible source of zoonosis	1993-2005	Spain	[160]
		44	571	X		cDAT	Unspecified	1993-1999	Norway	[159]
	Dama dama	18	79	X		MAT	Unspecified	1993-2005	Spain	[160]
	Ovis ammon	4	27	X		MAT	Unspecified	1993-2005	Spain	[160]
	Ovis gmelini	1	7	X		Isolation	Possible reservoir	2003-2008	France	[94]
	Ovis orientalis musimon	17	77		X	ELISA	Unspecified	-	Italy	[31]
	Rangifer tarandus	9	866	X		cDAT	Unspecified	1999-2000	Norway	[159]
	Rupicapra rupicapra	2	10	X		MAT	Unspecified	1993-2005	Spain	[160]
	Sus scrofa	26	148	X		MAT	Reservoir	2002-2008	France	[161]
		148	565	X		IFAT	Unspecified	1999-2005	Czech Republic	[158]
Theileria sp. OT3	*Cervus elaphus*			85.7			Reservoir		Spain	[147]

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	Capreolus capreolus			46.4			Reservoir		Spain	[147]
	Rupicapra pyrenaica			26.3			Reservoir		Spain	[147]
Theileria sp. 3185/02	*Cervus elaphus*			53.6			Reservoir		Spain	[147]
	Capreolus capreolus			10.1			Reservoir		Spain	[147]
Sarcoptes scabei	*Rupicapra rupicapra*	1696	10000	X			Unspecified	1995-2004	Italy	[162]
	Rupicapra pyrenaica parva		1600	12,9%		Observation	Unspecified	1994-1995	Spain	[163]
	Cervus elaphus	1		(case report)		M.E.	Unspecified	1995-2004	Italy	[162]
	Capreolus capreolus	1		(case report)		M.E.	Unspecified	1995-2004	Italy	[162]
	Ovis gmelini musimon	1		(case report)		M.E.	Unspecified	1995-2004	Italy	[162]
	Capra pyrenaica		2096	49.2 ± 7.9		M.E.	Unspecified	1995-2006	Spain	[164]
	Rupicapra pyrenaica	43	63	X		M.E.	Unspecified	1988	Spain	[165]
	Capra ibex	157		(case report)		M.E.	Unspecified	1995-2006	Italy	[166]
	Spanish ibex			100 (epizoology)	-	histopathology	New infection of a naive population		Spain	[165]
TREMATODA										
Dicrocoelium dendriticum	*Capreolus capreolus*	1	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	4	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Fasciola hepatica	*Capra pyrenaica*	10	2096$	X		Necropsy	Unspecified	1995-2006	Spain	[164]
		5	380$	X		Coprology	Unspecified	1995-2006	Spain	[164]
	Cervus elaphus	5	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	1	1	Case report		Necropsy	Unspecified	2006	France	[32]
		1	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Alces alces	1	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Fascioloides magna	*Cervus elaphus*			Case report		Necropsy	Unspecified		Croatia	[33]
Liorchis scotiae	*Alces alces*	4	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Parafasciolopsis fasciolaemorpha	*Alces alces*	8	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	2	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Paramphistomum cervi	*Cervus elaphus*	3	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Paramphistomum ichikawai	*Alces alces*	6	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	2	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
CESTODA										
Echinococcus	*Alces alces*	3	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]

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granulosus	*Cervus elaphus*	3	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Moniezia benedeni	*Alces alces*	5	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Taenia hydatigena	*Alces alces*	8	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	1	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	2	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Taenia krabbei	*Cervus elaphus*	2	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
NEMATODA										
Bunostomum trigonocephalum	*Alces alces*	5	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Chabertia ovina	*Capreolus capreolus*	8	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Dictyocaulus eckerti	*Alces alces*	4	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	2	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	9	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Nematodirus oiratianus	*Cervus elaphus*	4	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Oesophagostomum venulosum	*Alces alces*	3	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	5	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	5	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Onchocerca flexuosa	*Cervus elaphus*	10	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Setaria cervi	*Capreolus capreolus*	4	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Trichuris ovis	*Alces alces*	6	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Capreolus capreolus	6	18	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
	Cervus elaphus	5	16	X		H.E.	Unspecified	1981-1998	Belorussian Polesie	[155]
Trichinella spp.	*Sus scrofa*	13	1035		X	ELISA	Unspecified	2003-2004	Slovak republic	[167]
		30	1492	X		ELISA	Unspecified	2006-2008	France	[168]
Trichinella britovi	*Sus scrofa*	1	1		Case report	Artificial digestion + PCR	Unspecified	2004	Belgium	[169]
		3	3		Cases report	Artificial digestion + PCR	Unspecified	Unspecified	Roumania	[170]
Trichinella spiralis	*Sus scrofa*	2	2		Case report	Artificial digestion + PCR	Unspecified	Unspecified	Roumania	[170]
		-	458		6.8%	ELISA	Unpecified	Unspecified	The Netherlands	[171]
Toxocara spp.	*Sus scrofa*	85	1173		X	ELISA	Unspecified	2003-2004	Slovak republic	[167]
Ascaris suum	*Sus scrofa*	45	411		X	ELISA	Unspecified	2003-2004	Slovak republic	[167]

<u>Legend</u>: *: farmed animals; $: same study total of 2096 ibexes: all were analysed by necropsy and 380 of them were additionally analysed by coprology; cDAT: commercial Direct Agglutination Test; ELISA: Enzyme Linked Immuno Sorbent Assay; IF: immunofluorescence; IFAT:

Indirect Fluorescent Antibody Test; H.E.: Helminthological Examination: dissection and organ compression; MAT: Modified Agglutination Test; M.E.: Microscopic Examination; PCR: Polymerase Chain Reaction.

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Table I. Classification, origin of the populations and geographical distribution of ungulates presents in Europe (from [5])

Family	***Sub-family***	***Species***	**Latin name**	**Natural/ introduction**	**European location**
Suidae		Wild boar	*Sus scrofa*	Natural populations Introductions in Great Britain	All European countries
Cervidae	Cervinae	Chital	*Axis axis*	Introductions	Croatia, Istrian peninsula
		Fallow deer	*Dama dama*	Introductions Almost all populations are farmed animals.	All European countries
		Red der	*Cervus elaphus*	Natural populations Introductions in Corsica Introduction in Sardaigna	All European countries
		Sika deer	*Cervus nippon*	Introductions in the XIX^{e} century	Northern Europe
		Reeves' muntjac	*Muntiacus reevesi*	Introductions in beginning of XXe century (native from China)	Great Britain
	Hydropotinae	Chinese water deer	*Hydropotes inermis*	Introductions	Great Britain
	Capreolinae	European roe deer	*Capreolus capreolus*	Natural populations	All European countries
		Elk	*Alces alces*	Natural populations	Northern Europe
		White-tailed deer	*Odocoileus virginianus*	Introductions (native from North America)	Finland, Czech Republic, Serbia, Croatia
		Reindeer	*Rangifer tarandus*	Natural populations Introduction in Iceland	Scandinavia Iceland
Bovidae	Bovinae	European bison	*Bison bonasus*	Natural populations or reintroductions	Central Europe (Poland, Byelorussia, Lithuania, Ukraine)
	Caprinae	Barbary sheep	*Amnotragus lervia*	Introductions	Spain
		Muskox	*Ovibos moschatus*	Introductions	Norway, Greenland
		Mouflon	*Ovis gmelinii*	Natural populations and introductions	All central and South of Europe
		Alpine chamois	*Rupicapra rupicapra*	Natural populations	Alpine mountains
		Pyrenean chamois	*Rupicapra pyrenaica*	Natural populations	Pyrenean mountains (France and Spain) Cantabric mountains (Spain) Abruzzi (Italia)
		Wild goat	*Capra aegragrus*	Introductions	Mediterranean islands (Balearic Islands, Crete)
		Alpine ibex	*Capra ibex*	Natural populations and reintroductions	Alpine mountains (France, Switzerland, Italy)
		Spanish ibex	*Capra pyrenaica*	Natural populations and reintroductions	Mountains of Spain and Portugal

Table II. Evolution of European lands resources

	1990/1961	**2008/2000**
Country area	1,000	1,000
Agricultural area	0,993	0,967
Arable land	0,935	0,964
Arable land and Permanent crops	0,939	0,963
Fallow land	*	*
Forest area	*	**1,005**
Inland water	1,003	1,008
Land area	1,000	1,000
Other land	*	1,014
Permanent crops	**1,024**	0,948
Permanent meadows and pastures	**1,047**	0,973
Temporary crops	*	*

Legend:
Ratios (i) equal 1 mean that the area stayed constant during the period considered (ii) lower than 1: diminution of the area (iii) higher than 1: augmentation of the area concerned .

These ratios were obtained dividing land areas (in 1000 Ha) of 2 years. We performed 2 ratios, [area in 1990]/[area in 1961] and [area in 2008]/[area in 2000], to have a constant total European countries area (which changed between 1990 and 2000)

*unavailable data

Data obtained from the fao website, consulted 19 December 2010 (updated on September 2010). http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor. Request was effectuated with the selection: (i) Country: “Europe + (Total)” and “Europe > (List); (ii) Year: “1961, 1970, 1980, 1990, 2000, 2008”; (iii) Item: “Country area, Agricultural area, Arable land, Arable land and Permanent crops, Fallow land, Forest area, Inland water, Land area, Other land, Permanent crops, Permanent meadows and pastures, Temporary crops”.

Table III. Evolution of the number of living animals in Europe

	1970/1961	1980/1970	1990/1980	2000/1990	2009/2000	**Global rate 2009/1961**
Cattle	**1,13**	**1,15**	0,98	0,60	0,85	0,65
Goats	0,76	**1,01**	**1,28**	0,86	0,84	0,71
Pigs	**1,11**	**1,33**	**1,05**	0,77	0,94	**1,12**
Sheep	0,96	**1,04**	**1,11**	0,50	0,89	0,49
Donkeys	0,69	0,72	0,81	0,59	0,79	0,19
Buffaloes	0,89	0,85	**1,04**	0,40	**1,49**	0,47
Camels	0,86	0,97	**1,11**	0,04	0,70	0,02
Horses	0,70	0,72	0,92	0,69	0,90	0,29
Mules	0,57	0,52	0,63	0,70	0,85	0,11

Legend:
Ratios (i) of 1 mean the numbers remained constant during the period of concern (ii) ratios < 1: decreased number (iii) and > 1: increased number. These ratios were obtained by dividing numbers of animals aged 2 years.

Data obtained from the fao website, consulted 19 December 2010 (updated on September 2010). http://faostat.fao.org/site/573/default.aspx#ancor. Request was effectuated with the selection: (i) Country: “Europe + (Total)” and “Europe > (List); (ii) Year: “1961, 1970, 1980, 1990, 2000, 2009”; (iii) Item: “Cattle, Goats, Pigs, Sheep, Asses, Buffaloes, Camels, Horses, Mules”.

Figure 1. Spatial classification (local *vs*. global) of the main factors involved in the transmission of pathogens between wild and domestic ungulates