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Pathogens Transmitted by Migratory Birds: Threat Perceptions to Poultry Health and Production

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Abstract: The role of migrating wild birds in transmitting diseases of poultry or zoonoses is a contentious issue as the researchers and naturalists stands divided regarding their capability to disperse pathogens over continents. Recently, migratory birds got world wide attention during the bird flu outbreaks, as they were found capable to disseminate the deadly H5N1 avian influenza (bird flu) virus, without themselves getting affected. However, the death of migratory birds due to H5N1, reported from Asia, has fuelled anxiety and concern over the whole issue. Apart from avian influenza, migratory birds are also thought to play role in the transmission of avian viruses like Newcastle disease virus, avian pneumovirus and duck plague virus. Similarly, bacterial pathogens like *Chlamydophila psittaci* and *Pasteurella multocida* can be transmitted to domestic poultry via migratory birds. They are also known to spread West Nile virus, equine encephalitis virus, *Borrelia burgdorferi* and enteropathogens like *Campylobacter* and *Salmonella*, which could affect animals as will as human beings. To prevent such etiological agents from entering poultry premises, strict biosecurity and constant surveillance are of paramount importance. Hence, in the scenario of migratory birds contributing significantly to the global spread of infectious diseases, a better understanding of their role in the disease epidemiology has to be gained by implementing superior surveillance and tracking strategies.

Key word: Avian influenza, biosecurity, migratory birds, poultry diseases, surveillance, wild birds

Introduction

Migratory birds can disperse microorganisms across international borders and myriad pathogens harmful to poultry or other vertebrates have been associated with such birds (Hubalek, 1994, 2004). They circulate avian influenza virus (AIV), avian pneumovirus, Newcastle disease virus, duck plague virus, *Chlamydophila psittaci, Campylobacter* and *Salmonella* (Hubalek, 1994; Palmgren *et al*., 1997; Wobeser, 1997; Alexander, 2000; Hubalek, 2004). The pathogen disseminating potential of migrating birds has become a major concern during the spread of West Nile virus (WNV) in North America during the late 1990's (Rappole and Hubalek, 2000; Reed *et al*., 2003). During the last few years, migrating birds have introduced H5N1 influenza virus to many countries, choosing specific flyways in different continents (Brand, 1984; Rappole *et al*., 2000; Stroud *et al*., 2004). Migrating birds generally include species that cyclically cross one or more national boundaries and use a variety of habitats including wetlands, marshes and other water bodies (UNEP, 2005). Such migrants make series of shorter flights, traveling more at night and during stop-over, disseminate the harbored pathogens (Reed *et al*., 2003). Migration, a remarkable biological phenomenon having epizootic implications depends on factors like susceptibility of birds, pathogen viability, vectors and factors such as temperature and humidity (Keymer, 1958; Page, 1976). The stress associated with migration can increase the bird's susceptibility to pathogens or enhance their shedding rate. Migration is highly demanding and if the birds become infected, they may spread the pathogens, for shorter distances rather than distant destinations (Weber and Stilianakis, 2007; Feare, 2007). For the efficient dispersal of pathogens, they serve as biological carriers of microbes or mechanical dispersers of vectors that harbor pathogens (Hubalek, 1994; Singh *et al*., 2003; Hubalek, 2004). As biological carriers, the infection in migratory birds can be acute (Newcastle disease, Duck plague, Pasteurellosis) chronic (Pox) or asymptomatic (influenza, salmonellosis). Feces and nasal and respiratory exudates of infected migrants transmit AIV, paramyxovirus, herpes virus, *C. psittaci, Campylobacter, Salmonella, Mycobacterium avium*, *P. multocida* and *Clostridium* spp. Likewise, they transport ticks along with pathogens, from one site to another (Hubalek, 1994, 2004). Even though such birds carry influenza virus and other pathogens, as per the suggestions of Food and Agricultural Organization (FAO), eliminating these birds is not a sagacious measure. Instead, biosecurity and surveillance system has to be enhanced to ensure that the poultry dwelling zones are not contaminated by migrating birds.

Pathogens transmitted by migratory birds:

Avian influenza virus (AIV): Avian influenza virus (AIV) of genus *Influenzavirus* (type A), family *Orthomyxoviridae,* is the causative agent of avian influenza (bird flu), that causes high flock mortality in poultry. The H5N1 subtype of highly pathogenic avian influenza (HPAI) virus has caused severe outbreaks in poultry worldwide, accounting for huge economic losses (Alexander, 2000; Swayne and Halvorson, 2003; Dhama *et al.*, 2005; Burgos and Burgos, 2007a). It is a highly contagious, zoonotic and multi-systemic disease placed under 'List A' disease of OIE, having potential of rapid spread, irrespective of national borders. The H5N1 virus, earlier limited to poultry, is now capable of infecting migratory birds, animals and human beings (Chen *et al.*, 2006; Kataria *et al.*, 2006; Burgos and Burgos, 2007b). During the past few years, the H5N1 virus has led to losses of more than 250 million birds besides claiming 210 human lives, globally.

The isolation of pathogenic AIV in migratory birds (common tern - *Sterna hirundo*) was first reported in 1961 from South Africa (Becker, 1966; Alexander, 2000; Dhama *et al.*, 2005). After this, different low pathogenicity avian influenza (LPAI) viruses have been isolated from migrating ducks, geese, gulls and other shorebirds, throughout the world (Stallknecht and Shane, 1988; Alexander, 2000; Fouchier *et al.*, 2003; Liu *et al.*, 2005; Flint, 2007). Congregations of migratory waterfowl, increases the probability of contact infection to domestic avian species in a particular geographic region. Waterfowl and shorebirds are considered as natural and principal reservoir for most of the AIV subtypes (H1-H16 and N1-N9) (Alexander, 2000; Dhama *et al.*, 2005; Mathew *et al.*, 2006; Kataria *et al.*, 2006; Flint, 2007). However, majority of the AIVs that are circulating in migratory birds have been belonging to low pathogenic category (Swayne and Halvorson, 2003; Dhama *et al.*, 2005). During recent years, the outbreak of the H5N1 virus in Asia that has subsequently spread to Russia, Middle East, Europe and Africa, has put increased focus on the role of wild birds (Olsen *et al.*, 2006; Normile, 2006; Capua and Alexander, 2007). After the 1997 Hong Kong outbreak, a devastating one for poultry industry besides claiming human lives for the first time, the precursor virus, later detected in geese changed its host-range to ducks by undergoing reassortment (genetic shift) and moved further to chickens in 2002, changing a range of genotypes with increased virulence (Sturm-Ramirez *et al.*, 2004; Liu *et al.*, 2005; Zhou *et al.*, 2006). This virus has caused mortality in migratory birds in China and Mongolia for the first incidence after South African outbreaks of 1961 and ducks, bar-headed geese, gulls and cormorants were the migratory birds that were mostly affected (Sturm-Ramirez *et al.*, 2004; Youling, 2005; Sanjaatogtokh, 2005). The H5N1 virus in migratory waterfowl showed clinical signs like paralysis, head tilt and staggering gait and pathology in multiple organs, including the brain resulting in severe neurological dysfunction and was transmitted between migratory birds (Sturm-Ramirez *et al.*, 2004; Chen *et al.*, 2006). These isolates from migratory birds were found to be distinct from Southeast Asian H5N1 virus, but capable of inflicting highly pathogenic infection in chickens (Lei *et al.*, 2007). Besides occurrence of HPAI in such birds, it is a matter of concern that the LPAI viruses in migratory birds can mutate within them or get into the poultry population which later act as precursor for the generation of deadly HPAI viruses (Swayne and Halvorson, 2003; Dhama *et al.*, 2005; Mathew *et al.*, 2006; Mehrabanpour *et al.*, 2007). Geospatial analyses clearly prove that the distribution of HPAI outbreaks in domestic poultry has been strongly associated with free grazing water fowls present in the region (Gilbert *et al.*, 2006a).

Major migratory birds that may transmit the avian influenza viruses are; whistling duck, white-headed duck, common shelduck, mallard duck, spot-billed duck, long-tailed duck, mute swan, whooper swan, whistling swan, white-fronted goose, bar-headed goose, northern pintail, common teal, oriental stork, lesser and greater adjutant, Siberian crane, Sarus crane, black-necked crane, great black headed gull, brown-headed gull and cormorants (Stallknecht and Shane, 1988; Kawaoka *et al.*, 1988; Alexander, 2000; Gilbert *et al.*, 2006b; Shortridge and Melville, 2006).

Newcastle disease virus (NDV): Newcastle disease (ND) is an economically important, highly contagious and fatal disease causing respiratory and enteric infection in poultry. It is also an OIE list A disease. The etiological agent, Newcastle disease virus (NDV), belongs to genus *Avulavirus*, serotype avian paramyxovirus I (APMV-1), in family *Paramyxoviridae* (Alexander, 2003). NDV has been reported from many species of free-living birds and wild waterfowl is considered as a potential natural reservoir of APMV-1 (Takakuwa *et al.*, 1998; Alexander, 2003; Zanetti *et al.*, 2005). Takakuwa *et al.* (1998) reported that NDV strains isolated from waterfowl showed virulence while assessing the mean death time, which was further proved by sequencing of fusion (F) gene, as dibasic amino acids were present at the cleavage site. This suggests that potentially virulent strains of NDV may be maintained in migratory waterfowl populations that may get transmitted to poultry to acquire pathogenicity during circulation in chickens (Takakuwa *et al.*, 1998). However, researchers have reported the presence of non-pathogenic NDV in wild or migratory birds which are unable to show clinical signs in poultry (Kommers *et al.*, 2003). In another study, reverse transcriptase polymerase chain reaction (RT-PCR) and DNA sequencing proved NDV isolates from wild birds to be avirulent ones (Peroulis and O'Riley, 2004). The phylogenetic analysis also revealed that majority of such NDVs isolated from little terns, great cormorants, sandwich terns and common redshanks could be non-pathogenic, forming a subgroup related to viruses of genotype II (Zanetti *et al.*, 2005). However, only recently, Shchelkanov *et al.* (2006) reported that certain NDV strains isolated from wild birds were pathogenic during the molecular analysis. Hence, further studies are required to identify the precursor viruses for highly virulent NDV that may be brought in by migratory birds and this is only possible by continued surveillance of wild/migratory bird population.

Avian pneumovirus (APV): Avian pneumovirus (APV), belonging to the genus *Metapneumovirus* of the *Paramyxoviridae* family, causes a rapidly spreading respiratory disease recognized as turkey rhinotracheitis (TRT); or swollen head syndrome (SHS) in chickens (Shin *et al.*, 2000; Lwamba *et al.*, 2002; Gough, 2003; Jones, 2006). The disease has incurred serious economic losses to many commercial turkey rearing units. Secondary bacterial infections and immunosuppressive viral diseases are known to exacerbate the disease severity (Lwamba *et al.*, 2002; Gough, 2003; Jones, 2006). The isolation of APV from choanal swab or nasal turbinate samples of a variety of wild birds like geese, mallards, sparrows, swallows and starlings has prompted to ascertain the significance of wild/migratory birds in the epidemiology and persistence of APV infections in domestic flocks (Shin *et al.*, 2000; Bennett *et al.*, 2002). During APV outbreaks in Minnesota (USA), Bennett *et al.* (2004) observed a seasonal trend of disease occurrence and also suggested the suspected role of wild birds in APV transmission. Based on nucleotide sequencing it was deduced that the APV isolates from domestic turkeys, wild ducks and geese shared a common source and the viruses from different avian species can cross-infect, indicating close relationship (Shin *et al.*, 2002; Bennett *et al.*, 2005).

Duck plague virus (DPV): Duck plague or duck viral enteritis is a highly contagious disease of Anseriformes, causing high mortality and egg production decline in domestic waterfowl and chickens with variable mortality in wild waterfowl (Sandhu and Shawky, 2003; Dey *et al.*, 2005). *Alphaherpesvirus*, the etiological agent, is known to affect many species of ducks, geese and swans and the recovered birds act as carriers of DPV (Sandhu and Shawky, 2003). DPV strains have also been detected from cloacal swabs of pintail ducks, gadwall ducks and wood ducks and it was reported that wild ducks and geese that have survived natural outbreaks are known to carry the virus even after four years post infection (Burgess *et al.*, 1979). Birds like teal and geese, when inoculated with liver tissue of infected mallard ducks, were reported to evince signs of profound weakness, ataxia, tremors and convulsions (Wobeser, 1987). By using virological and serological methods, carrier wild birds have been identified and their role in the epidemiology and incidence of duck plague in wild and domestic birds has been ascertained (Ziedler and Hlinak, 1992). The major epizootic of duck plague (1973, USA) in wild waterfowl gave clear evidence that the most likely source of infection was the DPV-carrier wild mallards and American black duck that entered through the major flyways (Converse and Kidd, 2001). As the convalescent migrants are silent carriers, for DPV control in poultry, measures should include biosecurity, eradication of affected flocks and decontamination of the environment (Pearson and Cassidy, 1997; Converse and Kidd, 2001).

Egg drop syndrome virus (EDSV): Egg drop syndrome-1976 (EDS-76), a vertically transmitted and economically important disease of poultry, causes low egg production with high fragility of eggs together with substantial decrease in fertility and hatchability. The EDS-76 virus (EDSV) has been classified under group III of the genus *Aviadenovirus* in family *Adenoviridae*. Even though disease outbreaks are often seen in layer chickens, it is thought that ducks and geese are natural hosts for EDSV (McFerran and Adair, 2003; Senthilkumar *et al.*, 2003). Presence of EDSV antibodies have been reported from domestic ducks and geese (Lu *et al.*, 1985; McFerran and Adair, 2003). Antibodies against this virus have also been detected from migratory ducks, grebes, egrets, gulls and wild geese (Kaleta *et al.*, 1980; Malkinson and Weisman, 1980; Gulka *et al.*, 1984; McFerran and Adair, 2003). EDSV is thought to be disseminated by migratory anseriforms and the spread from wild ducks and geese to domestic flocks can occur via drinking water contaminated with droppings of infected birds, thus resulting in sporadic infections in poultry (McFerran and Adair, 2003; Hubalek, 2004).

Chlamydophila psittaci: Chlamydiosis, a contagious disease of pet birds and poultry having zoonotic implications, is caused by *C. psittaci* which is an obligate intracellular bacterium. It is considered as a List B disease by OIE and in parrots, parakeets and humans the disease is also known as psittacosis (Andersen and Vanrompay, 2000). The disease affects all types of poultry and is systemic and occasionally fatal; often transmitted by inhalation or ingestion of infectious fecal dust. Wild ducks, gulls, egrets, grackles, sparrows and other wild bird species present a significant reservoir of *Chlamydophila psittaci* that can spread the disease by direct contact or infectious aerosols to domestic poultry or other vertebrates including human beings (Page, 1976; Grimes *et al.*, 1979; Brand, 1989; Andersen and Vanrompay, 2000; Kaleta and Taday, 2003). Some chlamydial strains not normally pathogenic to wild avian hosts can be highly virulent for domestic fowl and humans (Grimes *et al.*, 1979). Chlamydiosis has been reported to occur in turkeys that are exposed to infected starlings and common grackles and hence wild birds should also be included in serologic surveys and surveillance studies on chlamydial organism (Grimes, 1978; Grimes *et al.*, 1979). Further, it has been suggested that grackles are potential reservoir hosts that could play an important role in the transmission cycle of *C. psittaci* in nature (Roberts and Grimes, 1978). Shore birds like gulls, reported to die due to chlamydiosis were presented with lesions such as splenomegaly, hepatomegaly and pericarditis, which are quite commonly observed in other domestic birds (Franson and Pearson, 1995). The mechanism of introduction of chlamydiosis in domestic flock is not clearly understood even though wild birds are often infected by the same strains as domestic flocks (Andersen and Vanrompay, 2000). Hence, migratory bird surveillance and screening has to be enhanced to find their role in the epidemiology of infection in domestic birds (Schwarzova *et al.*, 2006).

Pasteurella multocida: The bacterium *P. multocida*, having bipolar staining features, is the etiological agent of fowl or avian cholera, an economically important and highly contagious disease that cause significant mortality in domestic and wild birds alike (Hubalek, 1994; Wobeser, 1997; Dash *et al.*, 2004). Avian cholera (AC) is a disease with carrier status that spreads rapidly through waterfowls. Apart from ducks, turkeys followed by chicken are susceptible and the disease generally affects the young ones (Glisson *et al.*, 2003). During the disease outbreaks in USA (1979), about 70,000 migratory ducks and geese were reported to have succumbed to the infection (Brand, 1984). AC outbreaks are promoted by dense bird aggregations due to the gregarious nature of most waterfowl species and the bacterium is able to survive in water for several days to weeks; both these aspects enhancing the chances of rapidity and volume of disease spread (Botzler, 1991; Glisson *et al.*, 2003). Birds that recover from the infection have been reported to serve as long-term carriers of the infectious agent, thus helping in dissemination of the agent to distant wetland locations (Hunter and Wobeser, 1980; Wobeser, 1997). Numerous species of free-ranging wild birds have been naturally infected with *P. multocida* even though waterfowl experience the greatest magnitude of losses (Wobeser, 1997; Glisson *et al.*, 2003). The role of wild birds acting as *P. multocida* carriers has long been postulated as a major source for infection for poultry (Glisson *et al.*, 2003). It has been suggested that the only limit to the duration of the carrier state is the lifespan of the infected bird (Glisson *et al.*, 2003). Hence, surveillance of migratory birds and the timely submission of dead bird specimens to diagnostic laboratories are crucial to allow disease control activities to be initiated before the outbreaks reach uncontrollable levels.

Other pathogens: The migrating or wild birds may also transmit pathogens that are either of zoonotic significance or harmful to many animal species; some of them capable of causing occasional infections in domestic birds. Major diseases coming under this category include West Nile fever, campylobacteriosis and Salmonella infections. The West Nile Virus (WNV), which is a *Flavivirus* belonging to family *Flaviviridae*, is a mosquito-borne virus that can result in fatal encephalitis in human beings, equines and avian species (Hubalek and Halouzka, 1999; Rappole *et al.*, 2000; Rappole and Hubalek, 2000; Komar, 2000). WNV is maintained in an epizootic transmission cycle between mosquitoes and birds with humans and horses as incidental hosts. Wild or migrating birds are central to the epidemiology of WNV infections as they are the main amplifying hosts (Reed *et al.*, 2003). Likewise, migratory birds play crucial roles in the dissemination of zoonotic and enteropathogenic bacteria like *Campylobacter* and *Salmonella*. The incidence of human infection with *Campylobacter jejuni* is increasing and even though poultry is considered to be a major source, it is evident that other reservoirs also may exist (Sacks *et al.*, 1986; Tomar *et al.*, 2006). Environmental contamination of surface water with campylobacter might be mediated by aquatic/wild birds, where water bodies are used for recreational purposes (Moore *et al.*, 2002). Supporting the fact, campylobacter species has been frequently isolated from birds like migrating ducks, common terns, cranes, magpies, starlings and sparrows, thus proving their reservoir status (Broman *et al.*, 2002; Hubalek, 2004; Sensale *et al.*, 2006; Waldenstrom *et al.*, 2007). However, recent studies show that there is relatively low number of wild bird *C. jejuni* strains having clonal relationship to human and chicken strains, suggesting that wildlife avifauna may have lesser contribution to such infections in man or animals than earlier thought (Petersen *et al.*, 2001; Broman *et al.*, 2004). Similarly, in case of *Salmonella* infections, serovars of *S. enterica*, particularly Typhimurium and Enteritidis have been isolated from many species of gulls, ducks, terns, sparrows and finches (Hubalek, 1994; Hubalek, 2004; Pennycott *et al.*, 2006; Kobayashi *et al.*, 2007). Researchers have confirmed the involvement of dissemination of salmonella by migratory birds to human beings or other domestic animals and birds (Reche *et al.*, 2003; Millan *et al.*, 2004).

Besides the above mentioned pathogens, there are also possibilities of migrating birds transmitting avian poxviruses (Bolte *et al*., 1999), rotaviruses (McNulty, 2003), *E. coli* (Barnes *et al*., 2003), *Mycoplasma gallisepticum* (Ley, 2003) and *Mycobacterium avium* (Fulton and Thoen, 2003) to domestic poultry.

Biosecurity and surveillance as a preventive strategy: As an able preventive strategy, biosecurity has gained a special importance in maintaining domestic birds free of pathogens, to achieve better productive results. The risk of contracting diseases has nowadays increased due to intensive commercialization and also as a result of increased transportation, warranting biosecurity as an essential component in the prevention and control measures of poultry diseases. Likewise, epidemiologic surveillance is also critical to detect the role of migratory birds in transmitting diseases to poultry so that timely intervention strategies can be developed.

Biosecurity: Biosecurity, as a first line of defense, is an ideal system for controlling poultry diseases in order to reduce economic losses and health hazards in poultry sector. Most biosecurity measures are disease independent and will prevent most of the avian pathogens (Winkel, 1997; Mulder, 1997; Dhama *et al*., 2003). Biosecurity refers to the methods adopted to secure a disease free environment for preventing the exposure of the domestic birds to various pathogens derived from multiple sources. It is defined as "the safety from transmissible infectious diseases, parasites and pests and is a term that embodies all the measures that can or should be taken to prevent viruses, bacteria, fungi, protozoa, parasites, insects, rodents and migratory or wild birds from entering, surviving, infecting or endangering the well-being of the poultry flock" (Bermudez and Brown, 2003). Key principles of biosecurity include; isolation-confinement of birds within a controlled environment; traffic control - controlling traffic onto and within farms and sanitation and hygiene-disinfecting materials or equipments along with cleanliness of farm personnel (Winkel, 1997; Mulder, 1997; Bermudez and Brown, 2003; Dhama *et al*., 2003; Kataria *et al*., 2006). Hence, for ensuring protection of flocks from transmissible pathogens and to ensure hygiene of poultry food and by-products, biosecurity should be considered as an effective tool. More recently, the situation has become critical for both producers and consumers due to the threat of zoonotic diseases like avian influenza. Studies have shown that HPAI viruses can be transmitted from farm to farm by the movement of vehicles and farm personnel or the virus may enter the flocks from migratory birds, thus highlighting the importance of strictly following the principles of biosecurity (Ehlers *et al*., 2003; Swayne and Halvorson, 2003; Zepeda, 2007; Anaeto and Chioma, 2007; Burgos and Burgos, 2007c). Aside to this, care has to be taken to limit sources of food and water bodies for wild and free flying birds in and around the poultry dwelling premises (Dhama *et al*., 2005). Movement restrictions for live poultry and their products and establishment of protection and surveillance zones have together enabled a successful eradication of AIV in many countries (Capua *et al*., 2003; Khawaja *et al*., 2005; Dhama *et al*., 2005; Shortridge and Melville, 2006; Zepeda, 2007). To assist all such preventive measures, countries need to strictly check the illegal trade of wild or exotic species of birds, by implementing strict rules and regulations (Dhama *et al*., 2005; Burgos and Burgos, 2007b).

Monitoring, surveillance and tracking of wild / migratory birds: Early detection is of paramount importance for the control or eradication of avian influenza and other diseases transmissible to poultry, for which surveillance of the poultry and migratory bird niche where pathogen inter-transmission occurs is essential (Shortridge and Melville, 2006). Enhanced monitoring and surveillance of migratory birds, combined with ringing data could provide a better insight on the disease epidemiology, including information on their migratory patterns and routes. Food and Agricultural Organization (FAO), Organization International des Epizooties (OIE) and World Health Organization (WHO) together have established Global Livestock Early Warning and Response System (GLEWS) which is aimed at tracking the spread of HPAI in migratory birds. Global Avian Influenza Network for Surveillance (GAINS), another initiative in this direction, conducts regular monitoring and surveillance of migrating birds. Currently, FAO, through Emergency Prevention System for Transboundary Animal Diseases, EMPRES is playing a key role in collecting, recording and analyzing data on diseases like avian influenza, both in wild bird populations and domestic poultry. As part of improving the surveillance of wild birds, satellite-based tracking systems have to be exploited (Hay *et al*., 2000; Ehlers *et al*., 2003). Global positioning system (GPS) transmitters can be implanted on wild birds to track their wintering grounds (Weimerskirch *et al*., 2002; Puckett and Takekawa, 2006; Wikelski *et al*., 2007). Satellite tracking system would enable the global monitoring of birds and help create the scientific framework necessary for global projects such as ICARUS, the International Cooperation for Animal Research Using Space. Surveillance of the population ecology of hosts, pathogens or vectors, should also be addressed while using such global tracking systems (Wikelski *et al*., 2007). Likewise, sero-surveillance of wild or migratory birds, a more conventional approach for detecting birds that may shed the pathogens without showing clinical signs, is also important (Fereidouni *et al*., 2005; Chen *et al*., 2006). For this, serum samples are collected from migratory birds for conducting respective serological tests (Kataria *et al.*, 2001; Swayne and Halvorson, 2003; Dhama *et al.*, 2005). Diagnosis of the pathogens in dead birds can also be performed using the specific specimens for individual infectious agents. For influenza detection, specimens should include tracheal and cloacal swabs and faecal samples (environmental) from live birds and lung lavage, pooled tissue (trachea and lung) and cloacal swabs from dead birds (Kataria *et al.*, 2001; Swayne and Halvorson, 2003; Kataria *et al.*, 2005; Dhama *et al.*, 2005; Chen *et al.*, 2006). In case of zoonotic infections, specimens should only be collected by trained professionals and immediately sent to FAO or OIE referral laboratories, where the detection and molecular characterization of the agent will be performed.

Conclusion: The current global avian influenza outbreaks and the reports of migrating birds spreading pathogens harmful to poultry or other vertebrates, has shifted the focus of research community towards such bird species, that follows a cyclical migration pattern. The scenario warrants an urgent need to strengthen the research on the area of individual pathogens, while assessing the distribution and ecology of various pathogens in wild bird environments. Serological sampling and study of movements of high-risk wild bird species need to be intensified, especially at strategic sites on the migration route. Illegal trade of wild or exotic species of birds has to be strictly prevented. Within the epidemiological context of HPAI outbreaks, there is need to exploit the early warning systems (EWS) for an early detection and risk-assessment and to provide the opportunity for timely reaction in a most cost-effective manner. At this point, it is to be noted that the indiscriminate destruction of migratory bird populations is illogical and ineffective as it may cause dispersion of the birds, causing the spread of the infectious agent apart from altering the ecological balance. Instead, monitoring of wild birds has to be intensified and measures have to be taken to minimize or reduce their contact with domestic poultry. For this to achieve, biosecurity, a much novel and emerging consideration in disease prevention, should be considered with top priority. Multi disciplinary research is also required that can utilize the competency of veterinarians, wildlife specialists, ornithologists and life science researchers in a coordinated and effective way. To realize this, strengthening of collaborative opportunities have to be followed in a directional manner so that challenges posed by many transboundary diseases can be considerably minimized.

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