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Wildlife as sentinels for emerging zoonotic diseases: A review of surveillance systems in the USA

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Abstract

Wildlife plays a crucial role as sentinels for emerging zoonotic diseases, serving as early indicators of potential threats to human and animal health. This review examines the surveillance systems in the USA that utilize wildlife as indicators for the presence of emerging zoonotic pathogens. The review focuses on the methodologies, challenges, and implications of these surveillance systems. In the USA, wildlife surveillance for zoonotic diseases is primarily conducted through passive surveillance, where wildlife carcasses are collected and tested for pathogens. Additionally, active surveillance programs target specific wildlife species known to host zoonotic pathogens or species that may be in close contact with humans or domestic animals. These surveillance efforts are complemented by the use of sentinel species, such as birds or bats, which are monitored for signs of disease that could indicate the presence of zoonotic pathogens. Challenges in wildlife surveillance include the vast geographic range of many wildlife species, making it difficult to sample populations comprehensively. Additionally, the diversity of wildlife species and habitats in the USA presents logistical challenges for surveillance efforts. Furthermore, there are challenges related to data sharing and coordination among agencies responsible for wildlife and public health. The implications of wildlife surveillance for public health policy and practice are significant. Early detection of zoonotic pathogens in wildlife can lead to timely public health interventions, such as vaccination campaigns or changes in land use practices to reduce human-wildlife contact. Moreover, wildlife surveillance can inform the development of predictive models for disease outbreaks, enabling more effective preparedness and response measures. In conclusion, wildlife surveillance plays a critical role in the early detection and monitoring of emerging zoonotic diseases in the USA. Continued investment in surveillance systems and research is essential to enhance our understanding of zoonotic disease dynamics and improve our ability to protect human and animal health.

Keywords: Wildlife; Sentinels; Emerging Zoonotic Disease; Surveillance; Systems

1. Introduction

Zoonotic diseases, which are infections that can be transmitted between animals and humans, pose significant threats to public health worldwide. Surveillance of zoonotic diseases in wildlife plays a crucial role in detecting and monitoring emerging pathogens that have the potential to cause outbreaks in human populations (Etele & Akunne, 2023, Qiu, et. al., 2023, Rahman, et. al., 2020). This review examines the surveillance systems in the USA that utilize wildlife as sentinels for emerging zoonotic diseases, highlighting the methodologies, challenges, and implications of these surveillance efforts.

Zoonotic diseases are infectious diseases caused by bacteria, viruses, parasites, or fungi that can be transmitted from animals to humans. These diseases can be transmitted through direct contact with infected animals or their

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environment, through the consumption of contaminated food or water, or through vectors such as mosquitoes or ticks. Zoonotic diseases include well-known illnesses such as rabies, Lyme disease, and West Nile virus, as well as emerging threats like Ebola and Zika virus (Mokwelu, Etele & Akunne, 2023, Shaheen, 2022).

Wildlife surveillance is essential for early detection of zoonotic pathogens in animal populations before they spread to humans. Wildlife can serve as reservoirs for zoonotic pathogens, harboring viruses or bacteria that can spill over into human populations through various pathways. Monitoring wildlife populations for signs of infection can provide valuable insights into the presence and spread of zoonotic diseases, enabling public health officials to implement timely interventions to prevent outbreaks (Akunne, et. al., 2022, Sharan, et. al., 2023, Valentina, Chinyere & Azuji, 2021).

The purpose of this review is to provide an overview of the surveillance systems in the USA that use wildlife as sentinels for emerging zoonotic diseases. The review will examine the methodologies used in wildlife surveillance, the challenges faced by these surveillance systems, and the implications of wildlife surveillance for public health policy and practice. By highlighting the importance of wildlife surveillance in zoonotic disease detection and monitoring, this review aims to inform future research and policy decisions aimed at improving zoonotic disease surveillance and control efforts.

2. Literature Review

Wildlife play a crucial role in the transmission dynamics of zoonotic diseases, acting as both hosts and vectors for various pathogens. Understanding the interactions between wildlife populations and emerging zoonotic diseases is essential for effective surveillance and control measures. In the United States, surveillance systems are in place to monitor wildlife populations for signs of emerging zoonoses. This literature review aims to explore the role of wildlife as sentinels for emerging zoonotic diseases in the USA, focusing on existing surveillance systems and identifying research gaps in this field.

Wildlife populations serve as reservoirs for numerous zoonotic pathogens, including viruses, bacteria, and parasites. These pathogens can be transmitted to humans directly through contact with infected animals or indirectly through vectors such as ticks and mosquitoes. The spillover of pathogens from wildlife to humans can lead to outbreaks of emerging infectious diseases, posing significant public health threats. Examples of zoonotic diseases with wildlife origins include West Nile virus, Lyme disease, and hantavirus pulmonary syndrome.

In the USA, several surveillance systems are in place to monitor wildlife populations for signs of emerging zoonotic diseases (Daszak, 2000). One of the most well-established systems is the National Wildlife Health Center (NWHC), which conducts disease surveillance and research on wildlife diseases nationwide. The NWHC collaborates with state and federal agencies, academic institutions, and other partners to monitor wildlife health and detect emerging threats. Additionally, the Centers for Disease Control and Prevention (CDC) oversees surveillance programs for specific zoonotic diseases, such as rabies and avian influenza, which involve monitoring wildlife populations for signs of infection (Smith et al., 2014).

Despite the existing surveillance efforts, several research gaps remain in understanding the role of wildlife as sentinels for emerging zoonotic diseases in the USA. Firstly, there is a need for improved coordination and integration of surveillance data from different wildlife species and geographic regions. Many surveillance programs focus on specific pathogens or host species, which may overlook emerging threats from other sources. Integrating data from multiple sources could enhance early detection and response to emerging zoonoses. Secondly, there is a need for more comprehensive studies on the drivers of zoonotic disease emergence at the wildlife-human interface. Factors such as land use changes, climate change, and wildlife trade can influence the spillover of pathogens from wildlife to humans. Understanding these drivers is essential for implementing effective prevention and control measures. Thirdly, there is a need for the development of novel surveillance techniques and technologies for monitoring wildlife populations. Traditional surveillance methods, such as passive surveillance and wildlife sampling, have limitations in detecting emerging threats. Advances in molecular biology, remote sensing, and data analytics offer new opportunities for enhancing surveillance capabilities.

Wildlife plays a critical role in the transmission dynamics of emerging zoonotic diseases, serving as both hosts and vectors for various pathogens (Sleeman, 2008). Surveillance systems in the USA aim to monitor wildlife populations for signs of infection and detect emerging threats to public health. However, several research gaps remain in understanding the role of wildlife as sentinels for emerging zoonoses. Addressing these gaps through enhanced surveillance, interdisciplinary research, and technological innovation is essential for mitigating the risks posed by emerging infectious diseases.

2.1. The history of wildlife surveillance for zoonotic diseases in the USA

The history of wildlife surveillance for zoonotic diseases in the USA is marked by significant advancements in understanding disease dynamics and improving public health outcomes. Wildlife has long been recognized as important sentinels for emerging zoonotic diseases, providing early warning signs of potential threats to human and animal health. This review explores the historical development of wildlife surveillance systems in the USA and their role in detecting and monitoring zoonotic pathogens (Akunne & Nwadinobi, 2021, Etele & Akunne, 2023, Meurens, et. al., 2021).

Early efforts in wildlife surveillance focused primarily on the detection of specific zoonotic diseases, such as rabies and plague, which posed significant public health threats. Surveillance efforts were often limited to targeted monitoring of wildlife populations known to be reservoirs for these diseases, such as rodents and bats. These early surveillance systems relied on traditional methods of disease detection, such as trapping and sampling of animals, and were often constrained by limited resources and technology (Ahmad, et. al., 2024, Etele & Chinwe, 2021, Li, et. al., 2021). The late 20th century saw significant advancements in wildlife surveillance, driven by a growing recognition of the interconnectedness of human, animal, and environmental health. The emergence of new zoonotic diseases, such as hantavirus pulmonary syndrome and West Nile virus, highlighted the need for more comprehensive surveillance systems that could detect and monitor a wide range of pathogens in wildlife populations (Ejairu, et. al., 2024, Ogedengbe, et. al., 2024, Vicente, Vercauteren & Gortázar, 2021).

Advancements in technology, such as the development of molecular diagnostics and geographic information systems (GIS), revolutionized wildlife surveillance by allowing for more sensitive and efficient detection of zoonotic pathogens. These technologies enabled researchers to identify new disease threats, track the spread of pathogens, and understand the ecological factors driving disease transmission (Musvuugwa, 2022, Nwankwo, et. al., 2024, Ogedengbe, et. al., 2024). The 21st century has seen further improvements in wildlife surveillance, with the integration of new technologies such as next-generation sequencing and remote sensing. These technologies have enabled researchers to conduct large-scale genomic studies of zoonotic pathogens and monitor wildlife populations in real-time, providing valuable data for disease surveillance and control efforts.

Overall, the history of wildlife surveillance for zoonotic diseases in the USA reflects a continuous evolution of methods and technologies aimed at improving our ability to detect, monitor, and respond to emerging disease threats. As the field of wildlife surveillance continues to advance, it will be essential to maintain a proactive approach to disease surveillance and continue to innovate in response to new and emerging zoonotic diseases.

2.2. Methodologies for Wildlife Surveillance

Wildlife surveillance plays a crucial role in monitoring zoonotic diseases and detecting potential threats to human health. Various methodologies are employed in wildlife surveillance, each with its strengths and limitations (Akindote, et. al., 2024, Anyanwu, et. al., 2023, Wang, et. al., 2023). This review explores the key methodologies used in wildlife surveillance, including passive surveillance, active surveillance, the use of sentinel species, and the application of geographic information systems (GIS).

Passive surveillance relies on the collection and testing of samples from wildlife that are found dead, sick, or injured. This approach is based on the assumption that animals exhibiting signs of illness or mortality may be infected with pathogens of interest. Passive surveillance is cost-effective and can provide valuable data on disease prevalence and distribution in wildlife populations. However, it may miss asymptomatic infections or pathogens that do not cause obvious clinical signs in wildlife (Aderibigbe, et. al., 2023, MacDonald, et. al., 2022, Ohalete, et. al., 2023).

Active surveillance involves the targeted sampling of wildlife populations to detect the presence of specific pathogens. This approach is often used in conjunction with passive surveillance to obtain a more comprehensive understanding of disease dynamics. Active surveillance allows researchers to collect samples from healthy animals, providing insights into the prevalence of asymptomatic infections. However, active surveillance can be resource-intensive and may require specialized equipment and expertise (Adekanmbi, et. al., 2024, Adeleke, et. al., 2024, Cardoso, et. al., 2022).

Sentinel species are used in wildlife surveillance to monitor the presence of specific pathogens in the environment. These species are chosen based on their susceptibility to infection and their likelihood of encountering the pathogen. Sentinel species can provide early warning signs of disease presence and help identify high-risk areas for zoonotic transmission. However, the use of sentinel species requires careful selection and monitoring to ensure accurate and reliable results (Amadi, Frazzoli & Orisakwe, 2022, Odonkor, et. al., 2024, Oladeinde, et. al., 2023).

GIS technology is increasingly being used in wildlife surveillance to analyze and visualize spatial data related to disease prevalence and distribution. GIS allows researchers to map disease hotspots, identify high-risk areas, and track the movement of pathogens over time. GIS can also be used to integrate data from multiple sources, such as wildlife populations, environmental factors, and human population densities, to better understand the complex interactions driving disease transmission (Aranha, et. al., 2021, Daraojimba, et. al., 2023, Kaggwa, et. al., 2024).

In conclusion, the methodologies used in wildlife surveillance are diverse and complementary, each providing unique insights into the dynamics of zoonotic diseases in wildlife populations. By employing a combination of passive surveillance, active surveillance, the use of sentinel species, and GIS technology, researchers can enhance their ability to detect, monitor, and respond to emerging zoonotic threats.

2.3. Challenges in Wildlife Surveillance

Wildlife surveillance is crucial for monitoring zoonotic diseases and understanding their dynamics in wildlife populations. However, several challenges exist that can impede effective surveillance efforts. These challenges span geographic, ecological, sampling and detection, data sharing and coordination, as well as funding and resource limitations (Barroso, Acevedo & Vicente, 2021, Egieya, et. al., 2024, Orieno, et. al., 2024).

Wildlife populations often inhabit remote or inaccessible regions, such as dense forests, mountains, or wetlands. Accessing these areas for surveillance activities can be logistically challenging and costly. Wildlife species occupy diverse habitats, each with its unique environmental conditions and species compositions. Surveillance efforts must adapt to these varied habitats, requiring specialized techniques and equipment. Many wildlife species exhibit migratory behaviors, traversing vast distances seasonally. Monitoring migratory species presents challenges in tracking their movements and understanding disease spread across different regions (Akindote, et. al., 2023, Anyanwu, et. al., 2023, Biswas & Biswas, 2020).

Collecting samples from wildlife can be challenging due to the elusive nature of many species. Traps, cameras, and other methods are often used, but they may not capture a representative sample of the population. Proper preservation of samples is essential for accurate testing and analysis. However, preserving samples in the field can be difficult, especially in remote locations with limited access to laboratory facilities. Detecting pathogens in wildlife samples can be challenging due to low pathogen levels, sample degradation, or the presence of inhibitors. Specialized tests and techniques may be required for accurate detection (Ewuga, et. al., 2023, Oguejiofor, et. al., 2023, Zemanova, 2021).

Wildlife surveillance often involves multiple agencies and organizations, each with its data collection and management systems. Coordinating data sharing among these entities can be challenging, leading to fragmented surveillance efforts. Sharing wildlife surveillance data raises privacy and confidentiality concerns, particularly when it involves sensitive information about endangered species or protected habitats. Standardizing data collection and reporting procedures across different agencies and regions can be challenging. Lack of standardized protocols can lead to inconsistencies in data quality and comparability (Ahumada, et. al., 2020, Tula, et. al., 2023, Usman, et. al., 2024).

Wildlife surveillance requires significant financial resources for equipment, personnel, and data management. Limited funding may restrict the scope and scale of surveillance efforts. Skilled personnel are needed for wildlife surveillance, including biologists, veterinarians, and field technicians. Recruiting and retaining qualified staff can be challenging, particularly in remote areas. Adequate infrastructure, such as laboratories and field stations, is essential for wildlife surveillance. However, infrastructure may be lacking in some regions, hindering surveillance efforts (Gidiagba, et. al., 2023, Lahoz-Monfort & Magrath, 2021, Okogwu, et. al., 2023).

In conclusion, addressing these challenges requires collaboration among government agencies, research institutions, and conservation organizations. By overcoming these obstacles, wildlife surveillance efforts can be enhanced, leading to improved monitoring and control of zoonotic diseases in wildlife populations.

2.4. Implications for Public Health Policy and Practice

The implications of wildlife surveillance for public health policy and practice are profound, with direct implications for early detection and response to zoonotic disease outbreaks, informing public health interventions and policies, and contributing to the One Health approach (Dawodu, et. al., 2023, Ogunjobi, et. al., 2023, Singh, et. al., 2024).

Wildlife surveillance plays a critical role in early detection and response to zoonotic disease outbreaks. By monitoring wildlife populations for signs of disease, public health officials can identify potential threats to human health and implement timely interventions to prevent the spread of disease (Egieya, et. al., 2023, Meurens, et. al., 2021, Okafor, et. al., 2023).

For example, surveillance of wild bird populations has been instrumental in detecting outbreaks of avian influenza, allowing for early intervention to prevent transmission to humans. Similarly, surveillance of bat populations has helped identify the presence of coronaviruses, such as SARS-CoV and MERS-CoV, which can cause severe respiratory illness in humans. Data from wildlife surveillance can inform the development of public health interventions and policies aimed at preventing and controlling zoonotic diseases. Surveillance data can help identify high-risk areas and populations, allowing for targeted interventions such as vaccination campaigns or habitat modification to reduce disease transmission (Addy, et. al., 2024, Erkyihun & Alemayehu, 2022, Akinrinola, et. al., 2024).

For example, surveillance of wildlife reservoirs for Lyme disease has helped identify areas where tick populations are high, leading to targeted public health campaigns to educate residents about tick prevention and control measures.

Wildlife surveillance is a key component of the One Health approach, which recognizes the interconnectedness of human, animal, and environmental health. By monitoring wildlife populations for zoonotic diseases, public health officials can gain insights into the complex interactions between humans, animals, and their environments that can lead to disease emergence (Amoo, et. al., 2024, Bordier, et. al., 2020).

For example, surveillance of wildlife populations has helped identify the role of deforestation and habitat fragmentation in the emergence of zoonotic diseases such as Ebola and Zika virus. This information has informed policies aimed at protecting biodiversity and reducing the risk of disease spillover from wildlife to humans.

In conclusion, wildlife surveillance plays a critical role in public health policy and practice, providing valuable data that can inform early detection and response to zoonotic disease outbreaks, inform public health interventions and policies, and contribute to the One Health approach. Continued investment in wildlife surveillance is essential for protecting human and animal health in an increasingly interconnected world.

2.5. Case Studies and Examples

Wildlife surveillance plays a crucial role in detecting and monitoring zoonotic diseases, providing valuable insights into disease dynamics and informing public health interventions. Several surveillance programs in the USA have demonstrated the effectiveness of using wildlife as sentinels for emerging zoonotic diseases. This review presents case studies and examples of successful wildlife surveillance programs, highlighting their contributions to disease detection, prevention, and control (Ejairu, et. al., 2024, Li, et. al., 2021, Odeyemi, et. al., 2024).

The USA has implemented robust surveillance programs for WNV, a mosquito-borne zoonotic disease. Surveillance focuses on monitoring bird populations, as birds serve as amplifying hosts for the virus. Dead bird surveillance is conducted to detect WNV activity in bird populations. Public health agencies collect and test dead birds for the presence of the virus, providing early warning signs of WNV activity in an area. Mosquito surveillance is also conducted to monitor WNV transmission. Mosquitoes are trapped and tested for the virus, helping to identify high-risk areas for human transmission (Danforth, et. al., 2022, Eboigbe, et. al., 2023).

Rabies surveillance in wildlife is critical for detecting and controlling the spread of this deadly zoonotic disease. Surveillance efforts focus on monitoring rabies in wildlife populations, particularly in raccoons, skunks, bats, and foxes. Wildlife rabies surveillance involves testing brain tissue from animals that have been found dead or killed due to suspected rabies. Positive cases help identify areas where rabies is circulating in wildlife populations, guiding public health interventions such as rabies vaccination campaigns.

Bats are reservoirs for several zoonotic pathogens, including coronaviruses and lyssaviruses. Surveillance programs have been successful in detecting novel coronaviruses in bat populations, providing insights into the potential for spillover to humans. By monitoring bat populations for emerging infectious diseases, public health agencies can implement targeted interventions to prevent disease transmission to humans, such as promoting bat conservation and reducing human-wildlife contact (Farayola, et. al., 2023, Osasona, et. al., 2024, Shipley, et. al., 2019).

Wild bird surveillance has been instrumental in detecting avian influenza viruses, including highly pathogenic strains such as H5N1 and H7N9. Surveillance programs monitor wild bird populations for signs of avian influenza, providing early warning of potential outbreaks in poultry and humans. Surveillance data has helped identify the role of migratory birds in the global spread of avian influenza, leading to improved control measures and pandemic preparedness.

Integrating data from wildlife, domestic animals, and humans is essential for comprehensive zoonotic disease surveillance. Collaborative efforts among multiple sectors enhance early detection and response to emerging threats. Adopting a One Health approach that considers the interconnectedness of human, animal, and environmental health is critical for effective zoonotic disease surveillance. This approach emphasizes interdisciplinary collaboration and data sharing among relevant stakeholders (Houe, et. al., 2019, Olurin, et. al., 2024, Uwaoma, et. al., 2024).

Building capacity for wildlife surveillance, including training wildlife professionals and enhancing laboratory capabilities, is essential for maintaining effective surveillance programs. In conclusion, wildlife surveillance programs in the USA have demonstrated the importance of using wildlife as sentinels for emerging zoonotic diseases. These programs have contributed valuable data and insights into disease dynamics, leading to improved public health interventions and pandemic preparedness. Continued investment in wildlife surveillance is essential for protecting human and animal health from emerging zoonotic threats (Ihemereze, et. al., 2023, Panel, et. al., 2023).

Future Directions and Recommendations

The future of wildlife surveillance for emerging zoonotic diseases in the USA holds several promising directions and recommendations. These include improved coordination and data sharing among agencies, integration of new technologies such as genomics and artificial intelligence (AI) in surveillance, and enhanced research on wildlife-pathogen dynamics (Dharmarajan, et. al., 2022, Falaiye, et. al., 2024, Mhlongo, et. al., 2024, Sanni et al., 2024).

Enhancing collaboration between wildlife, public health, and environmental agencies is essential for effective zoonotic disease surveillance. Coordination can facilitate the sharing of data and resources, leading to more comprehensive surveillance efforts. Developing standardized protocols and guidelines for data collection, analysis, and reporting can improve the consistency and comparability of surveillance data across different agencies and regions. Establishing platforms for real-time data sharing and communication can enhance the timely exchange of information, enabling rapid response to emerging threats (Afua, et. al., 2024, Alahira, et. al., 2024, Woods, et. al., 2019).

Genomic sequencing of pathogens can provide valuable insights into their evolution, transmission, and virulence. Integrating genomic data into wildlife surveillance can enhance the understanding of disease dynamics and inform control strategies. AI algorithms can analyze large datasets from wildlife surveillance to identify patterns and predict disease outbreaks (Ukoba and Jen, 2023, Sanni et al., 2022). AI-driven surveillance systems can improve the efficiency and accuracy of detecting emerging zoonotic threats (Ajayi-Nifise, et. al., 2024, Eyre, 2022, Olubusola, et. al., 2024). Remote sensing technologies, such as satellite imagery, can monitor environmental factors that influence disease transmission. Integrating these technologies into surveillance can improve the understanding of the ecological drivers of zoonotic diseases.

Long-term studies on wildlife populations can provide insights into the persistence and transmission of zoonotic pathogens. Understanding the dynamics of pathogen circulation in wildlife can help predict and prevent spillover events. Research on the interactions between wildlife hosts and zoonotic pathogens can elucidate the factors that influence disease emergence. This knowledge can guide surveillance efforts and preventive measures. Establishing networks for monitoring wildlife health can facilitate early detection of emerging diseases. These networks can also serve as platforms for collaborative research and data sharing among scientists and stakeholders (Adeoye, et. al., 2024, Donkoh, 2011, Ecke, et. al., 2022).

In conclusion, future efforts in wildlife surveillance for emerging zoonotic diseases should focus on improving coordination and data sharing, integrating new technologies, and enhancing research on wildlife-pathogen dynamics. These initiatives can enhance the effectiveness of surveillance systems and contribute to the prevention and control of zoonotic disease outbreaks.

3. Conclusion

In conclusion, wildlife surveillance plays a crucial role in detecting and monitoring emerging zoonotic diseases, serving as sentinels for potential threats to human and animal health. This review has highlighted key findings from surveillance systems in the USA, demonstrating the importance of wildlife as indicators of disease transmission and the effectiveness of surveillance programs in detecting and responding to zoonotic disease outbreaks.

Wildlife surveillance programs in the USA have been successful in detecting zoonotic pathogens such as West Nile virus, rabies, and avian influenza, providing early warning of potential outbreaks. Surveillance efforts have focused on passive and active surveillance methods, as well as the use of sentinel species and geographic information systems (GIS) to track disease spread. Challenges in wildlife surveillance include geographic and ecological factors, sampling and detection issues, and data sharing and coordination challenges.

Given the ongoing threat of zoonotic diseases, there is a need for continued investment in wildlife surveillance to enhance early detection and response capabilities. Improving coordination and data sharing among agencies, integrating new technologies, and enhancing research on wildlife-pathogen dynamics are essential for future surveillance efforts.

Wildlife serve as important indicators of environmental health and can provide valuable insights into the transmission of zoonotic diseases. By monitoring wildlife populations, public health agencies can identify potential threats to human health and implement targeted interventions to prevent disease transmission. component of efforts to monitor and control zoonotic diseases. Continued investment in surveillance programs, along with the integration of new technologies and enhanced research efforts, is essential for protecting human and animal health from emerging zoonotic threats.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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