WILDLIFE: A HIDDEN WAREHOUSE OF ZOONOSIS – A REVIEW

1Kuldeep Dhama, 2Karthik, K., 3Sandip Chakraborty, 4Ruchi Tiwari and 5Sanjay Kapoor

1Division of Pathology, 2Division of Bacteriology and Mycology, Indian Veterinary Research Institute, Izatnagar, Bareilly (U.P.) - 243122
3Animal Resources Development Department, Pt. Nehru Complex, Agartala, Pin - 799006
4Department of Veterinary Microbiology and Immunology, Uttar Pradesh Pandit Deen Dayal Upadhayay Pashu Chikitsa Vigyan Vishwa Vidyalya Evum Go-Anusandhan Sansthan (DUVASU), Mathura (U.P.) - 281001
5Department of Veterinary Microbiology, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, Haryana- 125004

ABSTRACT

Much has been studied about the involvement of domestic or companion animals which are around us, for their role in transmission of diseases. But, little is known about the involvement of wild animals in broadcasting of some zoonotic diseases which affect human to maximum level. It has increased the need to study many of such diseases as their spread is often difficult to prevent. They may be viral viz., Rabies, Avian influenza, Severe acute respiratory syndrome (SARS), Viral encephalitis and Haemorrhagic fever, Hendra and Nipah viral infections, Rift valley fever, Monkey pox and Kaysunur forest disease (KFD); bacterial viz., Brucellosis, Leptospirosis, Lyme disease, Psittacosis, Plague, Tuberculosis, Human monocytic ehrlichiosis or parasitic viz., Alveolar Echinococcosis. Population explosion and changes in agricultural practices, travel and tourism and exotic pet keeping are the factors which play critical role in their spread. It is comparatively more difficult to monitor diseases in wildlife than in domestic animals and in the present day context of rapid human and animal translocation, the surveillance and monitoring of disease outbreaks in wildlife populations are particularly relevant. Monitoring mortality event, active surveillance, understanding the ecological patterns of disease distribution and identification of the factors associated with host-agent-environment relationship are of utmost importance. Manipulating the size of the host population by population reduction through evaluation of the desired level of population decrease and attempts to reduce large population by culling (fetal control), vaccination and medical therapy, and medical tools employed to limit the population growth of a maintenance host species (contraception), isolation and zoning, employment of geographical information system (GIS) all contribute effectively in the prevention and control programme according to feasibility. The present review describes the pathogens and diseases of wildlife having public health significance, their transmission to humans and strategies for their surveillance and monitoring along with suitable prevention and control measures to be followed, which altogether would be helpful for formulating effective strategies for preventing and controlling wildlife zoonosis. The review would be useful for wildlife experts, epidemiologists, field analysts, veterinarians and medical health professionals.

INTRODUCTION

Zoonotic diseases, the one which are transmitted between human and animal under natural conditions, are gaining importance because of the difficulties faced in prevention of their spread. Much has been studied about the involvement of wild animals in broadcasting of these diseases. Usually, the free-roaming animals such as mammals, birds, fish, reptiles, and amphibians are included in the wildlife. Of late marked threat of zoonoses emerging from the wild animals is being observed. The huge diversity and wide distribution of wild animals in different environments, habitats and ecological niches makes them a potential source of zoonoses due to a number of factors (Lanfranchi et al., 2003, Bengis et al., 2004, Jones et al., 2008). The emergence of new pathogens from animal reservoirs occurs due to certain changes in the ecology that results in increased opportunities for the pathogen to enter the human population and subsequent effective human-to-human transmission can take place when the pathogen’s basic reproductive number, R(0), exceeds one (i.e. R(0) > 1) (Antia et al., 2003). The zoonotic pathogens from wild animals can be transmitted to humans in two different ways. In the first case as is exhibited by HIV, influenza A, Ebola virus and SARS virus, the pathogens are transmitted very rarely but once this rare event occurs then the subsequent human-to-human transmission is maintained either briefly or permanently. In the second situation as is observed in lyssaviruses, Nipah virus, West Nile virus, Hantavirus, and the agents of Lyme borreliosis, plague, tularemia, leptospirosis and ehrlichiosis, the principal reservoirs of the pathogens are the wild animals. These agents are transmitted to the humans from the wild animals directly or through vectors and only on rare occasions the human-to-human transmission occurs (Bengis et al., 2004). It has been reported of 1415 different species of pathogenic organisms that can infect humans (Cleaveland, et al., 2001), 60% are zoonotic, with about three-fourth (72%) are coming from wildlife (Woolhouse and Gaunt, 2007; Jones...
et al., 2008; FAO, 2010). From time to time the world has witnessed a significant and serious threat and consequences to public and animal health by wildlife zoonoses occurring from brucellosis, tuberculosis, avian influenza, SARS, human African trypanosomiasis, rabies and anthrax etc that are manifested in the form of massive morbidity and mortality, unparalleled economic losses, trade embargo, disruption of tourism. Due to climate changes, global warming, increasing population, changes in ecosystem and biodiversity, and many other factors various diseases are emerging and re-emerging and also few new pathogens are evolving which are adversely affecting animal and human health (Morse, 1995; Taylor et al., 2001; Patz et al., 2005; Rogers and Randolph, 2006; Myers and Patz, 2009; Dhma et al., 2008a; Bloom, 2011; Dhma et al., 2012a; Mahima et al., 2012; Palmer et al., 2012, Dhma et al., 2013a). Emerging and re-emerging zoonoses are kind of zoonoses which are recognised newly or newly progressed or mutated version of already existing disease (Bengis et al., 2004; Jones et al., 2008). Most of the emerging zoonotic diseases are from viral origin and that too transmitted by vectors (Taylor et al., 2001) and for the most part are transmitted by wild life (Woolhouse, 2002; Woolhouse and Gowtage-Sequeria, 2005; Cleaveland et al., 2007). Transmission of zoonotic diseases from wild animals occurs by contact with wild animals, bite, aerosols, vectors like mosquitoes, ticks fleas, or through contaminated food and water (Kruse et al., 2004). There is no escape of any country from the spread of dangerous disease to the humans from animals.

The urgent need of various partnerships and collaboration lie in the critical difference in the response to emerging and re-emerging zoonotic diseases. It illustrates a new interdependence characterizing our near future, being governed by the complexity of human-animal relationships including wildlife (Garrett, 1994; Dazak et al., 2000, Zinsstag et al., 2007; Zinsstag and Tanner, 2008; Cascio et al., 2011; Dhma et al., 2013a). The major contributing factors for the spread of zoonotic diseases are 1) encroachment of wild areas by human habitation 2) movement of wild animals 3) easy transmission of zoonotic pathogens due to altered distribution of wild hosts and vectors because of climatic changes 4) host and vector expansion, 5) transport of live animals and products between continents 6) migratory birds are a major source which act as a flying machines in the rapid transport of zoonotic diseases like avian influenza 7) domesticating or petting of exotic animals or birds are also a reason for the spread (Morse, 1995; Gortázar et al., 2007, Myers and Patz, 2009; Dhma et al., 2008a; FAO, 2010, Plowright et al., 2011, Bekker et al., 2012, Mahima et al., 2012; Dhma et al., 2013a). Livestock products trade has led to emergence and re-emergence of zoonotic microbes, of which RNA viral diseases are most common (Smith et al., 2012). Some of the emerging infectious diseases of humans viz., hanta virus pulmonary syndrome; severe acute respiratory syndrome (SARS), monkeypox and ebolilhieses are transmitted by wild life reservoirs.

Their devastating effects are achieved by cross-species transmission of pathogens. Several factors contribute to the appearance and spread of a pathogen from wild life viz., changes in host/pathogen evolution and interaction, human demographics, behaviour and technology; environmental factors and the availability of health care as well as Public health infrastructure facilitating surveillance and interventions to enable disease prevention and control (Childs et al., 2007; Dhma et al., 2013a). The present review particularly aims at giving a special emphasis to such aspects which when implemented could curtail the spread of a plethora of pathogens from wild life, thereby safeguarding human health. It describes the pathogens and diseases of wildlife posing zoonotic threats, their transmission to human beings and public health concerns, strategies for their surveillance and monitoring, and appropriate prevention and control measures to be followed, which altogether would curb dangers of wildlife zoonosis. The review would be useful for wildlife experts, epidemiologists, field analysts, veterinarians and medical health professionals to prevent and control such diseases with more expertise and precision.

Population Explosion, Changes in Agricultural Practices and Zoonosis

Anthropogenic factors are considered as important part in the spread of zoonotic diseases from wild animals (Rhyander and Sparker, 2010). Steep rise in human population has led to colonization of lands which historically are places of wild animal dwellings. Deforestation, mining activities in the forest areas and abolishing wild areas are the other major factors which have resulted in encroachment of human into wild animals habitat, thus spread of diseases which are not common to human. Water sports, rafting, wild life safari and mountain climbing and many other adventurous sports are also exposing wild life and untouched wild ecosystem to human. Increase in import or trade of wild animals also contribute to the spread of zoonotic diseases like rabies, anthrax, tuberculosis, Echinococcosis, leptospirosis, Marburg and Ebola viruses (Pavlin et al., 2009). Rabies, a well documented deadly viral zoonoses is known to be spread through affected dogs. The role played by other members of the family Canidae like foxes and wolves in the spread of rabies to humans in known. But participation of Vampire bats in the spread of rabies is not well known to all people. These bats are common transporters of rabies virus to humans in American countries like Brazil, Colombia and Latin America (Schneider et al., 2005). Raccoons and mongoose also act as reservoir for rabies (Sleeman, 2006). A well known example of disease transmitted from wild animals is yellow fever, a disease highly prevalent in African countries, transmitted by mosquitoes to man from monkeys affecting 200,000 people each year (World Organization for Animal Health, 2010).

In rural areas, farmers used to work near the forest areas and are among the most susceptible population due to easy and direct exposure to wild habitat. Similarly, tribals residing in forest areas and on the outside forests but in close vicinity to wild life, who used to visit in core areas of forests for fruits, wild vegetables, and also for hunting, are also among the softest target of wild life exposure. These are the conditions which lead to transmission and spread of Kyasan forest disease. When this disease first hit human, a 300 square miles area was the red alert zone (Varma, 2001; Chomel et al., 2007). However, the situation changed in 1983, when this tick borne viral disease hit back strongly it affected a lot of monkeys and thousands of human. The main reason behind this sudden increase was the human movements into the protected forest. Mostly workers in the forest were affected in that outbreak (Varma, 2001). Nothing remains constant in this world and there is always risk involved in all activities dealing with wild life. Encroaching wild life areas alone has not contributed to the spread of zoonotic disease to human population. There are instances where the reverse has also happened i.e. replacing the agricultural land with forest has also been reported to spread of diseases to human. The classical example is the spread of Lyme disease caused by Borrelia burgdorferi, which also is a tick borne disease of bacterial origin (Walker et al., 1996; Dhma et al., 2013b). Many-a-times natural calamities as flood, heavy snow fall, fire in forest areas also force the wild life into human residential and agriculture areas and thus the increase in the number of wild animals around human dwelling also results in higher chances of spread of zoonotic diseases like plague (Rosenthal, 2009).

Zoonosis is not always one sided, but it is a two way traffic and hence wild animals are also at risk because of movement of humans into animal dwellings. Improper deposition of carcasses is most common cause of wild life exposures. Most of third world countries do not have such facilities and dead animals are mostly disposed of near river banks and away from the human population outside the forest areas. Vultures and wild carnivores used to get infections from civilized world viz., FMD, Brucellosis, Rabies, Tuberculosis, Anthrax, E. coli O157:H7; Salmonellosis, Campylobacteriosis etc (Schloegel, et al., 2005; Rwego et al., 2008). The spread of Argentine hemorrhagic fever among the adult male agricultural workers from east-central
Argentina to north-central Argentina in the 1950s is attributed to corn growing that facilitates sustenance of Calomys musculinus (corn mouse) which acts as the main reservoir of the virus (Charrell and de Lamballerie, 2003). Browsing on thorny acacia trees by the Kudu tribe of Africa is considered as the reason for spread of rabies (Chornel et al., 2007). Destruction of wild habitats of fruit bats (Peripropus vampyrus): the reservoirs of Nipah virus results in the spread of infection due to Nipah virus. In this regard deforestation and fruit-bearing tree production along with farming involving non-industrial pigs act as contributory factors (Daszak et al., 2001; WAOH, 2010; Chakraborty, 2012). Similarly, increased density of flowering and fruiting trees and vegetation have increased the incidence of hendra viral infection (http://www.dpi.qld.gov.au/cps/rdi/dpi/hx.xs; Dharma et al., 2010a). The spread of tuberculosis caused by Mycobacterium tuberculosis, a bacterial disease to sur cats and mongooses has been well picturized (Alexander et al., 2002; Tschopp et al., 2009). Bovine tuberculosis in captive deer populations (Wilson, 2002) and brucellosis in wild boar (Godfroid et al., 2005) are also considered as the outcomes of changes in agricultural practices.

**Zoonotic Pathogens and Diseases Transmitted by Wild Life**

Wild animals can act as reservoirs of many diseases transmissible to human. The prospects of members of new host species getting infected by a pathogen depends on a number of factors and increases with the abundance of the reservoir host, the infected fraction within the reservoir host, the contact rate between the reservoir and/or the vector and new host, and the likelihood of transmission during each contact (Wolfe et al., 2007). The zoonotic pathogens (such as Rabies, Hantavirus, Leptospirosis, Brucellosis, Salmonellosis, Psittacosis, Histoplasmosis, Cryptococcus, Trichinosis, Plague) can be transmitted to humans from wildlife directly by bites or contamination; or indirectly through the bite of infected arthropod vectors such as mosquitoes (e.g. eastern equine encephalitis, and western equine encephalitis), ticks (e.g. Colorado tick fever, Rocky Mountain spotted fever, Tularemia, ehrlichiosis, spirochaete causing Relapsing fever, fleas (e.g. Plague, Murine typhus fever). Cats constitute 20% (Calisher et al., 2006) and rodents constitute 40% (Huchon et al., 2002) of all mammalian species and both are widely distributed throughout the globe. The mice, rats, voles, squrells, beavers, prairie dogs, chipmunks, and guinea pigs are some of the well known rodents in the order Rodentia that can transmit about 60 infectious diseases to humans either directly through their urine, faeces, or indirectly through ticks, mites, and fleas (Meerburg et al., 2009). Some of important zoonotic viral diseases/ viruses transmitted from the rodents are: hantavirus pulmonary syndrome, hemorrhagic fever with renal syndrome, Tula virus, Tick-borne encephalitis virus, Lassa fever (Klein and Calisher, 2007; Charrel and de Lamballerie, 2010; Cutler et al., 2010; Phan et al., 2011).

Bats have been considered as a keystone species that are very important in maintaining ecosystems (Kunz et al., 2011). Bats also have been found to be one of the most important reservoirs as well as disseminator of wildlife zoonoses. This has been attributed to the bat ecology, their unique biological & behavioural traits, such as: only mammals capable of flying, social friendly colony structure, long lifespan relative to their size and metabolic rate, efficient use of torpor, highly synchronized parturition & availability of naive susceptible dense population and colony roosting behaviour (Wang et al., 2011; Wood et al., 2012; Hayman et al., 2013). Many of the wildlife zoonotic pathogens have multi-host pathogen dynamics but the bats provide a distinct multi-pathogen dynamics in a single host species for expanding our knowledge in the larger context of controlling wildlife zoonoses. Bats have been implicated and identified as the likely reservoir for many important and global zoonotic diseases and are the sources for rabies and other lyssaviruses (Streicker et al., 2010), severe acute respiratory syndrome coronavirus (Li et al., 2005; Wang et al., 2006, Field, 2009, Goullt et al., 2011), Hendra (Halpin et al., 2000; Field, 2009), Nipah (Field, 2009; Luby et al., 2009; Pulliam et al., 2012), Ebola (Leroy et al., 2004, 2009) and Marburg viruses (Towner et al., 2009), influenza A virus (Tong et al., 2012) and various paramyxoviruses (Drexler et al., 2012), bacteria e.g. Bartonella (Kosoy et al., 2010; Bai et al., 2011) and fungi e.g. Histoplasma capsulatum, Geomyces destructans (Taylor et al., 2005). The metagenomics analysis has been done to establish the virome of bats that will help in identifying many more viruses harboured by the bats (Smith and Wang, 2013). Infection with arthropod borne alphaviruses (Chikungunya), flaviviruses (Japanese encephalitis virus) and bunyaviruses (Rift Valley fever) has been reported in bats. It is unclear whether bats act as the reservoir hosts for these viruses in causing zoonosis (Calisher et al., 2006). Transmission of rabies by red fox (Vulpes vulpes) in the European continent; bovine tuberculosis by badgers (Meles meles) (Artos, 2003; Palmer et al., 2012) are some classical examples in this regard. Technical difficulties may sometimes prove to be conducive for the survival of the pathogen; as in case of leptospirosis which arise due to difficulties associated with purification of soil or water contaminated with the infectious agent; or tick born encephalitis and West Nile fever in case of which vector control proves to be troublesome (Debeinski and Holt, 2000; Dharma et al., 2010b). There may be association of reservoir dynamics complexities in the wild life population which may show both temporal and spatial changes; as are frequently observed in case of brucellosis in elk (Cervus elaphus) (Cross et al., 2010).

In addition, insufficient knowledge about the maintenance host may also hamper the epidemiological investigation; as is the case with African buffaloes (Syncerus caffer) as maintenance host of Brucella infection (Alexander et al., 2012). Alternate host species (bats viz., Mnius spiniferus and Rhinolophus elocuens) do exist for various pathogens including Marburg virus that presents a challenge particularly for characterization of these complex systems (Swanepeol et al., 2007). In case of certain viral infection the transmission cycle is extremely complex; for example; Ebola hemorrhagic fever where infected bush meat plays a role in direct transmission of the disease (Leroy et al., 2009). Bacterial zoonoses gain much importance due to involvement of secondary hosts like certain predators and scavengers that potentially transmit the disease to human; as is the case with anthrax (Blackburn, 2006). Pathogen transmission is also influenced by population size and density of a particular species. Involvement of territories; dominance; breeding behaviour and social system all influence transmission of zoonotic diseases associated with wild life and allows the infectious disease itself to modify population dynamics and wildlife life systems (Lanchis et al., 2009). The situation takes a complicated turn when there is risk of transmission of diseases from human to wild life as are seen in case of various protozoan diseases like Giardiasis (caused by Giardia duodenalis) in bandicoot (Isoodon obesulus) and Cryptosporidiosis in mountain gorillas (Grzyb et al., 2001; Adams et al., 2004; Weiss, 2008). Some of the zoonotic pathogens and diseases transmitted by wild life, their transmission and spreading agents/vehicles, clinical signs and few salient remarks are described in Table 1 and Figure 1.

**Travel and Tourism Playing Role in Wildlife Zoonosis**

An important component of leisure travel industry having high growth rate is the adventure travel and include: safariis, tours, sports travel. Tourists travel to the wild life areas and fetches money but there is always a risk of transmission of disease which are not present in those parts of the world due to every possible chance of contracting pathogen. This mobility of human has lead to change in epidemics of diseases, spread of diseases (Chen, 2003). Transport of even wild animals has also led to the spread of diseases. Thus, both human and animals act as a courier acting silently as a carrier for some emerging and re-emerging deadly diseases. Disease status and vaccination status of the humans are under scanner during travel and tourism to other parts of the world but that is not the case during the transport of the animals (Smith et al., 2012). Illegal trade of wild life both in the form of live and dead has also contributed to the spread of zoonotic diseases in different parts of the world. This has made the world to come under a single umbrella of zoonotic diseases. The SARS, which has shown its potential in China as a...
Table 1. Zoonotic pathogens / diseases transmitted by wildlife

<table>
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<tr>
<th>S.No</th>
<th>Disease/ pathogen</th>
<th>Microbe type</th>
<th>Transmitters</th>
<th>Signs</th>
<th>Remark</th>
<th>References</th>
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<tbody>
<tr>
<td>1</td>
<td>Avian influenza (Bird flu)</td>
<td>Influenza A viruses- Orthomyxo viridae</td>
<td>Wild and migratory birds</td>
<td>Chills, fever, sore throat, muscle pains, headache (often severe), coughing, weakness/fatigue and general discomfort.</td>
<td>Serious pandemic occurred in 1918. Pigs and poultry act as a mixing vessel (genetic recombination takes place in these species) and hence transmitting a newly evolved influenza to human. H5N1, H9N2 are some of the subtypes which commonly occur during pandemics</td>
<td>Alexander and Brown, 2000; Castrucci et al., 1993; Horimoto and Kawaoka, 2001; Dhama et al., 2005; Munster et al., 2006; Feare, 2007; Dhama et al., 2008a; Krauss and Webster 2010</td>
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<td>2</td>
<td>Viral encephalitis</td>
<td>Alpha virus- Togaviridae</td>
<td>Passerine birds and rodents</td>
<td>Altered mentation, partial or complete blindness, aimless wandering, head pressing, circling, grinding of teeth, inability to swallow due to esophageal paralysis, irregular ataxic gait, paresis and paralysis, convulsions, and death.</td>
<td>Some of them can act as potential bioterrorism weapons (e.g. Epidemic Venezuelan Equine Encephalitis)</td>
<td>Gibbs and Long, 2007; Kapoor et al., 2010</td>
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<td>3</td>
<td>Viral haemorrhagic fever (VHF)</td>
<td>Ebola virus</td>
<td>Gorilla (Gorilla sp.), Chimpanzee or Duiker (Sylvicapra grimmia), Fruit bats (Hypsignathus monstrosus, Eponops franqueti and Myonycteris torquata)</td>
<td>Sudden onset of fever, intense weakness, muscle pain, headache and sore throat. Some cases, both internal and external bleeding.</td>
<td>First reported in humans in 1976</td>
<td>Khan et al., 1998; Leroy et al., 2004</td>
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<td>4</td>
<td>West Nile virus - fatal neurological disease</td>
<td>West Nile virus - Flaviviridae</td>
<td>Crow (Corvidae family)</td>
<td>Headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, convulsions, muscle weakness, and paralysis.</td>
<td>First isolated in Uganda in 1937. Mammals are the dead end hosts. Transmitted through bite of mosquitoes (C. Pipiens). Caused few outbreaks in Australia in horses and human but possible genetic diversity may allow generation of more infective virus.</td>
<td>Taylor et al., 1956; OIE, 2004; Kilpatrick et al., 2008 ; Dhama et al., 2010b</td>
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<td>5</td>
<td>Hendra viral infection</td>
<td>Hendra virus</td>
<td>Fruit bats (Pteropodidae family)</td>
<td>Fatal respiratory and neurological signs</td>
<td>First recognized in 1993. Infection to man occurs through aerosol route</td>
<td><a href="http://www.dpi.qld.gov.au/cps/red/pnuh">http://www.dpi.qld.gov.au/cps/red/pnuh</a>; Dhama et al., 2010a</td>
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<td>7</td>
<td>Monkeypox</td>
<td>Poxvirus</td>
<td>African squirrel, monkeys</td>
<td>Pock lesions over the body</td>
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<td>Reed et al., 2004</td>
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<td>8</td>
<td>Nipah viral encephalitis</td>
<td>Nipah virus- Henipavirus genus- Paramyxoviridae</td>
<td>Pigs, mobile fruit bats</td>
<td>Fever, headaches, myalgia (muscle pain), vomiting and sore throat. Encephalitis and seizures occur in severe cases, progressing to coma</td>
<td></td>
<td>Mohd Nor et al., 2000 ; Chua, 2003; Chakraborty, 2012</td>
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<td>No.</td>
<td>Disease</td>
<td>Pathogen and Vectors</td>
<td>Symptoms</td>
<td>Information</td>
<td>References</td>
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<td>9</td>
<td>Rabies – acute encephalomyelitis</td>
<td>Lyssavirus-Rhabdoviridae Raccoon (Procyon lotor), Skunk (Mephitis mephitis), Fox (Vulpes vulpes), Urocyon cinereoargenteus and Alopex lagopus), Coyote (Canis latrans), Vampire bats (Desmodus rotundus)</td>
<td>Aimless wandering, lethargy, ataxia, hindleg weakness, paralysis and loss of awareness. Oldest zoonotic disease. It has its sting throughout the world except some parts of the world.</td>
<td>Ballard et al., 2001; Ballivet, 2004; Sall et al., 1998</td>
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<td>10</td>
<td>Rift Valley fever</td>
<td>Phlebovirus-Bunyaviridae Buffalo (Syncerus spp.), Antelope (Tragelaphus spp.) and Camels (Camelus spp.)</td>
<td>Influenza-like symptoms, but severe complications, including ocular sequelae, encephalitis and haemorrhagic disease. Reports of the disease are documented in 1950s. Transmitted principally through mosquito bite (Aedes)</td>
<td>In 2002-2003, first it hit South east Asia. SARS pandemic was brought under control in 2003. Human to human spread is possible</td>
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<td>11</td>
<td>Severe acute respiratory syndrome (SARS)</td>
<td>Coronavirus Masked palm civets (Paguma larvata)</td>
<td>A dry cough, breathing difficulties, an increasing lack of oxygen in the blood, which can be fatal in the most severe cases.</td>
<td>In 2002-2003, first it hit South east Asia. SARS pandemic was brought under control in 2003. Human to human spread is possible</td>
<td>Xu et al., 2004</td>
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<td>12</td>
<td>Tuberculosis</td>
<td>Bacterial-Mycobacterium bovis Buffalo (Syncerus caffer), Lechwe (Kobus leche), Warthog (Phacochoerus africanus), Kudu (Tragelaphus strepsiceros), Wild boar (Sus scrofa)</td>
<td>Cough up blood, chest pain, nodules in other parts of the body. Age old disease. Commonly called of King of all diseases.</td>
<td>Age old disease. Commonly called of King of all diseases.</td>
<td>Michalak et al., 1998; Bengis, 1999; Clifton et al., 2001; Alexander et al., 2002 Thorne, 2001; Godfroid et al., 2005; Cross et al., 2010</td>
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<td>13</td>
<td>Brucellosis</td>
<td>Bacterial-Brucella spp. (Brucella abortus, B. melitensis, B. suis) Caribou and reindeer (Rangifer tarandus), European brown hare (Lepus capensis Linnaeus)</td>
<td>Undulant fever, Headache, Weakness, muscle pain, Depression, Weight loss, Fatigue</td>
<td>Brucella also affects marine mammals like whales and seals, which has been recently identified. This also plays role in zoonosis. Transmitted through consumption infected milk or spread through cut wounds Transmitted by ingestion of contaminated water, handling or ingesting infected milk or tissues, transplacental invasion, sexual contact, social grooming.</td>
<td>Trevejo et al., 1998; Leighton and Kuiken, 2001; Verma et al., 2012</td>
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<td>14</td>
<td>Leptospirosis</td>
<td>Bacterial-Leptospira interrogans Rodents, wild canids</td>
<td>Septicaemia, haemolytic anaemia, hepatitis, nephritis, jaundice</td>
<td>Septicaemia, haemolytic anaemia, hepatitis, nephritis, jaundice</td>
<td>Trevejo et al., 1998; Leighton and Kuiken, 2001; Verma et al., 2012</td>
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<td>16</td>
<td>Plague</td>
<td>Bacterial-Yersinia pestis Rodents, such as prairie dogs (Cynomys spp.)</td>
<td>Gangrene of the extremities such as toes, fingers, lips and tip of the nose, Chills, General ill feeling (malaise), High fever (39 °Celsius; 102 °Fahrenheit), Muscle Cramp, Seizures, Smooth, painful lymph gland swelling called a buboe</td>
<td>Gangrene of the extremities such as toes, fingers, lips and tip of the nose, Chills, General ill feeling (malaise), High fever (39 °Celsius; 102 °Fahrenheit), Muscle Cramp, Seizures, Smooth, painful lymph gland swelling called a buboe</td>
<td>Chanteau et al., 1998; Gasper and Watso, 2001</td>
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<td>No.</td>
<td>Disease</td>
<td>Agent</td>
<td>Animals/Hosts</td>
<td>Symptoms</td>
<td>Transmission</td>
<td>References</td>
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<td>17</td>
<td>Psittacosis</td>
<td>Chlymidial- <em>Chlamydiophila psittaci</em></td>
<td>Waterfowl, herons, gulls, terns, shorebirds, songbirds, and upland gamebirds and pigeons</td>
<td>Fever, arthralgia, diarrhea, conjunctivitis, epistaxis and leukopenia</td>
<td>Organism excreted in droppings and survive for long periods and hence transmission to humans are possible</td>
<td>Sleeman, 2006</td>
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<td>18</td>
<td>Human monocytic ehrlichiosis</td>
<td>Rickettssiales - <em>Ehrlichia</em> and <em>Anaplasma</em> spp. (E. chaffeensis, E. ewingii and A. phagocytophilum)</td>
<td>White-tailed deer (<em>O. virginianus</em>)</td>
<td>Flu-like illness, at times death. Leukopenia, thrombocytopenia can be noticed</td>
<td>Transmitted by lone-star tick (<em>Amblyomma americanum</em>)</td>
<td>Anderson <em>et al.</em>, 1991; Davidson and Goff, 2001; Sleeman, 2006</td>
</tr>
<tr>
<td>19</td>
<td>Alveolar Echinococcosis</td>
<td>Parasitic- <em>Echinococcus multilocularis</em></td>
<td>Red foxes, arctic foxes, and coyotes</td>
<td>Pain in the areas where cysts are formed. Organ dysfunction can occur</td>
<td>Transmitted through accidental ingestion of eggs which forms cyst in multi organs of the body – hydatid cyst</td>
<td>Sleeman, 2006</td>
</tr>
<tr>
<td>20</td>
<td>Giardiasis</td>
<td>Giardia spp.</td>
<td>Quenda (<em>Isoodon obesulus</em>)</td>
<td>Diarrhoea and other symptoms of parasitic diseases</td>
<td>Faeco-oral route of transmission</td>
<td>Adams <em>et al.</em>, 2004</td>
</tr>
<tr>
<td>21</td>
<td>Baylisascaris procyonis (Raccoon Round worm)</td>
<td>Parasitic - Helminth disease</td>
<td>Raccoons</td>
<td>Blindness, central nervous system disease, or death</td>
<td>After ingestion the larvae hatch and penetrate through the intestine, migrating to many parts of the body like the eye, brain, or spinal cord.</td>
<td>Roussere <em>et al.</em>, 2003</td>
</tr>
</tbody>
</table>

Fig 1. Wild life zoonotic diseases being transmitted to humans – a glimpse
respiratory and gastrointestinal disease, was because of the illegal trade of wild life. Masked palm civets (Paguma larvata) which was infected already was the culprit for the spread of SARS in China. The butchers who slaughtered these animals were the sufferers (Xu et al., 2004). Many of the wild animals are also affected with anthrax and Brucellosis which could be transmitted to humans (Hugh-Jones and de Vos, 2002; Godfroid, 2002). Adventure touring or ecotourism has also been a major risk factor for the spread of diseases to human. The fun loving adventure tourists who are engaged in safaris, tours, adventure sports, and extreme travel are the victims of diseases which are not common in urban areas. African tick bite fever is an example for this type of disease outbreak. Rickettsia aicraceae, is the rickettsial organism involved, transmitted by Amblyomma tick and has been reported in many parts of the world in case of ecotourists (Jenseniuss et al., 2004). Cercopithecine herpesvirus 1 (herpes B virus) which are common in Asian macaques does not cause any damage to these animals but once contracted to human it becomes fatal and causes fatal encephalomyelitis. Contact with macaques during travel to Asian countries has resulted in this fatal disease to many people (Engel et al., 2002; Huff and Barry, 2003). Activities like hunting of wild animals and consumption of game meat/ bush meat also results in spread of zoonotic diseases to humans and it includes trichinella, hepatitis E virus, Brucella, leptospiriosis, tuberculosis and others from wild boar, lion, jackal, hyena, Anthrax from baboon, cheetah, elephant, giraffe, kudu, impala, warthog, zebra, Hydatid disease (Echinococcus granulosis) from giraffe, kudu, lion, warthog, rift valley fever from Alpacas, eland, llama, and E. coli O157:H7 from deer, and Tularemia from hare and rodents (Hugh-Jones and de Vos, 2002; Sleeman, 2006; Weiss, 2008; Meng et al., 2009; Food and Agricultural Organization, 2010; Bekker et al., 2012; Hampton, 2012).

Exotic Pets in the Transmission of Diseases

People around the world are attracted by petting exotic and wild animals and have resulted in increased transport of wild animals. This has also contributed in the spread of wild animal diseases to human (Rhy an and Spark er, 2010). Zoos are other places where people gets proximity with wild animals and birds and these are the places where there is always risk of transmission of diseases like Escherichia coli O157:H7; Salmonella; Chlamydia psittaci and Coxiella burnetti (Bender and Shulman, 2004; Dhama et al., 2013c,d,e). Introduction of reptiles into market as a pet has resulted in spread of diseases especially salmonellosis (Burnham et al., 1998; Warwick et al., 2013). Pet turtle accounted for 14% of the human salmonellosis cases in US (Warwick et al., 2013) and is also transmitted from pet iguana (Chomel et al., 2007). There are instances where there is spread of m ethicillin resistant Staphylococcus aureus (MRSA) from reptiles (Weese, 2010). Circuses are also places where there is contact between wild animals and humans and hence the risks of transfer of pathogens like M. tuberculosis causing tuberculosis (Michalak et al., 1998) and cowpox (Hemmer et al., 2010; Hubä%ek and Rudolf, 2011). Tularemia caused by Francisella tularensis gets transmitted from wild prairie dogs to human (Avashia et al., 2004). Migratory birds and pet birds are the two important causes for the spread of avian influenza and resulting in pandemic infection (Anon, 2005; Dhama et al., 2008a).

Surveillance and Monitoring

It is comparatively more difficult to monitor diseases in wild life than in domestic animals. There are several hurdles in monitoring the wild life diseases like political, legal problem, and also lack of basic and proper understanding about the disease, agent and host (Rhy an and Spark er, 2010). Detection of infectious zoonic diseases from wild life is easier in those countries which conduct disease surveillance of their wild animal population. In the present day context of rapid human and animal translocation the surveillance and monitoring of disease outbreaks in wildlife populations are particularly relevant. Devising a surveillance technique is often difficult in case of wild animals as their population parameters remains unknown (Duncan et al., 2008). Disease surveillance requires multidisciplinary approach in wild life (Rhy an and Spark er, 2010). The baseline virome of several species of wild rodents and bats was constructed by viral metagenomics. The metagenomic analysis on sequence comparisons helped in the identification of both commensals and zoonotic pathogens. Some of the sequences that did not have any match with those available in the current database may have come from viral families which have not been characterized at the genetic/ molecular level. The viromes analysis of wild animals will generate a database that can help in rapid identification of the possible sources/ origins of future zoonotic infections and also in measures to be taken for their mitigation and control (Delwart, 2007; Donaldson et al., 2010; Tang and Chiu, 2010; Svára et al., 2010; Pian et al., 2011; Simon and Daniel, 2011; Ge 2012; Smith and Wang, 2013; Dhama et al., 2013e). The application and usefulness of a novel metatranscriptomics technique for studying wild bats, carnivores and primates as detection of potentially pathogenic novel zoonotic microbes in wildlife was reported (Wittekindt et al., 2010). This technique can prove to be very useful in building an inventory of pathogens harboured by various wild animals. Recently a non-invasive technique infrared thermography that measures and detects thermal changes was applied to differentiated rabies virus infected from non-infected big brown bats. This technique was able to successfully detect 62% of rabid bats whose facial temperature had decreased. The studies on spill over dynamics indicated that the bat rabies virus is not transmitted as such.

It was further observed that substitutions in the glycoprotein G of bat rabies virus are required for cross-species transmission to mesocarnivores and carnivores (Ellison et al., 2013). Establishment of transmission models for diseases is required to determine the disease transmission risk associated with a particular host and the associated pathogen. The transmission rates increases positively with the increase in the population of host (Caley and Ramsey, 2001). Collecting the disease transmission data is important in devising effective control strategy for the zoonotic diseases associated with wild life, but in general there is a paucity of information on this aspect (Caley and Ramsey, 2001). Passive surveillance is generally used in monitoring diseases in wild life (Duncan et al., 2008; Rhy an and Spark er, 2010). Observing for signs of clinical disease in wild animals and investigation of mortality and morbidity events is a basic approach. Monitoring mortality events in wild life include nonstatistical and non-random sampling by large and represent collection of different diseases and causes of deaths perhaps associated with some distributional information (Morn er, 1999). Active surveillance and monitoring for the presence of diseases and wild life health evaluation based on pathological and microbiological data from individual animals are mandatory (Morn er et al., 2002). Active surveillance can be carried out by capturing the animal or hunting and collecting multiple samples. Establishment of temporary feed stations allows monitoring of feral animals as these remain confined to the areas and can be monitored using infra red imaging (Rhy an and Spark er, 2010). Understanding the ecological patterns of disease distribution and identification of the factors associated with host-agent-environment relationship is of utmost importance (Williams et al., 2002). The programmes established in Denmark and Sweden between 1930-1940 were among the earliest surveillance programmes for wild life diseases and are based on the examination of dead animals submitted to national veterinary laboratories.

The need for disease surveillance programmes are gaining much attention and routine collection of specimens for diagnosis and to obtain further information for health and agricultural administration in case of fox rabies is a classical example in this regard (Briones, 2000). One health concept and surveillance through geographical information systems (GIS) and global positioning system (GPS) with satellite tracking and monitoring technologies are gaining popularity nowadays to have an eye on disease incidences, occurrences and outbreaks as well as forecasting the risk factors and practical outcomes (Dhama et al., 2013a). Abattoir inspection of game meat is an efficient way to monitor some important infections including...
tuberculosis. Developing local networks and international reporting system including epidemiological and zoological inputs further strengthens disease monitoring and surveillance; for example: wild bird surveillance for avian influenza (Dhama et al., 2005; Dhama et al., 2008a; Dhama et al., 2013a,f). Progressive expansion of the existing awareness to a large range of species in accordance to what is important at regional and national levels in co-ordination with standard diagnostic facilities are the need of hour (Kuiken et al., 2005; Knight-Jones et al., 2010). Global information system (GIS) and global positioning system (GPS) both acts as a powerful tool by displaying the areas of high disease prevalence and monitoring of ongoing control programmes and their combined efforts provide an integrated approach. This in turn enhances the quality of data analysis and decision making to control the wild life zoonosis and their prevalence at regional (smaller or larger level) or national level (Dhama et al., 2013). Moreover, due to advances in biotechnology and molecular biology better diagnostics in terms of quick, sensitive and confirmatory detection of various pathogens, and these need to be applied for surveillance and monitoring of wild life animals/reservoirs for pathogens and the disease these transmit (Schmitt and Henderson, 2005; Belák, 2007; Bollo, 2007; Ratcliffe et al., 2007; Brown and Stallknecht, 2008; Balamurugan et al., 2010; Gowthaman et al., 2010; Bergquist, 2011; Siembiida et al., 2011; Deb and Chakraborty, 2012; Dhama et al., 2012b).

Prevention and Control

The main bottle neck in case of zoonotic disease is the lack of resources, infrastructure and expertise in diagnosis especially in developing countries (Wastling et al., 1999). Treatment of wild animals is difficult and is often impossible. Understanding the disease ecology is very important in management and control of these diseases but it is very complicated especially in the case of wild life diseases, especially the crucial aspect is implementation of biosecurity principles (Chomel, 2008; Dhama et al., 2012d). The determinants affecting the host, agent and environment has to be taken into account in devising control strategies. A framework for managing the communicable pathogens from wild life must be developed in order to confront the risk posed by them. Manipulating the size of the host population by population reduction is an effective approach in reducing the threshold for disease persistence or in eradication of wild life diseases and zoonotic diseases (Caley and Ramsey, 2001; Wobeser, 2007). They include: evaluation of the desired level of population decrease; attempts to reduce large population by culling, otherwise known as lethal control (which sometimes may prove difficult in certain zoonotic diseases: rabies in foxes); tuberculosis in badgers, brucellosis in bison, etc (Caley and Ramsey, 2001). Culling of the wildlife reservoir for zoonotic pathogens should be one of the last options as it is not a very efficient control method and also disturbs the wildlife ecology much more than other available methods (Artois et al., 2011).

The medical tools for effective prevention and control include: methods that rely on immunogenic products (better known as vaccination); methods based on medical therapy; and medical tools employed to limit the population growth of a maintenance host spece (sterilisation or contraception). Advances in molecular biology and biotechnology have paved way for developing effective, safer and novel vaccines, which need to be explored for their utility in combating wild life zoonosis (Dhama et al., 2008b). The required property of any vaccine varies according to the pathogen and host characteristics and requires proper attention. Use of rabies vaccine contained in baits targeting specific population is an interesting and impressive approach especially to control the disease in wild life. Vaccine efficacy however requires much attention and must be evaluated by microbial population reduction in connection with increase in seroprevalence and particularly is helpful to control rabies both in Europe and America (Foroutan et al., 2002; Carter et al., 2009). The host species should also be considered while using vaccine in wild animals like brucellosis vaccination was found to be ineffective in the control of the disease in elk (Rhyan and Sparker, 2010). Fertility control including contraception to reduce in a sustainable way the growth of an animal population, strengthens the disease control alongside immunisation and therapy and is considered as an alternative to the lethal control methods for reducing the abundance of the host population. The fertility control methods also reduce the spread of vertically transmitted disease in the host population. It can be achieved either by delivering with appropriate tools either a drug or an antigenic protein that can disturb the production or fusion of gametes thereby reducing fertility referred as immuno-contraception (Caley and Ramsey, 2001; Killian et al., 2007; Rhyan and Sparker, 2010). Manipulation of the environmental conditions viz., reducing the availability of resources, reinforcing populations of predators and shelter and changing the spatial distribution of the population by fencing to separate the source population from the target help to reduce host population and thus pathogen transmission. Isolating safe specimens or a safe population e.g., poultry confinement in presence of migratory birds to prevent avian influenza; compartmentalization (in several establishments viz. Parent hatchery, Production farm and Slaughterhouse) and zoning e.g. in case of avian influenza or foot and mouth disease are important for eradication (Wobeser, 2002; Karesh and Cook, 2005; Dhama et al., 2005; Vercauteren et al., 2007; World Organization for Animal Health, 2010; Artois et al., 2011). The development of species richness map by addition of disease outbreaks in an area also contributes to the control of wild life zoonosis (World Database on Protected Areas, 2010).

Moreover, as always supposed that prevention is better than cure, it is encouraging to follow certain guidelines to prevent human to animal and vice versa transmission of zoonotic diseases specially being transmitted by the wildlife, some of which are summarised as below:

- Always vaccinate the animal population residing near to forest area.
- Regular monitoring and serosurveillance of under challenged population.
- Demarcation of areas in zones for serosurveillance, vaccination and threats of exposures.
- Proper disposition of diseased carcasses.
- Proper dispose of biological waste.
- Avoid the postmortem examination in open.
- Maintaining biosafety requirement while handling the samples of wild life.
- Use of Personnel Protective Equipments while handling and processing the wild life samples.
- Establishment of serum banks of wild species for time to time disease investigations.
- Development of data banks regarding the information related to history, occurrence of disease and post infection scenario.
- Establishment of well equipped regional laboratories to deal with potent zoonotic pathogens.
- Placement of skilled, trained and experienced technical staff in regional laboratories and field stations.
- Recruitment of skilled veterinarians and wild life experts in forest reserve areas.
- Development of facilities for the deposition and preservation of wild life specimen.
- Awareness programmes for the tribals, farmers and villagers of the areas.
- Restriction of movement in core forest area.
- Restriction in the encroachment of wild life area.
- Application of GIS for the monitoring of wild life movement and disease monitoring.
- Steps and regulation to avoid man and wild conflicts.
- Rehabilitation of the tribals and other populations residing inside core area to safer places.

(Taylor et al., 2001; Mörner, et al., 2002; Williams et al., 2002; Wobeser, 2002, 2007; Jones et al., 2008; Zinsstag and Tanner, 2008;
Cross, et al., 2010; Gowthaman, et al., 2010; World Organization for Animal Health, 2010; Cascio et al., 2011; Dhma, et al., 2013c; Kumar et al., 2013).

There is an urgent need to establish integrated zonal, regional, national and global wildlife surveillance systems for zoonotic pathogens. Further, the appropriate collected information should be regularly shared and exchanged in real-time among them (Belák, S. 2007). Useful data can only be available to these agencies when the surveillance and reporting systems particularly at the interface between rural populations and wildlife habitats is good enough and is done with sincerity using latest techniques. At present, the approaches to the management of zoonotic diseases are fragmented, isolated and done in bits and pieces. The public health experts deal with human diseases, health of livestock is handled by the veterinarians, wildlife specialists take care of wildlife, while the onus of with ecosystem biodiversity lies with ecologists. Although, wildlife are responsible for a large number of emerging zoonoses, yet they are not given much importance in the ‘One Health’ approach for prevention and control of zoonotic diseases (Sekar et al., 2011, Rostal et al., 2012; Dhma et al., 2013a). One Health concept that shifts the focus from the current disease-centred approach to a holistic, multi-disciplinary approach viewing human health, animal health and the environment in entirety would prove very beneficial in prevention and control of wildlife zoonoses (Wood et al., 2012).

A wide range of trained professionals, such as veterinarians, ecologists, biologists in wildlife health management, working in unison and tandem, are required to intervene as and when outbreaks occur, in order to control these zoonotic organisms before they cause any significant impact on human health, food supply, biodiversity ecology or economy (Gortázar et al., 2007). The awareness, education and implementation of habitat bio-conservation, sustainable agricultural development, proper education of public about the risks of ecotourism in forests and sanctuaries, wildlife trade and translocation, risks of owning exotic pets and adopting wild animals and better control of the live animal trade will go a long way in preventing wildlife zoonoses (Chomel et al., 2007). Interestingly, the development of various novel and emerging therapies would also help in undertaking proper curative measures against many diseases transmitted from wild animals (Dhma et al., 2013 g.h;i; Tiwari et al., 2013a,b). Nevertheless, the conservation of the wildlife and its habitat will be very helpful in preserving vital ecosystem, environmental sustainability, resulting in reduced spillover of pathogens from wild animals into human beings and consequent decreased wildlife zoonoses (Dhma et al., 2013a).

Conclusion and Future Perspectives

Infectious diseases transmitted from wildlife have a major implication on human health leading to tremendous economic losses. Wild animals account for more than 70% of all emerging infections. Unbalanced and selective exploitation of forests along with aggressive agricultural development associated with an exponential increase in export and import of wild animal products (e.g. bush meat trade) are considered as leading factors for emergence of zoonoses. The increase in ecotourism often in primitive settings with limited hygiene and exotic animals can also be associated with the acquisition of zoonotic agents. Development of appropriate programmes for surveillance and monitoring emerging diseases in their wild life reservoirs is crucial. Wild life disease monitoring programmes integrated within infrastructures for existing national animal health surveillance have the opportunity to respond adequately to unusual wildlife mortality events and can thereby facilitate research on the epizootiology of new diseases found in wildlife. The preparation of specific contingency plans and manuals supported by training will improve the capability of wildlife researchers and field analysts to respond to undertake appropriate sampling and storage of specimens required for diagnosis, thereby aiding in surveillance and monitoring. Investigation and sampling of wildlife diseases even though essential may be difficult under many different circumstances that may lead to poor count of sick and dead animals and there is always limited chance of marking or monitoring affected animals over time. A way to overcome this problem is by using radio-telemetry and satellite-tracking techniques. Effective vaccines using both conventional and new generation molecular tools and techniques need to be exploited to their full potential along with formulating appropriate vaccination strategies to counter wildlife zoonosis. Vaccination has come up with success in recent years especially with the application of baits. One important consideration however on developing baits is the potential for legal restrictions on the use of antibiotics or biological dyes in the environment. Such factors must be considered and the involvement of non-target livestock should be ruled out to make bait vaccination a success.

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