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REVIEW ARTICLE

WILDLIFE: A HIDDEN WAREHOUSE OF ZOONOSIS – A REVIEW

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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 Kyasunur 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 (lethal 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 human beings 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 domestic or companion animal's role in transmission of zoonotic diseases. But only little is known about the involvement of wild animals in broadcasting of these diseases. Usually, the free-roaming animals such as mammals, birds, fish, reptiles, and amphibians etc 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

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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 trypanosomosis, 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; Dhama *et al*., 2008a; Bloom, 2011; Dhama *et al*., 2012a; Mahima *et al*., 2012; Palmer *et al*., 2012, Dhama *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; Dhama *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; Dhama *et al*., 2008a; FAO, 2010, Plowright *et al*., 2011, Bekker *et al*., 2012, Mahima *et al*., 2012; Dhama *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 ehrlichioses 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; Dhama *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 (Rhyan 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, Echniococcosis, 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). Racoons 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 Kyasanur 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; Dhama *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).

Zoonoses 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 carcasses and may acquire 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 (*Pteropus 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 vegetations have increased the incidence of hendra viral infection (http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xs; Dhama *et al*., 2010a). The spread of tuberculosis caused by *Mycobacterium tuberculosis*, a bacterial disease to suri 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, Cryptococcosis, 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, spirochete causing Relapsing fever), fleas (e.g. Plague, Murine typhus fever). Bats 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, squirrels, 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 zoontic viral diseases/ viruses transmitted from the rodents are: hantavirus pulmonary syndrome, hemorrahagic 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 colonial 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, Gouilh *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*) (Artois, 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 (Debinski and Holt, 2000; Dhama *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 kaffer*) as maintenance host of *Brucella* infection (Alexander *et al*., 2012). Alternate host species (bats viz., *Miniopterus inflatus* and *Rhinolophus elocuens*) do exist for various pathogens including Marburg virus that presents a challenge particularly for characterization of these complex systems (Swanepoel *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 in the wild life system (Lachis *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 Cryptosporidiasis in mountain gorillas (Grazyk *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: safaris, tours, adventure sports and extreme travel. Travel and tourism not only 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

S.No	Disease/ pathogen	Microbe type	Transmitters	Signs	Remark	References
1	Avian influenza (Bird flu)	Influenza A viruses- Orthomyxo viridae	Wild and migratory birds	Chills, fever, sore throat, muscle pains, headache (often severe), coughing, weakness/fatigue and general discomfort.	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	Alexander and Brown, 2000; Castrucci *et al*., 1993; Horimoto and Kawaok, 2001; Dhama *et al*., 2005; Munster *et al*., 2006; Feare, 2007; Dhama *et al*., 2008a; Krauss and Webster 2010
2	Viral encephalitis	Alpha virus- Togaviridae	Passerine birds and rodents	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.	Some of them can act as potential bioterrorism weapons (e.g. Epidemic Venezuelan Equine Encephalitis)	Gibbs and Long, 2007; Kapoor *et al*., 2010
3	Viral haemorrhagic fever (VHF)	Ebola virus	Gorilla (*Gorilla sp.*), Chimpanzee or Duiker (*Sylvicapra grimmia*), Fruit bats (*Hypsignathus monstrosus, Epomops franqueti* and *Myonycteris torquata)*	Sudden onset of fever, intense weakness, muscle pain, headache and sore throat. Some cases, both internal and external bleeding.	First reported in humans in 1976	Khan *et al*., 1998; Leroy *et al*., 2004
4	West Nile virus - fatal neurological disease	West Nile virus - *Flaviviridae*	Crow (*Corvidae family)*	Headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, convulsions, muscle weakness, and paralysis.	First isolated in Uganda in 1937. Mammals are the dead end hosts. Transmitted through bite of mosquitoes (*C. Pipiens)*.	Taylor *et al*., 1956; OIE, 2004; Kilpatrick *et al*., 2008 ; Dhama *et al*., 2010b
5	Hendra viral infection	Hendra virus	Fruit bats (*Pteropodidae family*)	Fatal respiratory and neurological signs	Caused few outbreaks in Australia in horses and human but possible genetic diversity may allow generation of more infective virus.	http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xs; Dhama *et al*., 2010a
6	Hantavirus Pulmonary Syndrome–in America, Haemorrhagic fever with renal syndrome (HFRS) – in Europe and Asia	Hantaan, Seoul, Dobrava and Puumala hantaviruses	New World rats and mice. Sin Nombre group of hantaviruses. Deer mouse (*Peromyscus maniculatus*)	Fever, headaches, myalgia, nausea, vomiting, diarrhea, dizziness, and chills. Severe respiratory distress and leads to death	First recognized in 1993. Infection to man occurs through aerosol route	Escutenaire and Pastoret, 2000
7	Monkeypox	Poxvirus	African squirrel, monkeys	Pock lesions over the body	Rare zoonosis in humans. Occurs in Africa. First found in monkeys in 1958. Transmission occurs by contact with infected animals or body fluids	Reed *et al*., 2004
8	Nipah viral encephalitis	Nipah virus- Henipavirus genus- Paramyxoviridae	Pigs, mobile fruit bats	Fever, headaches, myalgia (muscle pain), vomiting and sore throat. Encephalitis and seizures occur in severe cases, progressing to coma	Emerging zoonosis. First recognized in 1999 in Malaysia. Dogs and cats are susceptible	Mohd Nor *et al*., 2000 ; Chua, 2003; Chakraborty,2012

9	Rabies – acute encephalomyelitis	Lyssavirus-Rhabdoviridae	Raccoon (*Procyon lotor*), Skunk (*Mephitis mephitis),* Fox (*Vulpes vulpes*, *Urocyon cinereoargenteus* and *Alopex lagopus*), Coyote (*Canis latrans*), Vampire bats (*Desmodus rotundus)*	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	Ballard *et al*., 2001; Sihvonen, 2003; Sleeman, 2006
10	Rift Valley fever	*Phlebovirus-Bunya viridae*	Buffalo (*Syncerus* spp.), Antelope (*Tragelaphus* spp.) and Camels (*Camelus* spp.)	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)*	Linthicum *et al.,* 1985; Sall *et al.,* 1998
11	Severe acute respiratory syndrome (SARS)	Coronavirus	Masked palm civets (*Paguma larvata*)	A dry cough, breathing difficulties, an increasing lack of oxygen in the blood, which can be fatal in the most severe cases	In 2002-2003, first it hit South east Asia. SARS pandemic was brought under control in 2003. Human to human spread is possible	Xu *et al.,* 2004
12	Tuberculosis	Bacterial-*Mycobacterium bovis*	Buffalo (*Syncerus caffer*), Lechwe (*Kobus leche*), Warthog (*Phacochoerus africanus*), Kudu (*Tragelaphus strepsiceros*), Wild boar (*Sus scrofa*)	cough up blood, chest pain, nodules in other parts of the body	Age old disease. Commonly called of King of all diseases.	Michalak, *et al.,* 1998; Bengis, 1999; Clifton *et al.,* 2001; Alexander, *et al.,* 2002
13	Brucellosis	Bacterial- *Brucella spp. (Brucella abortus, B. melitensis, B. suis s)*	Caribou and reindeer (*Rangifer tarandus*), European brown hare (*Lepus capensis* Linnaeus)	Undulant fever, Headache, Weakness, muscle pain, Depression, Weight loss, Fatigue	Brucella also affects marine mammals like whales and seals, which has been recently identified. This also plays role in zooonois. Transmitted through consumption infected milk or spread through cut wounds	Thorne, 2001; Godfroid *et al.,* 2005; Cross *et al.,* 2010
14	Leptospirosis	Bacterial-*Leptospira interrogans*	Rodents, wild canids	Septicaemia, haemolytic anaemia, hepatitis, nephritis, jaundice	Transmitted by ingestion of contaminated water, handling or ingesting infected milk or tissues, transplacental invasion, sexual contact, social grooming.	Trevejo *et al.,* 1998; Leighton and Kuiken, 2001; Verma *et al.,* 2012
15	Lyme disease	Bacterial- *Borrelia burgdorferi*	White-tailed deer (*Odocoileus virginianus*), rodent reservoirs (*Peromyscus* spp. and *Tamias* spp.)	Multi systemic disease. Stiff neck, chills, fever, swollen lymph nodes, headaches, fatigue, muscle pain, and joint pain.	Tick borne disease, commonly transmitted by ticks which include *Ixodes ricinus, I. scapularis* and *I. pacificus*.	Gern and Falco, 2000; Brown and Burgess, 2001; Dhama, *et al.,* 2013a
18	Tularemia	Bcaerial - *Francisella tularensis*	Cottontail rabbits (*Sylvilagus* spp.,),black-tailed rabbits (*Lepus californicus*), snowshoe hares (*Lepus americanus*), Beaver (*Candor canadensis*), and muskrat (*Ondatra zibithecus*)	Fever and swollen lymph nodes, or oropharyngeal form typified by pharyngitis and tonsillitis.	Transmission occurs through the bites of haematophagous insects and ticks, direct contact with infected exudates and tissues, mucous membrane contamination, inhalation and ingestion.	Mörner and Addison, 2001; Avashia, *et al.,* 2004
16	Plague	Bacterial- *Yersinia pestis*	Rodents, such as prairie dogs (*Cynomys* spp.)	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	Recent outbreak occurred in Madagascar. Transmitted by rat flea	Chanteau *et al.,* 1998; Gasper and Watso, 2001

17	Psittacosis	Chlymidial- *Chlamydophila psittaci*	Waterfowl, herons, gulls, terns, shorebirds, songbirds, and upland gamebirds and pigeons	Fever, arthralgia, diarrhea, conjunctivi tis, epistaxis and leukopenia	Organism excreted in droppings and survive for long periods and hence transmission to humans are possible	Sleeman, 2006
18	Human monocytic ehrlichiosis	Rickettsiales -*Ehrlichia* and *Anaplasma* spp. (*E. chaffeensis*, *E. ewingii* and *A. phagocytophilum)*	White-tailed deer (*O. virginianus*)	Flu-like illness, at times death. Leukopenia, thrombocytopenia can be noticed	Transmitted by lone-star tick (*Amblyomma americanum*)	Anderson *et al.,* 1991; Davidson and Goff, 2001
19	Alveolar Echinococcosis	Parasitic- *Echinococcus multilocularis*	Red foxes, arctic foxes, and coyotes	Pain in the areas where cysts are formed. Organ dysfunction can occur	Transmitted through accidental ingestion of eggs which forms cyst in multi organs of the body – hydatid cyst	Sleeman, 2006
20	*Giardiaiasis*	Giardia spp.	Quenda (Isoodon obesulus)	Diarrhoea and other symptoms of parasitic diseses	Faeco-oral route of transmission	Adams *et al.,* 2004
21	*Baylisascaris procyonis* (Raccoon Round worm)	Parasitic - Helminth disease	Raccoons	Blindness, central nervous system disease, or death	After ingestion the larvae hatch and penetrate through the intestine, migrating to many parts of the body like the eye, brain, or spinal cord.	Roussere *et al.,* 2003

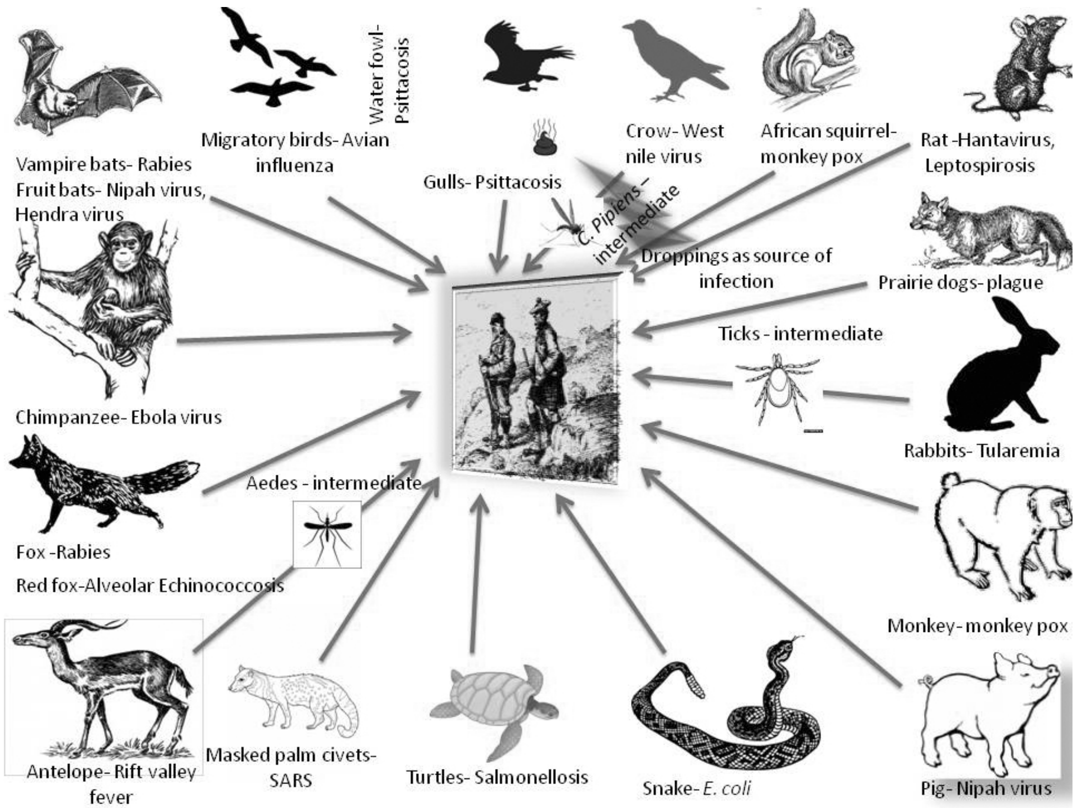

Fig 1. Wild life zoonotic diseases being transmitted to humans– a glimpse

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 africae,* is the rickettsial organism involved, transmitted by *Amblyomma* tick and has been reported in many parts of the world in case of ecotourists (Jensenius *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, leptospirosis, tuberculosis and others from wild boar, lion, jakal, 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 (Rhyan and Sparker, 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; *Salmonellae*; *Chlamydia psittaci* and *Coxiella burnetii* (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 methicillin 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; Hubálek and Rudolf, 2011). Tularaemia 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 (Rhyan and Sparker, 2010). Detection of infectious zoonotic 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 (Rhyan and Sparker, 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; Svraka *et al*., 2010; Phan *et al*., 2011; Simon and Daniel, 2011; Ge 2012; Smith and Wang, 2013; Dhama *et al*., 2013e). The application and usefulness of a novel meta-transcriptomics technique for studying normal microbiota, enzootic infections, as well 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 differentiate 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; Rhyan and Sparker, 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 non-statistical and non-random sampling by large and represent collection of different diseases and causes of deaths perhaps associated with some distributional information (Morner, 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 (Morner *et al*., 2002). Active surveillance can be carried out by capturing the animal or hunting and collecting sample. 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 (Rhyan and Sparker, 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,f). 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*., 2013f). 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; Ratcliff *et al*., 2007; Brown and Stallknecht, 2008; Balamurugan *et al*., 2010; Gowthaman *et al*., 2010; Bergquist, 2011; Siembieda *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 species (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 infective 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 disposure 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; Dhama, *et al*., 2013c; Kumar *et al*., 2013).

There is an urgent need to establish integrated zonal, regional, national and global wild life surveillance systems for zoonotic pathogens. Further, the appropriate collected information should be regularly shared and exchanged in real-time among them (Berkes, 2009). 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; Dhama *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 wild life 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 (Dhama *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 (Dhama *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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