The relation between different zoonotic pandemics and the livestock sector

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Abstract

This study examines the zoonotic disease risks posed by the livestock sector (including fur production), reviews the risks posed by different livestock species and production systems, and examines case studies of past zoonotic disease epidemics. Building on this evidence, it reviews EU zoonosis surveillance and control arrangements. It recommends improvements including integration of human and animal disease surveillance services, expanded use of syndromic surveillance and changes to the funding of Member States' zoonotic disease programmes under Regulation (EU) 652/2014.

CONTENTS

LIST OF ABBREVIATIONS

ADIS	Animal Disease Information System
ADNS	Animal Disease Notification System
AI	Avian Influenza
AMR	Anti Microbial Resistance
BSE	Bovine Spongiform Encephalopathy
CCCAs	Coordination, Communication and Collaborative Actions
DEFRA	UK Department for Environment Food & Rural Affairs
DG SANTE	Commission's Directorate-General for Health and Food Safety
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
ECHA	European Chemicals Agency
EFSA	European Food Safety Authority
EID	Emerging Infectious Disease
EMA	European Medicines Agency
EWRS	Early Warning and Response System
FAO	Food and Agriculture Organisation of the United Nations
HAIRS	Human-Animal Infections and Risk Surveillance
HPAI	Highly Pathogenic Avian Influenza
HSC	Health Security Committee of the European Union
IHR	International Health Regulations
IT	Information Technology
JIP	Joint Integrative Project
JRP	Joint Research Project

LA-MRSA	Livestock-Associated Methicillin-Resistant Staphylococcus Aureus
MRSA	Methicillin Resistant Staphylococcus Aureus
MS	Member State(s)
OH	One Health
OHEJP	One Health European Joint Programme
OHZDP	One Health Zoonotic Disease Prioritisation
OIE	World Organisation for Animal Health (former Office International des Epizooties)
PCR	Polymerase Chain Reaction
PHE	Public Health England
RISKSUR	Risk-based Animal Health Surveillance Systems
SARS-CoV-2	Virus causing coronavirus disease 19 (COVID-19)
SGB	Sheep and Goat Brucellosis
TESSy	The European Surveillance System (on communicable diseases)
TSE	Transmissible Spongiform Encephalopathies
UNEP	United Nations Environment Programme
vCJD	variant of Creutzfeldt-Jakob Disease
VTEC	Verotoxinogenic
WAHIS	World Animal Health Information System
WHO	World Health Organisation

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EXECUTIVE SUMMARY

Background

Zoonoses, infectious diseases which are transmissible from vertebrate animals to humans, present considerable public health, social and economic risks. Even before the COVID-19 pandemic, it was estimated that zoonoses caused up to one billion cases of illness globally every year (Karesh et al., 2012) and that 75% of new human pathogens detected over the past three decades had originated in non-human animals (Jones et al., 2008). Moreover, livestock farming has been implicated in many past zoonotic disease epidemics and pandemics, including those centred on the H1N1 influenza virus (known colloquially as swine flu) and H5N1 highly pathogenic avian influenza (HPAI). The current COVID-19 pandemic has heightened concern over the risks and impacts of novel zoonoses, and this has focused attention on the potential role of livestock production in facilitating the emergence and transmission of novel zoonoses. In this context, this in-depth analysis aims to support the European Parliament in addressing the following questions:

- What zoonotic disease risks do different livestock species and production practices pose, and what zoonotic disease emergence threats do they present? (Chapters 1 and 2)

- What lessons can be learned from past zoonotic disease epidemics? (Chapter 3)

- What recommendations can be made regarding improvements to the prediction, detection and control of zoonotic diseases within the EU? (Chapters 4-6)

This study also examines the zoonosis risks posed by fur production. Mink made up 94% of pelts produced in the EU in 2019 [European Food Safety Authority (EFSA), 2021], so our comments on the fur sector focus on mink farming.

The relationship between livestock production and zoonotic disease risk

Chapter 1 highlights that livestock frequently acts as intermediary hosts for emerging zoonotic pathogens, facilitating their transmission from wild animals to humans. Livestock production is also implicated in five drivers of zoonotic disease emergence identified by the United Nations Environment Programme (UNEP, 2020): 1) increasing animal protein production; 2) agricultural intensification; 3) unsustainable utilization of natural resources; 4) globalization of food supply chains, and 5) climate change. However, the relationship between livestock farming and zoonotic risk is complex and dynamic. The emergence of specific zoonoses is driven by numerous ecological, biological and socioeconomic factors, and there is a lack of validated risk assessment frameworks to identify the riskiest livestock systems. Consequently, it is very difficult to make precise assessments of which species, production systems and locations pose the greatest zoonotic disease emergence risks, and real-world testing of risk assessment frameworks suitable for a range of situations is urgently needed.

Chapter 2 identifies several risk drivers favouring the emergence or re-emergence of zoonoses within specific livestock species and systems. Intensive livestock production systems, in which large numbers of genetically similar animals are kept in high-density units, provide a suitable environment for the rapid transmission and evolution of pathogens circulating among livestock. By contrast, the less controlled environments characteristic of extensive production systems pose two challenges: (1) increased exposure of farmed animals to pathogens carried by humans and wild animals; and (2) greater opportunities for pathogen transmission from farmed animals to humans. Certain farm management practices present opportunities to manage risk across various production systems,

including 1) vaccination, 2) changing the location and type of feed provided to animals, and 3) biosecurity enhancement.

Lessons from past epidemics and strategies for controlling future outbreaks

Chapter 3 reviews three past zoonotic disease outbreaks (the Bovine Spongiform Encephalopathy epidemic in the United Kingdom (UK), the continuous re-emergence of HPAI in the EU, and the 2007-2011 Q fever outbreak in the Netherlands), highlighting the following general implications for surveillance and control of zoonoses which may emerge in the future:

- Well-known pathogens can be considered emerging zoonoses if they cause outbreaks in hitherto disease-free locations. However, some novel zoonotic pathogens are unknown to science at the time of their emergence. Forecasting exercises using historical data and surveillance programmes based on pathogen-specific testing are unlikely to address the risks posed by such pathogens, which are more likely to be detected through syndromic surveillance (i.e. analysis of unusual clusters of symptoms and mortality).

- Integrating communication between human and veterinary health services can accelerate the detection of emerging disease outbreaks. Rapid detection and containment of outbreaks of zoonoses are crucial to minimizing their economic, social and health impacts since control of epidemics in livestock often requires costly and controversial measures such as mass culling.

- Zoonotic disease emergence is a complex process involving rapidly changing transmission pathways shaped by dynamic interactions among livestock, wildlife and humans. Prevention of emergence should be managed holistically through measures such as maintaining biosecurity, ensuring input (e.g. feed) quality, and improving supply chain transparency.

Chapter 4 draws on these findings to develop a strategic approach to predicting, detecting, and controlling emerging zoonoses based on three key principles. First, the complexity of zoonotic disease emergence makes it highly unlikely that predictions about the identity of future zoonotic pathogens or about the livestock species, production systems and locations from which they will emerge will be accurate. Efforts should therefore focus on ensuring rapid detection and containment of emerging zoonoses. Disease-specific controls cannot be imposed until an outbreak has been identified, so effective surveillance is vital in controlling emerging zoonoses.

Second, the heterogeneity of emerging zoonoses means that there is no single best approach to their surveillance and control, and the strongest zoonotic disease strategies will combine multiple complementary approaches. Risk-based surveillance programmes targeting specific livestock species and systems may enable rapid detection and control of zoonoses whose epidemiology is well understood. However, novel pathogens for which testing capacity is not yet available or cost-effective may be detected more rapidly through syndromic surveillance of human and animal populations. Surveillance of changes in land use and livestock systems linked to zoonotic disease emergence may also provide a valuable proxy for the surveillance of disease events. We recommend that policymakers request the development of evidence-based protocols for syndromic and risk-based surveillance and monitoring land-use change.

Third, a multidisciplinary approach to surveillance and control could enhance the timeliness and effectiveness of control measures for emerging zoonoses, and surveillance programmes should therefore be designed to enable data sharing across medical, veterinary, environmental and other relevant professions. Such co-operation will need to extend beyond national and continental boundaries, given that many future zoonoses will initially emerge outside of Europe.

Review and recommendations regarding EU zoonosis control arrangements

Chapters 5 and 6 assess the extent to which current EU zoonotic disease control arrangements employ the approach outlined above and identify opportunities for improvement. **Chapter 5** observes that a One Health approach – which can be used to address multi-species health threats such as zoonotic diseases through developing integrated programmes, policies, legislation and research spanning human, animal and environmental health – might facilitate a more coordinated multidisciplinary approach to managing zoonoses. However, it finds that the EU's current zoonosis control arrangements rarely apply the One Health approach consistently and present several barriers to implementing it effectively. Notably, the EU animal and human health sectors lack arrangements for biological sample sharing; their datasets, early warning systems and reference laboratory networks are insufficiently interoperable; and differences in risk perception and assessment impede collaboration. It, therefore, recommends that three changes be made in order to implement a more integrated zoonotic disease surveillance and control model:

1. Pursuit of greater interoperability between EU early warning systems for human and animal health threats so that emerging zoonotic diseases may be detected rapidly and assessed more effectively.

2. The opening up of zoonosis surveillance, monitoring and risk assessment to a wider range of expertise (including specialists in One Health and environmental health) by creating a team with interdisciplinary knowledge spanning human, animal and environmental health to assess alerts generated by these systems. This should enable zoonotic disease risk assessments to address a wider range of risk drivers.

3. Provision by the Commission of support to assist the EU Member States in reframing their national preparedness and response plans for emerging diseases in humans, and their national contingency plans for emerging diseases in animals, to ensure that they utilize a One Health approach. This should help to provide an integrated framework for responding to emerging zoonoses at a national level.

Chapter 6 reviews the operation of two legal instruments that govern zoonotic disease surveillance and control programmes at the Member State level. Namely, Directive 2003/99/EC on the monitoring and reporting of zoonoses and zoonotic agents and the recently repealed Regulation (EU) 652/2014, which was replaced by Regulation (EU) 2021/690, both laying down provisions for the management of expenditure relating to the food chain, animal health and animal welfare. The review of Directive 2003/99/EC finds that, while substantial reporting gaps exist for Echinococcosis and E. Coli, the zoonosis monitoring and reporting obligations which the Directive establishes for Member State authorities generally provide a sound basis for EU-level surveillance and management of known zoonoses which present a well-understood public health risk. However, they are focused primarily on pathogen-specific testing programmes and may be less effective in detecting the emergence of novel zoonotic pathogens.

The review of Regulation (EU) 652/2014, which was in force until the end of 2020, finds that it effectively provided targeted short-term funding for the surveillance, eradication and control of specific zoonoses across various pathogens and livestock species. However, the national programmes funded focused solely on animal populations and were rarely coordinated with the human health sector. Certain Member States also report that the objectives of surveillance programmes were often not achieved due to insufficient staffing and resources within national veterinary authorities.

Chapter 6, therefore, recommends that:

1. Existing pathogen-specific zoonosis surveillance programmes should be complemented by expanded syndromic surveillance programmes, including humans and animals. Annex I (section 2.1) of Regulation 2021/690, which replaces and updates Article 12 of Regulation (EU) 652/2014, should therefore be amended to specify that programmes for eradicating, controlling, and surveillance of zoonoses that receive EU funding should adopt a One Health approach to promote greater integration between human-focused and animal-focused zoonosis control programmes at Member State level.

2. Measures that allow for simultaneous reductions in the incidence of multiple zoonoses, such as awareness campaigns, should be prioritised for reasons of cost-effectiveness.

3. Additional funding models, such as direct targeted funding of veterinary services in under-resourced Member States, should be considered to ensure consistent zoonotic disease surveillance and control across all Member States.

4. Given that many Member States have received funding to support surveillance for zoonoses of which they are currently free, budget allocations should be reviewed to identify any possibly redundant funds that may be reallocated to bridge resource gaps.

1. ASSESSMENT OF PUBLIC HEALTH RISKS AND THREATS POSED BY EMERGING ZOONOSES

1.1. The relationship between livestock production and zoonotic disease emergence

Outbreaks of zoonotic diseases involving livestock species can have catastrophic economic and public health impacts. Examples include influenza viruses originating in both poultry (Alarcon et al., 2018) and pigs (Smith, 2009), Q-fever from goats (van der Hoek et al., 2012), and BSE (Bovine Spongiform Encephalopathy or "mad cow disease") from cattle (Hueston, 2013). For instance, 'Swine flu' infected millions of people and caused almost 300,000 human deaths (Smith 2009), and BSE cost the EU €92 billion (Cunningham, 2003). Public health risks can arise from direct contact with infected livestock (meaning farmworkers are likely to be infected first), or people may acquire such infection from other (already-infected) people.

Emerging infectious diseases (EIDs) are commonly defined as "*Diseases that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range*" (Morse 1995). Thus, a disease may be emerging in one location (e.g., introduced to a new territory) but endemic (and therefore not emerging) in another area. There is thus a need for careful consideration of the local context and the current disease dynamics. Most EIDs of humans originate in animals, with transmission often taking place via an intermediary animal host, which may be wild or domesticated (Woolhouse & Gowtage-Sequeria 2005; Jones et al., 2008). Some, but not all, diseases originating in animals will evolve to be transmissible from human to human.

Therefore, it has been suggested that it would be advisable to differentiate between **EIDs of humans** (which originate in animals but where transmission subsequently takes place entirely or mostly between humans) and **zoonoses** (Grace et al., 2011; Wolfe et al., 2007). Notably, it has been stated that SARS-COV-2 should be considered an EID of probably animal origin rather than a zoonosis (Haider et al., 2020) because its origin remains unclear, it has no identified animal reservoir, and the vast majority of human infections are acquired from other humans. This distinction is relevant because optimal surveillance, prevention and control will differ between the two scenarios. For example, control of SARS-Cov-2 is almost entirely focused on interventions targeting humans, whereas control of zoonoses such as rabies often focuses on reducing the risk from the animal reservoir (e.g., vaccination of dogs).

Five of the seven major anthropogenic drivers of zoonotic disease emergence identified by the United Nations Environment Programme (2020) are associated with livestock production. These are:

1. **Increasing animal protein production:** A marked per capita increase in animal protein consumption in many low and middle-income countries, accompanied by significant global population growth, drives a rapid rise in demand for meat, milk and eggs. This trend is predicted to continue in the coming decades, with livestock product consumption rising markedly compared to other protein sources.

2. **Unsustainable agricultural intensification:** The intensification and industrialisation of livestock production have led to many genetically similar animals living in very close proximity. As detailed in Chapter 2, such ventures may have higher biosecurity levels than small-scale farms, meaning pathogen entry is less likely. However, conditions within intensive farms mean that if pathogens do get in, they are likely to spread rapidly with potentially catastrophic consequences (for example, influenza viruses in poultry and pigs).

3. **Unsustainable utilization of natural resources accelerated by urbanization, land-use change and extractive industries:** Deforestation (to create pasture for livestock) and

fragmentation of ecosystems and wildlife habitats make novel and diverse contacts among wildlife, livestock and people, which facilitates the transmission of novel pathogens across species barriers.

4. **Changes in food supply chains:** Global food supply chains are becoming longer and more complex. This creates more opportunities for zoonoses to emerge and to spread globally, for example, through cross-contamination of meat products of diverse origins.

5. **Climate change:** Livestock farming (including feed production) is a major cause of greenhouse gas emissions, particularly methane and nitrous oxide. Many zoonotic pathogens are climate-sensitive which means that a shift towards warmer, wetter and more unpredictable climates will affect zoonotic disease emergence. For example, some diseases such as the West Nile virus are spread by insects that previously would not have survived cold winters. Recent changes in climatic conditions, particularly increased ambient temperature and fluctuations in rainfall quantities, contributed to the maintenance of the West Nile virus in locations in southern Europe, western Asia, parts of the United States and Australia (Paz 2015). Climate change is likely to lead to more such occurrences of zoonosis emergence.

1.2. Systematic assessment of zoonotic risk from livestock production

The relationship between livestock farming and zoonotic disease emergence is highly complex and dynamic, as the zoonotic risk associated with livestock is driven by myriad ecological, biological and socioeconomic factors (Liverani et al., 2013). Therefore, rigorous assessment of emerging zoonotic disease risk must consider the bigger picture (including the type of pathogen, host, production system and human behaviour) and be context-specific and time and space-bounded. General statements regarding the species, production systems and geographies that pose the highest risk could result in unjustified complacency, underestimating the uncertainty inherent to zoonotic risks. Surveillance and contingency planning recommendations should, therefore, adequately take this uncertainty into account.

Despite their potential value for informing surveillance and preparedness and facilitating early emergence detection, there are relatively few examples of systematic risk assessments in this area. In addition, those available tend to focus on assessing the risk posed by individual hazards (e.g., a single virus) rather than identifying the riskiest livestock systems that are more likely to promote disease emergence. This means that there is scant evidence to make informed judgements about the levels of zoonotic disease emergence risk posed by particular livestock species and systems.

This scarcity of systematic risk assessments[1] with real-world examples demonstrating their use in practice contrasts with a large number of opinion and review papers stressing the importance of such assessments and proposing generic approaches (often without much if any evidence that they have been tested in the real world). However, a pertinent example of a useful systematic approach is the recently published assessment of the risk of emergence of coronaviruses in pigs (wild and domestic) in the United States (Pepin et al., 2021). The authors highlight the need for risk-based surveillance strategies rooted in the fundamental mechanisms of zoonotic emergence theory, ready for development as needed, and illustrate the design of such a surveillance strategy using coronaviruses in pigs as an example. In this study, zoonotic emergence is conceptualized as a series of sequential steps, and the relationship between (risk) factors and the probability of these steps is explicitly stated,

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[1] Risk assessment in this context is defined as a systematic evaluation of the likelihood and the consequences of the entry, establishment and spread of a hazard such as a new virus. Risk is described – either quantitatively or qualitatively – in terms of the likelihood (probability) and the impact (consequences) of an unwanted outcome (definition summarised from FAO, 2021).

allowing the generation of risk maps for coronavirus emergence at the wild pig-domestic pig-human interface that can be updated as more data become available. While the study focuses on a single country, a single group of viruses and a single species, the authors acknowledge that they did not capture temporal variation in several parameters that can have an essential role in transmission risk. For example, temporal fluctuations in host demography, movement ecology, and pathogen prevalence all determine transmission risk, and detection probability is likely to vary over time, e.g. with the stage of infection (Pepin et al., 2021). This illustrates how exercises aiming to forecast the emergence of multiple known (and even unknown) pathogens are often very speculative and produce results whose accuracy is highly uncertain.

1.3. Commonly used risk assessment frameworks

One of the few examples of an algorithm designed to assess the zoonotic risk of emerging animal diseases that has been extensively applied is described by Palmer et al. (2005). This framework refines the broad concept of emergence by judging the risk of the zoonotic potential of existing animal disease. Many of the risk assessment frameworks in use today were developed or evolved from this one.

An updated version of this assessment algorithm is used by the UK Human Animal Infections and Risk Surveillance (HAIRS) group, a cross-government body that acts as a forum to identify and discuss infections with potential for interspecies transfer (particularly zoonotic infections). Its risk assessment processes, which are published for public scrutiny (Public Health England, 2018), involve:

1. Hazard identification: Members of a panel identify possible hazards through epidemic intelligence activities, reports of outbreaks or increasing trends of known infections/syndromes and reports of new infections or undiagnosed syndromes.

2. Hazard review: initial information gathering, preliminary review, and determination of whether a full risk assessment is needed.

3. Formal qualitative risk assessment of shortlisted hazards to ensure uniformity. Uncertainty is captured and communicated.

4. Risk management: For incidents assessed as posing a higher potential threat to public health, the group alerts policymakers and other cross-government groups to the need for risk management action. Where the evidence used to assess the risk is deemed unsatisfactory, the output is reviewed by the group and management decisions are made on a case-by-case basis.

5. Risk communication: Risks assessed as high are immediately escalated and communicated to relevant government agencies and departments. Summary versions of the risk assessments are published in the public domain.

The HAIRS risk assessment approach is focused on horizon scanning and high-level overviews of risk rather than empirical sampling or data collection. It uses a quick, simple, iterative process which is documented and reported. The quality of evidence used to estimate the risk and confidence in the risk assessment output is assessed as one of three simple categories (good, satisfactory, unsatisfactory), and these are defined in the guidelines (Public Health England, 2018). Risk management options are suggested for each level of assessed risk: these are described for known pathogens and for novel syndromes whose cause is unknown at the time of the assessment. This framework is used regularly, and the results are reported online (HAIRS, 2021). It represents one of the clearest examples of an integrated risk assessment process spanning health surveillance in humans, livestock and wildlife.

The European Centre for Disease Prevention and Control [ECDC (2011)] and FAO (2021) use rapid risk assessment methodologies similar to those developed by HAIRS.

Three recent examples illustrate the usefulness of scientific risk assessment to evaluate emerging zoonotic risks when the meaning of emergence and scope of the assessment is well defined:

1. A rapid risk assessment of the risk to humans of SARS-CoV-2 variants from farmed mink, conducted by the European Centre for Disease Prevention and Control (ECDC, 2020). The usefulness of this assessment was that it differentiated risks to the medically vulnerable and the general population in areas close to and away from high concentrations of mink farms and in people with occupational exposure (such as workers in mink fur farms). As a result, four options for response were generated, focusing on each of these categories.

2. An assessment of the current situation (as of early 2021) in the EU and elsewhere with regards to the risk posed to human and animal health by SARS-CoV-2 infection in mink and other animals of the family Mustelidae, conducted jointly by the European Food Safety Authority and the European Centre for Disease Prevention and Control (EFSA, 2021). The usefulness of this assessment was that it produced clear guidelines for monitoring mink farms and farmworkers to detect the disease early.

3. A rapid risk assessment on the incursion of HPAI (predominantly H5N8) from wild birds to poultry, conducted by the UK's Department for Environment, Food and Rural Affairs (Defra 2021). This risk assessment was first conducted in November 2020 and then updated five times in the following five months as the risk situation evolved. This enabled the changes in risk over time, and the sensitivity of surveillance, to be rapidly visualised and interpreted. The report was updated and republished each time, enabling changes in risk status and assumptions to be communicated quickly and transparently.

The above agencies regularly assess public health risks and threats posed by emerging zoonotic infections using pathogen-specific frameworks, meaning that first the hazard is identified, and then the risk associated with it is assessed. However, these risk assessments do not directly compare hazards, so they do not identify which type of scenario (pathogen, livestock species or production system) poses the highest public health risks. Similarly, a recent elicitation-based risk assessment to rank viruses in terms of their zoonotic spillover potential (Grange et al., 2021) focuses on viral origins in wildlife and hence does not consider the riskiest livestock farming systems. This means that not all risk assessments are useful for determining risks from livestock, and care needs to be taken to select an appropriate tool.

An example of a semi-quantitative tool for prioritizing zoonoses in the absence of comprehensive prevalence data is the One Health Zoonotic Disease Prioritization tool, developed by the U.S. Centres for Disease Control and Prevention (Rist et al., 2014). This tool requires that human and animal health agency representatives jointly identify criteria (e.g., pandemic potential, human morbidity or mortality, economic impact) that are locally appropriate for defining a disease as being of concern. The outcome of this process is a ranked disease list that both human and animal health sectors can draw upon to promote collaborative surveillance, laboratory capacity enhancement, or other identified activities (Rist et al., 2014). Such approaches may be helpful, particularly in lower-income countries where there is a lack of resources often coupled with a lack of strategic deployment of these limited resources, such as Uganda (Sekamatte et al., 2018), Kenya (Munyua et al., 2016) and Ethiopia (Pieracci et al., 2016). Whilst such tools may be helpful, they require reliable, representative and up-to-date surveillance data, which is often lacking.

1.4. Conclusions

In conclusion, livestock farming has been implicated in the emergence of a large proportion of zoonotic diseases, yet very few validated risk assessment frameworks exist to establish which species and (changes in) production systems pose the greatest zoonotic disease risks. The relationship between livestock farming and zoonotic disease emergence is complex and dynamic, and the zoonotic risk associated with livestock is driven by myriad ecological, biological and socioeconomic factors. Rigorous assessment of emerging zoonotic risk must consider the bigger picture (including the type of pathogen, host, production system and human behaviour) and be context-specific and time and space-bounded. The lack of proven frameworks to enable systematic and transparent identification of the riskiest livestock practices means that surveillance programmes may not currently target the main zoonotic disease emergence threats. Real-world testing and refining of risk assessment frameworks suitable for a range of situations are urgently needed to help clarify livestock risks for future pandemics. In the next chapter, we review existing literature to identify possible drivers of zoonotic disease risk within different livestock species and production systems, which will help inform what should be included in future risk assessments.

2. LIVESTOCK SECTOR RISKS TO PUBLIC HEALTH RELATING TO ZOONOTIC DISEASE

This chapter provides an overview of the zoonotic disease risks associated with different livestock species and production systems. It reviews existing scientific literature to identify the key risk drivers (i.e., activities significantly associated with a higher risk of zoonotic disease) which favour the emergence or re-emergence of infection within specific livestock species and systems. Chapter 4 will draw on the results of this review to develop a strategic approach to the surveillance, assessment and control of emerging zoonoses.

Zoonotic disease risk commences with drivers of infection among animals and, after that, extends to the risk that pathogens will be transmitted from animals to humans. This chapter, therefore, examines cross-sector risks associated with various animal husbandry practices in two parts:

1. livestock risks (which are associated with particular animal species and animal husbandry practices);

2. human transmission risks (which are related to the degree of contact between humans and animals).

2.1. Livestock risks

2.1.1. Livestock production systems

While diverse production practices exist within the livestock sector, livestock production systems may be divided broadly into "intensive" and "extensive" models. Intensive livestock production typically refers to farms using animal feed sourced elsewhere and not produced on location (Eijrond, 2019). Intensive farms will also typically rear animals at high densities and keep them in indoor units for most or all their lives (Jones et al., 2013). On the other hand, extensive livestock production typically involves allowing animals to graze or forage outdoors and lower stocking densities. Due to their need for pasture to feed animals, extensive production systems tend to employ large land areas and use smaller agricultural inputs. However, it is important to note that while it is common for farm animals to have access to outdoor spaces, purely "extensive" systems are not common within the EU (Vidal-Gonzalez & Bueso-Rodenas, 2020).

2.1.2. Stocking density

Intensive livestock production can increase the risk of pathogen transmission between animals, primarily due to increased population size and density, which increase physical proximity between animals and concentrated wastes. The proximity associated with group housing increases horizontal transmission via aerosols, further exacerbated by continuous physical contact with contaminated animals and surfaces and shared water sources (Alonso et al., 2013). In enclosed settings (e.g., broiler houses), ventilation systems also expel high quantities of material (e.g., dust and pathogens), thereby risking infection of wildlife as well as other domesticated animals (Jones et al., 2013). Likewise, large quantities of faecal matter often spread over the land must be treated to reduce the risk of pathogen contamination and spread. Some zoonotic pathogens can survive for extended periods in faeces, soil, water, and other surfaces (Bandelj et al., 2016).

In 2007 the EU introduced stocking density restrictions in broiler houses, limiting hen capacity to 33 kg/m2 (European Commission, 2007). However, farmers have adapted to such restrictions by using "thinning" methods, with important implications for disease risk (Alfifi et al., 2020). Thinning allows farmers to increase the number of hens in broiler houses without violating stocking density

requirements by removing excess animals before their weight gain surpasses legal limits – typically about one week before slaughter. Studies have found that because thinning requires personnel to enter the broilers and remove excess hens, hygiene barriers are broken, and hens remaining in the flock are exposed to more significant risks of campylobacter infection (Allen et al., 2008).

2.1.3. Interaction with wild animals

Extensification of livestock production has the potential to mitigate zoonotic disease risks associated with physical proximity between animals and shared ventilation and water systems. However, it is likely to increase other risks by enabling more frequent interaction between livestock and wild animals. Notably, extensive systems might be expected to increase the probability of inter-species transmission of pathogens with zoonotic potential as approximately 75% of all diseases that have emerged in recent decades are believed to have originated in wild animals, including HPAI and swine brucellosis (Gortazar et al., 2007; Humphrey, 2007; Billinis, 2013).

Wild animals can act as natural reservoirs for many potential pathogens, including pathogens currently unknown to science. Several wild animal species are reservoirs for important zoonoses or are known to host pathogens with spillover potential. For instance, certain wild aquatic bird species are reservoirs for influenza type A viruses (Ma et al., 2008) which includes subtypes involved in several recent avian influenza outbreaks and are of significant concern to the livestock sector. Meanwhile, bats are hosts to an extensive array of zoonotic pathogens (Smith & Wang, 2013), some of which concern the livestock sector (for example, Nipah virus).

It is important to emphasise that the risk of zoonotic disease emergence does not come from wildlife itself but from human activities (such as the expansion of extensive livestock production), which increase contact between wildlife, farmed animals and humans and hence increase transmission potential. Undisturbed healthy ecosystems are an important buffer against the risk of zoonotic disease emergence. Furthermore, risk assessments of livestock interaction with wildlife should incorporate the impacts of global temperature and climate change on the expansion or introduction of disease vectors into novel regions. For example, increased ambient temperature and fluctuations in rainfall amounts across southern Europe, western Asia, the eastern Mediterranean, the Canadian Prairies, parts of the United States and Australia, contributed to the endemisation of the West Nile virus in these regions (Paz, 2015).

2.1.4. Livestock species

Livestock systems in which multiple animal species are present may be more likely to be involved with disease emergence than single-species systems. Specifically, multi-species livestock systems may increase the risk for interspecies disease transmission, thereby providing opportunities for the generation of adapted and novel diseases (Taubenberger & Kash, 2010). For example, dense populations of pigs and domestic and wild birds are associated with the transmission of novel influenza viruses. Therefore, poultry farms should ideally only be devoted to poultry farming to minimize risk (Humphrey et al., 2007; Taubenberger & Kash, 2010).

Pigs are a species of particular concern because they are relatively similar to humans in terms of anatomy, genetics, and physiology. They can transmit similar pathogens, acting as reservoirs and intermediate hosts for pathogens with pandemic potential in humans (Meurens et al., 2012; Pepin et al., 2021). Pigs have also been identified as "mixing vessels" for reassortment wherein two related viruses can exchange genes leading to novel genotypes (Ma et al., 2008). For example, in the case of influenza type A viruses, wild aquatic birds (which are the natural reservoirs for this pathogen) can transmit the virus to both domestic birds and pigs, human and avian influenza A viruses can infect pigs,

enabling reassortment to occur in pigs between avian, swine and human influenza A viruses. The 'Swine flu' pandemic in 2009 resulted from such reassortments leading to a novel zoonotic influenza virus (Smith et al., 2009).

Animals farmed for fur must also be considered. For instance, farmed mink acquired SARS-COV-2, resulting in mass culling, financial losses and concerns about the dangers of pathogen mutations [World Health Organisation (WHO), 2021]. In line with recent findings indicating that mink could represent animal reservoirs for SARS-CoV-2, a 2021 WHO report showed that the public health and wildlife risks associated with this virus in mink farms might have important impacts on the EU livelihoods (Pomorska-Mól et al., 2021; WHO, 2021). There have been reports of mutations in virus variants among mink populations, with possible transmission risks to both humans and wildlife. Furthermore, it has been suggested that mutations in SARS-CoV-2 may lead to changes in its propensity to cause disease (or pathogenicity) in humans or in vaccine efficacy (WHO, 2021; Sun, 2021). However, thus far, genetic changes associated with COVID-19 cases on mink farms have not led to changes in the epidemiology of cases in comparison to those infected with non-mink related variants (WHO, 2021). According to the WHO, the risk of infection is highest in Europe because the region has a higher number of fur farms, a wide variety of susceptible animal species, and the greatest number of reported transmissions between infected farms and local communities (WHO, 2021).

While some livestock species may have characteristics that would appear to make them more likely to be involved with zoonotic disease emergence, the likelihood that a spill-over event will occur will depend on the livestock management and biosecurity measures. Other species that have not been identified as "mixing vessels" or that are not closely related to humans also have the potential to be involved with zoonotic disease emergence (e.g., camels acting as reservoirs of MERS-CoV).

2.2. Human exposure risks

As noted above, different farm characteristics – such as production system, management, and visitation/sourcing rules – influence human proximity to and contact with infected animals, which has been identified as an important risk driver linked to the probability of a zoonotic disease outbreak. For instance, a 2019 study found that people who have more frequent contact with livestock, such as those directly involved in agricultural occupations, are at higher risk of contracting livestock-associated methicillin-resistant Staphylococcus aureus (LA-MRSA) (Anjum et al., 2019). Proximity to and contact with livestock are also zoonotic disease risk factors for people who are not employed in the livestock sector but simply live nearby. A 2013 study reviewing risk across four EU countries (Bulgaria, France, Germany, and the Netherlands) found that extensive production methods used in French and Bulgarian goat and sheep farming – in which these animals are permitted to move through local towns – presented the most significant risk of increased interaction with residents not involved in farming. Notably, most outbreaks of Coxiella Brunetti among animals raised in such production systems led to a spill over of infection to humans, with such events accounting for a large majority of recently recorded outbreaks of Q fever in these countries (Georgiev et al., 2013).

However, it is crucial to recognize that livestock systems are not static. They evolve, expand and contract because of market forces and other incentives and preferences. For instance, demand for products purchased directly from farms has grown in past years due to their potential reduced environmental impact, among other cultural and personal preferences. However, more frequent visits to farms by members of the public can increase the risk of zoonotic transmission and even very brief exposure may lead to the transmission of certain microorganisms. In Germany, for example, a 2016 study found that routine visits to farms to purchase eggs or milk increased the risk of carrying LA-MRSA even among those not living on, or employed by, farms. Similarly, visitors of an educational farm in

France were reported to be infected with Q-fever, and in the UK, infections linked to an outbreak of *C. parvum* on an adventure farm were observed among visitors (Krous, 2016).

Returning to the discussion on intensive versus extensive farming methods, lower levels of human-animal interactions on intensive farms suggest that instances of human infection from such systems are more likely to occur at other stages of the food supply chain than at the farm level (Norrung, 2008). On the other hand, extensive livestock production systems present greater risks of direct or indirect disease transmission from wild to farmed animals and from farmed animals to humans because they permit a greater degree of interaction between livestock and surrounding human communities (Bandelj et al., 2016).

2.3. Risk management

Several risk management measures may be applied to reduce the probability of infection with zoonotic pathogens among wildlife populations and farmed animals, including culling, vaccination, modifications to feeding practices, and biosecurity enhancement. However, it should be noted that zoonotic disease control measures are likely to be less effective if applied to either wild or farmed animals in isolation.

2.3.1. Culling

Given that contact between livestock and wildlife is a key driver of zoonotic disease risk, wild and farmed animal populations have often been culled to reduce transmission risk. However, this may not always be an optimal control strategy. For example, in wild badger populations, a 1998 culling program in the United Kingdom was found to have reduced the incidence of Bovine tuberculosis within the culled area. However, it increased the incidence of badger-to-badger and badger-to-bovine transmission in neighbouring areas due to changes in badger behaviour in response to culling activities (Donnelly et al., 2007). Instead of focusing on wildlife, changes in animal husbandry and farm management practices – such as quarantining or culling of infected livestock, vaccination schemes, altering feeding practices, and improvements to biosecurity – have been suggested as comparably effective (Williams et al., 2005).

2.3.2. Vaccination and feeding practices

While livestock vaccination is less logistically demanding than vaccination of wildlife, it may not provide complete protection from sources of infection in wildlife (see Chapter 6). Even where vaccination programmes are implemented successfully, specific grazing practices can complement control measures and strengthen protection. While allowing herds' constant access to pasture (also known as set-stocking) increases contact with wildlife and reduces avoidance between animals, rotational grazing is generally thought to decrease livestock-wildlife contact and reduce transmission risks. However, given the dependence of grazing patterns on animal behaviour, the effectiveness of rotational grazing on transmission risk will be variable and therefore cannot be considered genuinely preventive (Phillips et al., 2000 and 2003; Gallagher et al., 2003). Stricter methods, such as herd guarding and housing in enclosures, have been shown to reduce exposure to wildlife transmission, such as pasteurellosis and brucellosis for sheep in the French Alps (Richomme et al., 2006). Where grazing practices cannot be amended, reducing stocking densities provides an alternative avenue to risk reduction as larger herds lead to greater dispersion and increased probability of exposure to wildlife (Phillips, 2002).

Similarly, providing food on pasture increases the risks of direct contact with wildlife. While innovative trough designs may decrease the risk of wildlife access, practices such as elevated placement have

been found to be ineffective (Garnett et al., 2003). Moreover, a 2006 study found a positive association between the provision of salt licks at pasture and exposure to sheep-born pasteurellosis and brucellosis—further suggesting in-house feeding may reduce the risk of infection (Richomme et al., 2006).

Beyond the feeding location, adjusting the type of feed provided to livestock may also offer opportunities as animal feed can be specially selected or treated to control the spread of pathogens. For example, dietary changes among cows and feeding mink with raw poultry by-products have been found to be positively associated with disease risk (Bandelj et al., 2016; Sun et al., 2021). Treatment options include fermentation, acidification, or heat treatments (Norrung, 2008). Alternatively, farmers may choose to incorporate probiotics into their animals' diets to either modify environmental factors in the gut or produce antimicrobial compounds. Regarding monogastric animals such as pigs and poultry, diets can also apply the "competitive exclusion concept" that incorporates complex mixtures of bacteria into the feed, reducing the ability of pathogens to attach to the gut mucosa. For example, salmonella risk in intensive poultry farms can be reduced by including the gut content of mature hens into chicks' feed. However, given that numerous farm-related variables impact disease risk, the comparability of findings on the effects of diets on pathogen shedding is low (Norrung, 2008).

2.3.3. Biosecurity

The importance of biosecurity enhancement in mitigating disease emergence risk cannot be overstated. A 2006 study surveying farms across the UK found that the threat posed by low levels of biosecurity, which allow wildlife to access farm buildings, is of similar severity as that posed by wildlife exposure via grazing and outdoor access (CSL, 2006). Electric fences were suggested as one effective means of excluding wildlife access (Poole et al., 2002).

Moreover, a 2005 study found that employing strict hygiene practices requiring personnel to wear specific outer clothing and footwear within hygiene barriers in poultry farming reduced infection risk by 67% (Humphrey et al., 2007). The introduction of new birds into a recently occupied broiler house may present carry-over risks when evidence of poor cleaning regimes is present. The potential of enhanced biosecurity to reduce the risk of infection is illustrated by the achievement by the facilities of poultry breeding companies of "compartment" status with recognition from government bodies (DEFRA, 2016). The concept of "compartmentalization" was introduced by the World Animal Health Organization (OIE) as a way of increasing biosecurity within the livestock sector while ensuring safe and uninterrupted trade through the establishment of a "disease risk boundary" using biosecurity protocols and/or geographic isolation (Scott et al., 2006).

2.3.4. Transportation

Finally, the transportation of animals for slaughter or market usually increases their risk of contracting infectious diseases as microbial cross-contamination can occur between animals or via contaminated surfaces—on which specific pathogens, such as *Salmonella* or *E. coli,* can survive even after sanitation. Moreover, animals experience increased stress levels during transport, placing them at increased risk of infection (Norrung, 2008). However, it is important to make clear that livestock and poultry "normally" harbour foodborne pathogens. Harvest and postharvest processes operate under the assumption that any animal can harbour such foodborne pathogens and that the manipulation of farming practices, such as limiting contact between animals, can have significant potential for zoonotic disease risk management. However, such potential is contingent on the financial and logistical ability to implement control measures to limit transmission risk—which varies across farms (Ward et al., 2006). A 2006 survey of 151 farmers found that approximately 50% would not, or could not, invest in such

measures, while a 2005 study found that only a few perceive biosecurity and wildlife access to be a problem (Bennett and Cooke, 2005; CSL, 2006).

2.4. Conclusions

Distinctive patterns of zoonotic disease risk characterise both intensive and extensive production systems. Intensive large-scale production, in which genetically similar animals are kept in high-density units, provides a suitable environment for the rapid transmission and evolution of pathogens circulating within a livestock population. By contrast, extensive production systems pose two main challenges: 1) less controlled environments lead to increased exposure of farmed animals to pathogens from humans, wild animals, and other domestic species; and 2) greater opportunities for pathogen transmission from farmed animals to humans (including those not employed on the farm). While neither of these risks associated with extensive systems is individually grave, there is potential for serious risk if both cross-species jumps occur together.

Certain livestock husbandry and farm management practices present opportunities to manage risk across various production systems. Beyond control elements of livestock vaccination, three key areas present potential for risk reduction: 1) grazing practices, 2) changes in the location and type of feed provided to animals, and 3) biosecurity enhancement. Specifically, implementing rotational grazing and providing feed only indoors may decrease livestock exposure to wildlife, which may host pathogens of potentially zoonotic character. Enhanced biosecurity measures can keep wildlife from accessing and contaminating housing infrastructure, but strict hygiene standards are critical, given that zoonotic pathogens can also be transmitted from humans to livestock. Recognising that zoonotic disease risk is both complex and context-specific, the following chapter will move beyond the identification of broad risk indicators through examining previous zoonotic outbreaks to draw out lessons learned which can be used to inform the design of a strategic approach to zoonotic disease surveillance and control.

3. LESSONS LEARNED FROM PAST ZOONOTIC DISEASE OUTBREAKS

This chapter identifies lessons learnt from previous zoonotic disease outbreaks involving livestock by exploring three case studies: the BSE epidemic in the UK and the continuous re-emergence of Highly Pathogenic Avian Influenza in the EU and the 2007-2011 Q fever outbreak in the Netherlands.

These case studies show that emerging zoonotic diseases can be caused by a range of pathogen types: viruses (such as influenza), bacteria (Q-fever), and infectious proteins (BSE). Each pathogen type has very different epidemiological features (such as how long they survive in the environment and the major routes of transmission), and the prion example shows that new forms of a pathogen may emerge, highlighting the limitation of forecasting exercises which necessarily focus on known pathogens and emphasising the importance of preparedness for novel zoonotic agents. Table 3.1 summarises the three case studies, which are then described in further detail.

3.1. Case study 1: Bovine Spongiform Encephalopathy (BSE)

KEY POINTS

- The BSE epidemic represents one of the most critical episodes of zoonosis emergence among livestock in Europe due to its unexpected nature and impact on society.

- BSE is a fatal neurodegenerative disease caused by a prion (a misfolded protein). This agent is completely different from any other known pathogen (bacterial, virus, fungi).

- The main route of infection to cattle was through contaminated feed.

- The disease was first confirmed in cattle in 1986. Ten years later, the agent was linked to a new variant of Creutzfeldt-Jakob disease (vCJD) in humans (Will et al., 1996), causing degenerative neurological disorders, such as memory loss, lack of coordination, progressive dementia and death.

- Early research into vCJD suggested that most of the human population in Europe could have been exposed to this novel pathogen by consuming contaminated meat and raised the possibility that it might have dramatic public health consequences in the mid-late 1990s. Limited knowledge about this novel pathogen and a long incubation period (with symptoms occurring years and possibly decades after exposure) contributed to uncertainty about this disease's potential public health impact.

- Despite these challenges, BSE can now be considered as an example of successful control of an emerging zoonosis, with fewer than 10 cases detected per year in the EU since 2003 (EFSA, 2020) and with the prospect of disease eradication in the UK by 2026 (Arnold et al., 2017).

3.1.1. Lessons learnt on detection

Given the novelty of the pathogen, no specific surveillance existed at the time of its emergence. BSE detection started in 1984 with a UK farmer contacting their private veterinarian to report a cow with unusual behaviour, which emphasises the importance of passive surveillance systems for rare and unusual events. Samples from this cow were then processed nine months later (September 1985) by the governmental Central Veterinary Laboratory. Although this initiated suspicions of scrapie-like disease in cattle, the formal discovery of the disease occurred only when more cows from the same herd started to develop similar signs. It took almost two years to acknowledge the emergence of BSE (O'Brien, 2000).

This highlights the importance of establishing and maintaining strong linkages between private veterinarians and government animal (and public) health officers to detect novel diseases quickly. Additional links with the academic research community, such as those working in health surveillance, epidemiology, pathogen discovery, and diagnostic development, are likely to further support and accelerate the detection of novel pathogens.

Table.1: Summary of three zoonotic outbreak case studies

	BSE	Avian Influenza (highly pathogenic)	Q-fever
What?	Prion (infective protein)	Virus	Bacterium
Where?	28 countries (22 in EU)	Worldwide	Worldwide
When?	First detected in 1985. Peaked in 2002 in the EU. Only rare cases currently.	Annual outbreaks (seasonal pattern)	Largest recorded outbreak was 2007-11 in the Netherlands
Livestock	Cattle	Poultry	Mostly goats (some sheep)
Cause	Mammal proteins in cattle feed	Migration of Infected wild birds	Dairy goats, after expansion of this livestock system
Size of outbreak in animals	200,000 cattle affected (<20 cases in the last 6 years)	3,000 farms in 29 countries (2016/17 outbreak)	100 farms (2007-11 outbreak)
Size of outbreak in humans	>200 cases of CJD (>100 in the UK)	900 human cases identified since 2003. None in the EU	24 deaths >40 000 people infected
Human symptoms	Memory loss, lack of coordination, progressive dementia and death	Respiratory signs primarily, with a 50% mortality rate	Half of the infections result in an acute flu-like illness. Half develop chronic disease, which can be fatal.
Transmission mechanisms	Cow-to-cow and through the environment. Cow to humans through contaminated meat. No human-to-human transmission.	Wild bird to poultry and farm-to-farm. No human-to-human transmission detected.	Mainly aerosolized bacteria from infected animals during birth or abortions. Anecdotal evidence of human-to-human transmission.
Key control measures used	Culling (4.4 million cattle culled in the UK alone)	Culling (>8m poultry culled in 2016/17)	Culling, vaccination, and movement restrictions (sheep and goats) Vaccination (people at risk of chronic disease)
Surveillance measures in place before outbreak	None	Passive surveillance (identification of dead wild birds and clinical signs observed in poultry) Active surveillance (detection of infection in poultry farms, since 2003) and in wild birds (since 2005 but not mandatory in all EU MS).	Notifiable disease in humans since 1975. Testing of suspected cases. First animal case recorded in 2005. Testing where high number of abortions.
Surveillance measures in place after outbreak	Passive surveillance (farmers and vets report suspicion of disease) Active surveillance (testing of cattle over 48 months of age which die or are killed other than for human consumption)	Unchanged	Notifiable disease in animals since June 2008.
Economic impact	€92 billion	€150m in 2003	€200-600m

Source: Authors' own elaboration.

3.1.2.   Lessons learnt on the origin and transmission of BSE

The causes of the emergence and transmission of this pathogen in cattle were linked to the use of animal proteins (meat and bone meal), including ruminant protein, in cattle feed. Early studies by Wilesmith et al. (1988, 1991 and 1992) highlighted that the temperature used in the rendering of meat and bone meal had been lowered in the late 1970s and early 1980s, leading to a ban on the use of animal protein in ruminant feed. This ban was the most effective step taken to control BSE and demonstrates the importance of funding research and conducting epidemiological studies in the early phases of disease recognition and emergence. In addition, it is vital to ensure the adequacy of inputs into livestock systems, such as allowing animals to eat their natural food (O'Brien, 2000) and ensuring the traceability of animal feed and animal products.

3.1.3.   Lessons learnt on the link to human health

Given that the disease was thought to be similar to sheep scrapie (which is not transmissible to humans), the discovery of BSE was not initially considered alarming (Peutz, 2000). However, an important criticism is the 10-year delay in acknowledging the public health significance of the disease and the poor communication between agricultural and health ministers (O'Brien, 2000). The perception of human health impact was already established in many consumers' minds in the early 1990s (Ashworth et al., 1995), which generated a significant loss of confidence in beef products, with attempts from ministers to reassure the public on product safety, and this resulted in public mistrust of the government. Furthermore, it was argued that an early scientific committee in the UK was used "to provide spurious scientific legitimation for policy decisions which government officials believed ministers, other government departments, the meat industry and the general public might not otherwise accept" (Millstone et al., 2001). Lack of clear communication and reliable sources were seen as major issues that contributed to the crisis. Regularly updated risk assessments and better coordination would have allowed the faster realisation of the problem and subsequent control measures and risk communication. As a consequence, the importance of rapid and trustworthy risk communication is now acknowledged and practised.

3.1.4.   Lessons on disease control and policy reactions

Based on the early evidence, a partial feed ban concerning mammalian tissues in farm animal feed was implemented in the UK in 1988. However, it was only implemented in the EU six years later, in 1994, representing a major delay in research uptake (Ducrot et al., 2008). The EU was waiting for the results from research commissioned in 1988 on the effectiveness of rendering techniques (the processes used to convert animal tissue into products such as protein meal) in preventing the transmission of BSE via animal feed (Chalus, 2000). Before then, EU policies implemented in 1986 and 1990 focused on banning imports of cattle and associated products from the UK and the compulsory notification of the disease. A total ban on the use of animal proteins in cattle feed only came into force in 2001 (Regulation (EC) 999/2001). In addition, a series of new policies were introduced with the removal of newly classified 'Specified Risk Materials' (i.e. cattle brain, spinal cord, eyes and other tissues) from the food chain in 1997 (97/534/EC), which was controversial as many EU countries felt they were BSE-free. As a result, its implementation only began in 2000 (2000/418/EC) when it became evident that the disease was present in many EU countries. The maximum age of cattle to be slaughtered for food consumption was also specified. These measures played an essential role in reducing public health risks, although their effects do not appear to have been evaluated.

Members of the UK government's Spongiform Encephalopathy Advisory Committee first stated publicly that cases of vCJD in humans were likely to be linked to exposure to BSE via contaminated beef

on 20 March 1996, and in June 1996 the EU established a Multidisciplinary Scientific Committee to seek expert advice (Millstone & van Zwanenberg 2001). Until then, only the Commission's Scientific Veterinary Committee had been consulted, representing an important limitation in the capacity to react and highlighting the need for a more integrated approach to controlling emerging diseases. Severe control measures were then put in place, such as mass slaughtering of cattle, passive surveillance (i.e. detection based on clinical signs) in April 1998 (D 98/745/EC) and active surveillance (i.e. detection based on testing healthy animals) in 2001. Implementation of active surveillance resulted in 16 countries detecting BSE cases for the first time and showed the peak of the epidemic in the EU in 2002, 10 years after the peak observed in the UK. It also showed that passive surveillance was insufficient to detect infection at low levels given the long incubation period, especially since many farmers were unwilling to report cases.

By April 2000, the economic impact in terms of total expenditure on BSE control measures was estimated at £4.2 billion in the UK alone (BSE inquiry, 2000), while at the European level, the cost of the epidemic was estimated at 10% of the annual output of the beef sector, totalling to €92 billion for the epidemic period (Cunningham, 2003). The large majority of this impact was experienced after March 1996. Furthermore, this disease generated important scientific controversies focusing on its causation and whether or not it was zoonotic in nature. There were also conflicts between consumers and producer groups, and governments perceived to be protecting the industry at the expense of consumers. These were seen as an obstacle, and the importance of separating responsibilities between commerce and public health was an important lesson learnt (O'Brien, 2000). Consequently, the UK Food Standards Agency was created in 2000, representing an independent government department tasked with protecting public health and consumers' wider interest in food.

3.2.   Case study 2: Avian Influenza (AI)

KEY POINTS

- The emergence of AI involves multiple host species (wild and domestic birds), rapid evolutionary dynamics of the virus, and inter-continental transmission. AI epidemics have a clear seasonal pattern, with most detections occurring in the winter period from October to February.

- AI is caused by a large array of Influenza A viruses. Some of these, such as H5N1 viruses, are classified as Highly Pathogenic Avian Influenza (HPAI) as they can cause high mortality rates (up to 100% in poultry farms).

- The monitoring and control of these viruses have been given exceptional attention, with billions of euros spent on infection control worldwide because of their potential to jump species and infect humans. This is due to their fast mutation rate and capacity for gene assortment (exchange of genes) (Mehle et al., 2012).

- The first report of highly pathogenic influenza in poultry occurred in Hong Kong in 1997. It subsequently infected humans, with 18 people hospitalized and six deaths, leading to the realisation that avian influenza viruses can cause severe illnesses in humans. The fear that the virus could jump to humans and mutate to allow human-to-human transmission, combined with the fact that three major influenza pandemics in humans had already occurred in the last century (in 1918, 1957 and 1968), created concern that avian influenza viruses could be a potential candidate for the next pandemic (WHO, 2005).

- A fourth influenza pandemic (commonly termed the 'Swine flu') subsequently occurred in 2009, leading to 300,000 human deaths and millions of people infected. The swine flu virus contains genes found initially in AI viruses (Smith, 2009).

- Several episodes of Influenza A virus transfer from poultry to humans have since been reported. Since 2003 almost 1,000 human cases have been identified, of which over half died. Most of these cases were recorded in Indonesia and Egypt (WHO, 2020) and involved people infected through direct or close contact with infected poultry.

- No human cases have yet been found in the EU, but cases of influenza in poultry are detected every year in Europe, with the largest outbreaks of HPAI occurring in 2005/06 (H5N1 virus; 17 countries), 2016/17 (H5N8 virus; 29 countries), and 2020/21 (H5N8 virus; 22 countries) (Cornelia et al., 2021; Alarcon et al., 2018). These epidemics are thought to have been mediated via migratory wild birds, which are responsible for the intercontinental transmission of the virus.

3.2.1. Lessons learnt on origin and transmission

It has been reported that most, if not all, avian influenza epidemics have resulted from virus incursions from outside the EU. In the 2005/06 and 2016/17 epidemics, based on the spatial-temporal progression of the epidemics and phylogenetic analyses, it was suggested that two corridors of viral incursion occurred: one through central-east Europe (through Hungary) and one through Northern-East Europe (Denmark and Finland) (Alarcon et al., 2018). These corridors are related to movements of northern duck species, which move after breeding across northern Eurasia. The patterns of migratory birds are highly complex and could be affected by climate changes and other human activities.

Many avian influenza viruses persist in the wild bird population without any apparent impact on wild bird health. These viruses can mutate in these populations, leading to the emergence of new pathogenic strains. However, the transmission does not only occur via wild birds. In Asia, the poultry trade – especially live poultry markets where large numbers of live birds from different sources are mixed – have been identified as important factors for virus transmission and amplification (Sims, 2007). No live poultry markets formally operate in the EU, but farm-to-farm transmissions – especially between domestic duck farms – have been blamed for many outbreaks. These farms' poor biosecurity and hygiene practices, coupled with their husbandry practices and bird movement, were believed to be among the major causes of on-farm outbreaks (Alarcon et al., 2018). Nevertheless, the importance of different transmission pathways (e.g., movement of people, poultry or fomites[2] between farms) remains unclear, and therefore further investigation of the specific risk factors involved has been recommended (EFSA, 2017).

3.2.2. Lessons learnt on detection

The EU carries out extensive surveillance of avian influenza in wild birds and poultry farms across MS, the value of which is demonstrated by frequent early detection of outbreaks. This is composed of passive and active surveillance (carried out in poultry farms since 2003 and in wild birds since 2005 but is not currently mandatory in all MS). Analysis of 2005/06 and 2016/17 epidemic curves between wild bird population and poultry populations showed that the initial peak of wild bird detections preceded the peak of poultry cases (Alarcon et al., 2018). This finding was repeated in the recent 2020/21

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[2] Fomites are inanimate objects that can carry infectious pathogens and help transmit these to other animals or peoples. Example of fomites are contaminated vehicles, equipment or clothes.

epidemic and highlights the importance of maintaining and enhancing wild bird surveillance (Cornelia et al., 2021). As such, the latest EU annual surveillance report recommends the need for research "to provide a plausible list of wild bird species less likely to die if infected with HPAI to be sampled under active surveillance". In addition, further recommendations were provided on the need to identify areas "outside and inside the EU, where active surveillance could occur at specific times of the year" (Baldinelli et al., 2020). These recommendations support Chapter 1's finding that current zoonotic disease surveillance processes are probably not being targeted effectively at sites of greatest zoonotic disease emergence risk and emphasise the importance of improving risk-based surveillance approaches, as discussed in Chapter 4.

Given the role of wild birds, it can be considered impossible to avoid yearly outbreaks of the virus and the emergence of new pathogenic strains. Therefore, constant and extensive surveillance is needed in the EU and Asia and worldwide. The exchange of information between EU countries and between Asian and EU governments on surveillance design, implementation, and results is crucial for better targeting surveillance strategies (Sims, 2007).

3.2.3.   Lessons learnt on control

Several Asian countries rely on passive surveillance only, meaning that vaccination becomes the primary recommended control method (OIE, 2007; Swayne et al., 2014). However, in some cases, the industry carries vaccination and diagnostic services in commercial poultry farms without government control or notification. As a result, the proportion of farms vaccinated (i.e. vaccination coverage) is unclear for some countries. Although vaccines have successfully reduced infection pressure, they are insufficient to eliminate the virus (primarily due to its persistence in wild birds). As a result, mass culling of birds in infected farms is employed, but this relies on effective reporting and detection of cases, and the probability of re-infection makes this strategy less beneficial in the long term (Sims, 2007). In contrast to BSE, where culling had a long-term impact on pathogen transmission, when applied to avian influenza, culling is only a temporary measure that needs to be used as part of a more comprehensive and elaborated programme of control measures.

In Europe, constant surveillance with rapid diagnostic services, culling of birds from farms with positive HPAI cases, movement restrictions and investigation of epidemiological links of affected farms remain the main control measures. This strategy, also called a 'stamping-out strategy', is deemed successful when there is adequate "governmental veterinary services, sufficient economic resources for rapid mobilization and implementation, transparency of government in reporting outbreaks and good governance" (Pavade et al., 2011; Swayne et al., 2014). However, this strategy will not eliminate the virus from countries, given its persistence in the wild bird population. The mechanism to control infection pressure in wild birds centres on eliminating the virus from domestic poultry. For this reason, establishing and maintaining good biosecurity in poultry farms is also seen as a fundamental control measure (Swayne et al., 2014). Consequently, new legislation was implemented in the EU in 2018 to increase farm biosecurity measures (2018/1136/EC).

3.3. Case study 3: Q fever

> KEY POINTS
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> - Q fever – a bacterial infection caused by *Coxiella burnetii* and transmitted primarily via aerosolized bacteria from infected animals – was first described in 1937 in Australia, after which it has been identified throughout the world, except New Zealand.
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> - Q fever is widely prevalent in various host species and has been known to the public and veterinary health services for seven decades. However, it was not endemic to the Netherlands before the 2007-2011 outbreak, which is therefore considered to constitute an emerging zoonotic disease outbreak. It is the largest known outbreak of Q fever recorded worldwide, and it resulted in large scale public health consequences and economic losses.
>
> - The characteristics of the endemic and epidemic situations in different countries are diverse, with some EU countries experiencing sporadic endemic cases, some regions considered as hyper endemic areas (with a high incidence of infection) and others only experiencing large outbreaks (Eldin et al., 2017).

3.3.1. Lessons learnt on origin and transmission

One of the contributing factors that coincided with the emergence of Q fever in the Dutch dairy goat sector was the emergence of this livestock sector. The Netherlands underwent rapid growth in dairy goat farming between 1983 and 2009, during which the national goat population grew from just over 7000 animals to over 370 000, representing a 50-fold increase in 26 years. The introduction of the European milk quota system for dairy cattle in 1984 (Roest et al., 2011), which limited the growth of dairy cattle farms, played a role in the emergence of the dairy goat sector. Other significant factors included classical swine fever and foot and mouth disease outbreaks (in 1997 and 2001, respectively), which resulted in mass culls in other livestock sectors. The combination of these factors contributed to farmers shifting their business to goats. It is important to note that zoonotic diseases considered endemic and of low public health concern for decades can potentially present an outbreak with significance for public health. It is also important to note that livestock systems are not static, and constant changes in management systems, numbers of animals, and geographical distributions can contribute to the changing environment, contributing to a zoonotic disease outbreak.

Q fever is highly infectious to the extent that it has been classified as a potential target for bioterrorism. The majority of human cases are the result of inhalation of dust particles carrying the causative agent. Although many other zoonotic livestock diseases may require close contact with animals for infection or the ingestion of uncooked or unpasteurised infected animal products to occur in humans, many human cases in this Q fever outbreak were simply downwind from infected goat farms. One of the legislative changes introduced during the control efforts of the outbreak focused on reducing the contamination of the environment, including requiring farmers to store goat or sheep manure after kidding/lambing season for 90 days before removal, essentially putting the manure in "quarantine".

3.3.2. Lessons learnt on detection

Both human and animal cases present symptoms that are not specific to Q fever, such as high fever, fatigue, muscle pain, sore throat, pneumonia and reproductive problems (e.g. abortions or stillbirths), amongst other symptoms. This may have contributed to many undiagnosed or misdiagnosed cases and the delay in recognising the outbreak, particularly in humans. Q fever was identified as the cause of abortions on goat farms as early as 2005 and on multiple occasions through 2006-2008.

However, the outbreak in humans was not detected until 2007, and most cases occurred in 2008. Better communication between the veterinary and medical sectors may have expedited the detection of the outbreak. Equally, prospective syndromic surveillance in the human population might have enabled the outbreak to be detected two years earlier (Van den Wijngaard et al., 2011).

3.3.3. Lessons learnt on control

Legislation on responding to the outbreak and imposing control measures was first introduced in June 2008. Several items were added, and existing control measures were adjusted until December 2009 (Roest et al., 2011). Voluntary vaccination campaigns in dairy goats were implemented at the end of 2008 and then made mandatory in affected areas in 2009, and these were shown to be effective in reducing bacterial shedding of animals and disease prevalence (Hogerwerf, 2011). One of the final control strategies was to order the mass culling of all pregnant sheep and goats on Q fever positive dairy goat and dairy sheep farms; a measure introduced reluctantly after attempting to avoid economic losses. However, later epidemiological modelling of the disease concluded that the culling of goats after an abortion storm[3] is unlikely to lead to eradication in the long term or reduce human health risk in the short term (Bontje, 2016).

Owing to the presence of Q fever in livestock systems worldwide (including within the EU), diversity of endemic and outbreak scenarios, and diversity of animal hosts (from domestic ruminants to dogs, cats, horses, rabbits, rodents and many others), it is not feasible to conduct ongoing disease-specific active surveillance in an attempt to prevent future outbreaks of public health interest. Therefore, surveillance should instead focus on detecting outbreaks in livestock with clinical presentation and alerting the medical profession to such outbreaks to improve detection of human cases.

3.4. Overarching conclusions from all three case studies

- Outbreaks of emerging zoonoses can be extremely costly and result in long-term and short-term human suffering. Moreover, their impact is not only the result of morbidity and mortality in livestock and humans but also of the effects of control measures such as mass culling of livestock and international trade restrictions. As such, it is crucial to reduce the risk of such outbreaks through preventative measures such as maintaining high levels of biosecurity, ensuring the adequacy of production systems (e.g. allowing animals to eat their natural food and requiring risk assessments on the use of inputs), and improving the transparency of supply chains for both animal feed and animal products.

- Disease emergence is a complex process involving different sources depending on the type of disease-causing agent, factors that modify the likelihood of emergence in specific times and places, and rapidly changing transmission pathways shaped by human activity. Indeed, changes in the livestock sector may facilitate the emergence of a zoonotic disease without requiring changes in the pathogen itself (e.g. increased goat populations facilitated the emergence of Q fever in the Netherlands). Therefore, prevention of emergence should be managed holistically, considering the complex and dynamic nature of interactions between livestock, wildlife and humans, and research that addresses key data and knowledge gaps regarding disease emergence should be supported.

- Pathogens that are well known and endemic can cause an unprecedented outbreak and be considered an emerging zoonosis (e.g. HPAI, Q fever). Therefore, risk-based surveillance

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[3] Abortion storms are situation where a large proportion (normally over 10%) of reproductive females within a herd or flock experience abortion in a particular period.

practices should be adopted for these pathogens as they may result in better detection and cost-effective programmes.

- Some zoonotic pathogens are entirely unknown to science at the time of their emergence (as the case of BSE shows), meaning that there will not initially be any specific tests for them. In such situations, novel diseases may be discovered through syndromic surveillance of unusual cases. Thus, forecasting exercises based on historical data on known pathogens are unlikely to consider the risk posed by unknown pathogens.

- For zoonotic pathogens circulating in poultry, particularly avian influenza, it is imperative to address the emergence of zoonotic strains and the amplification of the pathogen in areas with important poultry-human interaction, such as live poultry markets or large poultry farms with poor biosecurity in densely human-populated areas (Fournie et al., 2013). Such sites are mainly located in low and middle-income countries. These production systems and their value chains provide an essential service to food security and people's livelihoods, and international cooperation and support for their surveillance and control should be provided given the global transmission of these viruses. In addition, different countries' animal disease surveillance programmes should also be harmonized (e.g., through more consistent use of risk-based approaches) to improve their cost-effectiveness, assist in detecting infections earlier, facilitate data sharing across countries and enhance the understanding of risk factors and patterns of emergence.

- Integrating communication between human and veterinary health services can reduce the time it takes to detect an outbreak and minimise emerging diseases' public health, economic, and social impacts. We, therefore, recommend that coordination between private veterinarians and government officers, between experts in different disciplines (animal health and public health), and between experts and policymakers be improved. This is particularly important at the early stages of disease discovery.

- Control of epidemics involving livestock often relies on mass culling, a measure that can be costly and controversial and whose effectiveness relies heavily on early detection of the outbreak and timely decision making.

4. DEVELOPMENT OF AN INTER-DISCIPLINARY STRATEGIC APPROACH TO ZOONOTIC DISEASE SURVEILLANCE AND CONTROL

As discussed in Chapters 2 and 3, emerging zoonoses are highly heterogeneous, meaning that there is no single best strategic approach to their surveillance and control. This chapter focuses on emerging zoonotic diseases, and its premise is that a suite of complementary approaches, rather than a single approach, are more likely to maximise the speed with which zoonotic disease emergence is detected and the cost-effectiveness of control measures. In the context of emerging diseases, surveillance and control are inextricably linked. Only once emergence has been identified through surveillance can disease-specific controls be implemented. Furthermore, the timeliness of detection will determine whether local and focused control measures will suffice. If surveillance is ineffective, then it is likely that the infection will be so widespread by the time it is detected that only costly large-scale controls are likely to be effective.

This section of the report includes a brief discussion of previous approaches to predicting the emergence of zoonotic diseases, provides an overview of risk indicators that may make emergence more likely, and highlights surveillance methods that may be useful as part of a strategic approach to detect and control emerging zoonotic diseases.

4.1. Research on predicting the emergence of zoonotic disease

Drivers of disease emergence are complex and dynamic. Making predictions about which infectious agent will cause the next pandemic, when, where and in which species is a highly speculative exercise. To even begin to do so, we need to understand the complexity and interrelatedness of the environmental, biological, economic, and social dimensions of zoonotic pathogen emergence (Jones et al., 2013). Knowledge of mechanisms and drivers of emergence and their distribution across infectious agents, geographies and production systems allows differences in risk of emergence to be characterized, enabling judgements to be made about which infectious agents, livestock systems or regions are a priori more likely to be involved in disease emergence events in the future (as discussed in Chapter 2). Such exercises can be used to target surveillance efforts, although caution in doing so is warranted as their results are likely to include a high level of uncertainty.

One popular approach among researchers and policymakers is to identify so-called "hotspots" for emergence based, for example, on geographic patterns of mammal biodiversity or anthropogenic land-use changes related to agriculture (Allen et al., 2017). Although seemingly attractive, approaches aiming at identifying areas of high risk of emergence of "any" zoonotic disease are likely to suffer from much more inherent uncertainty than, for example:

1. those aiming at predicting the likelihood of epidemic spread of specific pathogens following their emergence (Cauchemez et al., 2013);

2. those seeking to rank known pathogens according to their risk of emergence in a given geographic area or country (Bianchini et al., 2020), or;

3. those aiming at ranking a number of known pathogens according to their potential of emergence in a given livestock species (Ciliberti et al., 2015).

Thus, attempts at identifying "hotspots" for emergence are likely to benefit from narrowing the focus of such searches by focusing on specific pathogens, host species, or geographic areas. Ranking a closed list of existing pathogens based on their prior potential of emergence in a given setting (geographic area, animal species, production system) is likely to be a more realistic exercise than predicting the emergence of unknown (i.e., yet undiscovered) pathogens. However, this will still miss the 'known

unknowns' and the 'unknown unknowns'. Therefore, it may be better to identify (and try to prevent) conditions that promote zoonotic emergence than the pathogens themselves. Many existing risk-ranking exercises are based on expert opinion, and this is a clear reflection of the lack of empirical data on which to base ranking exercises (Rist et al., 2014, Sekamatte et al., 2018, Munyua et al., 2016, Pieracci et al., 2016).

An approach that has attracted considerable funding and attention is zoonotic virus detection efforts such as the PREDICT project (UC Davis, 2021), which collected 164,000 human, domestic animal and wild animal samples. The project was initiated in 2009 and had partners in 30 countries. The aim was to enable global surveillance for pathogens that can spillover from animals to humans by building the capacity to detect and discover viruses with pandemic potential. The project detected 949 novel viruses and identified 217 known viruses, some in new locations and hosts. However, far more undiscovered viruses are out there, and it is impossible to detail all of them. An important question is how we might translate this increased (but far from complete) knowledge of new potential pathogens into better surveillance and prevention?.

4.2. Indicators of zoonotic disease emergence risk

As described in the preceding chapters, some commonalities and indicators from previous zoonotic emergence events can be used to estimate what is more likely to occur in the future. However, there are also many examples of zoonoses emergence which did not display these characteristics. Therefore, the sections below refer to risk "indicators" discussed in the academic literature on the emergence of zoonoses rather than risk factors. These indicators include factors inherent to the pathogen, factors within the livestock sector, wildlife contact factors, and the environment and human socioeconomic and behavioural factors.

4.2.1. Pathogen characteristics

Most previous pandemics caused by pathogens originating in animals were caused by viruses (Morse et al., 2012). It seems reasonable to assume that viruses with a broader host range and wider geographical distribution have a higher potential to spill over into humans (Kreuder Johnson et al., 2015). Coronaviruses were identified as exhibiting just these characteristics, and this group of viruses were already known to have the potential to infect humans and escalate to pandemics, as seen with SARS-CoV-2 and MERS-CoV. The emergence and re-emergence of coronaviruses were discussed in scientific literature years before the SARS-CoV-2 pandemic (Lau & Chan, 2015). Pathogen characteristics associated with a greater propensity to spill-over include genetic instability allowing for rapid evolution (for example, in RNA viruses including influenza viruses and coronaviruses), broad cell tropism (i.e. the ability of the pathogen to infect a wide range of cell types or tissues), ability to circumvent immune responses, and antigenic immunodominance (Morens & Fauci, 2020).

4.2.2. Livestock species

As noted in Chapter 2, pigs may be an important target for surveillance and risk-based control efforts owing to the species transmitting similar pathogens as humans, including coronaviruses, and acting as reservoirs and intermediate hosts for notable human pandemics (Pepin et al., 2021). For example, avian influenza viruses can occasionally transmit directly to humans, as with the H5N1 virus (as described in the AI case study in Chapter 3). Another pertinent example is the emergence of Hepatitis E virus infection in humans in several parts of the world in recent years, with the increase in the number of autochthonous human cases often preceding the detection of high seroprevalence of asymptomatic infection in the pig population (Denner, 2019; Sooryanarain & Meng, 2019).

This is an example where surveillance in humans was able to identify an emerging trend faster than surveillance activities in the livestock reservoir.

Chapter 2 likewise touches on animals farmed for fur, highlighted as an indicator for consideration here. Concerns about the dangers of pathogen mutations and the spread of SARS-CoV-2 in fur farms impacts animal welfare and poses a risk of spill-over to native wildlife, which may affect the biodiversity of species (WHO 2021). In addition, mink can transmit coronaviruses as well as human and avian influenza viruses (Sun et al., 2021). In regard to husbandry practices and control, Chapter 2 recommends specific feeding practices to decrease risk. However, this chapter goes on to recommend surveillance of mink for influenza viruses.

4.2.3. Livestock systems

As Chapters 1-3 point out, specific livestock systems, such as those with mixed species, have a higher probability of involvement with disease emergence. Moreover, dense populations of pigs, domestic and wild birds are also associated with novel influenza virus risks (Taubenberger & Kash, 2010). While Chapters 1-3 provide further detail, this chapter confirms that strategic approaches to zoonotic disease surveillance should pay particular attention to expanding livestock systems. They should ensure that such expansion does not occur without adequate surveillance mechanisms nor ensuring high biosecurity standards.

4.2.4. Wildlife

Given that wildlife can act as natural reservoirs for many potential pathogens, including pathogens unknown to science, surveillance of pandemic risk from human activities that increase human-wildlife contact is critical. Further, while some wild animal species act as reservoirs for important zoonotic pathogens that are of concern to the livestock sector—for example, Nipah virus hosted by bats and influenza type A viruses hosted by wild aquatic birds—others do not (Ma et al., 2008; Smith & Wang, 2013). Therefore, surveillance and control efforts should focus on species of significant concern to the livestock sector.

4.2.5. Environmental factors

Many important drivers for zoonosis emergence are either downstream or upstream from livestock production systems, including deforestation, changes in land use, encroachment on wildlife habitats, and consumers' demand for animal-derived foods. The emergence of many previous pandemics was driven partly by ecological, behavioural and socioeconomic changes (Morse et al., 2012). In addition, environmental change and agricultural intensification have been identified as playing an important role in zoonoses emergence in multiple studies (Jones et al., 2013). However, it is not explicit whether non-intensive livestock systems encroaching on wild habitat are less or more likely to be risky or what role the further intensification of production using existing agricultural land plays in environmental drivers for zoonoses emergence. Overall, it appears indisputable that anthropogenic land-use changes are a factor for zoonoses emergence (Gibb et al., 2020; Hassell et al., 2017). Anthropogenic land use may even drive increased diversity in wild animal zoonotic disease hosts, as it has been shown that the proportion of local wildlife species that are known hosts of zoonotic pathogens and their total abundance is higher in locations undergoing "substantial human use" in comparison to undisturbed neighbouring sites (Gibb et al., 2020). Therefore, areas of rapid environmental change that result in increased wildlife-livestock and wildlife-human contact could be targeted for strategic multisectoral surveillance activities. However, avoiding encroachment of wildlife habitats and expansion of agricultural frontiers wherever possible would ultimately be the preferred strategy to prevent the emergence of zoonotic diseases.

4.3. Strategic approach to detection and controlling emerging zoonotic disease

The sections above have discussed attempts to predict zoonoses emergence and reviewed broad, potential indicators that may make emergence more likely. This section will discuss disease surveillance and control.

Surveillance systems for zoonotic disease emergence should target livestock systems and other potential sources of zoonoses and pathogens of animal origin. If anything, creating a livestock-only response may induce a false sense of security and is against a genuinely interdisciplinary approach. For example, COVID-19 could not have been prevented by an improved surveillance system in livestock.

Given that prediction of when, where and in which species the next zoonosis will emerge is highly uncertain, a better use of resources would be to focus on targeted surveillance for early detection, considering as much as possible the complex multiplicity of factors driving emergence when identifying the pathogens and animal subpopulations to be targeted. Some of the indicators known from previous emerging zoonoses may help guide surveillance strategy, but it is also important to invest in the ability to detect unknown and unexpected emerging zoonoses. As with the example of BSE described in Chapter 3, there could not have been a targeted surveillance mechanism to detect an entirely novel disease with a disease-causing agent entirely unknown to science at the time. In such circumstances, scanning surveillance is relied upon to detect unusual patterns in health or laboratory data, which may represent the emergence of new diseases.

Known indicators or factors associated with a higher risk of emergence (e.g., specific livestock production systems) can also inform preventive measures, such as specific biosecurity measures, and reduce the risks arising from anthropogenic land use. The majority of political interest regarding land use is centred around climate change, conservation and environmental protection. Pandemic prevention should be included in research and legislative efforts. The list of zoonotic disease emergence risk indicators should be developed further, with a more far-reaching and thorough literature search and further research, which is based on practical and not theoretical findings. Combining knowledge to create indicators across factors spanning pathogen characteristics, livestock species, livestock systems, wildlife, and the environment requires an interdisciplinary approach, including specialists from several scientific domains.

The following section discusses options for surveillance of emerging zoonoses, suggesting syndromic surveillance for unknown pathogens and risk-based surveillance for known pathogens. It also highlights the importance of monitoring changes in how land is used and how livestock are farmed.

4.3.1. Syndromic surveillance for rare and unknown pathogens

Current surveillance systems in livestock are primarily focused on testing for specific pathogens. Syndromic or symptomatic surveillance can enhance the capacity to detect rare, emerging and unknown diseases for which testing capacity does not exist or is not cost-effective to utilise. This would entail developing protocols for syndromic surveillance, including for unusual cases and mortalities and unusual clusters of cases. Syndromic surveillance for unknown pathogens increases the chances of detecting outbreaks more rapidly (Koopmans, 2013). Findings from syndromic surveillance in livestock and humans should be shared and integrated. Some syndromic surveillance is already utilised, such as abortion cases on large goat farms above 5% being notifiable in the Netherlands as a response to the Q fever outbreak of 2007-2011. However, this Q fever outbreak would have been detected sooner if unusual events in the human population were linked more quickly to the unusual events in the animal population. Therefore, this type of syndromic surveillance should be broadened and extended into human clinical data, and these data systems should be more applicable for this purpose.

Mortality surveillance in wildlife may also serve to inform the assessment of zoonotic risks in livestock. For example, wild bird mortality can provide early indications of HPAI and mortality in non-human primates can precede human outbreaks of Ebola (Merianos, 2007). Crucially, health surveillance involves not only data collection but also timely data sharing, analysis and interpretation. Thus, in addition to establishing new streams of data gathering, it is crucially important to ensure that data are integrated and shared among relevant sectors, including but not limited to agricultural/livestock, environment/wildlife and public health.

4.3.2.   Risk-based surveillance for known pathogens

Risk-based surveillance provides higher efficiency than traditional (random or representative) surveillance. To be useful, however, risk-based surveillance requires detailed knowledge of risk factors, and hence an up-to-date quality risk assessment process is necessary. To benefit from the greater efficiencies of risk-based sampling, there are two requirements: a reasonable understanding of risk factors influencing disease occurrence; and ready access to information about the population and the distribution of these risk factors. If accessing the necessary information is difficult and time-consuming, risk-based surveillance may no longer be more efficient than traditional approaches.

The large-scale EU-funded RISKSUR project (2017) developed decision support tools to design cost-effective risk-based surveillance systems that integrate the most recent advances in epidemiological methodologies, based on an interdisciplinary approach and tailored to the needs of individual EU MS. Where risk-based information and population data are available, risk-based surveillance allows for risks to public health, economic and trade consequences to be used to target the surveillance. Targeted surveillance of high-risk populations could, therefore, in theory, provide a cost-effective early warning system for zoonotic disease emergence. However, such systems rely on accurate knowledge of risk factors – knowledge which is often lacking. A structured risk assessment approach that evaluates risks systematically and transparently with full acknowledgement of uncertainties could help inform such surveillance efforts and identify key data gaps that dedicated research efforts should target.

4.3.3.   Monitoring land use and changes to livestock environment

Considering the importance of land use and the potential of changes in livestock systems to be associated with the emergence of zoonoses, a multidisciplinary approach to surveillance should incorporate parameters on these aspects. Further research may need to be conducted on which parameters would be helpful within the EU and how the data could be best combined with other domains to form an alert system for informing risk-based surveillance. Furthermore, the EU imports large quantities of animal products, particularly animal-source foods (for instance, meat, eggs and dairy products), some of which originate from countries whose agricultural systems and land use policies pose a higher risk of zoonoses emergence and transmission. Providing a market for these products may thus lend economic support to (and even contribute to the expansion of) higher-risk livestock production systems. Perhaps the broader implication for zoonoses surveillance would be to look out for processes rather than actual pathogens.

4.3.4.   The use of social science for disease surveillance

Social science could provide critical elements for the successful design, implementation and interpretation of surveillance data. For instance, adequate risk-based surveillance and risk assessments need to be based on knowledge about the type and evolution of livestock production systems and their value chains, an area that is dealt with extensively within agricultural economics. As such, understanding the connectivity and reach of livestock value chains, including the international movement of animals, products and people in an increasingly globalised industry, could help provide

the necessary framework for epidemiologists to determine and evaluate disease emergence pathways. Furthermore, value chain analysis offers a systematic approach to describe the role and responsibilities of people and institutions in the food system and, hence, for surveillance, determine its financial impact on stakeholders (Irvine, 2015). Finally, socio-psychological and ethnographic studies can further understand social factors that contribute to success in disease reporting and influence the feasibility of disease surveillance and control measures (Barnet et al., 2020).

4.4. Conclusions

The risk of zoonotic disease emergence is driven primarily by human activities, including how and what we farm. Accurate prediction of what the next zoonotic pathogen to emerge from livestock will be unlikely due to constant changes in livestock production practices (e.g. in response to market changes) and in the ways in which livestock, wildlife and humans interact and the myriad opportunities for disease emergence around the world. As a result, efforts should focus on accelerating detection (and interventions) in the event of emergence.

Broad indicators of commonalities associated with the emergence of zoonoses (including pathogen characteristics, livestock species, livestock system type, degree of interaction with wildlife and environmental changes) can provide some information to inform targeted surveillance efforts that can enhance early detection of emerging events and facilitate control. Therefore, it is important to support research that provides more robust evidence to refine these potential risk indicators for disease emergence.

The implementation of syndromic surveillance is suggested for unknown pathogens, and risk-based surveillance is suggested for known pathogens in human and animal populations. Surveillance of changes in land use and livestock systems linked to disease emergence may also provide a valuable proxy for the surveillance of disease events. The protocols for these three types of surveillance need further development, and we recommend that policymakers request the development of evidence-based protocols for syndromic and risk-based surveillance and monitoring changes in land use as a matter of urgency. Data collection must be designed (or adapted) to utilise information across medical, veterinary, environmental, and other relevant professions. Such co-operation needs to go beyond national and continental boundaries, given that many future zoonoses are likely to emerge outside of Europe but will affect the population here. International cooperation must continue to improve surveillance in third countries, including capacity building and data sharing activities. It is precisely at the level of data sharing and interpretation that a multidisciplinary approach to surveillance and control could further enhance the timeliness and effectiveness of risk mitigation and control efforts against emerging zoonoses.

In the next chapter, we examine the prospects for implementing a One Health approach to detecting, surveillance, and controlling zoonoses within the EU. We identify barriers presented by existing EU instruments to the integration of zoonotic disease surveillance and risk assessment activities (and the data that they produce) across the human and animal health sectors, and we propose an integrated model for the control of zoonoses within the EU based on One Health principles which address these barriers.

5. ONE HEALTH CONCEPT ASSESSMENT AND MODEL DEVELOPMENT

5.1. Introduction to the One Health concept and approach

The One Health (OH) concept foresees an integrated approach to achieve optimal public health outcomes. The concept assumes that interdisciplinary and intersectoral solutions are able to address health threats more effectively and efficiently than solutions that target a single sector in isolation. Disciplines and sectors are not defined *a priori* but need to cover all the aspects contributing to understanding the complexity of a given health threat.

The OH approach comprises coordination, communication and collaborative actions (CCCAs) across relevant disciplines and sectors (WHO, FAO and OIE, 2019). It may be used to develop plans, programmes, policies, and legislation to address health threats such as zoonotic diseases, Anti Microbial Resistance (AMR), food safety, and food security. More specifically, in our case, it provides an opportunity to implement a more effective, multidisciplinary approach to surveillance and control of zoonoses as envisaged in Chapter 4.

As noted in the previous chapters, zoonotic diseases emerge and develop pandemic potential within the human-animal-environment interface. Many zoonotic pathogens are climate-sensitive; some zoonotic diseases are water-borne or food-borne; others may be spread by insects and be transmitted to humans through livestock or wild animals. Therefore, it follows that responding effectively to zoonotic disease emergence requires CCCAs across human health, animal health and environmental disciplines and sectors and access to a range of specialists who can appreciate relationships across these domains.

The foundation of OH dates back to the 1980s when epidemiologist Calvin Schwabe coined 'one medicine' to indicate a unified approach across human health and veterinary sciences to combat zoonotic diseases. In the early 2000s, the concept began to be discussed in international fora and then evolved over the years into a trademark protected term of the Wildlife Conservation Society 'One World One Health™' (Zinsstag et al., 2011). In 2007, an International Ministerial Conference organised in New Delhi to review the progress made in controlling the avian and pandemic influenza outbreak of 2006 recommended that the international community develop a medium-term strategy for addressing EIDs. In late 2008, this recommendation led to the development of the 'Contributing to One World, One Health' framework for reducing risks of infectious diseases at the animal-human-ecosystems interface. The framework was a joint exercise of the international community[4] and led to a permanent work on OH by WHO, OIE and FAO. These three organisations have since formed a tripartite alliance that aims to address health threats associated with interactions between humans, animals and the environment (WHO, FAO & OIE, 2018). Among the joint activities of the alliance on OH are the implementation of the Global Action Plan on AMR; engagement with national governments to reinforce national and regional human health, animal health and food safety services; and the improvement of inter-agency foresight, preparedness and response to emerging, re-emerging and neglected infectious diseases at the animal-human-environment interface. In 2018, WHO/FAO/OIE prepared a guide to establish country-based collaborations across the animal and human health sectors. The guide was updated in 2019 to address zoonotic diseases in countries following a multi-sectoral OH approach (WHO, FAO and OIE, 2019) and accompanied in 2020 by a Joint Risk Assessment Operational Tool (WHO, FAO and OIE, 2020).

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[4]   It was prepared by the Food and Agriculture Organization (FAO), the World Organisation for Animal Health (OIE), the World Health Organisation (WHO), the UN System Influenza Coordination, the United Nations Children's Fund (UNICEF), and the World Bank (WB).

While the international community has played a prominent role in encouraging an OH approach to controlling zoonotic pandemics, at the EU level, the OH concept is only applied consistently to the fight against AMR[5] The following section reviews the operation of relevant EU instruments in areas related to the control of zoonoses, drawing attention to the main implementation challenges to OH and highlighting where there is room for improving current practices through a more integrated approach. Finally, opportunities for improvement according to an OH perspective are proposed.

5.2. Review of the operation of relevant EU instruments

In the absence of a dedicated EU policy framework for the integrated control of zoonoses, existing relevant initiatives are fragmented and framed by individual pieces of EU legislation that determine actors' mandates and the scopes of instruments. Figure 1 summarises the main actors and instruments involved in controlling zoonotic pandemics at the EU level. In addition, the figure maps the coordination, communication and collaborative actions which link these actors and instruments. It also indicates Member States' obligations under relevant international and EU legislation. In particular:

- Shapes indicate actors (grey boxes), instruments (blue boxes), and legislation (yellow boxes).

- Lines indicate: coordination actions (black), communication actions (blue), collaborative actions (green), and legal obligations (white).

Figure 1: Overview of key actors, instruments and CCCAs in the control of zoonotic pandemics
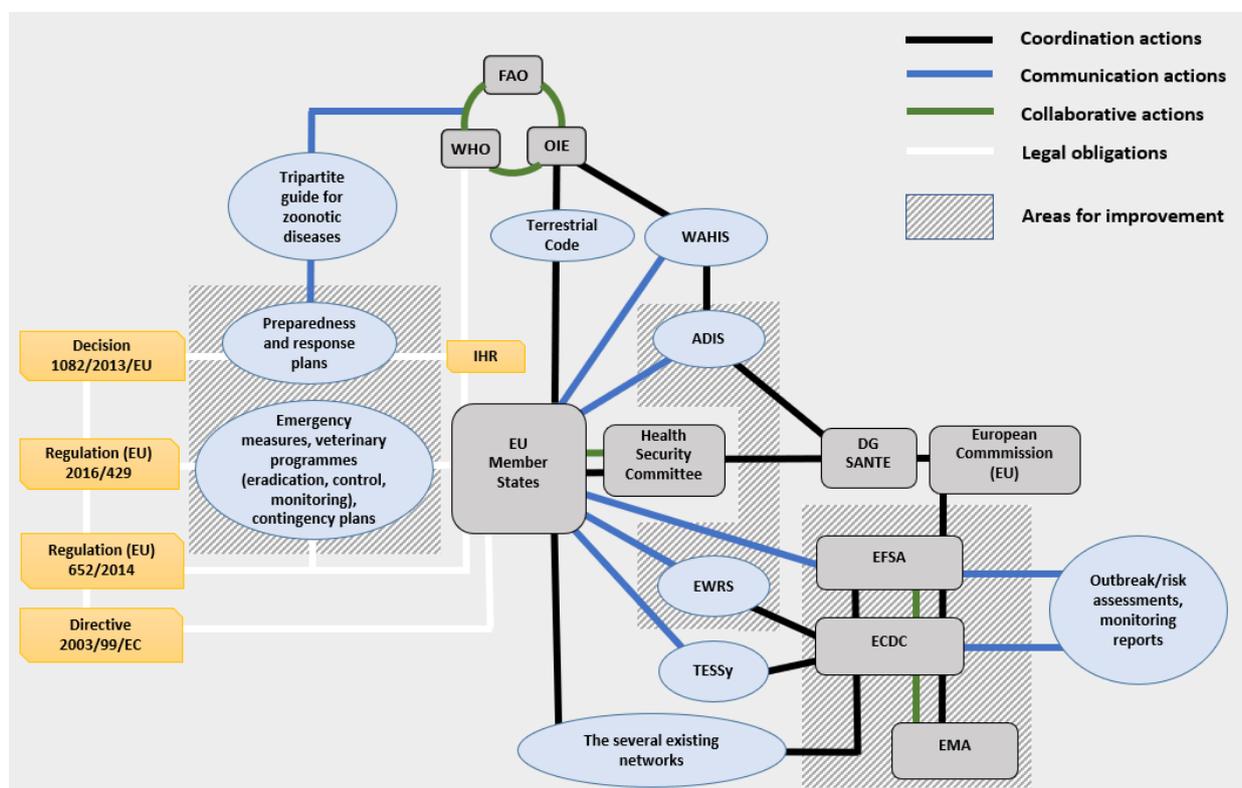
Source: Author's own elaboration.

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[5]   In 2017, the EU introduced a 'One Health Action Plan against AMR', which provides a policy framework for coordination, engagement, collaboration, and communication through the EU AMR One Health Network. The European Parliament also has a dedicated interest group on AMR which aims to give political visibility and support to the issue of AMR using an OH perspective.

The figure shows the **absence of shared instruments spanning the human health and animal health domains**. In particular, the national preparedness and response plans required under Decision 1082/2013/EU are not linked to the emergency measures, veterinary programmes and contingency plans foreseen by Regulation (EU) 2016/429 on transmissible animal diseases (see the shaded area on the left side of the figure). Likewise, the early detection systems for human health threats (**EWRS**) and animal diseases (**ADIS**) **do not communicate with each other** (see the shaded area in the central part of the figure where the two systems are not connected). Figure 1 also highlights that **currently, there is no environmental dimension built in the control of zoonotic pandemics** (see the shaded area on the right side of the figure where no environment-focused agency is present).

5.2.1. Early detection of and response to emerging zoonoses

At the EU level, two instruments are used for early warning of emerging diseases (including zoonoses), the Early Warning and Response System (EWRS) for human health cross-border threats and the Animal Disease Information System (ADIS) for animal diseases.

Through the EWRS, established in 2013[6] and operated by the ECDC, MS issue rapid alerts for cross-border severe health threats that meet specific criteria. Upon the issuing of an alert in the system, the Commission is responsible for making a risk assessment available to MS through the ECDC or other agencies, according to their mandate. In addition, risk assessments are addressed to both the EU/EEA countries and the Commission to support their preparedness and response. This process is coordinated by the Health Security Committee[7].

ADIS is used for the notification and reporting of infectious animal diseases. Since **21 April 2021**, the system's operation has been regulated by the 'Animal Health Law'[8] and successive implementing acts. An essential feature of the new notification system is its (expected) interoperability with the World Animal Health Information System (WAHIS) managed by OIE (2021), which will provide a single data entry point for MS so that they do not have to notify the OIE separately[9].

Through ADIS, EU MS provide rapid alerts of so-called 'primary outbreaks' while 'secondary outbreaks' are notified on the first working day of each week[10]. In this case, veterinary authorities in EU countries, rather than European Commission services, carry out the risk assessments. The Commission's role is to correlate data and information and send it back to MS for review. Further to risk assessment, risk management is a shared task between EU MS and the Commission.

Review

ECDC has a key role in early detection of and response to emerging diseases as it is, by mandate, responsible for surveillance, detection and risk assessment of threats to human health from communicable diseases and outbreaks of unknown origin. Contrary to the notification process of animal diseases, where risk assessment is made at the national level, ECDC is responsible for preparing human health risk assessments based on the information provided by MS.

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[6] Decision 1082/2013/EU (Art.8).

[7] HSC provides political coordination of the response to emerging diseases. It is chaired by a representative of the Commission and includes representatives of the MS. It pursues sharing of information and consultation towards a coordinated response of EU countries to health threats.

[8] Regulation (EU) 2016/429 on Transmissible Animal Diseases.

[9] Veterinary Authorities of Member Countries are required under the Terrestrial Animal Health Code, or Terrestrial Code, to report cases of EIDs in animals to the OIE. The code provides international standards for the improvement of terrestrial animal health and welfare and veterinary public health.

[10] A primary outbreak is an outbreak not epidemiologically linked with a previous outbreak in the same notification and reporting region of a MS or the first outbreak in a different notification and reporting region of the same MS.

If this information is lacking or insufficient, then the ECDC will be unable to perform its mandate. This was evident in the early stages of the COVID-19 outbreak when the agency had to rely on the information provided by other organisations and sources (i.e. obtained through epidemic intelligence screenings of official sources) to publish its first threat assessment of pneumonia cases possibly associated with a novel coronavirus on 9 January 2020.

The COVID-19 crisis has highlighted important inadequacies at the level of countries' preparedness for emerging diseases. For example, a WHO global assessment of the functioning of the International Health Regulations (IHR)[11] during the pandemic refers to shortcomings across countries in the areas of surveillance, health systems, equipment and training, emergency legislation, risk communication and coordination (WHO, 2021). In addition, the EC Communication on 'Building a European Health Union'[12] admits a varying operationalisation capacity across EU MS concerning their preparedness and response plans and envisages the launch of an audit process technically supported by the ECDC to understand where and how national-level capacity may be improved.

Another key issue is that the two alert systems do not communicate and are managed by different organisations (ECDC manages EWRS and the Commission, through DG SANTE, administers ADIS). No mechanism allows early signals of threats coming from both humans and animals' health alert streams to be shared. This especially impedes joint public outreach, communication, and coordinated functioning of different sectors' surveillance and early warning systems. Awareness and alerts should be concurrent across sectors, and a mechanism that enables early signals of threats to be shared should be in place (ECDC, 2018). This would also smooth differences in risk perception between the two sectors. The human health sector applies the precautionary principle, meaning that an uncertain level of risk requires preventative action, while adherence to this principle in the animal health sector is less stringent.

Finally, it is important to note that the environmental dimension provides no input into the whole detection and response process. This is a crucial shortcoming at the level of both communication and response. For example, early in the coronavirus pandemic, incorporating such a dimension could have contributed to clarify the role of the environment in transmission (contamination through surfaces, contacts among people, etc.) or to deepen the understanding of the relation between air pollution or climate, and the number of infections.

5.2.2. Controlling zoonotic diseases in animal reservoirs

Control of zoonotic diseases relies on regular reporting of epidemiological data by MS and processing this information into EU level reports by EFSA and ECDC. The concept of OH is pursued most consistently in this area. Here, collaboration across European agencies and extension sectors and disciplines is better achieved (as reflected in joint outputs). The relevant instruments are the reporting from MS on epidemiological surveillance and the networks established at the EU level to widen the knowledge base on which EU reporting relies.

In particular, EFSA is responsible for monitoring and analysing zoonoses, zoonotic agents, AMR, microbiological contaminants and foodborne outbreaks across Europe according to data communicated by the MS (as required under Directive 2003/99/EC, as discussed in Chapter 6). These data are submitted annually to EFSA and are used by the agency to produce EU summary reports. The ECDC complements these data with information collected through the European Surveillance System

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[11]   The scope of WHO's IHRs, to which all EU MS are parties, is to prevent, protect against, control and provide a public health response to the international spread of disease.

[12]   COM(2020) 724 final.

or TESSy. TESSy is the technical platform to which national data on infectious diseases under European surveillance are uploaded by MS using standard formats. Data are submitted and validated by European expert networks nominated by the MS and coordinated by the ECDC[13].

Review

EFSA plays a key role in the implementation of an OH approach in the control of zoonotic pandemics. Its mandate is to provide information and communicate regarding risks in the domains of nutrition, animal health, animal welfare, plant health and plant protection. It must also provide scientific and technical support in the epidemiological analysis of animal disease outbreaks and assess surveillance data. In doing so, EFSA has established collaborations with the European Medicines Agency (EMA) and the ECDC regarding AMR, foodborne disease outbreaks and zoonoses, and with the European Chemicals Agency (ECHA) for work on chemicals. According to a 2018 review, cooperation with these agencies is regulated through Memoranda of Understanding (MoU) and delivers joint outputs effectively (Ramboll and Coffey, 2018). The last agreed MoU (2021) between EFSA and ECDC, for example, mentions as collaborative outputs the '*joint assessments of cross-border public health threats related to foodborne outbreaks and zoonotic diseases*' and '*opportunities for joint communication activities on issues of common interest*' (EFSA & ECDC, 2021, p.5). Among the joint outputs which reflect an OH approach are the EFSA summary reports mentioned above, to which the ECDC has contributed data and analysis on zoonotic infections in humans since 2005 (from 2008, the data on human cases have been received via TESSy) (EFSA & ECDC, 2021). Another joint output is the annual 'EU One Health Zoonoses Report' on the results of zoonosis monitoring activities across European countries. This report, which is the only one explicitly pursuing an OH approach, is prepared by the two agencies using data from several networks[14]. The annual OH reports are considered helpful by stakeholders because they collate a large quantity of data and represent a valuable repository of information for risk assessors. Moreover, from OH's specific point of view, stakeholders believe that information on zoonotic diseases in humans and animals is combined satisfactorily while still reflecting the individual objectives of EFSA and ECDC (ICF, 2019).

EFSA data collection for zoonoses, AMR and food-borne diseases is based on ad-hoc models tailored to the disease and the specific mandate of the investigation. The agency has a Data Collection Framework in place, and MS are provided with instructions for reporting to ensure that individual country reports contain comparable descriptions on sampling, monitoring schemes and results and that EU trends and analysis can be derived. This process is supported by the Scientific Network for Zoonoses Monitoring Data, whose members are national representatives appointed by EFSA. However, this system is not functioning well. In 2018, a report highlighted that '*EFSA's data warehouse is not connected with the EC's Animal Disease Notification System (ADNS) and data submission and validation is not automated, the animal health data collections are labour intensive for both EFSA and the data providers of the MS. Data transmission is now mainly done via e-mail exchange of Excel/XML files, which is time-consuming, prone to copy/paste mistakes with a high risk of erroneous reporting of variables.*' (EFSA, 2018, p.3). The agency currently has an ongoing project (SIGMA) to improve data collection on animal diseases.

From an OH perspective, the main implementation challenge in this area is to improve interoperability between human health and animal health datasets and reporting systems (ECDC, 2018). In addition,

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[13] TESSy is now integrated into the European surveillance portal for infection diseases 'EpiPulse'. EpiPulse, launched on 22 June 2021, combines data from different sources and actors and is a first step to connect multi-sectoral information and facilitate interdisciplinary collaboration.

[14] Data is contributed by the EFSA Scientific Network for Zoonoses Monitoring Data (whose members are appointed by EFSA), the ECDC Food and Waterborne Diseases and Zoonoses Network (coordinated by the ECDC since 2007), the ECDC Emerging and Vector-borne Diseases Network, and the ECDC Tuberculosis Network (jointly coordinated by ECDC and WHO Office for Europe) (EFSA & ECDC, 2021).

similarly to the early detection area, there is no mechanism through which the environmental dimension may provide input into the surveillance of zoonotic diseases.

5.2.3. Prevention of epidemic and pandemics

As noted in chapters 3 and 4, rapid and effective detection of and response to zoonotic disease outbreaks enables them to be contained before they can spread, preventing them from escalating into epidemics or pandemics. The prevention of epidemics and pandemics relies heavily upon Member States' national veterinary programmes (regarding zoonotic disease surveillance and eradication), preparedness and response plans, and contingency plans. These instruments are intended to enable the timely provision of diagnostic tools, vaccination, and medical treatment and facilitate the rapid imposition of biosecurity measures, restrictions on the movement of animals, killing of animals, and disposal of carcasses in the event of an outbreak.

Animal health visits and surveillance activities are carried out at the national level. Veterinary authorities undertake surveillance activities within the framework of a surveillance programme. Eradication programmes can also be used to avoid reinfection. MS are responsible for establishing these two types of veterinary programmes[15,16].

MS must report to the Commission every three years on their preparedness and response planning at the national level in the human health sector. Planning has to provide information on the pursued interoperability between the health sector and the veterinary sector, and any other critical sector in an emergency[17]. In the animal health sector, MS must prepare contingency plans and manuals that specify the measures to be taken in case of an emerging disease outbreak. These plans are expected to ensure a high level of disease awareness and preparedness as well as the ability to launch a rapid response. The plans must include a description of the national, regional and local chain of command (both within and outside the competent authority); the framework for cooperation between the competent authority and the other public authorities and stakeholders involved; access to facilities, laboratories, equipment, personnel, emergency funds; and provisions for emergency vaccination[15].

Review

A lack of cross-sectorial communication at the level of preparedness can cause delays in detecting outbreaks of zoonotic diseases (see Chapter 4) and may impede a coordinated response (ECDC, 2018). Contingency plans in the animal health sector are supposed to describe the cooperation framework with other stakeholders and the access to facilities and equipment. In contrast, preparedness and response plans in the human health sector are required to illustrate the interoperability between the health sector and any other critical sector, particularly the veterinary one. These two requirements aim to facilitate cooperation between the animal and the human sector. However, there is no requirement for these two types of plans to communicate.

The main implementation challenge in this area is to ensure that an OH approach informs contingency plans for zoonotic disease outbreaks and preparedness and response plans to a public health emergency to pursue the necessary coordination of functions or interoperability clarity of roles. In addition, an OH approach would ensure that both types of plans indicate inter-sectoral communication

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[15]   Regulation (EU) 2016/429.

[16]   Veterinary programmes for animal diseases and zoonoses have been so far presented by MS and co-funded according to Regulation (EU) No 652/2014.

[17]   Decision 1082/2013/EU.

and coordination activities so that roles and functions during outbreaks are clearly attributed across sectors.

5.2.4. Sharing of health resources between the medical and veterinary sectors

The Commission has recently reported that during the COVID-19 crisis, in some countries, veterinary services and laboratories and EU Reference Laboratories[18] contributed to the screening and testing of surveillance and diagnostic samples from humans (EC-DG SANTE, 2020). However, this represents more an exception than a rule as there is no evidence of relevant EU instruments facilitating the sharing of health resources between the medical and veterinary sectors. Rather, the ECDC (2018) highlights insufficient sharing of data and biological samples between agencies representing different sectors at the national level and a lack of mechanisms to harmonise diagnostic laboratory tests as barriers to adopting an OH health approach.

The challenge in this area is to make this sharing of resources happen at the national level. This collaboration would entail adding to the inter-sectoral communication and coordination of activities envisaged above a collaborative dimension between the contingency plans for zoonotic disease outbreaks and preparedness and the response plans to a public health emergency. Thus, for example, collaboration may be planned with veterinary laboratories to strengthen the diagnostic capacity of human health services or with veterinary professionals' organisations to address hospital staff shortages.

5.2.5. The contribution of health research and innovation

The most relevant OH initiative under Horizon 2020 is the One Health European Joint Programme (2018-2022). OHEJP is a partnership of 41 food, veterinary and medical laboratories and research institutes from 19 EU MS. One of the consortium members is the Med-Vet-Net Association, launched in 2009 to continue the European Network of Excellence Med-Vet-Net on the integration of medical, veterinary and food science research on the prevention and control of prevention and control zoonoses and foodborne diseases. The focus of OHEJP is to reinforce transdisciplinary cooperation, integration of activities, and training in the fields of foodborne zoonoses, AMR, and emerging threats. Joint research projects (JRPs), joint integrative projects (JIPs) and training activities (for example, PhD courses) are implemented within the framework of OHEJP to harmonise approaches, methodologies, databases and procedures for the prevention, detection and control of foodborne zoonoses, AMR and emerging threats across Europe. Through its One Health EJP Outcome Inventory (OHOI), a catalogue of the project's results and findings, the project aims to facilitate their use by interested stakeholders. As OHEJP is a very focused initiative on the implementation of OH, the project should be asked to go further and suggest concrete ways to transfer its results into initiatives aimed at improving the prevention and control of zoonoses and foodborne diseases at the national and EU level.

More generally, from an OH perspective, the main challenge is for relevant health research and innovation activities to provide a tangible contribution to the implementation of the approach, for example, by:

- defining the contribution of environmental and social sciences to surveillance and control of zoonoses (see Chapter 4), so that the most appropriate actors and instruments from these sectors and disciplines may be identified and engaged;

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[18] EU Reference Laboratories are designated to ensure the application of uniform practices and reliability of methods of analysis, tests and diagnosis across national reference laboratories (Regulation (EU) 2017/625).

- developing IT solutions based on Artificial Intelligence or big data analytics that modernise health data reporting, information analysis, and the filling of data gaps;

- developing OH competencies and skills, or training of professionals who are highly qualified to support integrated early detection, risk assessment and response activities;

- filling specific knowledge gaps such as the identification of parameters to consider while carrying out a multidisciplinary approach to surveillance (e.g. land use, changes in livestock systems), or the type of data needed from other domains to develop an alert system for informing risk-based surveillance (see Chapter 4).

5.3. Conclusions and recommendations for integrating the OH approach into the control of zoonoses

Previous sections have highlighted the need to improve a number of areas to optimise the prevention and control of zoonoses. This section identifies opportunities to improve current arrangements for zoonotic pandemics' control by adopting an OH perspective. Recommendations do not imply disruptive changes in actors' mandates and the scope of instruments but changes in how they interact, communicate and/or cooperate.

5.3.1. Recommendation 1: Interlinking the EU alert and risk assessment systems in the animal health and human health sectors while improving data collection processes

Regarding alert and risk assessment, there is a lack of communication mechanisms between EWRS and ADIS (the two European warning systems for emerging diseases) and an uneven quality of infectious disease reporting by EU MS, leading to the emergence of information gaps.

- **The interoperability of the early warning systems for human and animal diseases should be pursued at the EU level by the European Commission**. This would require the definition of commonly recognised early warning and surveillance signal/red-flag thresholds in the animal and human health sectors. It would also require substantial investment in modernising the reporting systems linked to the rapid risk assessment of health threats. Surprisingly, these systems are still based on the exchange of excel files (i.e. EFSA) or on the screening of official sources to fill gaps in epidemic intelligence (i.e. ECDC). Linking the two systems would make more information available to support risk assessment and, in turn, increase the effectiveness of early detection of EIDs.

- **Changing the data provided by MS and/or data input modalities may be necessary at the national level**. Data collection should be designed or adapted by ECDC to utilise information across medical, veterinary, environmental, and other relevant disciplines. National programmes for eradicating, controlling and surveillance of zoonoses, as sources of input of the data and information, should be adapted accordingly by MS (as discussed further in the following chapter). Improved data flows (i.e. type of data provided and/or data input modalities) would be instrumental in improving the quality of data provided by MS.

5.3.2. Recommendation 2: Opening up the analysis of zoonotic disease data and information to a wider range of expertise

There is a lack of consideration of environment-related factors in the rapid assessment of risks. The surveillance and monitoring of zoonoses are not open to and inclusive of integrated expertise.

- **At the EU level, a team with cross-sectoral knowledge (human-animal-environment) should be placed in charge of assessing alerts generated by the early warning systems.**

The integration of environment-related expertise to link data and information obtained through EWRS and ADIS with environmental data on climate, land, air, or wastewater would improve the understanding and assessment of the risks posed by emerging diseases. In addition, as noted in Chapter 1, a severe challenge when conducting rapid risk assessments of most infectious disease threats is that data are often scarce and incomplete. In such situations, expert knowledge elicitation may be used to fill evidence gaps. Environment-related expertise needs to be an integral part of this process and not only participate on an ad-hoc basis. The European Commission should consider the opportunity for the European Environment Agency to take up this role.

- **The input of OH professionals** (i.e. individuals with a verifiable qualification in OH such as the graduates from the OHEJP Doctoral Programme) **into zoonotic disease surveillance and monitoring activities should be considered by the European Commission** to improve the quality of risk assessments and coordinated monitoring activities. Furthermore, such input could also improve communication activities' relevance, especially those addressed to the general public.

5.3.3. Recommendation 3: Framing of national preparedness/response plans (human health) and contingency plans (animal health) within an OH approach

There is a lack of coordination of functions due to the unintegrated nature of preparedness, response and contingency plans at the national level, a lack of clarity about the chain of command, roles and responsibilities of the key actors involved in implementing containment and response measures, and a lack of systematic and coordinated sharing of resources across the human and veterinary sectors during emergencies. EU MS are responsible for the preparation and implementation of these plans. Therefore, the national level is where the OH approach may concretise into a coordinated and collaborative approach across sectors and disciplines.

- **MS should be supported by the European Commission to develop their zoonotic disease strategies according to an OH approach, for instance, by strengthening the capacities of competent authorities and providing guidance**. This support to MS could be externalised (e.g. technical assistance), or a helpdesk could be established at the EU level to provide ad-hoc advice or training.

- **Using the 'Tripartite Guide to Addressing Zoonotic Diseases in Countries' as a first guiding document for EU MS should be considered by the European Commission**. The aim would be to pursue consistency with the ongoing international effort in promoting an OH approach to control zoonotic pandemics and building on the tools and guidance already developed.

In conclusion, existing OH initiatives in the surveillance and control of zoonoses are currently fragmented at the EU level. The lack of a political EU framework for OH in controlling emerging diseases weakens the positive impact that individual initiatives may have. Adopting an OH approach at the EU level would be helpful as it can enhance the analytical ability to process available information and data. Nevertheless, it makes more sense if the same approach is pursued at the country level because EU MS and their nominated networks remain the main entry point of information and data into the whole system.

6. ZOONOSIS MONITORING LEGISLATION FINDINGS AND REVIEW

6.1. Introduction to EU zoonosis monitoring legislation

The previous chapter recommends updating current EU arrangements for zoonotic disease surveillance and control to facilitate a One Health approach to managing zoonoses. It also highlights that EU institutions depend heavily on Member States' national authorities to gather the zoonotic disease surveillance data that informs EFSA and ECDC risk assessments and implement control measures. This chapter undertakes a more detailed review of the operation of two key legal instruments, with the aim of providing recommendations for improvement: Directive 2003/99/EC on the monitoring and reporting of zoonoses and zoonotic agents and Regulation (EU) 652/2014 laying down provisions for the management of expenditure relating to the food chain, animal health and animal welfare, and relating to plant health and plant reproductive material[19]. This section summarises the provisions of Directive 2003/99 EC and the original Regulation (EU) 652/2014, while the subsequent sections examine their implementation by the different MS.

During the preparation of this report Regulation (EU) 652/2014 was repealed and replaced with Regulation (EU) 2021/690. We therefore examine the implications of our findings for the implementation and effectiveness of Regulation 2021/690 where possible, and we highlight recommendations which may hold relevance for the new Regulation. However, it is important to note that no data or reporting relating to the implementation of Regulation 2021/690 by Member States was available at the time of writing and as a result it was not possible to carry out a full review of this Regulation as part of this study.

Directive 2003/99/EC establishes a legal requirement for EU MS to collect and publish data on the occurrence of zoonoses in animals, food, feed and humans within their territory, to investigate food-borne disease outbreaks, and to submit to EFSA an annual report on trends and sources of zoonotic diseases. The data shown in these annual reports by MS underpins the annual One Health zoonoses reports prepared jointly by EFSA and the ECDC. These reports enable identifying trends and sources of zoonotic disease incidence within the EU, supporting risk assessment and the detection of emerging zoonoses. Annex I of the Directive specifies the zoonoses on which MS must collect and publish data as outlined above – all MS must monitor Category A zoonoses. At the same time, MS are obliged to monitor Category B zoonoses only if the epidemiological situation warrants it. Annex IV specifies the information which must be included in Member States' annual reports to EFSA.

Regulation (EU) 652/2014 enabled the competent authorities of MS to apply for EU funding to support national programmes for the surveillance, control and/or eradication of animal diseases, plant pathogens, and zoonoses. MS were (and continue to be under Regulation 2021/690) permitted to apply for EU funding to support routine national zoonotic disease surveillance, control and/or eradication programmes, while programmes targeting pathogens that affect only animals or plants may be funded only on an emergency basis. Articles 9-12 specified that MS may receive EU funding to support the costs of delivering zoonotic disease surveillance, control and eradication activities, including sampling and testing animals for zoonotic pathogens; slaughtering or culling infected animals; compensating the owners of slaughtered animals or destroyed animal products; purchasing, distributing and administering vaccines; and cleaning and disinfecting affected holdings. In addition, article 14 required

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MS to report annually to the Commission on the costs and outcomes of national zoonotic disease programmes for which EU funding has been provided.

Taken together, these two pieces of legislation govern the national programmes, which underpin the existing EU-level architecture of zoonotic disease surveillance, identification, monitoring and control instruments.

6.2. Review of Member States' implementation of Directive 2003/99/EC

Directive 2003/99/EC requires that MS maintain monitoring programmes only for the eight 'Category A' zoonoses described in Annex I[20], and it is important to establish the degree to which the number and type of non-Category A zoonoses monitored by MS varies. Through reviewing Member States' annual reports to EFSA for 2019, we assessed the extent to which existing reporting requirements provide the Commission with adequate coverage of trends and sources of zoonoses, zoonotic agents and AMR, identifying reporting gaps as well as trends regarding non-mandatory reporting. The analysis of Member States' 2019 EFSA reports[21] focused on four reporting areas: disease status, prevalence, AMR, and foodborne outbreaks[22]. Our classification assigns 'reported' status if the zoonotic agent was mentioned in at least one of these areas. In general, the analysis shows a high degree of harmonisation in reporting across countries and zoonoses. While two MS – Denmark and Slovenia – have a non-harmonised way of reporting, their coverage of zoonotic agents is consistent with the Directive's requirements.

Table 2: Underreported mandatory zoonoses

Category A - Mandatory	
Underreported zoonoses	**Countries missing**
Echinococcosis	Austria, Croatia, Lithuania, Netherlands, Portugal
Verotoxinogenic E. coli	Denmark, Hungary, Lithuania, Luxembourg, Poland
Listeriosis	Hungary, Malta
Trichinellosis	Cyprus

Source: Author's own elaboration.

In general, most MS show a high degree of compliance with the Directive. As shown in Table 2, four zoonotic agents lack any reporting. At the MS level, only two countries – Hungary and Lithuania – exclude more than one zoonosis and eight countries exclude only one; the rest include data for all mandatory zoonoses. Disease status[23] is presented for *brucellosis* and *mycobacterium bovis* in 25 MS.

Meanwhile, prevalence information[24] is not reported for all Category A zoonoses. Hungary and Malta covered the fewest zoonoses, and 16 MS exclude at least two zoonoses from their prevalence reporting.

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[20]   Category A zoonoses and zoonotic agents include: brucellosis, campylobacteriosis, echinococcosis, listeriosis, salmonellosis, trichinellosis, tuberculosis due to Mycobacterium bovis, and verotoxinogenic Escherichia coli.

[21]   Available at https://www.efsa.europa.eu/en/biological-hazards-data/reports.

[22]   Denmark and Slovenia reports were analysed only in terms of zoonoses coverage. They are excluded from the analysis of specific areas of reporting, as these are available only for the 25 MS who used a harmonised format.

[23]   Disease status focuses on the analysis of herds in relation to brucella and mycobacterium (bovine, ovine or caprine variants. Reported variables include the numbers of: infected herds tested under surveillance; herds tested under surveillance by bulk milk; animals or pools tested under surveillance by bulk milk; infected herds tested under surveillance by bulk milk; notified abortions whatever cause under investigation of suspect cases; isolations of Brucella abortus under investigation of suspect cases; abortions due to Brucella infection under investigation of suspect cases; animals tested by microbiology under investigations of suspect cases.

[24]   Prevalence information is presented in line with the Directive's requirements. Reporting for all zoonoses includes at least: area of sampling; various sampling information (matrix, sampling stage, sampling origin, sample type, sampling context, sampler, sampling strategy); sampling unit, sampling details; method employed; total units tested; total units positive; zoonoses tested; number of units positive. When relevant, sample weight and weight unit are also specified.

Diseases or zoonotic agents underreported in terms of prevalence data include *brucellosis* and *mycobacterium bovis*; however, all reports provide information about their disease status. Prevalence data for *salmonellosis* and *trichinellosis* is supplied in most MS. *Echinococcosis and verotoxinogenic Escherichia coli* prevalence data are missing in five countries (Austria, Croatia, Lithuania, Netherlands and Portugal). In most MS, AMR information[25] focuses on variants of *campylobacteriosis*, *salmonella*, and *VTEC Escherichia coli*. All 25 harmonised MS reports present this information for variants of *salmonella*, 17 for *campylobacter*, and 10 for *VTEC E. coli*. Foodborne outbreaks are reported in at least one MS for all mandatory diseases, except for *echinococcosis* and *mycobacterium bovis*, which have no existing outbreaks reported. Appendix 1 provides a detailed breakdown of reporting by country.

Table 3: Reporting of non-mandatory zoonoses

Category B - Listed		Category B - Other	
Most frequently reported	**Number of countries**	**Most frequently reported**	**Number of countries**
Lyssavirus	21	Norovirus	19
Yersiniosis	15	Coxiella	16
Toxoplasmosis	12	E. coli non-pathogenic	16
Hepatitis A virus	8	Flavivirus	14
Cystercosis	8	Cronobacter	12
Calicivirus	7	Clostridium perfringens	11
Cryptosporidiosis	5	MRSA	11
		Bacillus cereus	10

Source: Author's own elaboration.

The left panel of Table 3 shows the most frequently reported zoonoses or zoonotic agents included in Annex I, section B. The rest of the zoonotic agents listed in the Directive are not reported by any MS,[26] although it is unclear whether this is due to low incidence rates. Some of the missing zoonoses are documented on the ECDC's Surveillance Atlas of Infectious Diseases[27]: 77 botulism cases were reported across EU countries in 2019, although only France, Italy and Romania present more than ten occurrences. Leptospirosis is documented only in Bulgaria's and Denmark's reports; however, the ECDC Atlas' data shows 956 confirmed cases across MS, and about 15 countries have confirmed ten or more occurrences[28]. While MS report other tick-borne diseases such as tick-borne encephalitis, harmonised borreliosis data is scarce, and recent literature suggests that this agent presents high incidence (e.g. in Lithuania) and that better surveillance schemes are necessary. Harmonised data is also lacking for anisakiasis; however, recent publications suggest advancing monitoring activities as its epidemiological status is almost unknown in Europe. Prevalence information is provided mainly for *lyssavirus* (19) and *toxoplasmosis* (12). Other zoonoses with prevalence data supplied by less than 10 MS are yersiniosis, cysticercosis, calicivirus, vibriosis, hepatitis A virus, and leptospirosis. Foodborne outbreaks are reported mostly for yersiniosis (6), hepatitis A virus (5), calicivirus (4), cryptosporidiosis (4), and vibriosis (2). Neither disease status nor AMR information is provided for any listed category B zoonoses. For details, please see Appendix 2.

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[25]   Antimicrobial resistance information involves testing against a set of antibiotics depending on the zoonotic agent under study. Sampling information is also provided.

[26]   These include anisakiasis, borreliosis, botulism, other forms of tuberculosis, and viruses transmitted by arthropods. For the latter, there are voluntary reports of flavivirus (West Nile virus) in 14 MS.

[27]   ECDC Surveillance Atlas of Infectious Diseases, does not include information on anisakiasis, borreliosis, nor psittacosis; it does not inform about specific types of tuberculosis.

[28]   MS without leptospirosis cases reported in 2019 are Cyprus, Finland, Lithuania and Luxembourg. Those with less than 10 cases are Latvia, Malta, Poland, Estonia, Slovakia, Bulgaria and Sweden.

About 57 different zoonotic agents are classified as 'other' under the Directive and are reported voluntarily by MS. Those that are informed by at least 10 MS are shown on the right panel of Table 3. AMR information is shown mostly for *E. coli non-pathogenic* (15), along with other non-pathogenic enterococcus variants. Most zoonotic agents classified as 'other' are reported in foodborne outbreaks tables; MS report most frequently on the following: norovirus (17), *clostridium* variants (16), *Bacillus cereus* (10) and other staphylococcus variants (~6). In addition, 18 MS reported foodborne outbreaks caused by unknown agents. MS also reported the presence of proteins and toxins, which may indicate infection with a zoonotic agent such as histamine (16) and staphylococcal enterotoxins (10). Please see Appendix 3, Parts 1-3 for more information.

6.2.1.   Conclusions and recommendations

Regarding Directive 2003/99/EC, our review finds that MS are compliant in reporting most category A zoonoses and including methods and sampling information. However, a small number of MS have not been reporting at least one of the notifiable Category A zoonoses, contrary to their legal obligations under the Directive. We would recommend that non-reporting MS be encouraged strongly to provide more comprehensive data to EFSA in the future.

We found that substantial reporting gaps which threatened to compromise the adequacy of submissions as an evidentiary basis for EFSA's and the ECDC's annual reports existed for two Category A zoonoses: Echinococcosis and E. Coli. For each of these zoonoses, five MS failed to submit a monitoring report to EFSA in 2019,[29] suggesting that EFSA and the ECDC are likely to have encountered significant difficulties in establishing the prevalence of these diseases across the Union and in assessing the magnitude of the public health risk which they present. In the case of E. Coli, these gaps in routine monitoring and reporting may have been remedied to some degree by these Member States' reporting of foodborne outbreaks. However, no food-borne outbreaks of Echinococcosis were reported in 2019, suggesting substantial gaps in Member States' monitoring of this category A zoonosis. As such, we would suggest that improving monitoring and reporting of Echinococcosis should be considered a high priority.

While reporting of Category B zoonoses is highly variable, this is unsurprising given that MS are currently expected to report Category B zoonoses only if they actually occur within their territory. More surprisingly, category B agents classified as 'other' zoonoses are reported more frequently than those explicitly listed in Annex I of Directive 2003/99/EC, and most are reported as part of the analysis of foodborne outbreaks. This suggests that the most frequent foodborne agents are not necessarily reported in terms of disease status, prevalence, or AMR by MS as they are not mandatory. The lack of details on prevalence, AMR or disease status for some of the most frequent agents present in foodborne outbreaks – e.g., norovirus and clostridium variants – limits comparability and understanding of the monitoring measures taken by the different MS (e.g. variables included in prevalence reporting such as sampling information, methods of detection, units tested positive, etc.). Updating the list of explicitly mentioned agents in section B to include the most frequent 'others' could help advance monitoring of highly prevalent zoonotic agents and increase adherence to harmonised reporting. Examples of frequently reported Category B zoonoses also highlighted in 2019 One Health Report are: flavivirus – variants of which affect the Mediterranean area (Jourdain et al., 2019) – and Coxiella, for which passive monitoring has increased reliance on stakeholder awareness and reporting (Winter et al., 2021).

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[29]   In the case of Echinococcosis the non-reporting MS were Austria, Croatia, Lithuania, the Netherlands and Portugal, while in the case of E. Coli Denmark, Hungary, Lithuania, Luxembourg and Poland.

These reporting gaps aside, our findings suggest that MS' zoonosis reporting under Directive 2003/99/EC provides a sound basis for EFSA's and the ECDC's decision-making concerning the surveillance and management of zoonoses which are already endemic either within the EU or in other parts of the world and which therefore present a well-understood public health risk. However, we would also observe that the zoonosis monitoring and reporting obligations created by Directive 2003/99/EC are focused primarily on pathogen-specific testing programmes targeting the zoonotic agents specified in Annex I of the Directive. Chapters 3 and 4 highlight that while such pathogen-specific surveillance activities are well suited to rapid detection and control of outbreaks of pathogens of known concern in hitherto disease-free areas, they may be less effective in detecting the emergence of novel zoonotic pathogens. In line with the strategic approach to surveillance outlined in Chapter 4, we suggest that these existing pathogen-specific zoonosis surveillance activities should be complemented by syndromic surveillance programmes and procedures to ensure that anomalous symptoms in both humans and animals are investigated.

6.3. Review of Member States' implementation of Regulation (EU) 652/2014

The Commission has required MS to report annually on the nature and the effectiveness of any national zoonotic disease surveillance, control or eradication programmes that receive funding from the Commission under the recently repealed Regulation (EU) No 652/2014, as well as the newly established Regulation (EU) 2021/690. Therefore, the team reviewed the Member States' annual reports to the Commission for 2019 to assess the strengths and weaknesses of the funded national programmes for the surveillance, control and eradication of zoonoses under Regulation 652/2014, with the aim of developing recommendations for improvements. As mentioned above, we highlight the implications of our analysis for the new Regulation 2021/690, but consider its full review out of scope for this study. We summarise our overarching findings from this analysis below, then outline disease-specific findings regarding the types of EU-funded zoonosis programmes delivered by MS.

To ensure early detection of disease across farms, most MS complement passive surveillance across entire territories by engaging in active surveillance in high-risk areas to ensure routine testing of commercial livestock. Passive surveillance refers to systems where notification of suspected disease cases is legally required, but the frequency is not stipulated, meaning that adherence is difficult to enforce. While this approach is useful due to its continuous nature and low resource needs, it risks underreporting. By contrast, active surveillance provides a more robust estimate of disease circulation and frequency as health departments require routine information on disease and actively monitor reporting (LaMorte, 2017).

In regard to wildlife surveillance, while MS implemented passive surveillance across their entire territories, active surveillance was most often only implemented in affected areas by cooperating with local hunters. Moreover, serological testing is of critical importance as several MS reported that cases found with seropositive results are at times Polymerase Chain Reaction (PCR) negative. For the broad range of zoonotic agents, PCR testing is more accurate at the early stages of infection but involves a rapid decline in detection rates over time. By contrast, serological assays – based on antibody detection – can detect the presence of infection at later stages or in asymptomatic cases. This is relevant for cases that may not raise the alarm early enough to apply PCR testing (Steinberg, 2002; Maurin & Melenotte, 2020). Therefore, coupled testing or a combination of laboratory techniques for timely detection is crucial for disease control. This issue mainly affects zoonoses such as Echinococcosis, which lacks a standardised serological assay and requires a multi-approach diagnostic, and Cysticercosis, which requires imaging and serology assays (Schwartz et al., 2017).

Further measures for controlling infection circulation across numerous MS include awareness campaigns for farmers and other relevant actors. Finally, regarding prevention and control, some MS implement obligatory vaccination programmes, while others are voluntary. Where outbreaks are confirmed, confinement zones and trade restrictions are established.

MS with the continued presence of specific zoonoses and those that did not experience new outbreaks but continued to implement zoonosis monitoring activities, face difficulties meeting programme targets. Challenges included retrieving and transporting samples from farms to laboratories for testing within the appropriate time. In addition, Hungary, Poland, and Romania highlighted insufficient storage and disposal facilities for intensive sanitary culling in commercial pig holdings and storing carcasses. Certain socio-cultural traditions regarding backyard holdings also caused technical difficulties in numerous MS, such as Romania's Danube Delta region, which is difficult to access and has low levels of biosecurity. Moreover, staffing insufficiencies combined with high outbreaks in short periods led to overwhelming workloads for field teams and laboratories technicians. Finally, regarding wildlife surveillance, Hungary and Romania reported challenges in securing hunters' cooperation in sampling hunted animals and complying with biosecurity measures. While financial incentives were established, challenges continued, particularly concerning insufficient diagnostic shooting and searching.

Two of the most commonly cited challenges regarded finding appropriate sentinel animals for testing and insufficient staffing and resources. Regarding sentinel animals for testing, challenges most commonly arose from the limited selection of sentinel animals—reflecting difficulties in meeting testing targets and successes in vaccination programmes. Moreover, both Greece and Malta highlighted insufficient staffing and resources. Numerous surveillance programmes did not achieve their targets due to inadequate personnel in veterinary authorities coping with enormous workloads.

Below, we provide an overview of disease-specific findings drawn from EU-funded zoonosis programmes delivered by MS. The presented diseases below are selected based on all available 2019 Final Reports submitted on behalf of MS and directly draw from the 95 available Final Reports.

6.3.1. Avian Influenza

As of 2019, AI remained present in five MS, including Bulgaria, Croatia, Italy, the Netherlands (not officially reported), and Slovenia (EC-BG-AI, 2020; EC-HR-AI, 2020; EC-IT-AI 2020; EC-NL-AI, 2020; EC-SL, 2020). However, 25 states received funding for active and passive surveillance activities across domestic poultry and wild bird populations, as several with no new outbreaks also continued monitoring programmes. Thus, risk-based, passive surveillance and representative sampling for active surveillance are combined across MS.

While some MS implement passive surveillance activities across their territories, others establish protection and surveillance areas around outbreak points for active surveillance. For instance, the Czech Republic implements a series of restrictions, biosecurity measures and extra monitoring for poultry in the protection zones, bans on movement, exhibitions and release of poultry, and disinfection measures in surveillance which are broader than the protection areas. In general, its surveillance programme involves passive surveillance for wild birds and active surveillance for poultry. This country also draws on migratory bird flight paths, epidemiological data and ornithological data to justify the lack of high-risk areas and its decision to engage only in passive surveillance for wild birds (EC-CZ-AI, 2020).

On the other hand, in MS where AI remains active, such as Italy, specific surveillance and control measures have been reported for 2019. After a farm referred mild respiratory symptoms in poultry, an

outbreak was confirmed in Modena. Based on the evidence collected through the epidemiological inquiry, it was assumed that the infection could have entered the farm through contact with wild birds as the broilers had access to an outdoor area. A restriction zone of a 1km radius around the affected holding was established, and movement restrictions were applied within this zone. All birds in the affected holding were culled, and the carcasses were disposed of under supervision (EC-IT-AI, 2020).

Both MS that reported the continuing presence of AI and those reporting no new outbreaks faced difficulties in meeting AI programme targets, particularly with the adequate sampling of the species listed by the Commission Decision 2010/367/EU. While in some MS, such as Cyprus, discrepancies result from dependency on weather conditions during winter, other MS highlighted more severe challenges such as lack of personnel, funds, and reduced public awareness in Greece and Luxembourg (EC-CY-AI, 2020; EC-HL-AI, 2020; EC-LX-AI, 2020). Romania also reported technical difficulties in accessing backyard holdings with low levels of biosecurity in the Danube Delta region (EC-IT-AI, 2020). Latvia likewise noted the need to improve passive surveillance systems, especially for wild birds (EC-LV-AI, 2020). Numerous MS also organize campaigns to increase public awareness to increase reporting of dead wild birds. While such measures show some success, their cost-effectiveness is unclear as more notifications were received for birds not considered target species (EC-LV-AI, 2020).

6.3.2. Bovine Tuberculosis

As of 2019, Bovine Tuberculosis (BT) remained present in, and funding continued for four MS, including Ireland, Italy, Portugal, and Spain (EC-IE-BTB, 2020; EC-IT-BTB, 2020; EC-PL-BTB, 2020; EC-ES-BTB, 2020). Programmes entailed active and passive surveillance. Whereas eradication is expected for Italy and Portugal by 2025, the situation is worse in Ireland and Spain, where complete eradication is not expected until 2030 (EC DG SANTE, 2016). However, according to its latest report, Ireland met its 2019 surveillance targets as 98.35% of herds were subjected to at least one test during the year.

Surveillance activities include epidemiological surveys and slaughterhouse samples, while control measures include pasture inspections to check for cleaning and disinfection of positive herds and on-site inspections for compliance with movement restrictions. Actions are implemented with varying degrees of surveillance across MS territories and type of livestock according to the risk level. Certain areas of Italy, for example, are currently BT free and only engage in passive surveillance (EC-IT-BTB, 2020). However, local veterinary services in other regions that have not been declared officially TB free (OTbF) continue to implement active measures.

However, Portugal did not meet its 2019 targets and cited several difficulties preventing it from doing so. First, in some regions with reduced herd populations, any slight increase in positivity translates into a significant increase in the prevalence of the disease. Notably, the majority (71%) of infected herds were located in two areas of Portugal which have a higher density of wild deer and boars (and therefore a greater risk of tuberculosis infection). Second, all animals which tested positive were slaughtered, and those coming from newly infected herds were subjected to organ collection for bacteriology (EC-PL-BTB, 2020).

Large amounts of funding have historically been granted for measures against TB. However, given its limited impact on health and trade, alongside the reduction of future available EU funds, as well as the rise of new risks, a progressive decrease of co-financing for such measures has been suggested (EC DG SANTE, 2016).

6.3.3. Rabies

As of 2019, Rabies remained present only in three MS, Estonia, Poland, and Romania, where infections were suggested to have occurred from contact with wildlife migrating from Belarus and Russian

borders (EC-ET, 2020; EC-RO, 2020; EC-PL, 2020). However, 12 states received funding for continued monitoring programmes and surveillance activities across domestic cats and dogs and wild fox populations. As a result, a combination of passive and active surveillance was reported across the 12 states.

All countries reported mandatory oral vaccination for domestic animals and wildlife vaccination in areas of concern to reduce rabies cases. In addition, given challenges associated with trans-border rabies spread, several MS have collaborated with different localities to distribute vaccinations in bordering territories. Finland, for example, has been distributing vaccinations in bordering Russian regions since 2003, formally signing bilateral agreements with the Leningrad Region and the Republic of Karelia in 2011 for continued cooperation in rabies control. While the last rabies case in Greece was observed in 1987, the country continues to implement surveillance and control programmes due to the high prevalence of disease in neighbouring countries, including Bulgaria, Turkey, and North Macedonia. In response, the government adopted the Greek National Rabies Control and Eradication Programme in 2012, which required sampling of suspected animals from 16 areas along its Northern and Eastern borders.

6.3.4. Salmonella

While various kinds of Salmonella remained present across most MS in 2019 for surveillance and control measures, all remained below target percentages set by Regulation No 200/2010/EC except for Bulgaria, Croatia, Poland, and Spain (EC-AT-SM, 2020;). However, 23 states continued to receive funding for active and passive surveillance activities across domestic poultry and wild bird populations.

EU targets have been defined for breeding flocks of Gallus gallus, laying hens, broilers, and fattening turkeys, corresponding to an annual maximum of positive flocks for S. Enteritidis, S. Typhimurium, S. Infantis, S. Vircow and S. Hadar. A target of 1% or less of positive results has been set for breeding flocks of Gallus gallus, broilers and fattening turkeys, and 2% or less has been set for laying hens.

Several MS require mandatory vaccination of laying hens, including the Czech Republic and Greece. However, Greece noted several challenges in achieving EU targets in 2019, including difficulties in maintaining official controls, sampling and enforcement. The most serious and recurring challenge was presented by the extreme shortage of official veterinary staff in the country. Meanwhile, Malta observed difficulties posed by its Food Business Operators (FBOs) mixing poultry of different age groups within the same house. In addition, the use of a first-in, first-out system creates particular challenges for reporting flock numbers and classifying rearing and adult flocks. Finally, Ireland reported specific requests for funding to cover costs for sampling and analytical tests and compensation for owners of Broiler Breeder sites that required depopulation.

6.3.5. Sheep and Goat Brucellosis

As of 2019, Sheep and Goat Brucellosis (SGB) remained present in, and funding was provided to, five MS including Croatia, Greece, Italy, Portugal, and Spain (EC-HR-SGB, 2020; EC-EL-SGB, 2020; EC-IT-SGB, 2020; EC-PL-SGB, 2020; EC-ES-SGB, 2020). Programmes entail active and passive surveillance as well as control measures via zoning restrictions and vaccination schemes.

While surveillance measures are implemented across territories, levels of surveillance, eradication, and control differ according to risk. All animals older than six months are tested in Croatia, Portugal, Spain, and Greece's Eradication Zone (EZ). All serologically positive goats and cattle are euthanised. In Greece's Vaccination Zone (VC), all healthy non-pregnant female animals over three months old, as well as young male animals (3-6 months old), must undergo compulsory vaccination (EC-EL-SGB, 2020). In

Portugal, epidemiological inquiries collect data on the origin of infection—establishing possible links to other farms and risk factors (EC-PL-SGB, 2020).

Member States reported several difficulties in meeting SGB programme targets, including the challenges of calculating the targets themselves—especially when implementing representative surveillance in low-risk areas. Furthermore, an accumulation of exogenous challenges between 2011-2019 was cited, including the financial crisis, massive retirement of official vets, new disease emergence, and complications in vaccine purchase which barred Greece's EZ from achieving its 2019 target of 80% vaccination (EC-EL-SGB, 2020). Finally, Portugal faced difficulties in accessing small herds in marginal areas (EC-PL-SGB, 2020).

6.3.6. Transmissible Spongiform Encephalopathies (TSE)

While BSE risk is negligible in all MS except France and Spain, Scrapie remained present in 15 MS, and 26 MS continue to receive funding for active and passive surveillance among domestic and wild animal populations and eradication measures for both TSEs (EFSA, 2020).

Under both active and passive surveillance, most MS use rapid BSE tests and only carry out further examinations for confirmation upon a positive result. While active surveillance applies representative sampling, passive surveillance only conducts tests once a suspected case is identified based on relevant clinical symptoms. Once the competent veterinary authorities confirm a positive result, the infected animal is killed. Greece also requires compulsory ante mortem examination of all bovines slaughtered for human consumption (EC-EL-TSE, 2020).

Further control measures include breeding programmes and feeding practices. Cyprus and Italy attribute decreasing numbers of positive samples in sheep to breeding programmes that significantly improved their resistance to Scrapie. While the programme in Italy is in its first year, Cyprus has implemented breeding programmes for the past decade, which resulted in about 99% of sheep and 61% of goats having at least one resistant allele in their genotype (EC-CY-TSE, 2020; EC-IT-TSE, 2020). Additionally, BSE has never occurred in an indigenous Hungarian herd, which the country attributes to the fact that feed containing protein of animal origin was not widely used there even before the EU-wide ban (EC-HU-TSE, 2020).

Greece and Italy both reported difficulties in meeting targets during the reporting period. Greece has experienced a reduction in the number of animals tested, citing insufficient staffing at its veterinary departments and problems accessing sheep and goat holdings in remote mountainous areas. In response, Greece plans to re-allocate funds to recruit eight additional veterinarians to five local veterinary authorities with large ruminant populations (EC-EL-TSE, 2020). Italy also cited challenges in accessing animals on remote pastures and its small ruminant breeding system, which poses difficulties in complying with the minimum national sample size of 10,000 animals for this category (EC-IT-TSE, 2020).

6.3.7. Conclusions and recommendations

Our review of the recently repealed Regulation (EU) 652/2014 highlights various implementation challenges reported by numerous MS across different zoonoses. Some issues are directly relevant to the Regulation itself, and appear likely (as discussed below) to hold continuing relevance for its successor legislation, Regulation (EU) 2021/690. However, other challenges vary across MS, and relate to the implementation of their national programmes funded by this legislation. First, challenges related to national programmes include difficulties in complying with the minimum national sample sizes and challenges in calculating dynamic and future target numbers based on present static data, leading to overestimated target numbers and administrative burden. Second, insufficient personnel, funds,

storage, and disposal facilities significantly impede MS' ability to meet programme targets. Complications in the procurement of resources such as entomological surveillance traps and vaccines further challenge targets. Below we provide four recommendations based on the above findings:

1. Chapter 5 highlights that while MS are responsible under EU legislation for preparing national surveillance programmes and control plans for both animal diseases and zoonoses, these instruments do not always provide for communication, coordination and collaboration between human and animal health systems as recommended by the OH approach. Our review of the recently repealed Regulation (EU) 652/2014 supports and expands this analysis, finding that all national zoonotic disease surveillance, eradication and control programmes for which MS received Union funding focused exclusively on animal populations. None referred to coordination with public health measures in human populations, meaning that there is little evidence that national programmes for controlling zoonotic diseases in animal populations, which received funding under Article 12 of Regulation (EU) 652/2014, were coordinated with public health measures targeted at human populations. Therefore, we recommend that Annex I (section 2.1) of Regulation 2021/690, which replaces and updates Article 12 of Regulation (EU) 652/2014, be amended to include an explicit requirement that emergency measures and national programmes for eradicating, controlling, and surveillance of animal diseases and zoonoses financed under the Regulation should be implemented according to an OH approach.

2. Measures that allow for simultaneous reductions across various zoonoses, such as awareness campaigns, should be reviewed for priority. Article 8.2.(a) of Regulation 2021/690 commits the EU to the empowerment of actors via awareness campaigns to promote understanding of and access to Union internal market rules, the rights of businesses and consumer protections. However, the Regulation is advised to consider the cost-effectiveness of funding local awareness campaigns focusing specifically on increased infection risks as a method to increase local engagement with passive surveillance.

3. This review identified a lack of state regulatory and veterinary capacity as a principal barrier to implementation. While the repealed Regulation (EU) 652/2014 was effective in providing targeted funding for zoonotic disease surveillance, control, and eradication programmes, the implementation of these programmes in some MS was impeded by inadequate resource availability, including staff capacity and training. Section I, (20) as well as Article 31(1) of the Regulation outline a commitment to provide Union Reference laboratories and MS competent authorities with financial and technical support for training and exchange programmes. Nevertheless, MS continued to cite a lack of general-purpose funding, which is stable over the longer term, to maintain resources such as staff capacity and training as a principal barrier. Section I, (55) and Article 12(4) of Regulation (EU) 2021/690 again commit the EU to provide funding for training of MS' competent authorities. However, given implementation challenges of such commitments under Regulation (EU) 652/2014 evidenced by the continued lack of resources, we recommend the consideration of additional targeted funding models—such as the priority of direct funding for veterinary services in under-resourced MS–to ensure Regulation (EU) 2021/690 addresses the funding gaps evidenced by Regulation (EU) 652/2014.

4. Some MS have received funding to support surveillance for zoonoses of which they are currently free. Monitoring for the reintroduction of previously eliminated zoonoses is a sensible preparedness measure that may help quickly contain any future outbreaks on their territory. However, given insufficient staffing and resources across some MS, which are not free of certain zoonoses, it is recommended to review budget allocations to earmark any possibly redundant

funds to bridge resource gaps. For example, a reduction in programme funding for BT surveillance was suggested in 2016 to prioritise funds for other areas needing additional resources (DG SANTE, 2016).

7.   CONCLUSIONS AND RECOMMENDATIONS

In Chapter 4, we outlined a strategic approach to the prediction, detection and control of emerging zoonoses which was based on the following three principles:

1.   The complexity of zoonotic disease emergence makes it highly unlikely that predictions about the identity of future zoonotic pathogens or the livestock species, production systems and locations from which they will emerge will be accurate. Efforts to prevent emerging zoonoses from causing future epidemics and pandemics should therefore focus on developing more effective surveillance programmes in order to enable rapid detection and containment of outbreaks.

2.   The heterogeneity of emerging zoonoses means that there is no single best approach to their surveillance and control, and the strongest zoonotic disease strategies will combine multiple complementary approaches.

3.   A multidisciplinary approach to zoonosis surveillance and control could enhance the timeliness and effectiveness of control measures for emerging zoonoses, and surveillance programmes should therefore be designed to enable data sharing across medical, veterinary, environmental and other relevant professions.

This chapter highlights and syntheses key recommendations made in previous sections of the report to identify ways in which the EU's arrangements for zoonotic disease surveillance and control might be revised in order to enable the implementation of this strategic approach. The following two sections highlight impediments to implementing our proposed approach to the prediction, detection, and control of emerging zoonoses at the EU level and suggest actions that might be taken to address these barriers. The final section builds on our finding in Chapter 6 that a lack of state regulatory and veterinary capacity impedes the effective implementation of EU-funded zoonotic disease surveillance, control and eradication programmes in certain MS to offer recommendations regarding the resourcing of zoonotic disease programmes at the national level.

7.1.   A combined approach to zoonotic disease surveillance

Chapter 4 highlights that the timely detection of different types of zoonoses is likely to require different approaches to surveillance. It, therefore, proposes a surveillance strategy for emerging zoonotic diseases which combines three forms of surveillance activity:

1.   Risk-based zoonosis surveillance programmes targeted at pathogens of known concern in order to rapidly detect and control outbreaks in hitherto disease-free jurisdictions.

2.   Syndromic surveillance in order to detect the emergence of previously unknown pathogens.

3.   Surveillance of changes in land use and livestock systems linked to disease emergence in order to provide a proxy for the surveillance of disease events.

However, Chapter 6 found that existing EU monitoring and surveillance arrangements for zoonoses focus primarily on testing for and reporting cases of a relatively short list of known zoonotic pathogens specified in Annex I of Directive 2003/99/EC. Thus, while MS typically display a high compliance level with the pathogen-specific zoonosis monitoring and reporting requirements placed on them by this Directive, substantial reporting gaps exist for Echinococcosis and E. Coli. Moreover, Directive 2003/99/EC does not explicitly require MS to monitor or report some of the zoonoses detected most

frequently through investigation of food-borne disease outbreaks, which negatively impacts the quality and consistency of reporting for these pathogens.

We found no evidence of formal arrangements for syndromic surveillance of zoonotic diseases in animals (although the ECDC engages in some syndromic surveillance of zoonotic infections in humans via its epidemic intelligence function, and Directive 2003/99/EC's requirement that MS investigate food-borne disease outbreaks also encourages investigation of unusual case clusters in humans). While existing pathogen-specific zoonosis monitoring and reporting requirements provide a sound basis for EU-level surveillance and management of most known zoonoses that present a well-understood public health risk, they may be less effective in detecting the emergence of novel zoonoses. We therefore recommend:

1. That MS whose annual reports to EFSA on the occurrence of zoonoses within their territory do not cover all pathogens specified in Annex I of Directive 2003/99/EC (section A) be encouraged strongly to provide more comprehensive data in the future, and that improving monitoring and reporting of Echinococcosis be considered a particularly high priority.

2. That zoonoses which are reported frequently but are not currently listed in Annex I of Directive 2003/99/EC (e.g. flaviviruses and Coxiella) be added to section B of this Annex to improve consistency of zoonotic disease surveillance and reporting across MS.

3. That the pathogen-specific approach to surveillance, monitoring and control of zoonotic diseases prescribed by Directive 2003/99/EC and Regulation 2021/690 (which replaces Regulation (EU) 652/2014), should be complemented by development of syndromic surveillance programmes and procedures for the investigation of anomalous symptoms in both humans and animals. Consideration could also be given to developing a capacity for monitoring changes in land use and livestock production systems to support the detection, identification and containment of novel zoonotic pathogens as they emerge.

7.2. A multi-disciplinary approach to the management of zoonoses

Chapter 4 proposed that surveillance for emerging zoonotic diseases should not focus exclusively on livestock and should instead enable data and expertise to be shared across medical, veterinary, and environmental health services and professions. It argued that the enhanced communication and coordination enabled by a multidisciplinary approach to the surveillance and control of emerging zoonoses could improve the timeliness and effectiveness of risk mitigation and control activities and thus help to minimise the impacts of zoonotic disease outbreaks.

Chapter 5 found that current EU zoonotic disease management arrangements present several barriers to implementing an integrated, multi-disciplinary approach to the surveillance and control of zoonoses. Notably, the EU animal and human health sectors lack arrangements for biological sample sharing; their datasets, early warning systems and reference laboratory networks are insufficiently interoperable; and differences in risk perception and assessment impede collaboration. Chapter 5 recommended that three changes be made to EU zoonotic disease management arrangements in order to overcome these barriers to communication and coordination and to facilitate the implementation of an integrated model for the control of zoonoses grounded in the One Health approach:

1. Greater interoperability between EU early warning systems for human and animal health threats should be pursued so that emerging zoonotic diseases may be detected rapidly and assessed more effectively.

2. Zoonosis surveillance, monitoring and risk assessment should be opened up to a wider range of expertise (including specialists in One Health and environmental health) through creating a team with interdisciplinary knowledge spanning human, animal and environmental health to assess alerts generated by these early warning systems. Doing so should enable zoonotic disease risk assessments to address a wider range of risk drivers.

3. The Commission should provide support in order to assist the EU Member States in reframing their national preparedness and response plans for emerging diseases in humans, and their national contingency plans for emerging diseases in animals, to ensure that they utilize a One Health approach. This should help to provide an integrated framework for responding to emerging zoonoses at the national level.

Recommendation 3 is essential because EU institutions depend heavily on MS authorities to implement zoonosis surveillance, control and eradication programmes (many of which received Union funding under Regulation (EU) 652/2014 but are carried out at the national level). However, Chapter 6 highlighted that all national zoonotic disease surveillance, eradication and control programmes for which MS had received Union funding focused exclusively on animal populations and that none made reference to coordination with public health measures in human populations. This apparent lack of coordination between national programmes to control zoonotic diseases in animal populations and public health measures targeted at human populations perhaps reflects that MS are not currently required to implement national zoonosis programmes according to a One Health approach. Introducing such a requirement might encourage a more integrated approach to zoonosis surveillance, control and eradication at the MS level. We therefore further recommend that:

4. Annex I (section 2.1) of Regulation 2021/690, which replaces and updates Article 12 of Regulation (EU) 652/2014, should be amended to specify that programmes for the eradication, control, and surveillance of zoonoses that receive EU funding should adopt a One Health approach to promote greater integration between human-focused and animal-focused zoonosis control programmes at the MS level.

7.3. Resourcing of Member States' national zoonosis programmes

As noted above, EU institutions rely heavily on MS authorities to implement zoonosis surveillance, control and eradication programmes on their behalf. However, Chapter 6 identified a lack of state regulatory and veterinary capacity as an important barrier to implementing zoonosis programmes for which Union funding was provided under the recently repealed Regulation (EU) 652/2014 (and replaced by Regulation 2021/690). While the Regulation was effective in providing targeted short-term funding for the surveillance, eradication and control of specific zoonoses across a range of pathogens and livestock species, the implementation of these programmes in certain MS is often impeded by a lack of general-purpose funding, which is stable over the longer term, to maintain resources such as staff capacity and training. In order to address this issue, we recommend that:

1. Measures that allow for simultaneous reductions in the incidence of multiple zoonoses, such as awareness campaigns, should be prioritised for cost-effectiveness reasons.

2. Additional funding models, such as direct funding of veterinary services in under-resourced MS, be considered in the interests of facilitating the consistent provision of zoonotic disease surveillance and control across all MS.

3. A number of MS have received EU funding to support surveillance for zoonoses of which they are currently free. Monitoring for the reintroduction of previously eliminated zoonoses is a sensible preparedness measure that may help to contain any future outbreaks on their territory

quickly. However, given insufficient staffing and resources across some MS that are not free of certain zoonoses, we suggest that budgets be reviewed to identify any possibly redundant funds that might be used to bridge resource gaps.

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APPENDIX 1: REPORTING OF CATEGORY A ZOONOSES OR ZOONOTIC AGENTS

Category A	Country reporting																											Total MS reporting				
Agent	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	R	D	P	A	F
Brucellosis	D F	D	D P	D	D	D	R	D	D	D P	D P	D P	D P	D	D P	D P	D P	D	D P	D	D P	D P	D P	D P	D P	R	D P	27	25	15	0	1
Campylobacteriosis	P A F	P A F	P	P	P A	P A F	R	P A F	P	P A F	P A F	P F	P A F	F	P A	P A F	P A F	P A	P F	F	P A F	P	P A	P A	P A F	A	P	27	0	23	17	16
Echinococcosis		P	P	P	P	P	R	P	P	P	P	P		P	P	P		P	P	P		P		P	P	R	P	22	0	20	0	0
Listeriosis	P F	P F	P	P	P	P F	R	P	P	P F	F	P	P		P	P F	P	P	P		P F	P	P	P	P F	R	P	25	0	22	0	8
Salmonellosis	P A F	P A F	P A	P A	P A F	P A F	R	P A F	P A F	P A F	P A F	P A F	P A F	P A F	P A F	P A F	P A F	P A	P A F	P A F	P A F	P A F	P A	P A F	P F	A	P A	27	0	25	25	20
Trichinellosis	P	P	P F		P	P	R	P	P	P	P	P	P F	P	P	P F	P	P	P	P	P	P	P	P F	P	R	P	26	0	24	0	4
Tuberculosis due to Mycobacterium bovis	D	D	D	D	D	D	R	D	D	D P	D	D P	D P	D	D P	D P	D	D	D P	D	D P	D	D	D	D P	R	D P	27	25	9	0	0
Verotoxinogenic Escherichia coli	P A F	P A F	P F	P	P A	P A F		P A	P	P F	P A	P A F	P A		P F	P F			P	F	P		P A	P	P F	A	P	22	0	20	10	10
Total Reported	7	8	8	7	8	8	7	8	8	8	8	8	8	7	6	8	8	6	7	8	7	7	7	7	8	8	8					
Total Disease Status	2	2	2	2	2	2	NA	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	NA	2					
Total Prevalence	5	6	7	5	6	6	NA	6	6	8	6	8	7	3	8	8	5	5	8	3	7	6	6	7	8	NA	8					
Total AMR	3	3	1	1	3	3	NA	3	1	2	3	2	3	1	2	2	2	2	1	1	2	1	3	2	1	3	1					
Total Foodborne Outbreaks	5	4	2	0	1	4	NA	2	1	4	3	3	3	2	3	5	2	0	2	3	3	1	0	2	4	NA	0					

Note: R = Any reporting; D = Disease Status; P = Prevalence; A = Antimicrobial Resistance; F = Foodborne Outbreak; NA = Not Applicable.

APPENDIX 2: REPORTING OF LISTED CATEGORY B ZOONOSES OR ZOONOTIC AGENTS

Category B listed	Country reporting																											Total MS reporting		
Agents	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	R	P	F
Anisakiasis																												0	0	0
Borreliosis																												0	0	0
Botulism																												0	0	0
Calicivirus									F			P, F	P	F		F							P	P				7	4	4
Cryptosporidiosis						F	R								F	F									F			5	0	4
Cysticercosis		P	P							P	P							P		P					P	R		8	7	0
Hepatitis A virus						F				F		P				F				F			P		P, F	R		8	3	5
Leptospirosis			P				R																					2	1	0
Lyssavirus	P	P	P		P	P	R		P	P	P	P				P	P	P	P		P	P	P	P	P	R	P	21	19	0
Psittacosis [a]																												0	0	0
Toxoplasmosis	P					P			P	P	P			P	P	P		P			P			P			P	12	12	0
Tuberculosis - other	P																											1	1	0
Vibriosis			P									F				F					P				P			5	3	2
Viruses transmitted by arthropods																												0	0	0
Yersiniosis		P				P, F	R	P		P	F	F				P	P	F				P	F		P, F	R	P	15	9	6
Total Reported	1	3	4	0	1	5	4	1	3	5	4	5	1	2	3	7	2	2	2	1	4	3	2	4	6	4	3			
Total Prevalence	3	3	4	0	1	3	NA	1	2	4	3	3	1	1	2	3	1	2	2	1	4	1	2	4	5	NA	3			
Total Foodborne Outbreaks	0	0	0	0	0	3	NA	0	1	1	1	3	0	1	1	4	1	0	0	0	0	2	0	0	3	NA	0			

Note: R = Any reporting; P = Prevalence; F = Foodborne Outbreak; NA = Not Applicable. Neither disease status nor AMR are reported for non-mandatory zoonoses or zoonotic agents.

[a] See entry for Chlamydia in Appendix 3-Part 1.

APPENDIX 3A: REPORTING OF 'OTHER' CATEGORY B ZOONOSES OR ZOONOTIC AGENTS

Category B 'other'	Country reporting																											Total MS reporting			
Agent	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	R	P	A	F
Adenoviridae										F																		1	0	0	1
Arobacter butzleri		F																										1	0	0	1
Atropine												F																1	0	0	1
Bacillus							P																					1	1	0	0
Bacillus cereus		F				F				F	F	F		F		F						F	F		F			10	0	0	10
Bacterial toxins												F																1	0	0	1
Bovine spongiform encephalopathy							R																					1	0	0	0
Chlamydia	P						R		P																			3	2	0	0
Clostridium															P													1	1	0	0
Clostridium botulinum										F		F				F						F		F				5	0	0	5
Clostridium difficile																										R		1	0	0	0
Clostridium perfringens		F				F			PF	F	F	F	F	F		F							F		F			11	1	0	11
Coxiella	P	P	P	P	P		R		P	P	P				P	P					P	P		P	P	R	P	17	15	0	0
Cronobacter	P	P		P		P		P	P			P		P								P		P		R	P	12	11	0	0
Dermatophytosis																										R		1	0	0	0
Enterococcus																										R		1	0	1	0
Enterococcus, non pathogenic - E. faecalis		A				A		A						A														4	0	4	0
Enterococcus, non pathogenic - E. faecium		A				A		A						A														4	0	4	0
Enterococcus, non-pathogenic			P																									1	1	0	0
Enteropathogenic E. coli																			F				F					2	0	0	2
Enterotoxigenic E. coli										F									F				F					3	0	0	3
Escherichia coli										F																		1	0	0	1
Escherichia coli, nonpathogenic, unspecified	P		PA						PA	A				A	A	A	A	A	PA	A		A	A	A	A		A	16	4	15	0

Note: R = Any reporting; P = Prevalence; A = Antimicrobial Resistance; F = Foodborne Outbreak; NA = Not Applicable. Disease status is not reported for this group.

APPENDIX 3B: REPORTING OF 'OTHER' CATEGORY B ZOONOSES OR ZOONOTIC AGENTS

Category B 'other' Agent	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	R	P	A	F
Escherichia coli, pathogenic, unspecified																		A										1	0	1	0
Flavivirus	P		P	P	P				P	P	F	P		P		P							P	P	P		P	14	13	0	1
Francisella	P																							P				2	2	0	0
Giardia						F						F	F					F	F									5	0	0	5
Hepatitis E virus						F																				R		2	0	0	1
Hepatitis virus																F												1	0	0	1
Histamine	P	PF	P		P	PF	R	P		PF	F	PF	PF			P	PF	P		PF	F		P	P	F		P	21	16	0	10
Klebsiella									P												A							2	1	1	0
Leishmania									P																			1	1	0	0
Leptospirosis			P				R																					2	1	0	0
Marine biotoxins			P							F		F																3	1	0	2
Microorganisms														F														1	0	0	1
Mushroom toxins										F							F					F						3	0	0	3
Mycotoxins																						F						1	0	0	1
Norovirus	F	F			F	F	R			F	F	F	F		F	F	F		F	F	F	F	F		F	R		19	0	0	17
Parasites																					F							1	0	0	1
Proteus								P																				1	1	0	0
Rotavirus																	F		F			F						3	0	0	3
Sapporo virus											F																	1	0	0	1
Sarcocystis		P																										1	1	0	0
Scrombotoxin																				F								1	0	0	1
Shigella				F		F						F										F		PF				6	1	0	5
Staphylococcal enterotoxins			P	PF	P	F			P	PF						P	PF						PF	P			P	11	10	0	0
Staphylococcal enterovirus						P					F	F																3	1	0	2

Note: R = Any reporting; P = Prevalence; A = Antimicrobial Resistance; F = Foodborne Outbreak; NA = Not Applicable. Disease status is not reported for this group.

APPENDIX 3C: REPORTING OF 'OTHER' CATEGORY B ZOONOSES OR ZOONOTIC AGENTS

Category B 'other'	Country reporting																											Total MS reporting			
Agent	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	R	P	A	F
Staphylococcus																								F				1	0	0	1
Staphylococcus aureus													F	F								F	F	F	F			6	0	0	6
Meticilin resistant staphylococcus aureus	PA	PA	PF			PF			P					P							P	P	PA				R	11	9	3	2
Streptococcus									P																			1	1	0	0
Tick-borne encephalitis virus							R	F						F													R	4	0	0	2
Toxins										F																		1	0	0	1
Transmissible spongiform encephalopathy							R																					1	0	0	0
Tuberculosis - other	P																											0	1	0	0
Unknown		F	F		F	F			F	F	F	F	F	F	F	F		F			F	F	F	F	F			18	0	0	18
Virus						F				F		F																3	0	0	3
Total Reporting	9	12	10	5	6	16	8	5	13	19	8	13	9	7	9	14	6	2	6	4	9	13	10	9	14	9	6				
Total Prevalence	9	5	9	4	4	4	NA	2	12	5	1	2	2	1	5	5	1	0	2	0	3	2	4	5	4	NA	5				
Total AMR	1	3	1	0	0	2	NA	2	1	1	0	0	2	1	1	1	1	2	1	1	1	1	2	1	1	NA	1				
Total Foodborne Outbreaks	1	6	2	2	2	11	NA	1	2	14	7	12	6	5	3	10	4	0	5	3	5	10	6	3	9	NA	0				

Note: R = Any reporting; P = Prevalence; A = Antimicrobial Resistance; F = Foodborne Outbreak; NA = Not Applicable. Disease status is not reported for this group.

This study examines the zoonotic disease risks posed by the livestock sector (including fur production), reviews the risks posed by different livestock species and production systems, and examines case studies of past zoonotic disease epidemics. Building on this evidence, it reviews EU zoonosis surveillance and control arrangements. It recommends improvements including integration of human and animal disease surveillance services, expanded use of syndromic surveillance and changes to the funding of Member States' zoonotic disease programmes under Regulation (EU) 652/2014.

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