ANNEX

MIGRATORY SPECIES AND HEALTH: A REVIEW OF MIGRATION AND WILDLIFE DISEASE DYNAMICS, AND THE HEALTH OF MIGRATORY SPECIES, WITHIN THE CONTEXT OF ONE HEALTH AND ECOSYSTEM APPROACHES TO HEALTH

SUMMARY DOCUMENT

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This is a summary document describing our approach and the main expected takeaways from this review, with our key messages and recommendations. A final, more detailed report will be produced ahead of the Fourteenth Meeting of the Conference of the Parties (CMS COP14) in Samarkand, Uzbekistan on 23-28 October 2023.

EXECUTIVE SUMMARY

KEY MESSAGES

→ Healthy, well-managed, resilient ecosystems positively influence health across sectors. Preventative approaches to managing health are more cost effective than addressing health problems once they emerge.

→ Disease is often viewed as a matter of survival or death when, in fact, its effects are often far more subtle, affecting productivity, development, behaviour, ability to compete for resources or evade predation, or susceptibility to other diseases which can consequentially influence population status.

→ Diseases can affect the conservation status of migratory species, and the usual drivers of population decline are also the drivers for disease emergence which can then exacerbate pre-existing threats. Therefore, addressing wider conservation threats contributes to reducing disease risks to migratory wildlife, livestock, and people.

→ Interfaces, whether direct or indirect, between domestic livestock and wildlife significantly risk negative health outcomes from infectious diseases in both sectors.

→ Responsibilities for health of ecosystems and migratory wildlife populations lie with environment sections of government.

→ There are significant gaps in contingency planning for wildlife disease threats. Inadequate surveillance for wildlife diseases contributes to poor understanding of both diseases and means to manage them. Moreover, regulations for transporting diagnostic samples from many species are delaying outbreak responses and hampering our understanding of epidemiology of diseases of wildlife.

→ The disease dynamics associated with the physiological costs of migration are complex and health outcomes for individuals and populations are situation dependent.

→ Migration itself does not necessarily increase infection burden or introduce new pathogens, it can reduce infection within a population by in effect removing those not fit enough to migrate, and with them their genes for disease susceptibility.

→ Increased exposure of migrants to different and diverse infectious agents can increase their resilience to infectious disease.

→ Therefore, migration may serve to safeguard the health of wildlife, and the risk of infection in domestic animals and people, depending on the local context.

→ Migration can, however, bring novel infectious agents to new areas and to naïve populations, increasing the likelihood of infection and disease.

→ Infectious agents may influence migratory behaviour and migration outcomes.

→ Human activities are profoundly influencing migratory patterns. Changes in migration, along with the drivers of these change, can increase infection burdens in migratory populations.

→ These increased infection burdens may compromise the health of migratory wild animals, and/or the health of domestic animals and even people.

PRELIMINARY RECOMMENDATIONS

→ Healthy resilient ecosystems create the setting for and determine health. Preventative approaches are both cost effective and required to promote health in migratory wildlife, livestock, and people. The role of those involved in biodiversity conservation and sustainable livelihoods should therefore be recognised for, and actively supported in, their contribution to health across all sectors. The role of UNEP in the FAO UNEP WHO WOAH Quadripartite is welcomed.

→ Efforts to address the drivers of population decline such as climate change, habitat loss and degradation, pollution, invasive species, and barriers to migration should be enhanced since these are also drivers of disease emergence across sectors.

→ Rather than seeing animal health as the sole responsibility of agriculture ministries, environment sections of government need to engage and lead on wildlife and ecosystem health.

→ One Health approaches appreciate the interconnectivity of health between wildlife, livestock, and people, yet can often be anthropocentric – such approaches should be used equitably in decisions about health management appreciating that promoting health of wildlife reduces risks to humans and our interests as well as bringing conservation benefits.

→ Preventing and responding to wildlife diseases requires good cross-sectoral working. Governments, their agencies, and all those managing wildlife are encouraged to contingency plan in peacetime involving all relevant stakeholders to both prevent wildlife health problems occurring but also to respond appropriately in emergency situations. This will minimise the adverse impacts of disease outbreaks and inappropriate control measures.

→ Livestock-wildlife interfaces caused by, for example, agricultural development and encroachment into wild areas, are particularly problematic for disease spillover and spillback. Every effort should be made to manage livestock to reduce these risks for the benefit of all. This might include improved biosecurity, better planning or significant changes and reassessment of livestock management particularly in medium and high-income countries where choices can be made about protein sources.

→ The health of migratory populations will be protected and fostered by strengthening 'wildlife health systems' comprising the expertise and resources to enable effective and prompt disease surveillance, diagnosis and management. Building this capacity is relatively inexpensive compared to the potential costs associated with reactive management of disease outbreaks.

→ Robust wildlife health surveillance, with conservation (rather than livestock protection) as its goal, is required to support robust planning and risk assessment, and surveillance can be integrated with ecological and population monitoring. Improvements in wildlife diagnostics, testing facilities and reporting systems, along with appropriate capacity building, are needed worldwide. Regulations for transporting specimens from threatened species across national boundaries are delaying outbreak responses and this also needs addressing.

→ There are significant knowledge gaps concerning the epidemiology and drivers of many diseases of migratory species which prevent good health management. Research and resourcing should be targeted at priority health threats to migratory species, particularly those of poor conservation status.

1 INTRODUCTION

1.1 Aims and objectives

The aim of this programme of work is to conduct a review of the health of migratory species for the United Nations Environment Programme's Convention on Migratory Species (UNEP CMS) based on the terms of reference set out in UNEP/CMS/ScS-SC5/Doc.6.4.1. This will inform the work of the new CMS Working Group on Migratory Species and Health under the CMS Scientific Council (UNEP/CMS/ScC-SC5/Outcome 11).

While the CMS has an extant resolution on wildlife disease and migratory species that was adopted at COP12 in 2017 (UNEP/CMS/Resolution 12.6 Wildlife Disease and Migratory Species), and has played an important role in responding to poisoning and avian influenza in migratory species, it is recognised that there is scope for increased CMS focus on this topic. Wildlife disease was not prominent on the COP13 agenda, however, the COVID-19 pandemic has since led to renewed interest in One Health. This interest was spurred on and informed by reports such as the UNEP's Preventing the Next Pandemic (UNEP, 2020). Following COP13, the CMS Scientific Council decided to undertake action regarding the health of migratory species, and consequently proposed establishment of the above working group, alongside this review.

1.2 Main subject areas

The report comprises the following main sections:

- → A '**One Health and ecosystem health**' section summarising the context of health in relation to conservation; the interdependence of health across the sectors; and the need for One Health and ecosystem approaches to health and its management.
- → A '**migration and disease dynamics**' section, which discusses disease in relation to migration and the potential impacts of migration and its disruption on the health of wildlife, domestic animals and humans (i.e. zoonotic risks).
- → A '**key health issues for migratory species**' section reviewing key health issues affecting migratory species, at a high level, with an emphasis on known issues for CMS-listed species.

These sections are summarised on the following pages.

2 ONE HEALTH AND ECOSYSTEM HEALTH

In this section, we review the concept of One Health and how ecosystem and wildlife health are integral and connected to this approach. We also highlight opportunities for health management to be more holistic across sectors.

2.1 Definitions

2.1.1 Health dimensions

Wildlife health

For this review, we define wildlife health '*as the physical, physiological, behavioural, and social wellbeing of wild-living animals measured at an individual, population and wider ecosystem level, and their resilience to change*' (Meredith et al., 2022).

From this perspective, 'health' in individuals and wider populations infers that their basic needs are met and they are able to adapt to environmental change. This means that individuals and populations are resilient to associated social changes and able perform to their usual functions, both for themselves and for what we expect of a 'healthy' functioning population (Stephen, 2014). It relates closely to the concept of ecosystem health discussed below.

Ecosystem health

"A healthy ecosystem is defined as being 'stable and sustainable'; maintaining its organisation and autonomy over time and its resilience to stress" (Rapport et al., 1998).
The concept recognises that ecosystem health is interconnected to the health of others, and that our actions on ecosystems can significantly affect the health of their inhabitants and their ability to adapt to change.

One Health

"*One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent" (*OHHLEP, 2022).

This is the most used and accepted term describing a collaborative and interdisciplinary approach to managing large-scale health issues affecting humans, animals (livestock and wildlife) and the environment. One Health approaches are intended to achieve better health equity across all these sectors, emphasising that for human health problems spanning these sectors, optimal management requires attention to the animal and environmental factors linked to disease problems.

Other health dimensions

A healthy wildlife population is a genetically diverse one. Small population sizes are more at risk of detrimental changes at a genetic level, such as inbreeding, harmful genetic mutations and a reduction in genetic variation. This can reduce their resilience to change, and can increase their susceptibility to infectious disease, thus increasing the risk of extinction for some populations (Frankham *et al*., 2012).

Indigenous concepts of health have historically been overlooked, however, people who have grown up surrounded by, and learning from, nature have a unique perspective and understanding of how ecosystems function. They can perceive subtle changes as early indicators of significant health issues, for example, hunters can identify their prey losing condition, which may be an early indicator for local population stressors and declines (Kutz and Tomaselli, 2019). The health of the environment is a key feature of many indigenous cultures and beliefs, which are commonly consistent with the ethos of One Health. They are also custodians of some of the most natural and biodiverse ecosystems remaining in the world (Riley *et al*., 2021).

2.1.2 Health conditions

What is disease?

Disease can be defined as '*any impairment that interferes with or modifies the performance of [an organism's] normal functions, including responses to environmental factors such as nutrition; toxicants and climate; infectious agents; inherent or congenital defects, or combinations of these factors*' (Wobeser, 1981).

From this definition, it is important to appreciate that not all disease is caused by infectious agents, but also from non-infectious causes. Disease also does not always lead to death of individuals: it may make them ill or impair their normal physiological or behavioural functions; or it may lead to ongoing health issues; but animals can recover from disease and may be more resistant to challenge in the future, e.g. through development of immunity. See Table 1, below for descriptions of some common related terms, including ‘infection’ and ‘zoonosis’.

Table 1. Common terminology (adapted from Wobeser., 2006)

Terminology	Description
Infection	The presence in an individual of an agent that can cause disease. An individual can be ‘infected’ with an agent, but may or may not suffer from disease as a consequence of the infection
Infectious (agent)	An agent which can cause infection in an individual (see Table 2 below)
Disease (clinical)	Impairment of normal functions due to the presence of an infectious agent or other impairment
Contagious	An agent which can cause infection and can also be transmitted from individual to individual
Subclinical or ‘silent’ infections	An infection by an agent causing little or no outward symptoms of disease in the individual. There may be little to no observable negative impact on the individual
Non-infectious disease	Health impairments that are not infectious. This includes genetic diseases; disease resulting from physical extremes (heat, cold); trauma, degenerative (e.g. age-related) diseases; nutritional diseases or deficiencies; and diseases due to chemicals (human-related or natural toxins), heavy metals or other toxic substances
Zoonosis (or zoonotic disease)	Diseases than can be transmitted between animals and humans

What causes disease?

As discussed, not all disease is caused by infectious agents: in many cases, non-infectious conditions are responsible for the disruption of normal functions. These conditions in animals can be natural in origin or originate from human activities. Table 2 lists infectious agents and non-infectious conditions as categorised for the purpose of this review.

Table 2. Infectious agent and non-infectious conditions of disease (adapted from Beckmann et al., 2022).

Infectious agents	Non-infectious conditions
Viruses Bacteria Fungi and yeasts Protozoa Endoparasites (worms) Ectoparasites (fleas, ticks, mites, etc) Other e.g. transmissible tumour (as relevant) Prions	Toxins, pollution, eutrophication Physiological response to climate (e.g. hyperthermia) Undernourishment (e.g. starvation), nutritional disease or deficiency Stress or disturbance from people (e.g. noise or light pollution) Unintentional trauma from humans (e.g. vehicle collision, entanglement, bycatch); trauma from intentional injury, predation or competition[1] Ingestion of foreign objects (e.g. plastic) Environmental injury (e.g. electrocution, drowning, burn injury) Other conditions, including developmental, genetic, or behavioural issues

[1]Trauma from intentional injury, predation or competition is included for completeness here, but is categorised separately, under ‘other problems’ (specifically ‘persecution’ and ‘ecological problems’) in Section 3 of this review.

However, it is worth noting that health concerns in wildlife are not just from infectious and non-infectious disease (Stephen, 2022). There are many other threats affecting wildlife health which often stem from deep-rooted socio-political issues such as the increasing drive for economic wealth, agricultural expansion, urbanisation and political conflict to name a few (Manfredo *et al.*, 2020).

2.2 Wildlife health, biodiversity conservation and spillover

2.2.1 Conservation status of migratory species

Many migratory species are declining, due to a multitude of factors, many of which are commonly driven by human activity. Most of these ‘drivers’ (described later in this section) are contributing to the decline of not only migratory species, but wildlife species worldwide. These declines and their drivers are explored further in another UNEP CMS report, currently in preparation.

2.2.2 Wildlife health and conservation

Taking into account the above definitions of wildlife health and disease, and given that a low level of disease is to be expected in any wildlife population, diseases of concern to wildlife conservation are those to which the population in question is unable to respond or is non-resilient to over time (Hanisch *et al*., 2012; UFWS., 2020; Bacon *et al*., 2023). In this review we use the term ‘threat’ to denote such significant disease conditions, for which there may evidence of a negative impact at the population level.

As above, disease in wildlife populations can be a natural occurrence and a mechanism for natural regulation of the number of individuals of a particular species within an ecosystem. However, when populations are declining as a result of other stressors such as habitat encroachment, pollution or persecution, then disease in an at-risk population can cause a decline of such severity that the population is unable to rebound. This can lead to local extinction events (Aguirre & Tabor., 2008).

Disease-induced declines in wild animal populations can then further negatively impact ecosystems. Many species provide ecosystem benefits. For example, grazing ungulates in large herds provide essential nutrients to grasses and plants via their excretions. Their feeding or foraging behaviours can regulate plant growth, sustaining the overall biodiversity of plant and animal species in the ecosystem they inhabit (Kauffman *et al*., 2020). Thus, disease outbreaks in wildlife can sometimes have wider ecosystem impacts.

Case example
Population reduction of prairie dogs (*Cynomys spp.*) by infection with *Yersinia pestis* (sylvatic plague) leads to changes in grassland plant species and altered nitrogen content in soil. Mountain plovers (*Charadrius montanus*) nest on the ground of prairie dog burrows, so when prairie dog numbers decline from *Y.pestis* infection, mountain plover populations often concurrently decline (Eads & Biggins, 2015).

2.2.3 Wildlife health and 'spillover'

Wildlife disease outbreaks can occur within wildlife populations and/or between different wildlife species. Their infectious agents can also potentially 'spillover' to, and cause disease in, domestic animals (including livestock) and people (Acevedo-Whitehouse & Duffus., 2009). 'New' emerging infectious diseases are more likely to come from wildlife via spillover events as a result of increasing pressure from human activities. However, direct zoonotic disease transmission from wildlife to people is rare. The vast majority of zoonotic disease transmission derives from domesticated animals (companion animals and livestock), for example from consumption of livestock products as foodborne zoonoses (Grace *et al.,* 2012). Where transmission to people from wildlife does occur, it is mostly through indirect transmission i.e., via an intermediate ('vector') species such as the mosquito (e.g. West Nile virus) (Kock & Caceres-Escobar., 2022).

Livestock often are the source of disease for wildlife species, and spillover also occurs from livestock to wildlife. This is a significant concern for many wildlife species and can have severe consequences. For example, in 2016-2017 mass mortalities numbering thousands of Mongolian saiga antelope (*Saiga tatarica mongolica)* occurred following the introduction Peste des petits ruminants virus (PPRV) from small ruminant livestock (sheep and goats). Deaths also occurred in other wildlife species including the Siberian ibex (*Capra sibirica*) and goitered gazelle (*Gazella subgutturosa*). The virus is thought to have been introduced from movements of sheep and goats using the same lands as saiga, and significantly reduced the saigas' population size (Pruvot *et al.*, 2020).

Case example
The strain of H5N1 highly pathogenic avian influenza (HPAI), which since 2020 has significantly affected wild bird populations globally, originated in domestic geese in China in 1996. The virus was largely maintained in poultry in Asia until a large spillover event to wildlife occurred at Lake Qinghai, China, in 2005. Early high mortality of wild birds was followed by years of episodic outbreaks. Changes in the virus and pathways to new hosts such as seabird breeding colonies has led to serious conservation concerns and calls for better protection of wildlife from livestock diseases (Kuiken & Cromie, 2022).

2.3 Conservation threats as drivers of disease

There is great overlap between the conservation threats to endangered or vulnerable species and the drivers of disease emergence. The main drivers contributing to the decline and extinction of wildlife species are also drivers of disease outbreaks (Machalaba *et al*., 2020). Disease then further exacerbates the threats to conservation status.

For example, habitat loss and encroachment from human activities, such as agriculture and development, puts pressure on populations by reducing their available inhabitable areas or degrading habitat quality. These changes can predispose them to disease outbreaks in a number of ways, such as leading to closer contact with domesticated animals (livestock) and humans, increasing the likelihood of disease transmission from livestock to wildlife, or vice versa (Kock & Caceres-Escobar., 2022). Table 3 outlines the drivers of threats to wildlife conservation and disease emergence. We use these categories of driver in our review (Section 3, below).

Thus, the presence of infectious and non-infectious diseases in wildlife, and their severity, can be indicators of the health of the ecosystem they inhabit, and wildlife can act as sentinels (warning systems) for the health status of ecosystems. Actions to improve the health of wildlife, and their ecosystems, by reducing pressures through more sustainable human actions can additionally improve the health of humans and livestock. Interdisciplinary approaches are required to develop solutions to these difficult and complex issues (Meredith *et al*., 2022).

Table 3. Drivers of conservation threats, which also act as drivers of disease emergence (adapted from IUCN, 2023).

Driver	Description
Agriculture or aquaculture	Agricultural expansion or intensification, including an increased livestock-wildlife interface
Other habitat loss, degradation, or disturbance	Human related settlement; changing land use; roads or other infrastructure; alteration, destruction, or disturbance of habitats from other human activities (including energy production and extractive industries); transportation and service corridors; noise disturbance; war and conflict; recreation. Can lead to increased proximity to human settlements or non-farmed domestic or feral species (e.g. dogs/cats).
Overexploitation (harvesting or persecution)	Deliberate or unintentional consumptive overuse of wild resources by hunting, collection, fishing, harvesting resources
Invasive species	Invasive alien species, other problematic species or genes[1]
Pollution	Introduction of exotic and/or excess or toxic materials or energy to the environment. Includes chemical and plastic pollution; agricultural, forestry, industrial run-offs/effluents, domestic wastewater, solid waste
Climate change or severe weather events	Threats from long-term climatic changes, which may be linked to global warming and other severe climatic/weather events. Includes droughts, temperature extremes, storms, and flooding
Other	Catastrophic geological events

[1]The IUCN and CMS definition includes invasive diseases from these species, but we consider these separately for the purpose of this review.

2.4 Holistic health approaches: challenges and opportunities

2.4.1 Limitations of current approaches

It is important to recognise the weaknesses in how society currently views wildlife health, with a predominant focus on ill-health/disease and emergency responses to outbreaks. These then dominate the funding and expenditure in health. Whilst this focus is no doubt important, it distorts the health equation, and does not address what ‘determines’ health (or ill-health). That failure can result in unnecessary burdens of disease for humans, domestic and wild animals. Moreover, animal health is often viewed as a responsibility of agriculture ministries with too little engagement in health from environmental sections of government.

For wildlife health, this is often viewed through the prism of how it immediately affects humans and our interests. Responses to disease outbreaks in which wildlife play a role have generally been reactionary, rather than preventative. This can quickly lead to negative outcomes. A recent example has been the COVID-19 pandemic. Wildlife was quickly blamed as the source of the virus with some reports of bats being targeted as part of fear-based responses. Similarly, H5N1 HPAI spilling into wild birds led to both killing of wild birds and destruction of nests and some wetland habitats in the early days of disease. These responses fail to both understand the root causes and realise the interconnectedness of health in animals, the ecosystem, and people. Using rational, preventative approaches – such as improving planning of farming activities or biosecurity practices in farms and markets, or improving agricultural practices to reduce stressors on wildlife – can allow people to live more sustainably alongside wildlife and with fewer negative outcomes (Machalaba *et al*., 2020). Reactive management may not only be detrimental in the long term but is also economically costly – and much more so than preventative approaches (Dobson *et al*., 2020).

The One Health approach has come under criticism for frequently remaining too anthropocentric, focusing most of its attention on improving the health of humans and reducing the risks facing humans, with little regard to the health and wellbeing of non-human animals (Stephen *et al*., 2023). As above, this can lead to great costs to animal populations, such as when culling or containment is used as a method of disease control. It also puts a great emphasis on wildlife being the cause of disease outbreaks and risk to humans, rather than understanding how all these systems are interlinked, and that human actions are a frequent underlying causal factor. To improve this, new frameworks are being proposed to make One Health more holistic and less human orientated, such as the framework recently proposed by Stephen *et al*. (2022): a health '*equity informed one health framework*'.

Added to the above are multiple logistical difficulties that negatively impact responses to wildlife disease problems. For example, many countries have inadequate surveillance and diagnostic facilities, or lack of capacity for appropriate investigative approaches and storage of samples. Moreover, countries which appear to be hotspots for emerging diseases (zoonotic and otherwise), are often those with weakest health infrastructures and investigative systems (Watsa *et al*., 2020). Compounding this are the regulations in transporting samples from threatened (CITES-listed) species which can delay sample analysis and thus responses to disease outbreaks (Machalaba *et al*., 2020). Voluntary reporting systems for wildlife disease or mortality incidents are frequently inadequate and ineffective, and collaborative efforts worldwide are required to improve this situation.

2.4.2 Opportunities for improvement

Biodiversity plays a key role in the functioning of ecosystems. Indeed, health can be seen as a property of an ecosystem and a biodiverse natural ecosystem is intrinsically healthy and resilient. Thus, maintaining and improving ecosystem biodiversity should be part of a holistic health approach that reduces disease risks to wildlife, domestic animals and/or people. Changes in biodiversity can alter disease dynamics in wildlife populations.

Fully understanding these determinants of health will lead to preventative or ecosystem approaches to health which are likely to have better outcomes when considering the broader contexts of sustainable agriculture, socio-economic development, environment protection and sustainability, and complex patterns of global change (Cromie *et al*., 2012).

Wildlife health can be protected and fostered by strengthening 'wildlife health systems', namely the expertise and resources fundamental in enabling effective and prompt disease surveillance, diagnosis and management. Global and national organisations have capacity to improve approaches to health across sectors by, for example:

- Improving capacity for wildlife disease surveillance, diagnostics and outbreak investigation.
- Establishing a global reporting system to track disease outbreaks and understand wildlife diseases (with full contextual ecological data for measuring the impacts of outbreaks).
- Establishing international guidance on preventative and constructive disease risk management approaches, to prevent ineffective and potentially damaging responses to wildlife disease outbreaks
- Promoting an understanding of the true determinants of health and the role of resilient biodiverse ecosystems within this context
- Encouraging equity in One Health approaches, and using these in decisions about planning, development, and in particular agricultural practices.
- Encouraging more effective contingency planning for wildlife health – both in terms of mitigation plans for minimising risks to wildlife and emergency response planning in outbreak situations to ensure the most appropriate and rapid management actions are taken.
- Preventative and prompt management is key. Disease risks to wildlife alongside the standard human and livestock risks should be included and considered in environmental impact assessments. This could help to identify which management actions could be used to reduce or mitigate disease risks. This will not stop all disease outbreaks, but may help to contain them more quickly, thus reducing the impact on both animals and humans (Machalaba *et al*., 2020; Kock & Caceres-Escobar, 2022).

KEY MESSAGES: On One Health and ecosystem health

→ Healthy, well-managed, resilient ecosystems positively influence health across sectors. Preventative approaches to managing health are more cost effective than addressing health problems once they emerge.

→ Disease is often viewed as a matter of survival or death when, in fact, effects are often far
more subtle, instead affecting productivity, development, behaviour, ability to compete for
resources or evade predation, or susceptibility to other diseases factors which can consequentially influence population status.

→ Diseases can affect conservation status of species, and the usual drivers of population decline are also the drivers for disease emergence which can then exacerbate pre-existing threats. Therefore, addressing wider conservation threats contributes to reducing disease risks to wildlife, livestock, and people.

→ Interfaces, whether direct or indirect, between with domestic livestock and wildlife significantly risk negative health outcomes from infectious diseases in both sectors.

→ Responsibilities for health of ecosystems and wildlife lie with environment sections of government.

→ There are significant gaps in contingency planning for wildlife disease threats. Inadequate surveillance for wildlife diseases contributes to poor understanding of both diseases and means to manage them. Moreover, regulations for transporting samples from many species are delaying outbreak responses and hampering our understanding of epidemiology of diseases of wildlife.

→ Stronger wildlife health systems are required to enable effective prevention and control of disease in wildlife. These should be integrated with human and domestic animal health systems within a One Health framework.

3 MIGRATION AN DISEASE DYNAMICS

In this section, we review infectious disease dynamics in relation to migration, and the potential disease consequences of migration, and its disruption, for wildlife conservation as well as the health of domestic animals and people.

3.1 Migration

3.1.1 Definitions

Migration is typically the recurrent, usually seasonal, movement of animals to different geographical locations in search of beneficial resources and conditions for certain life stages (Dingle, 2014).

The Convention of Migratory Species (CMS) definition of migratory species is:
"…the entire population or any geographically separate part of the population of any species … of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries" (CMS., 2023).

3.1.2 Physiological impact

Migration, while providing access to resources and/or a means to escape unfavourable conditions, can come at considerable physiological expense. Migration can typically take a huge physiological toll on the individual, so to warrant this behaviour its benefits must outweigh the costs. The physiological costs may differ depending on fluctuating environmental conditions along with any stressors the migrants may encounter. Anthropogenic activities (stressors) which create greater costs for the individual can shift the balance and result in poorer health outcomes.

Table 4. Some costs and benefits of migration

Costs of migration	Benefits of migration
High energy expenditure	Utilise increased environmental resources
Time	More suitable habitat for breeding/wintering/moulting
High expenditure of body fat reserves	Can increase health and resilience[3]
Mortality	Can escape high parasite burdens[4]
Stress, immunosuppression	Can exploit currents and winds to reduce migration time
Possible increased exposure to parasites[1]	Reduced predation in some situations

Weather and environment influencing migration[2]	Less harmful parasite strains[5]

[1]Encountering other species en route can increase exposure to parasites.

[2]For example storms and adverse windy weather can affect birds' flight patterns and increase their mortality; terrestrial migratory animals can be affected by poor ground quality, impeding their movement, and extreme weather in e.g. grasslands can make it difficult for them.

[3]By utilising better resources at the migratory destination, can improve health

[4]Migration can serve the host by their escaping areas with high parasite burdens

[5]There is some evidence that migratory animals can host less harmful strains of parasites than resident counterparts (Altizer *et al*., 2011).

3.2 Migration and disease

3.2.1 Principles

Infectious disease events reflect a complex interplay between the infectious agent, host animal and their wider environment. Factors to consider with respect to infectious agents include: how harmful an agent is, host numbers and presence of vectors/intermediate hosts. Factors relevant to hosts include: species, age, sex, nutritional status, immune status and genetics. And factors relevant to the environment include: habitat quality, competition, pollution, climate and interference. The balance between health and disease of an individual or population depends on the complex interplay between these three elements (Thrusfield *et al*., 2018). In this way, we can see how anthropogenic changes, such as habitat degradation or loss, or climate change, which impact animal populations can also considerably influence disease dynamics.

3.2.2 How migration can impact on health

Migration can have both positive and negative health consequences for the wider environments that migratory species visit, and knock-on impacts for other species and humans. Migration can improve the health of an individual, by promoting access to better resources, and potentially 'escaping' parasite burdens. Migrants can introduce infectious agents to naïve hosts, potentially playing a role in disease emergence. A frequent assumption is that migrants are responsible for introducing infectious agents to new areas and for spreading diseases in both animals and people. This assumption can compromise conservation efforts for such species. While this can be true, the act of migration can equally serve to decrease infection burden (Table 5) (Altizer *et al*., 2011).

Table 5. Consequences of migratory behaviour. Key: ✓ = positive ✗ = negative

Migratory behaviour may:	Consequences for wildlife health, or the health of domestic animals or humans
Reduce the proportion of individuals with infection in the migratory population	✓
Increase the proportion of individuals with infection in the migratory population	✗
Increase exposure of migratory animals to novel infectious agents	✗

Increase the diversity of infectious agents in the migratory population	✓ / ✗
Improve health and resilience to infection	✓

We discuss each of the points in Table 5 in more detail, below:

→ Migration can reduce numbers infected in the migratory population

This reduces the likelihood of infectious disease in migratory animals, safeguarding their health and conservation status and reducing the likelihood of disease transmission to other wildlife, domestic animals, or people.

How?

- Animals may move away from habitats with a high infection burden to ‘escape’ infection burdens. They can also avoid such habitats on their migratory routes or stopover locations.
- Infected individuals may succumb during migration, thus removing infected individuals from a population. The intensive energy costs associated with migration may also reactivate dormant infections in individuals, exacerbating this effect. This may additionally in effect ‘remove’ genes for disease susceptibility from the population.
- Migration to habitats with better resources may improve the health of individuals and their resilience to infection.
- Through the act of migration, migrants can separate themselves from vulnerable individuals in the population, such as juveniles, therefore reducing both their own exposure to infectious agents and that of immunologically naïve, vulnerable individuals.
- Infected animals may choose to remain resident and not migrate; they may also delay migration or take longer to migrate.
- Once animals leave for migration, it can allow the environment to ‘recover’, in effect, decontaminating the environment.

Case example

Avian malaria infections in shorebird populations vary depending on which habitats they utilise during their migratory routes. Populations of shorebirds using the East Atlantic Flyway which travelled to northern and coastal environments had much lower levels of infection in comparison to southern populations using tropical habitats, inland and freshwater environments. This is thought to be due to shorebirds in marine and saltwater habitats ‘escaping’ the chance of exposure to infected mosquitos, as these habitats do not support the vectors as well as tropical and freshwater habitats (Mendes et al., 2005).

→ Migration may increase exposure to novel infectious agents for both migrants and other animals encountered en route.

This increases the likelihood of infectious disease in migratory animals, potentially compromising their health and conservation status and increasing the likelihood of disease transmission to other wildlife, domestic animals, or people.

Migration can therefore act as a means of increasing the distribution of a disease, by bringing it to new regions.

How?

- Many individuals can congregate at stopover, breeding, or non-breeding sites, increasing the chances of exposure to infectious agents.
- The intensive energy costs associated with migration can cause stress (immunosuppression), which may reactivate dormant infections in individuals.
- Migrants follow the most favourable environmental conditions; however, these conditions may also be beneficial for infectious agent survival and transmission, especially for those agents that persist long-term in the environment.
- Infectious agents can have varying impacts on different species, different age groups, and differing life stages. For example, older animals often have more resilience/immunity to infection in comparison to juveniles which are more immunologically naive. Pregnant animals can be more immunosuppressed, thus more likely to contract infections than non-pregnant counterparts. Migration can therefore 'introduce' more susceptible individuals into non-migratory populations which can have consequences for disease dynamics.

Case example
Avian influenza viruses (AIVs), which more commonly infect juvenile birds, can be transmitted by migratory birds, to each other and other resident bird populations at their destinations or stop over sites. Habitat loss and degradation from human activities can lead to overcrowding at these sites, and/or closer contact with domestic animals and livestock (and people). For example, where domestic ducks are grazed in natural wetlands increasing the risk of transmission to livestock and subsequently to people (Hall *et al*., 2022).

→ **Migration may increase the diversity of infectious agents in the migratory population**

This may have a range of consequences: a higher likelihood of infectious disease or conversely, improved resilience to infectious disease, in the migratory population.

How?

- As above, encounters with different habitats and species at stopover sites can expose migrants to a wider variety of agents.
- Exposure to new parasites, combined with the stresses (immunosuppression) associated with migration, may increase susceptibility to disease (Poulin and Dutra., 2021).
- Exposure from previous infection from parasites (Hoye *et al*., 2016) and/or increased parasite diversity (Faria *et al*., 2008) can improve resilience to negative impacts of infection (Moller and Erritzoe., 1998).

Case example
Previous exposure (natural infection) to low pathogenicity avian influenza (LPAI) in Bewick's swans (*Cygnus columbianus berwickii*) appeared to improve resilience to negative effects of infection if exposed to LPAI again. In contrast, naïve birds with no antibodies to LPAI demonstrated more negative effects of infection (Hoye *et al*., 2016).

3.2.3 Impacts of infection status on migration

→ **Infected animals may choose not to migrate**

Infected animals often reduce their movement due to the physiologic costs of infection, either as an immune strategy to cope with infection, or from negative effects of infection on the body. Thus, infection can lead to individuals choosing to remain resident rather than risk migration and potential mortality (Narayanan *et al*., 2020).

→ Infected animals may move away from habitats with a high infection load
The presence of parasites may even act as a force to encourage migration, such as animals migrating to move away from high-parasite areas, especially during vulnerable life stages. For example, caribou (*Rangifer tarandus*) migrate for breeding which reduces their exposure to damaging warble flies (*Hypoderma tarandi*) (Folstad *et al*., 1991).

3.3 Migratory change

With ecological changes at a global scale, some populations are becoming more resident and choosing not to migrate; others are struggling to acclimatise to the changing climate and environment around them (Bowlin *et al*., 2010).

3.3.1 Disruption to migration

Anthropogenic changes along with climatic changes are having an influence on migratory behaviour; many migratory species are sensitive to changes in land-use. Examples of migratory disruption, and its consequences, are given in Table 6.

Table 6. Consequences of disruption to migration

Migratory Disruption	Sequelae
Delays in migration	Missed resource abundance, increased competition, continuing parasite burden from 'source site' (see main text), difficult terrain (e.g. ice melt meaning terrestrial species need to swim)
Migrating earlier	Missed timings, seasonal resources not ready
Remaining resident / skipping migration	Reduced resources, competition, increased parasite burdens (see main text)
Habitat loss or degradation	Overcrowded stopover sites, increasing contact between populations, increased risk of spillover events (see main text)
Altered migration range or routes	Exposure to novel infectious agents in environments or different species; increasing disease distribution (see main text)

→ Barriers to migration
Physical barriers (such as fences, wind turbines, roads, buildings, other infrastructure) can disrupt migration in some populations so they either try to cross these migratory barriers or they remain resident and choose not to migrate (Altizer *et al*., 2011).

Case example
Fencing in an important migratory area can be catastrophic to mass migratory behaviour. In one year (1983) with reduced rainfall and drought, approximately 50,000 wildebeest died in the Kalahari, largely thought due to their inability to access water due to veterinary cordon fencing (for foot and mouth disease) blocking their path. They had to access water from Lake Xau, which had a significant human presence, and consequently were hunted, prevented from drinking by farmers with their livestock and stressed by getting chased (Williamson *et al*., 1988).

→ Climate change
Climatic changes are predicted to alter habitats including reduction of suitable breeding or non-breeding sites, and stopover sites. This can and is already causing discrepancies in resource and prey availability. Potential consequences include changes in normal migration patterns and timings; alterations in migratory ranges; changes in breeding and mortality rates;

delayed migration; populations remaining resident; or increased mortality from migration (Lopez-Hoffman *et al*., 2017). Climate change will also alter the distribution and abundance of disease vectors, many of which are arthropods whose distribution is largely determined by climate. The potential impacts on both migratory species and disease risks together are therefore complex and challenging to predict.

3.3.2 Potential disease-related impacts of migratory change

By considering the complex interplay between migratory strategy and infection status, it is possible to see how alterations in migration patterns may have a significant impact on disease dynamics in migratory species (McKay & Hoye, 2016).

→ **Migratory change may increase infection burdens in migratory populations**
Changing migratory routes and ranges in response to climatic changes can expose migrants to novel parasites and/or transmit their parasites to naïve populations, increasing disease transmission.

→ **Migratory change and its associated drivers may act together to increase infection burden and contact with other species**
Habitat loss and degradation is a significant driver of disease emergence and could reduce the size of stopover sites. With increased numbers of animals and species occupying smaller and overcrowded areas, exposure to more and novel infectious agents is highly likely. Climate change can alter vector dynamics, with the warmer temperatures promoting range expansion for vectors. This could lead to a reduced ability for species to avoid/escape them by migration, thus leading to heightened parasite transmission (Hall *et al*., 2016). In a species of conservation concern, this could be significant future risk to them. This could also lead to increased migration range as populations alter their routes to adapt to the changing climates and differing resources.

→ **Population declines of migratory species can increase the likelihood of disease events**
Emerging infectious diseases are more likely to appear in populations which are stressed by other factors. As above, stressors can include habitat fragmentation, loss or degradation from human activities, and increasing encroachment from people and domestic animals and livestock. Small, isolated wildlife populations are at a greater risk of disease outbreaks due to these stressors on their populations and genetic vulnerabilities, potentially increasing the chances of extinction (Aguirre & Tabor., 2008).

KEY MESSAGES: On migration and disease

- → The disease dynamics associated with migration are complex, and health outcomes for individuals and populations are situation dependent.
- → Migration itself does not necessarily increase infection burden or introduce new infectious agents, it can reduce infection within a population by removing those not fit enough to migrate, and with them their genes for disease susceptibility.
- → Therefore, migration may serve to safeguard the conservation status of wildlife, and the risk of infection in domestic animals and people, depending on the specific context.
- → Conversely, migration can bring novel infectious agents to new areas and to naïve populations, increasing the likelihood of infection and disease.

→ Meanwhile, increased exposure of migrants to different and diverse infectious agents can increase their resilience to infectious disease.

→ Infectious agents may influence migratory behaviour and migration outcomes.

→ Human activities are profoundly influencing migratory patterns. Changes in migration, along with the drivers of these changes, have the potential to increase infection burdens in migratory populations.

4 KEY HEALTH ISSUES FOR MIGRATORY SPECIES

In this section, we will provide an overview of the main health issues that taxon-specific experts perceive to be affecting migratory species, specifically CMS-listed species, and the drivers of these issues. The output, i.e. disease table, has been designed as a living platform for the CMS Migratory Species & Health Working Group to work from in future, enabling identification of priority disease threats, patterns across taxa, drivers of disease emergence and important knowledge gaps.

4.1 Introduction

Infectious agents and non-infectious conditions

As briefly discussed in the One Health and Ecosystem Health section, health of wildlife is threatened by both infectious agents and non-infectious conditions. These may not cause disease in one species but may have severe effects in another.

Infectious agents cause infection in the host animal, which may then show clinical signs of illness; or can cause a ‘silent’ infection without outward signs. This means that some animals may look well but potentially be carrying agents which could cause infection in other individuals. Such agents can be transmitted directly between individuals; or indirectly through a vector, such as a mosquito or tick; or from environmental contamination via their bodily fluids.

Non-infectious agents can also be responsible for ill-health or death in animals. These include genetic diseases, physical agents (such as heat or cold), trauma (including unintentional trauma from humans such as vehicle collisions, or bycatch), nutritional issues, stress or disturbance from people like noise or light pollution, foreign object ingestions (such as plastic), and other forms of injury from the environment (e.g. drowning, burn injuries).

Drivers

To recap on Section 2, some drivers of biodiversity declines also cause disease emergence which can compound threats to populations. There is a lot of overlap between these, and most of the threats impacting ecosystem health also play a part in disease outbreaks. See Table 3, above, for our categorisation of drivers.

4.2 Methods

To determine the key health issues for CMS-listed migratory species, and their likely drivers, a disease table was constructed in order to solicit expert opinion on threats to the health of migratory species (see end of section).

Disease table

There are currently 657 CMS-listed species across different taxonomic groups. We grouped different species together to streamline completion of this task in our limited timescale. We generally grouped species into orders. However, given the number of orders we needed to consider and the varying amount of knowledge regarding health conditions in these taxa, we used a higher taxonomic grouping for some fish (Class Chondrichthyes) species; for Orders Carnivora and Artiodactyla we grouped species according to family; and we grouped some avian orders together (for example, four orders were grouped together under 'birds of prey'). From our own review of the literature and expert knowledge, we identified infectious, non-infectious, and other problems that can affect the health of wildlife species. These were listed in this disease table with extra lines for expert contributors to add any agents/conditions we may have missed, and to provide comments on these threats as appropriate.

There were two other sections in the table. These were:

→ Ranking: proven/suspected impacts (ranked 5-1, 5 = highest priority).
The intention for this section was to prioritise identified threats to health with an emphasis on their wider impact at a conservation level, on domestic animal health (human livelihoods and economics) or human health, and to also identify potential future or emerging threats.

→ Drivers
The intention of this section was to identify the suspected or confirmed drivers of the identified threats. The drivers in the table were outlined in the above One Health and ecosystem health section (Table 3).

Expert consultation

The core research team identified the most appropriate experts with knowledge of health of each taxonomic group, from their contact networks. ‘Snowball recruitment’ was used to recruit additional experts for some taxa. Experts (aiming for a minimum of two experts per taxonomic group) were contacted and requested to complete the disease table: to add any extra health threats that we may have missed in our own review; to rank them according to their perceived threat level under each of the above categories (see Figure 1-Figure **3** below); and to identify possible drivers of these threats.

This consultation exercise is currently ongoing, and the information gathered will be collated and analysed ahead of submission of the final report.

4.3 Case studies

We will use information gathered from the experts consulted for this review to present case studies in the final report, illustrating how human activities are negatively impacting the health of CMS-listed wildlife species, and how this is driving disease problems.

Taxonomic details as per CMS listing		Proximate threat to health		Ranking - proven/suspected impacts (1-5, 5=highest priority)					Drivers*							
Class, Order	No. of species represented (see Species List for details)	Potential threat	Category	Negative impact on biodiversity conservation*	Risk of epidemic in people*	Negative impact on human livelihoods or economics*	Top 5 Threats*	One to watch: a possible future threat*	Agriculture or aquaculture	Other habitat loss, degradation or disturbance	Harvesting or persecution (overexploitation)	Invasive species	Pollution	Climate change or severe weather	Other*	Undetermined / unknown
4. Order Charadriiformes (waders/shorebirds, gulls)	98	**Infectious**	**Category***													
		Avian influenza viruses - particularly highly pathogenic strains	Virus	5	5	5	5	Medium	☑	☑	☐	☐	☐	☐	☐	☐
		Avian paramyxoviruses (APMVs) including Newcastle Disease virus (APMV-1)	Virus			3		Unlikely	☑	☑	☐	☐	☐	☐	☐	☐
		Infectious bursal disease virus	Virus					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Avian poxvirus	Virus					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		~~Puffinosis (viral disease, unknown cause)~~						Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Salmonella sp	Bacterium			4		Unlikely	☑	☑	☐	☐	☐	☐	☐	☐
		Erysipelothrix spp	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Camplyobacter spp	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Chlamydia sp	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Yersinia sp	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Mycoplasma sp	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Mycobacterium avium complex	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Klebsiella pneumoniae	Bacterium					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Aspergillosus (A.fumigatus)	Fungus or Yeast					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Eimeria spp (~~renal~~ coccidiosis)	Protozoa					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Cestodes, trematodes & acanthocephalans - various spp	Helminth					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Nematodes - various including Capillaria spp	Helminth					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Trematodes (Cyclocoelum spp)	Helminth					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Ectoparasites including lice, mites & others	Arthropod ectoparasite					Unlikely	☐	☐	☐	☐	☐	☐	☐	☐
		Coronavirus	Virus		4			Low	☐	☑	☐	☐	☐	☐	☐	☐
		Circovirus, reovirus & various other viruses	Virus					Medium	☐	☑	☐	☐	☐	☐	☐	☐
		Pasteurella multocida (avian cholera)	Bacterium						☐	☐	☐	☐	☐	☐	☐	☐
		Avian malaria (Haemoproteus sp, Plasmodium sp)	Protozoa					Low	☐	☑	☐	☐	☐	☑	☐	☐
									☐	☐	☐	☐	☐	☐	☐	☐
		Non-infectious	**Category***													
		Chemical pollutants: pesticides, heavy metals, industrial chemicals, petroleum products (oil spills)	Toxin, pollution or eutrophication					Medium	☑	☑	☐	☐	☑	☐	☐	☐
		Eutrophication and changes in water quality	Toxin, pollution or eutrophication	3			3	Medium	☑	☑	☐	☐	☑	☑	☐	☐
		Road traffic or fence collisions, entanglements	Incidental anthropogenic trauma						☐	☐	☐	☐	☐	☐	☐	☐
		FB ingestion	Foreign body ingestion						☐	☐	☐	☐	☐	☐	☐	☐
		Bycatch (incidental offtake)	Incidental anthropogenic trauma	5			5		☐	☐	☑	☐	☐	☐	☐	☐
		Algal blooms - reducing quality of feeding areas and potential for direct toxicity	Toxin, pollution or eutrophication	3			3	Medium	☑	☑	☐	☐	☑	☑	☐	☐
		Avian botulism	Toxin, pollution or eutrophication	1			1	Low	☐	☑	☐	☐	☐	☑	☐	☐
		Nest disturbance	Anthropogenic stress or disturbance						☐	☐	☐	☐	☐	☐	☐	☐
		Microplastic or nanosilver pollution	Toxin, pollution or eutrophication					Medium	☐	☐	☐	☐	☑	☐	☐	☐
		Other problems*	**Category***													
		Habitat loss due to agricultural intensification and development - at wintering, breeding & stopover sites	Environmental conditions													
		Habitat degradation due to agricultural practices, wetland drainage and other developments - at wintering, breeding & stopover sites	Environmental conditions													

Figure 1: Screenshot of the table that has been provided to expert contributors to fill in. This image demonstrates the ranking system and the drivers completed for Order Charadriiformes (waders, shorebirds, and gulls).

Taxonomic details as per CMS listing		Proximate threat to health		Ranking - proven/suspected impacts (1-5, 5=highest priority)				
Class, Order	No. of species represented (see Species List for details)	Potential threat	Category	Negative impact on biodiversity conservation*	Risk of epidemic in people*	Negative impact on human livelihoods or economics*	Top 5 Threats*	One to watch: a possible future threat*
4. Order Charadriiformes (waders/shorebirds, gulls)	98	**Infectious**	**Category***					
		Avian influenza viruses - particularly highly pathogenic strains	Virus	5	5	5	5	Medium
		Avian paramyxoviruses (APMVs) including Newcastle Disease virus (APMV-1)	Virus			3		Unlikely
		Infectious bursal disease virus	Virus					Unlikely
		Avian poxvirus	Virus					Unlikely
		~~Puffinosis (viral disease, unknown cause)~~						Unlikely
		Salmonella sp	Bacterium			4		Unlikely
		Erysipelothrix spp	Bacterium					Unlikely
		Camplyobacter spp	Bacterium					Unlikely
		Chlamydia sp	Bacterium					Unlikely
		Yersinia sp	Bacterium					Unlikely
		Mycoplasma sp	Bacterium					Unlikely
		Mycobacterium avium complex	Bacterium					Unlikely
		Klebsiella pneumoniae	Bacterium					Unlikely
		Aspergillosus (A.fumigatus)	Fungus or Yeast					Unlikely
		Eimeria spp (~~renal~~ coccidiosis)	Protozoa					Unlikely
		Cestodes, trematodes & acanthocephalans - various spp	Helminth					Unlikely
		Nematodes - various including Capillaria spp	Helminth					Unlikely
		Trematodes (Cyclocoelum spp)	Helminth					Unlikely
		Ectoparasites including lice, mites & others	Arthropod ectoparasite					Unlikely
		Coronavirus	Virus		4			Low
		Circovirus, reovirus & various other viruses	Virus					Medium
		Pasteurella multocida (avian cholera)	Bacterium					
		Avian malaria (Haemoproteus sp, Plasmodium sp)	Protozoa					Low
		Non-infectious	**Category***					
		Chemical pollutants: pesticides, heavy metals, industrial chemicals, petroleum products (oil spills)	Toxin, pollution or eutrophication					Medium
		Eutrophication and changes in water quality	Toxin, pollution or eutrophication	3			3	Medium
		Road traffic or fence collisions, entanglements	Incidental anthropogenic trauma					
		FB ingestion	Foreign body ingestion					
		Bycatch (incidental offtake)	Incidental anthropogenic trauma	5			5	
		Algal blooms - reducing quality of feeding areas and potential for direct toxicity	Toxin, pollution or eutrophication	3			3	Medium
		Avian botulism	Toxin, pollution or eutrophication	1			1	Low
		Nest disturbance	Anthropogenic stress or disturbance					
		Microplastic or nanosilver pollution	Toxin, pollution or eutrophication					Medium
		Other problems*	**Category***					
		Habitat loss due to agricultural intensification and development - at wintering, breeding & stopover sites	Environmental conditions					
		Habitat degradation due to agricultural practices, wetland drainage and other developments - at wintering, breeding & stopover sites	Environmental conditions					

Figure 2: A closer screenshot of the table demonstrating the threats identified and how they have been ranked.

Taxonomic details as per CMS listing		Proximate threat to health	Drivers*							
Class, Order	No. of species represented (see Species List for details)	Potential threat	Agriculture or aquaculture	Other habitat loss, degradation or disturbance	Harvesting or persecution (overexploitation)	Invasive species	Pollution	Climate change or severe weather	Other*	Undetermined / unknown
4. Order Charadriiformes (waders/shorebirds, gulls)	98	**Infectious**								
		Avian influenza viruses - particularly highly pathogenic strains	☑	☑	☐	☐	☐	☐	☐	☐
		Avian paramyxoviruses (APMVs) including Newcastle Disease virus (APMV-1)	☑	☑	☐	☐	☐	☐	☐	☐
		Infectious bursal disease virus	☐	☐	☐	☐	☐	☐	☐	☐
		Avian poxvirus	☐	☐	☐	☐	☐	☐	☐	☐
		~~Puffinosis (viral disease, unknown cause)~~	☐	☐	☐	☐	☐	☐	☐	☐
		Salmonella sp	☑	☑	☐	☐	☐	☐	☐	☐
		Erysipelothrix spp	☐	☐	☐	☐	☐	☐	☐	☐
		Camplyobacter spp	☐	☐	☐	☐	☐	☐	☐	☐
		Chlamydia sp	☐	☐	☐	☐	☐	☐	☐	☐
		Yersinia sp	☐	☐	☐	☐	☐	☐	☐	☐
		Mycoplasma sp	☐	☐	☐	☐	☐	☐	☐	☐
		Mycobacterium avium complex	☐	☐	☐	☐	☐	☐	☐	☐
		Klebsiella pneumoniae	☐	☐	☐	☐	☐	☐	☐	☐
		Aspergillosus (A.fumigatus)	☐	☐	☐	☐	☐	☐	☐	☐
		Eimeria spp (~~renal~~ coccidiosis)	☐	☐	☐	☐	☐	☐	☐	☐
		Cestodes, trematodes & acanthocephalans - various spp	☐	☐	☐	☐	☐	☐	☐	☐
		Nematodes - various including Capillaria spp	☐	☐	☐	☐	☐	☐	☐	☐
		Trematodes (Cyclocoelum spp)	☐	☐	☐	☐	☐	☐	☐	☐
		Ectoparasites including lice, mites & others	☐	☐	☐	☐	☐	☐	☐	☐
		Coronavirus	☐	☑	☐	☐	☐	☐	☐	☐
		Circovirus, reovirus & various other viruses	☐	☑	☐	☐	☐	☐	☐	☐
		Pasteurella multocida (avian cholera)	☐	☐	☐	☐	☐	☐	☐	☐
		Avian malaria (Haemoproteus sp, Plasmodium sp)	☐	☑	☐	☐	☐	☑	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐
		Non-infectious								
		Chemical pollutants: pesticides, heavy metals, industrial chemicals, petroleum products (oil spills)	☑	☑	☐	☐	☑	☐	☐	☐
		Eutrophication and changes in water quality	☑	☑	☐	☐	☑	☑	☐	☐
		Road traffic or fence collisions, entanglements	☐	☐	☐	☐	☐	☐	☐	☐
		FB ingestion	☐	☐	☐	☐	☐	☐	☐	☐
		Bycatch (incidental offtake)	☐	☐	☑	☐	☐	☐	☐	☐
		Algal blooms - reducing quality of feeding areas and potential for direct toxicity	☑	☑	☐	☐	☑	☑	☐	☐
		Avian botulism	☐	☑	☐	☐	☐	☑	☐	☐
		Nest disturbance	☐	☐	☐	☐	☐	☐	☐	☐
		Microplastic or nanosilver pollution	☐	☐	☐	☐	☑	☐	☐	☐
		Other problems*								
		Habitat loss due to agricultural intensification and development - at wintering, breeding & stopover sites								
		Habitat degradation due to agricultural practices, wetland drainage and other developments - at wintering, breeding & stopover sites								
		Predation (particularly of nests & pre-fledged young)								
		Flooding of breeding sites								
		Persecution or offtake								

Figure 3: A closer screenshot of table demonstrating the threats identified and their potential drivers.

5 KEY MESSAGES AND RECOMMENDATIONS

In conclusion, the health of migratory species is dependent on healthy ecosystems, which are an important platform for One Health approaches. The relationships between migration and disease dynamics are highly complex and many factors influence disease emergence. There is growing, global evidence demonstrating the severe impacts of human activity on populations and ecosystems, with many of the same drivers for conservation declines and ecosystem degradation being drivers of disease emergence.

Our understanding of the many diseases affecting migratory species, and how migration influences infection dynamics, is limited. Modelling papers exist but there have been limited real-world case studies. Further research is needed to improve our understanding of how migration, and migratory change, can alter infection and disease status in migratory populations.

PRELIMINARY RECOMMENDATIONS

→ Healthy resilient ecosystems create the setting for and determine health. Preventative approaches are both cost effective and required to promote health in migratory wildlife, livestock, and people. The role of those involved in biodiversity conservation and sustainable livelihoods should therefore be recognised for, and actively supported in, their contribution to health across all sectors. The role of UNEP in the FAO UNEP WHO WOAH Quadripartite is welcomed.

→ Efforts to address the drivers of population decline such as climate change, habitat loss and degradation, pollution, invasive species, and barriers to migration should be enhanced as these are also drivers of disease emergence across sectors.

→ One Health approaches appreciate the interconnectivity of health between wildlife, livestock, and people, yet can often be anthropocentric – such approaches should be used equitably in decisions about health management appreciating that promoting the health of wildlife reduces risks to humans and our interests, as well as bringing conservation benefits.

→ Rather than seeing animal health as the sole responsibility of agriculture ministries, environment sections of government need to engage and lead on wildlife and ecosystem health.

→ Preventing and responding to wildlife diseases requires good cross-sectoral working. Governments, their agencies, and all those managing wildlife are encouraged to contingency plan in peacetime involving all relevant stakeholders to both prevent wildlife health problems occurring but also to respond appropriately in emergency situations. This will minimise the adverse impacts of disease outbreaks and inappropriate control measures.

→ Livestock-wildlife interfaces caused by, for example, agricultural development and encroachment into wild areas, are particularly problematic for disease spillover and spillback. Every effort should be made to manage livestock to reduce these risks for the benefit of all. This might include improved biosecurity, better planning or significant changes and reassessment of livestock management particularly in medium and high-income countries where choices can be made about protein sources.

→ The health of migratory populations will be protected and fostered by strengthening ‘wildlife health systems’ comprising the expertise and resources to enable effective and prompt disease surveillance, diagnosis and management. Building this capacity is relatively inexpensive compared to the potential costs associated with reactive management of disease outbreaks.

→ Robust wildlife health surveillance, with conservation (rather than livestock protection) as its goal, is required to support robust planning and risk assessment, and surveillance can be integrated with ecological and population monitoring. Improvements in wildlife diagnostics, testing facilities and reporting systems, along with appropriate capacity building, are needed worldwide. Regulations for transporting specimens from threatened species across national boundaries are delaying outbreak responses and this also needs addressing.

→ There are significant knowledge gaps surrounding the epidemiology and drivers of many diseases of migratory species which prevent good health management. Research and resourcing should be targeted at priority health threats to migratory species, particularly those of poor conservation status.

6 References

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